New ACS SASSI NQA V4.2 Capabilities for Improving SSI Analysis of Embedded Structures and SMRs Based on ASCE 4-16 and JEAC 4601-2015 Guidelines

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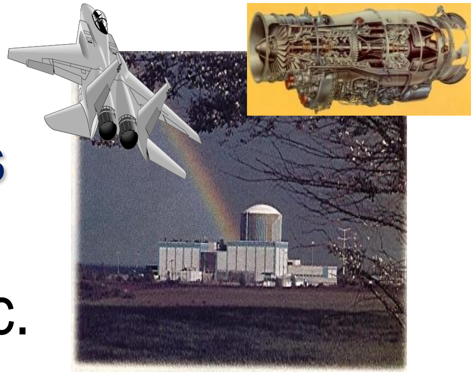


Brief Introductory Slide Presentation

New York Office, August 25, 2020

Note: A detailed technical brochure will be available by early October

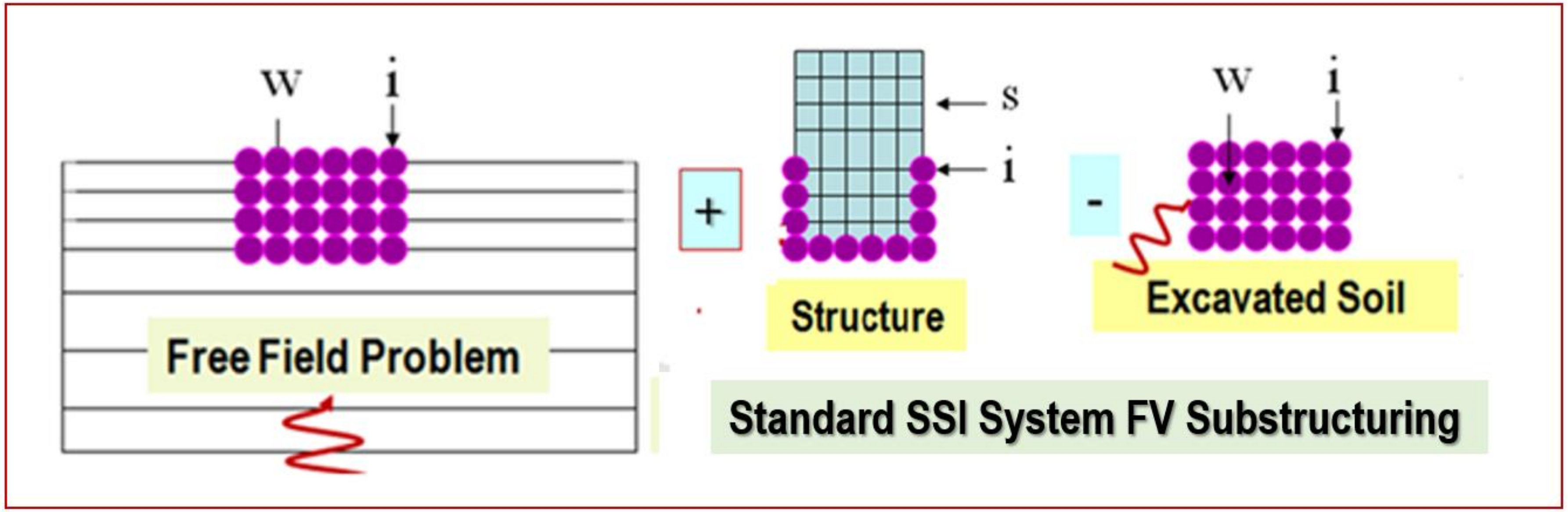
New ACS SASSI V4.2 SSI Capabilities

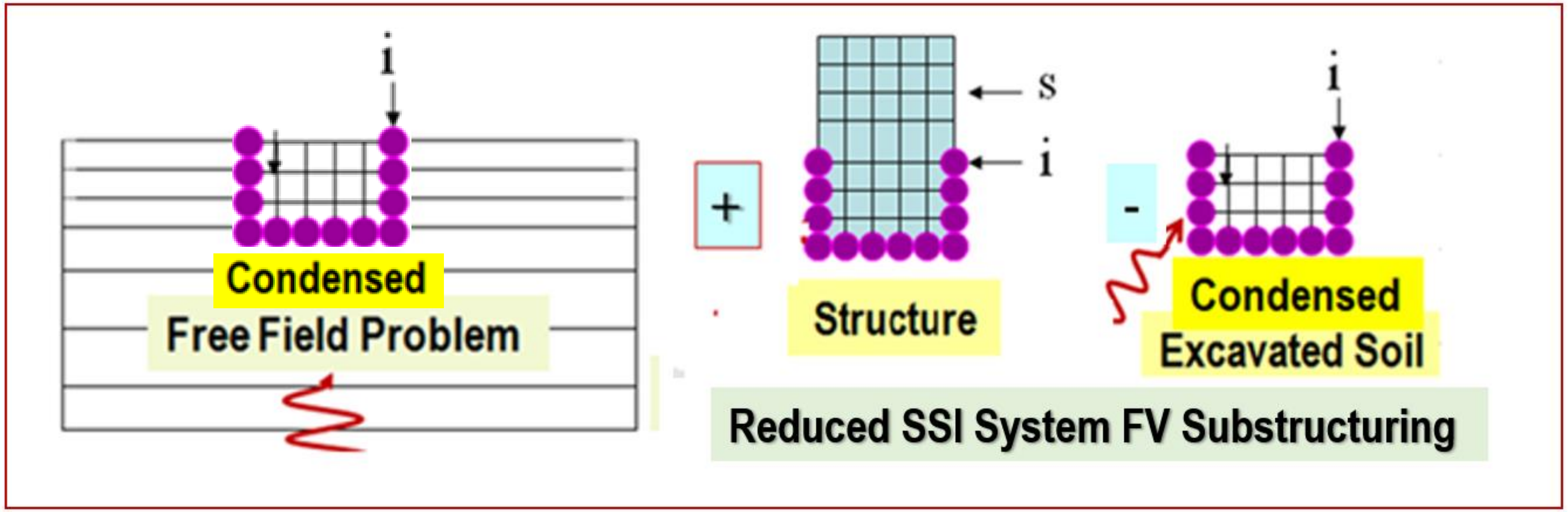
1. Fast and Accurate SSI Analysis Using Flexible Volume Reduced-Order Modeling. Applicable to Deeply Embedded Structures and SMRs (Slide 3-10). *Main Software*
2. Fast Nonlinear SSI Analysis Via Hybrid Complex Frequency-Time Domain Approach Combined with Reduced-Order Modeling for Nonlinear Structures (Slide 11-33). *Option NON.*
3. Foundation Uplift SSI Analysis Using Hybrid Complex Frequency-Time Domain Approach with Reduced-Order Modeling of Foundation-Soil Interface (Slide 34-41). *Option UPLIFT.*
4. Nonlinear Force PSD-Shape Based Iterative Equivalent-Linearization (Slide 42-45). *Option NON.*

1. Fast and Accurate SSI Analysis Using Flexible Volume Reduced-Order Modeling. (Main Software)

Note: Highly Efficient for Deeply Embedded Structures and SMRs.
It reduces the overall SSI analysis runtime for deeply embedded or large-size SMRs by 5-10 times!

Fast and Accurate SSI Analysis Using FV Reduced-Order Modeling





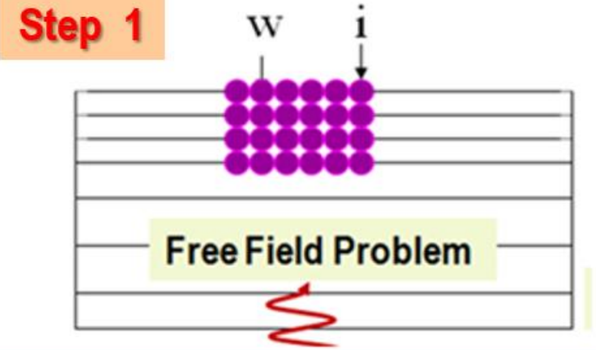
The excavated soil dynamic matrix is a frequency-dependent large-size full complex matrix.

Due to its lack of sparseness, the inclusion of this matrix in the SSI solution affects largely the numerically efficiency of the FV substructuring as defined in the original SASSI approach.

Using a frequency-dependent matrix condensation scheme, the size of this large-size matrix can be hugely reduced, and by this large speedups of SSI solution are obtained.

Fast ACS SASSI Analysis Using Condensed Excavated Soil Matrix

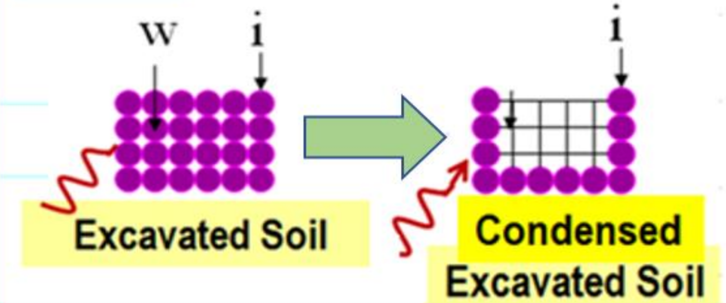
Step 1



Identify Key Frequencies Based on Free-Field Excavated Soil Dynamics

Perform the site response analysis by *running the SOIL module* to identify a reduced set of key frequencies for the excavated soil dynamics in free-field. Both the frequency-dependence of the excavated soil impedance matrix and its associated seismic load vectors are considered. The *dense SSI frequencies* for the SITE module which will be used for final SSI analysis are automatically *adjusted* based on the *key frequencies.*

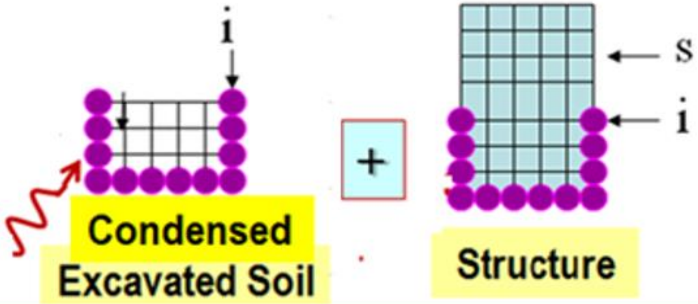
Step 2



Condense Soil Matrix for Key Frequencies and Interpolate for All Frequencies

The frequency-dependent excavated soil dynamic matrix is condensed for the foundation-soil interface nodes for *key frequencies only*. This is accomplished by *running ANALYS option "Condense Impedance" (Mode 7).* Then, the reduced excavation dynamic matrix and seismic load vector are interpolated *for all dense SSI frequencies* by *running the CNDS_INTERP module*. Reduced soil matrices can be also exported to ANSYS for performing a SSI harmonic analysis via SASSI methodology.

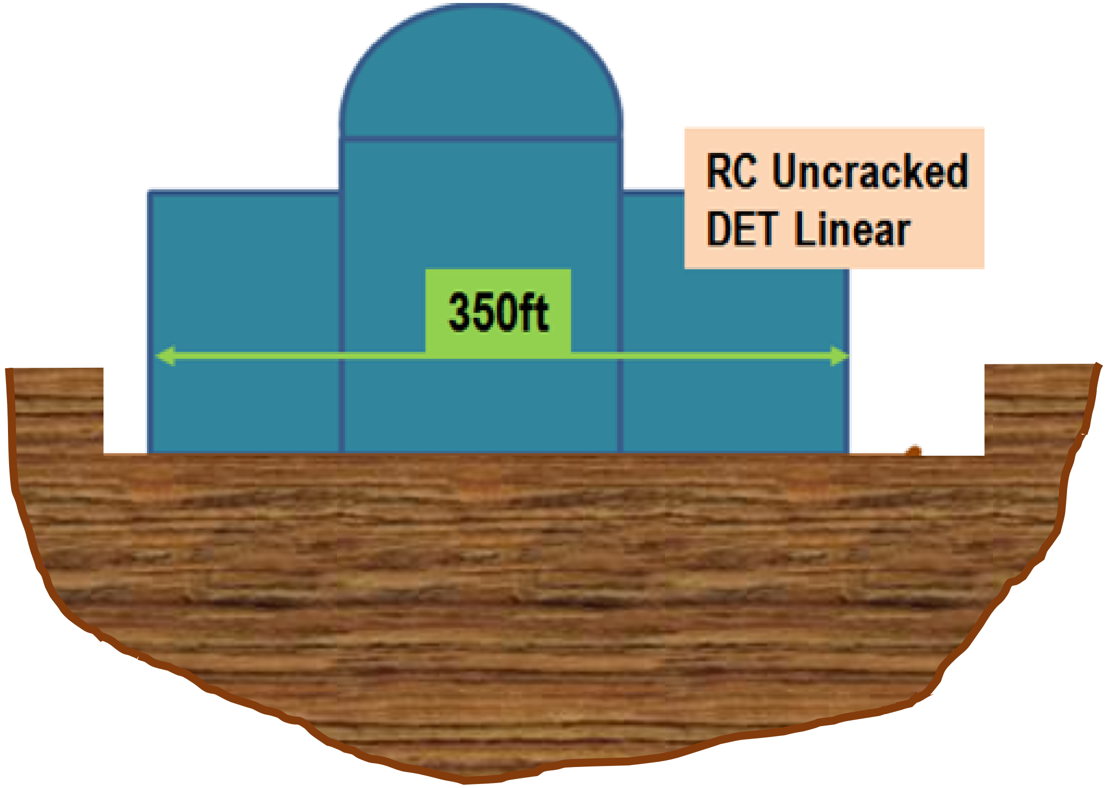
Step 3



Compute SSI Solution Using Reduced Excavation Matrix for All Frequencies

The interpolated reduced excavation dynamic matrix and seismic load vectors computed *for all SSI frequencies* are assembled with the structure model, and the SSI solution is obtained for each frequency. This is accomplished by *running ANALYS option "SSI with Condensation" (Model 8).* The final SSI solution running time and the soil impedance file sizes are much smaller since the number of interaction nodes is minimal. Speed ups of 5-15 times are expected for detailed deeply embedded models.

Embedded RB ACS SASSI Analysis for Direct SSI vs. Reduced SSI



RB Complex SSI Model Information:

- Number of Nodes: About 80,000
- Number of Interaction Nodes: About 8,000
- Embedment Depth: 45 ft
- Excavation includes 6 Embedment Layers
- Direct SSI Approach: Fast FV with 4 out of 7 interaction node layers

Seismic SSI Analysis Runtime:

ACS SASSI Direct Runtime: 733 units

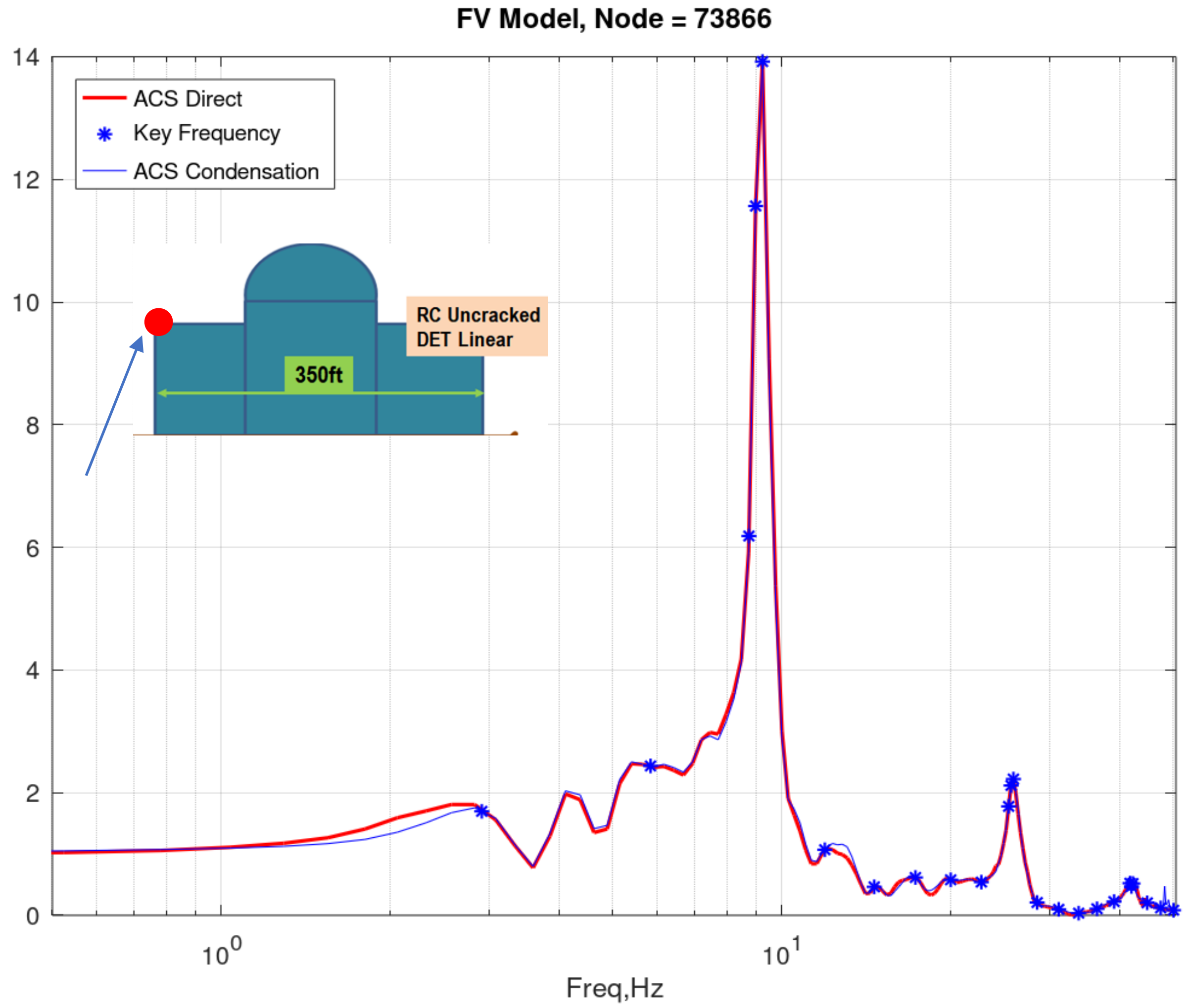
ACS SASSI with Condensation Runtime: 176 units

Speed Up due to Condensation: 4.2

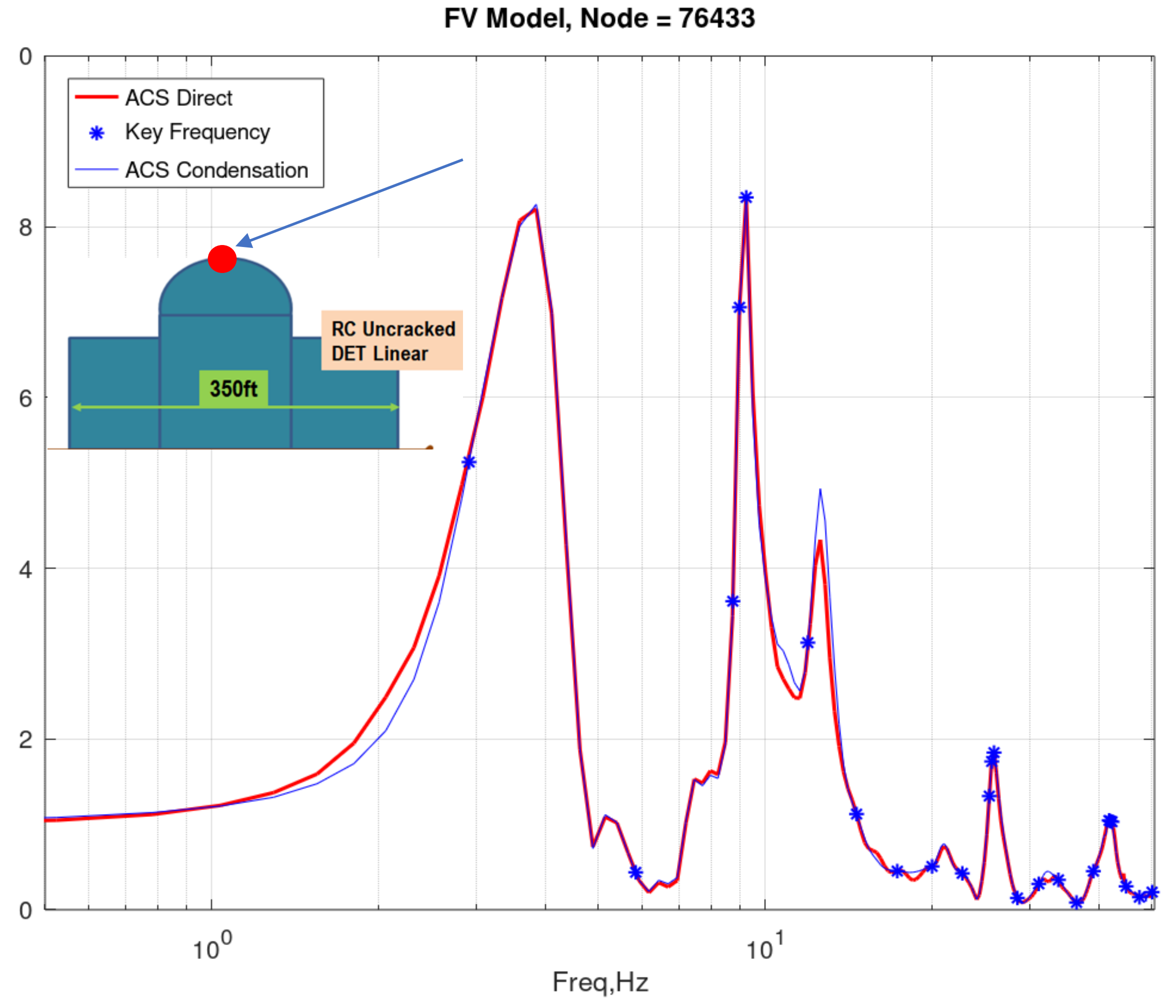
Larger speed ups up to 10 times or even more are expected for larger-size SSI models with deep embedment and larger number of interaction nodes.

Embedded RB SSI Analysis: Direct SSI (FFV) vs. Reduced SSI

Top Corner of NI

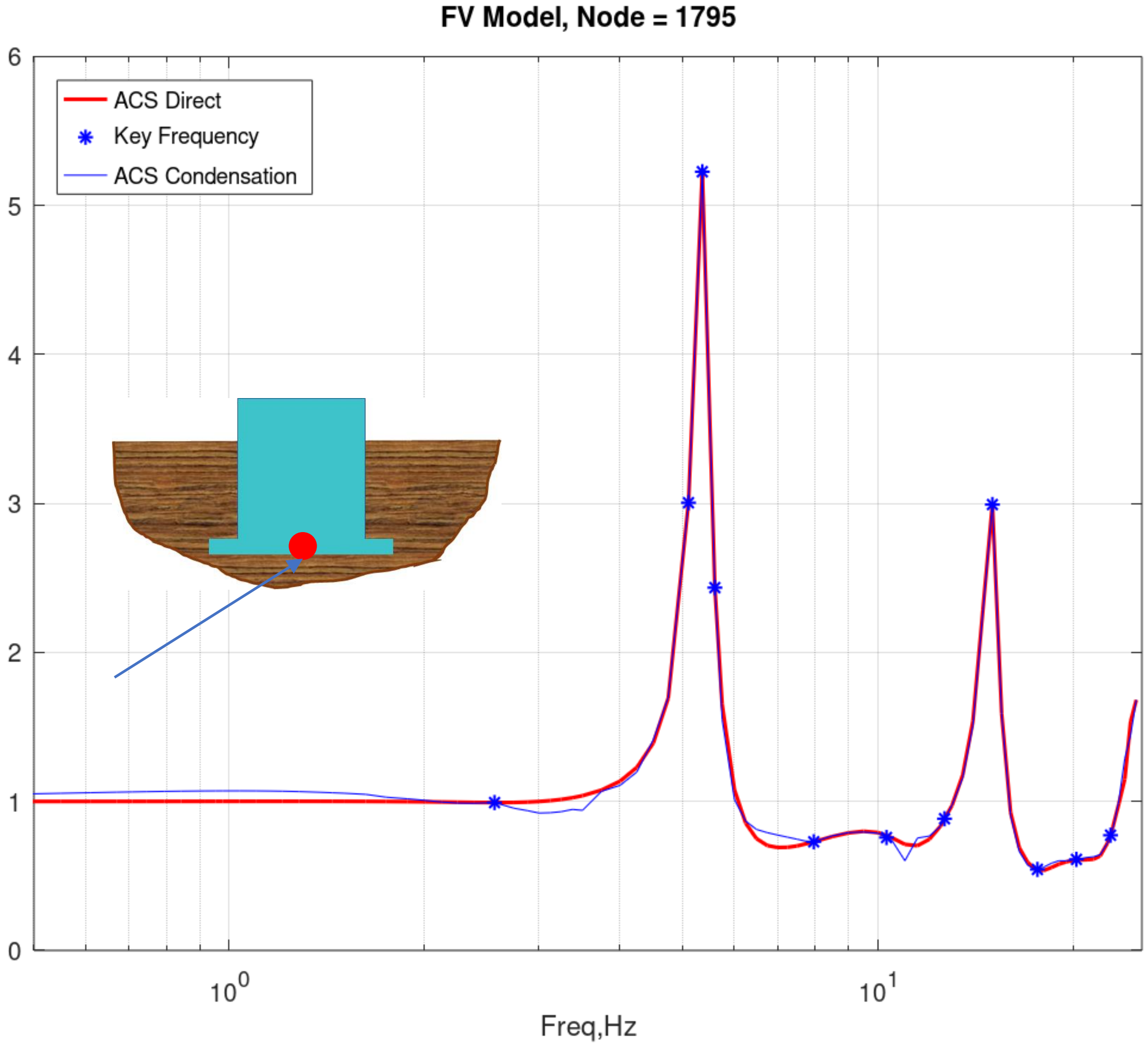


Top of Containment Shell

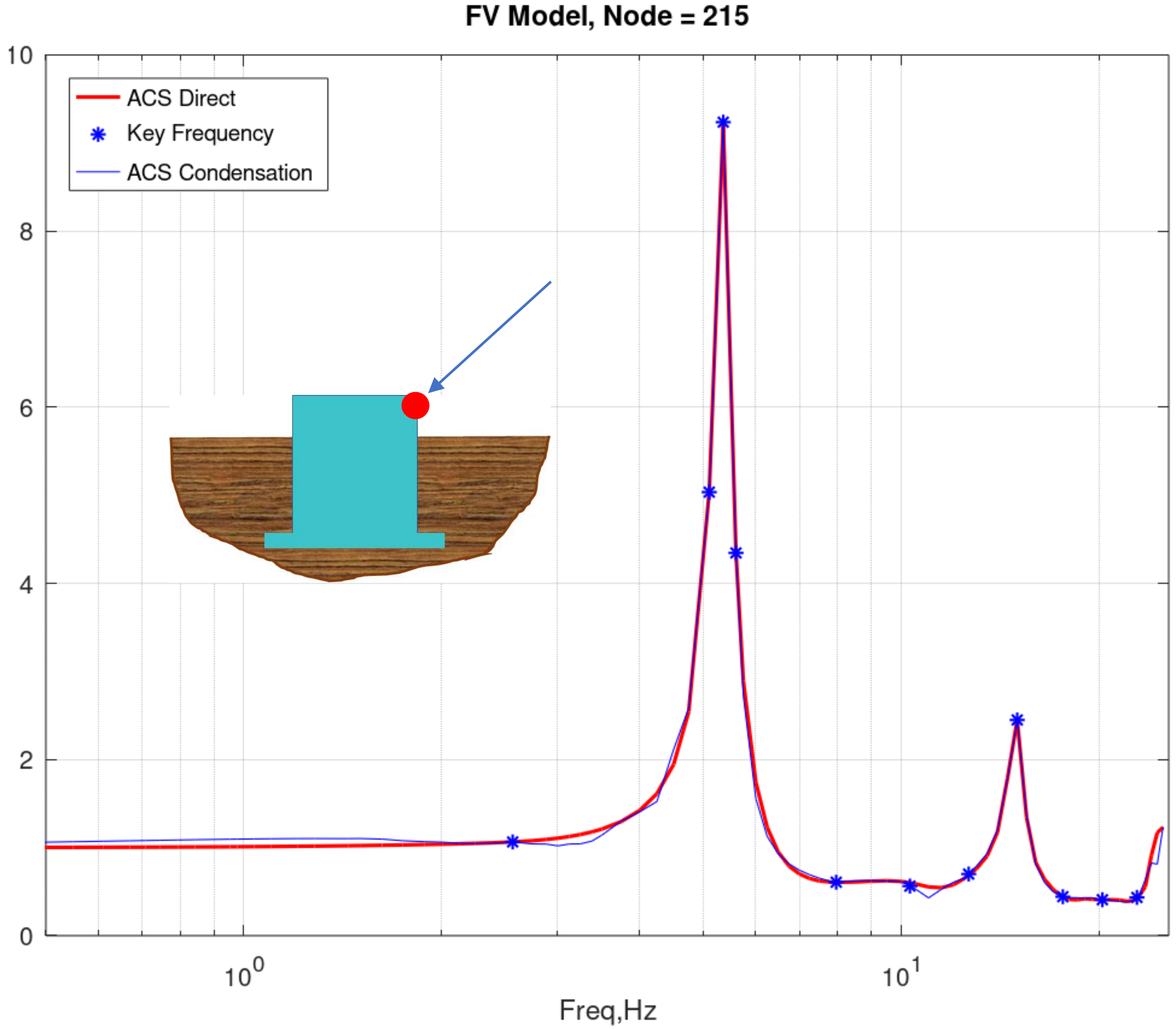


Deeply Embedded SMR Analysis; Direct SSI (FV) vs. Reduced SSI

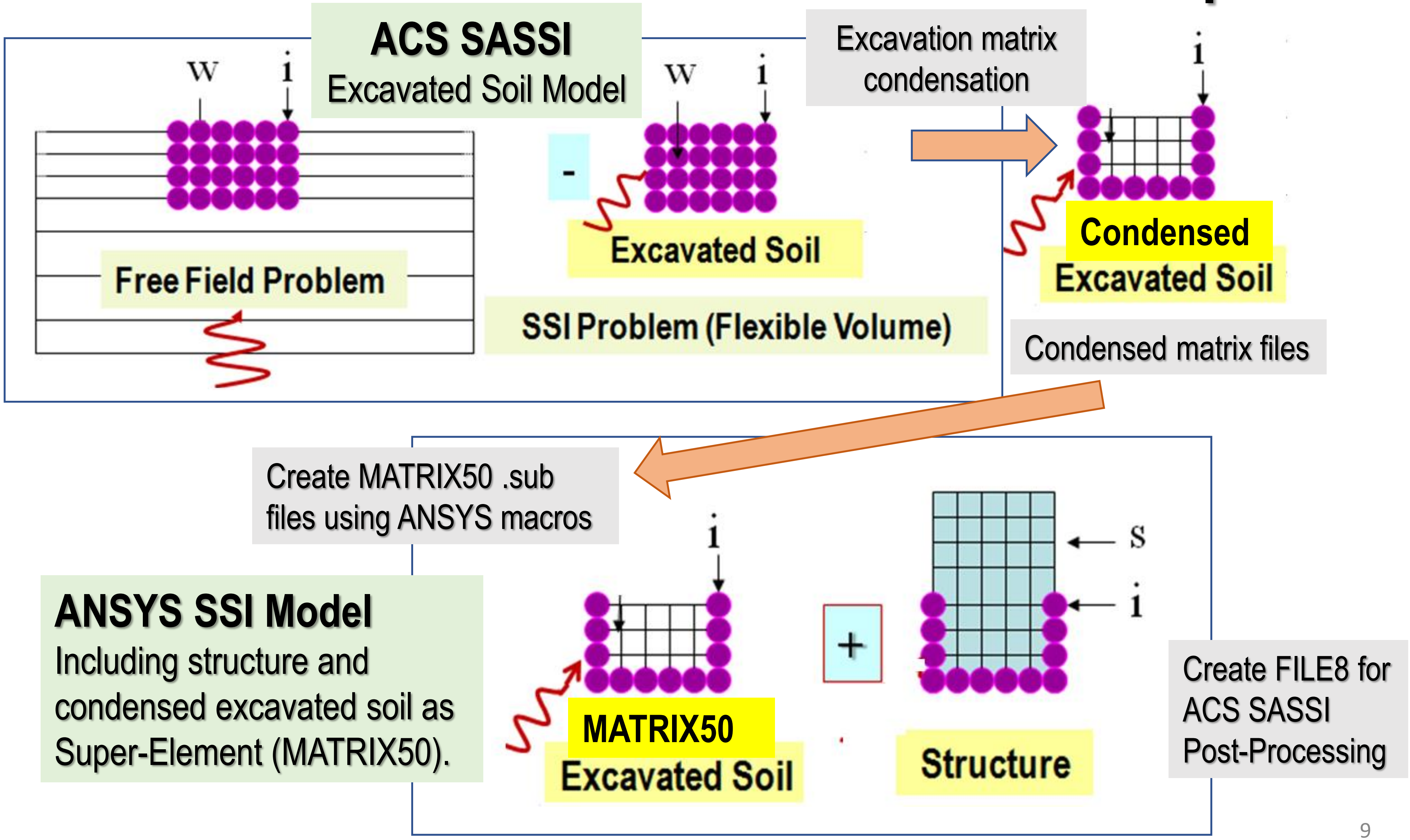
Basemat Center



Top of SMR Structure



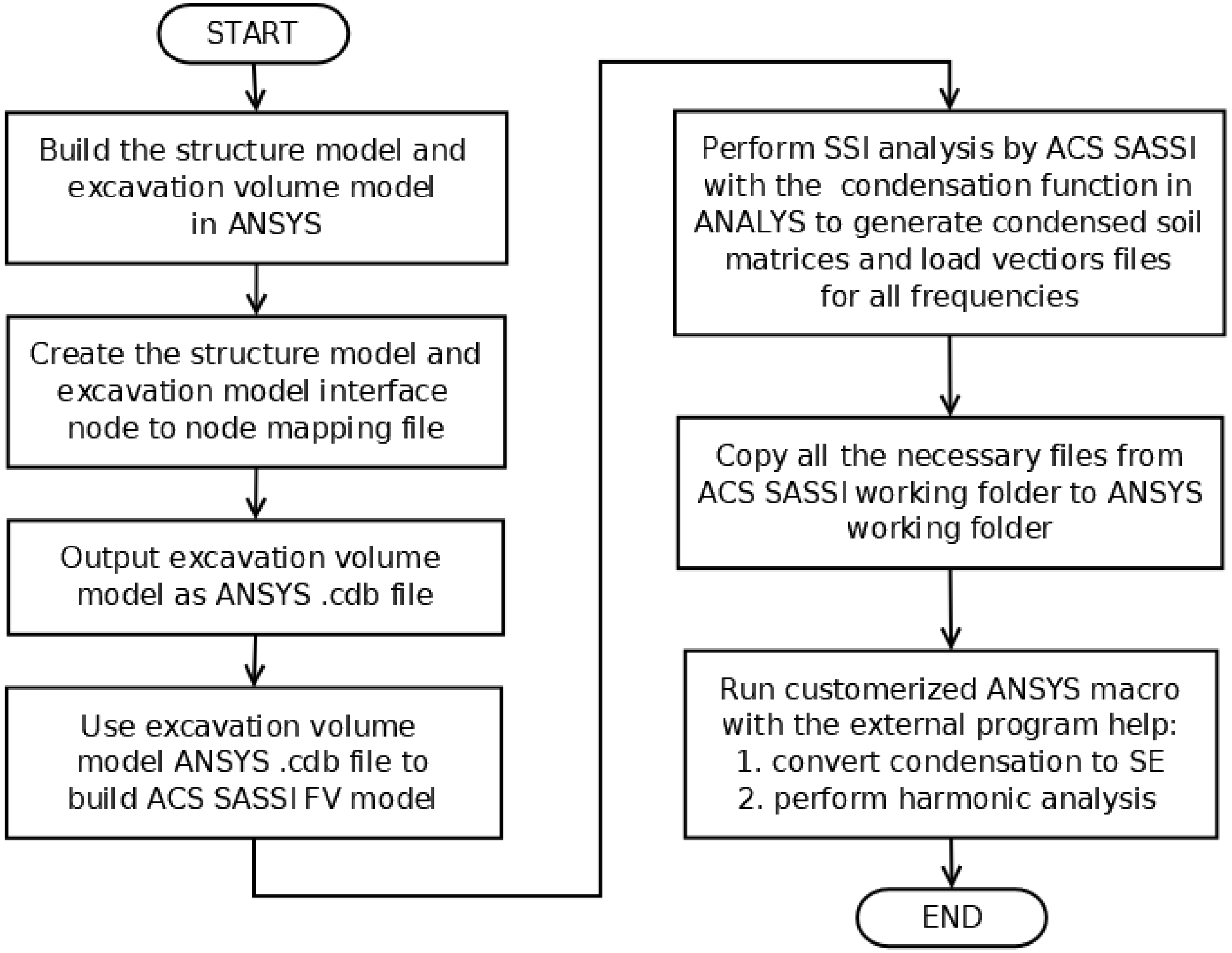
ACS SASSI Option AA-R for ANSYS Fast-Harmonic SSI Analysis Using Reduced Excavated Soil Matrix as MATRIX50 Super-Element



ANSYS Fluid SSI Analysis (with FLUID30) Via ACS SASSI Option AA-R. Condensed Excavation Soil Matrix is Passed to ANSYS for FSSI Analysis.

The ACS SASSI condensed excavated soil impedance matrix passed as a super-element (SE) to ANSYS that is automatically integrated with ANSYS structure model.

ANSYS or ACS SASSI to prepare excavation FE model for ACS SASSI condensation run



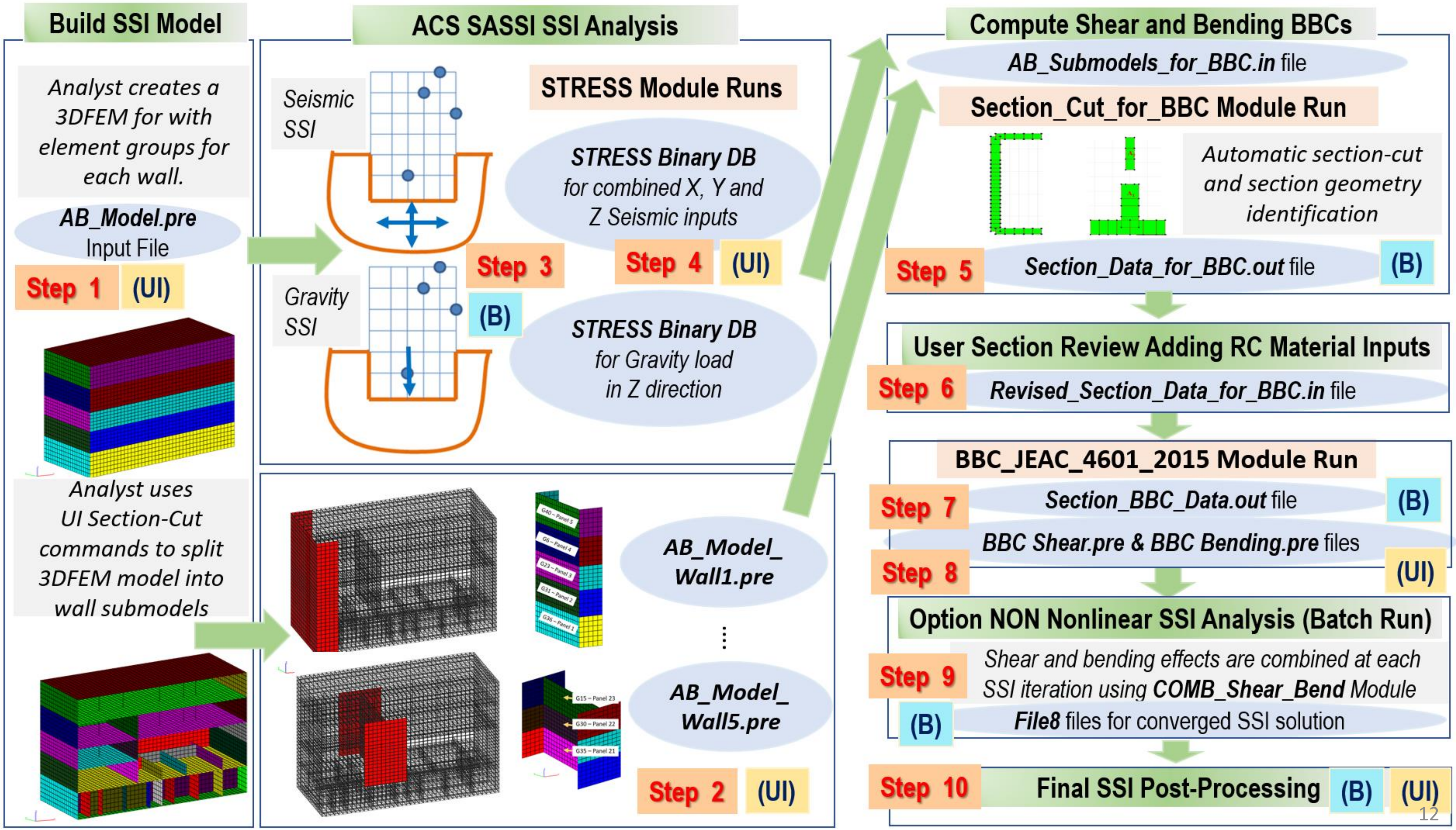
ACS SASSI excavation impedance condensation run

ANSYS SSI harmonic analysis run using prepared macros

2. Fast Nonlinear SSI Analysis Via Hybrid Frequency-Time Domain Approach Combined with Reduced-Order Modeling for Nonlinear Concrete Structures (Option NON)

Note: Nonlinear SSI approach is developed in compliance with the recent ASCE 4-16 and JEAC 4601-2015 standard recommendations. Validated against actual project results, OpenSees software and wall test data.

ACS SASSI Nonlinear SSI Analysis Flowchart (Option NON)



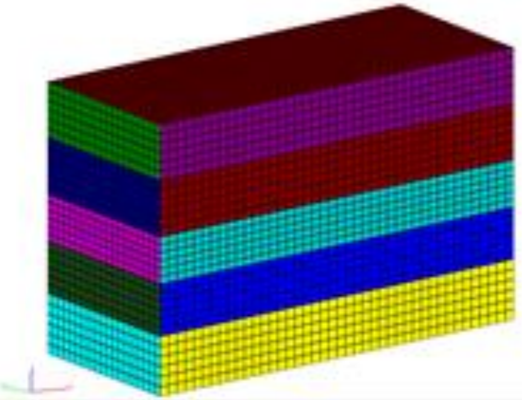
Steps 1-2: Prepare the 3DFEM with Separate Shell Groups for Walls

Build SSI Model

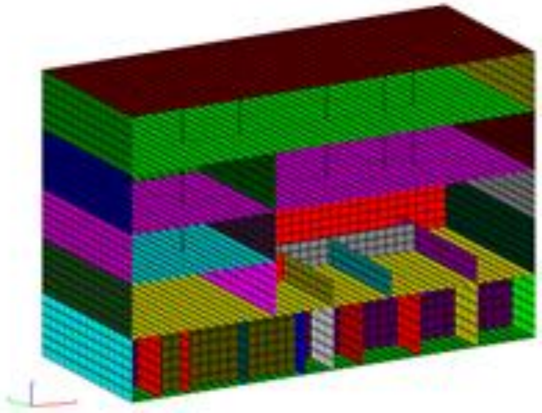
Analyst creates a 3DFEM for with element groups for each wall.

AB_Model.pre
Input File

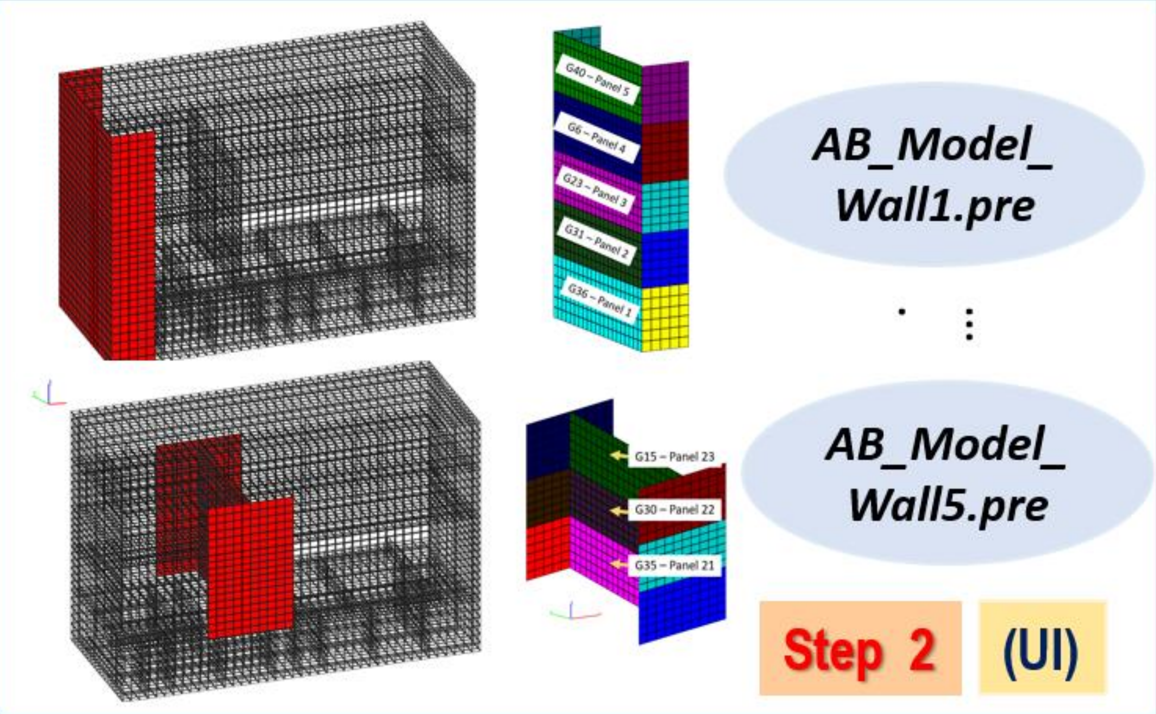
Step 1 **(UI)**



Analyst uses UI Section-Cut commands to split 3DFEM model into wall submodels

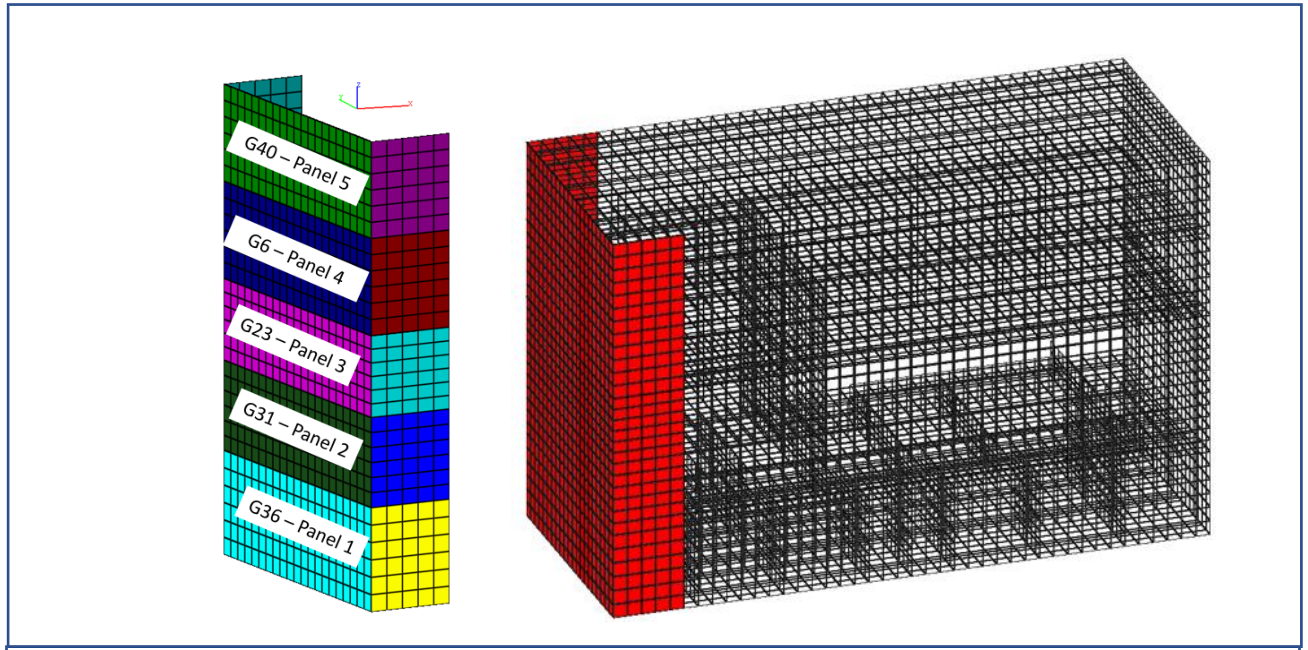


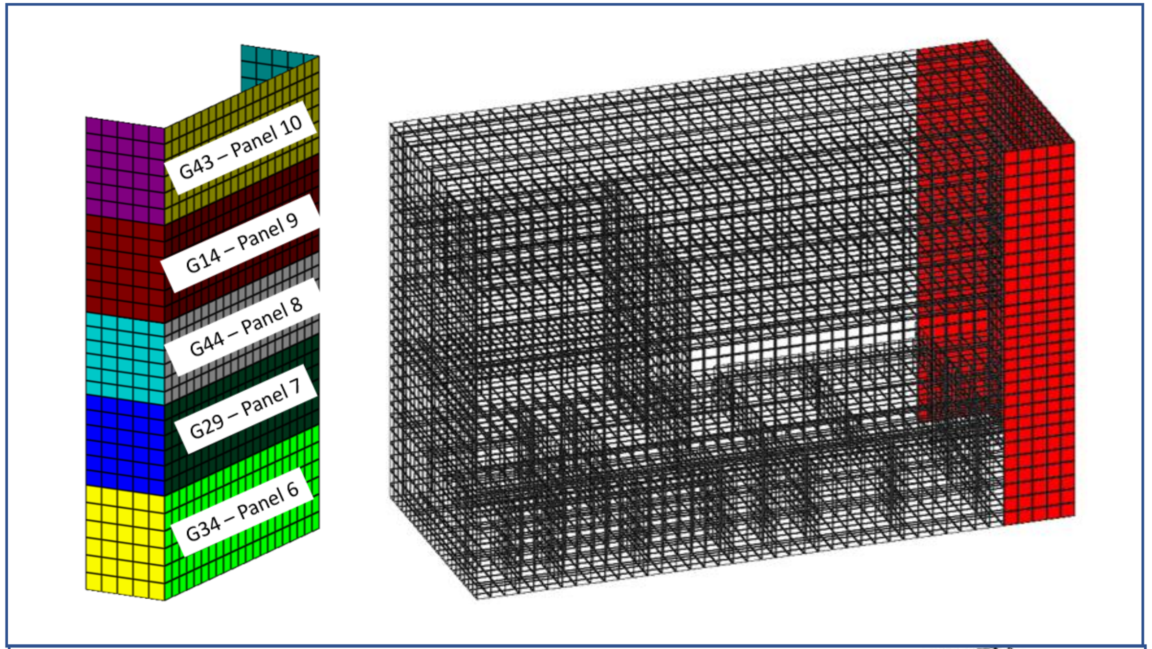
Use ACS SASSI UI Section-cut commands to split the 3DFEM model in Wall submodels (Shell Groups).

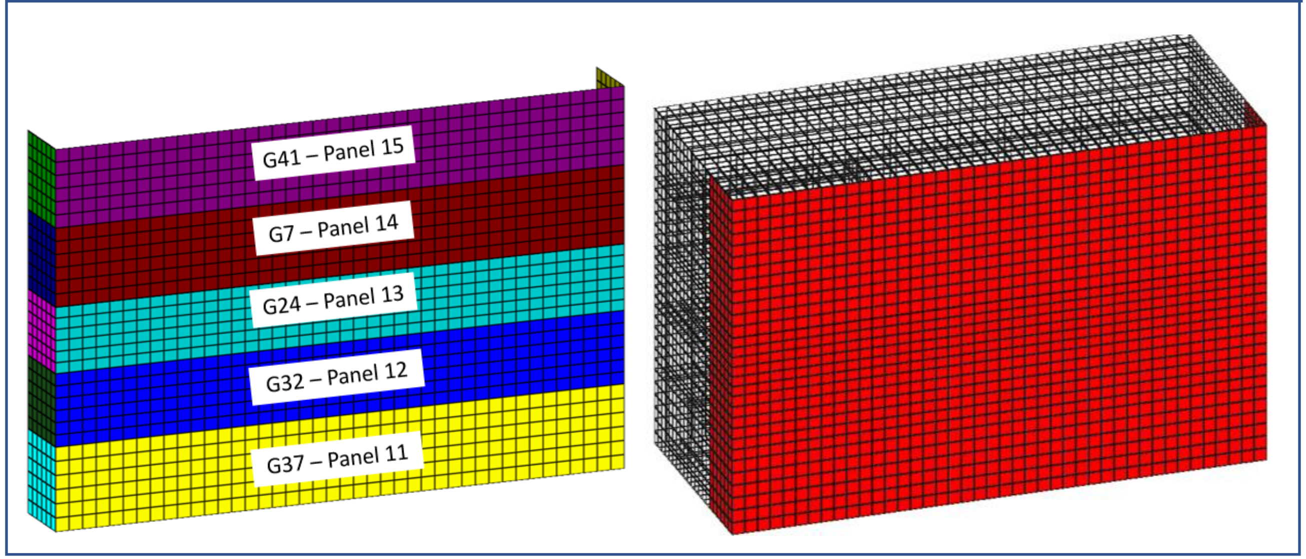


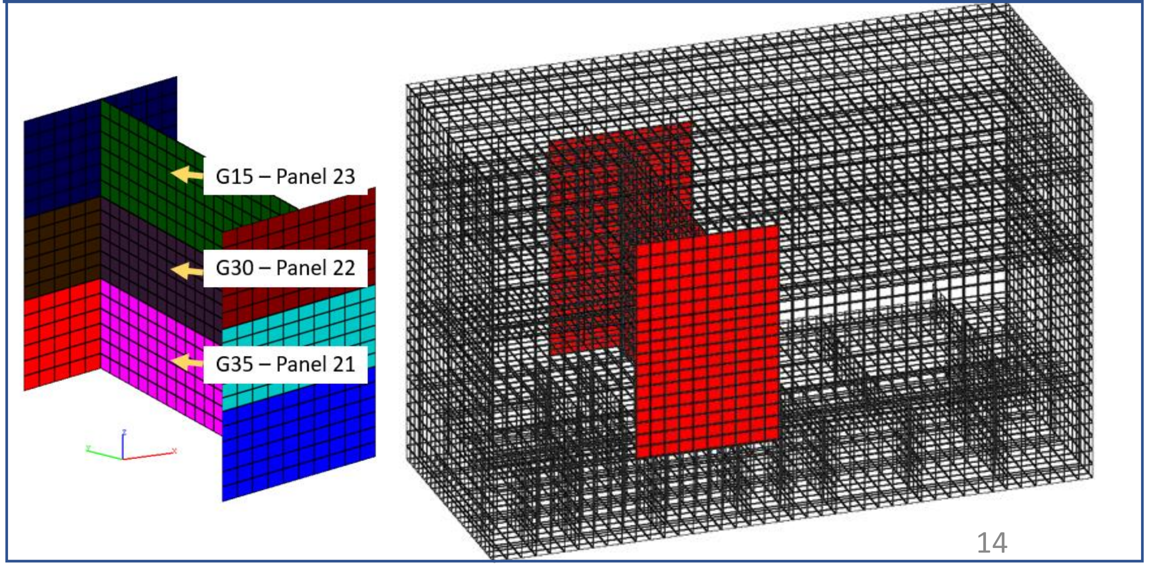
The 3DFEM and Wall submodel .pre file are used next to perform automatic section-cuts, section geometry identification for each wall submodel.

Examples of Splitting 3DFEM Model in Wall Submodels

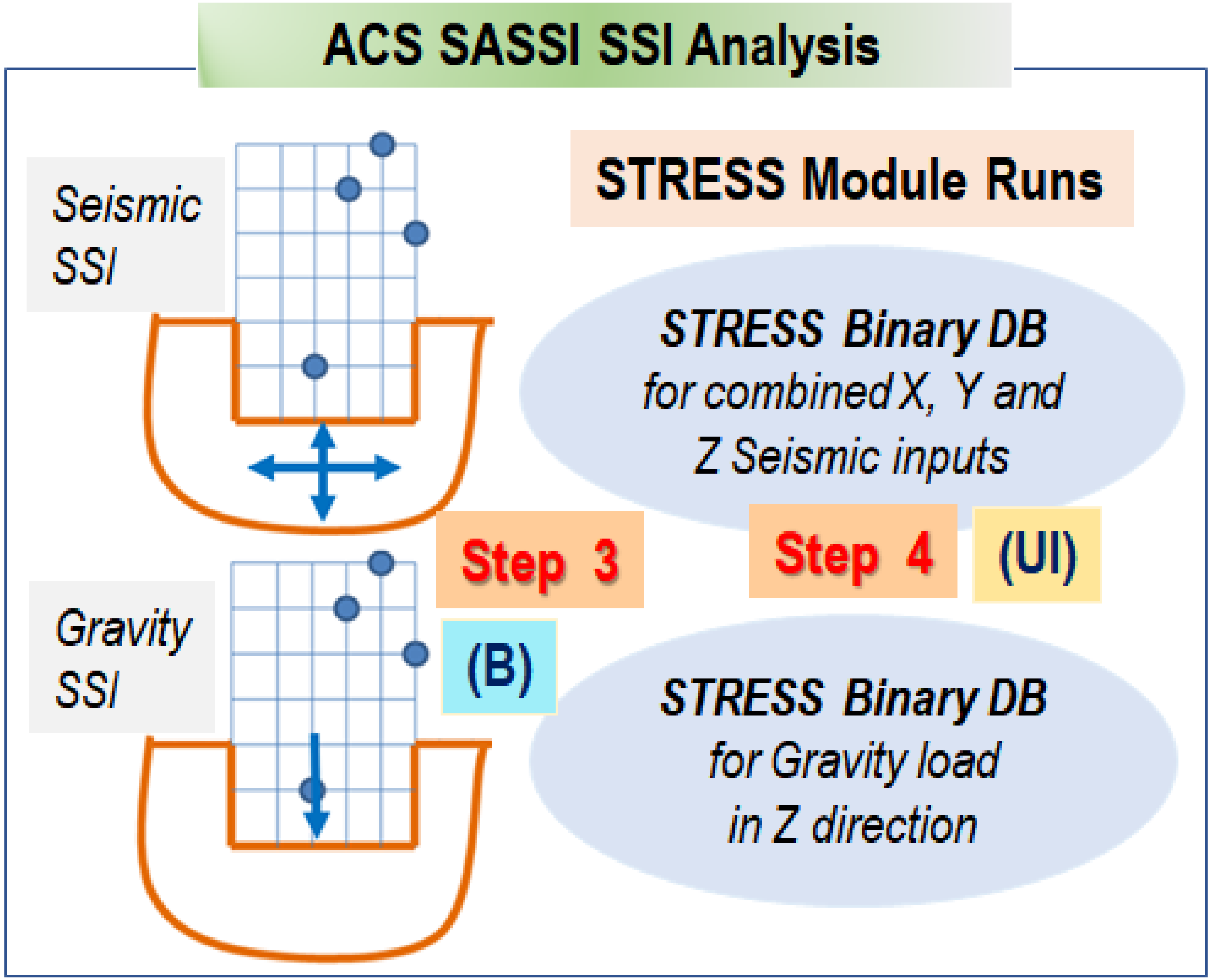








Steps 3: Perform SSI Analysis for Gravity and Seismic Loads



Step 3:

Perform SSI analysis (Batch)

1) Perform seismic ACS SASSI SSI analysis for the 3DFEM model using "Simultaneous Cases" ANALYS option to get FILE8s for post-processing

Step 4:

STRESS post-processing runs (Batch):

2) Run STRESS for the seismic inputs in X, Y and Z directions and create three binary DB for each input direction.

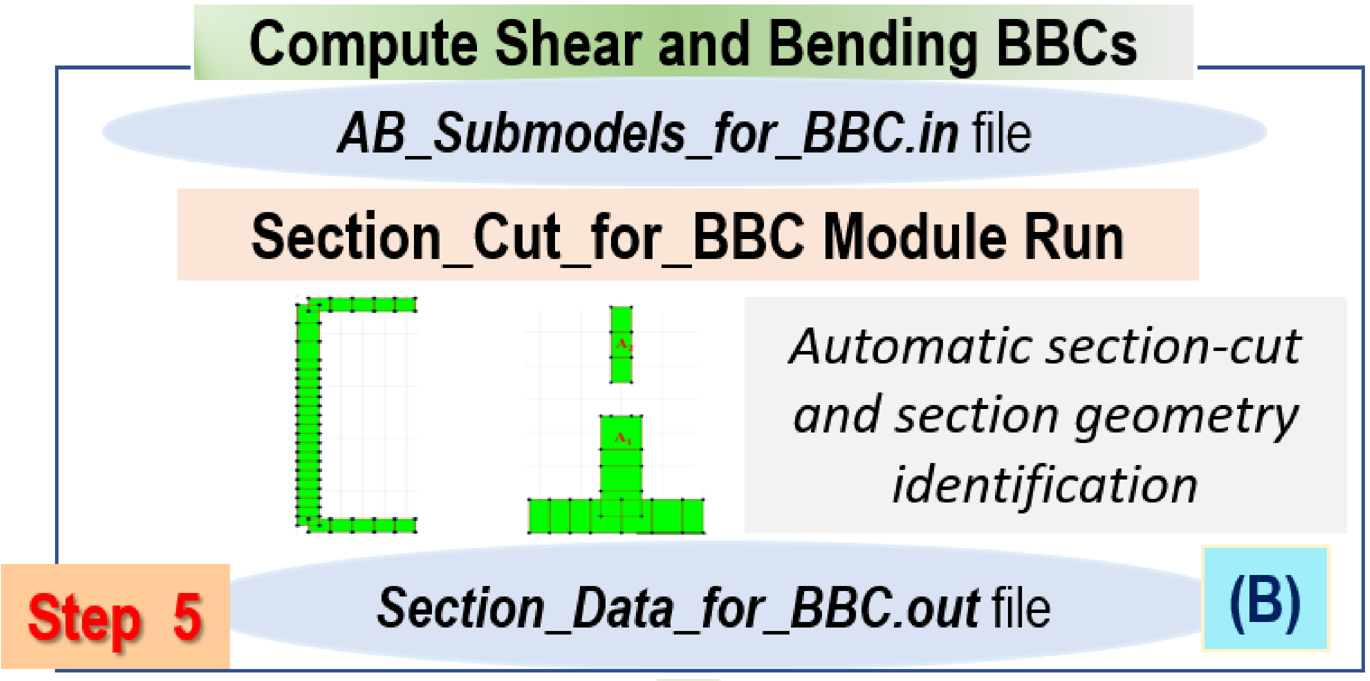
3) Run STRESS for the gravity (static) load for Z direction and create gravity binary DB

Combine Three Seismic STRESS binary BD:

4) Use COMBTHSDB to combine the seismic binary DBs for X, Y and Z in a single binary DB.

The Gravity and Seismic binary DBs are used in Step 5 for automatic section-cut calculations.

Section_Cut_for_BBC Module Run and Files (Step 5)



Step 5:

Batch *Section_Cut_for_BBC* Module_runs:
This module performs automatic section-cuts and identify the section geometries for all floor levels.

Output files:
The *Section_Data_for_BBC.out* output file produced by the run includes section-cut forces and geometry to be reviewed by the user in Step 6.

The *Modelname_Section_Data.out* as the general output file with input data and section geometry results.

The *Modelname_Section_Data.txt* , *output* file with the section data and other required input data for next step

Analyst Review of Section_Data_for_BBC.out File (Step 6)

Step 6:
Analyst shall edit the *Section_Data_for_BBC.out* file for checking the automatic generated section-cut geometries (web and effective flanges sizes including floor openings effects). The analyst can modify section parameters based on engineering judgements and need to input concrete and steel nonlinear material parameters. Analyst should save the revised file as *Revised_Section_Data_for_BBC.in* file. This file is used as an input of Step 7.

Section data are provided in international units (kN and m)

User Section Review Adding RC Material Inputs

Step 6 *Revised_Section_Data_for_BBC.in* file

Automatic Section_Data_for_BBC.out

```
 5
-8.0264     0.0000     16.764
 1
  0.949395E+05   0.336417E+07   0.153516E+06
-3.3650     7.9827     1.5240     7.9827     1.5240     24.079     1.5240     5.0674     5.0674
 0
0.0000     0.0000     0.0000     0.0000
  0.248546E+08   0.106216E+08   0.0000E+00   0.0000E+00   0.000000E+00   0.000000E+00   0.0000E+00
 2
  0.964498E+05   0.223449E+07   0.193119E+06
 4.7488     7.9827     1.5240     7.9827     1.5240     24.079     1.5240     7.3088     7.3088
 0
0.0000     0.0000     0.0000     0.0000
  0.248546E+08   0.106216E+08   0.0000E+00   0.0000E+00   0.000000E+00   0.000000E+00   0.0000E+00
```

Revised_Section_Data_for_BBC. in (Step 6)

```
 5
-8.0264     0.0000     16.764
 1
  0.949395E+05   0.336417E+07   0.153516E+06
-3.3650     7.9827     1.5240     7.9827     1.5240     24.079     1.5240     5.0674     5.0674
 0
1.1950     1.5980     1.2460     0.95300
  0.248546E+08   0.330000E+05   0.2000E-02   0.4000E-02   0.205000E+09   0.345000E+06   0.1850E-02
 2
  0.964498E+05   0.223449E+07   0.193119E+06
 4.7488     7.9827     1.5240     7.9827     1.5240     24.079     1.5240     7.3088     7.3088
 0
1.1950     1.5980     1.2460     0.95300
  0.248546E+08   0.330000E+05   0.2000E-02   0.4000E-02   0.205000E+09   0.345000E+06   0.1850E-02
```

Revised_Section_Data_for_BBC.in File Data Description

Input Parameters for Each Wall Submodel:

Line 1: NSECT which is total number of wall sections

Line 2: ZBOT, AL, AR where

ZBOT = The Z coordinate of the foundation mat top level.

AL = The wall left span clearance.

AR = The wall right span clearance.

Loop lines 3-8 for all sections (defined at mid-height of each floor):

Line 3: ID which is the order number of the wall section from wall bottom to the wall top

Line 4: N, M and Q (units are either K and ft or kN and m), which are the Gravity N-axial force and the Seismic In-Plane M-moment and Q-shear force computed by automatic section-cut

Line 5: ZPTS, L1, T1, L2, T2, D, Tw, L1C, L2C (Geometry Section Data) where

ZPTS = Z coordinate of each wall panel bottom

L1 = Flange 1 length (top)

T1 = Flange 1 thickness (top)

L2 = Flange 2 length (bottom)

T2 = Flange 2 thickness (bottom)

D = Web length from the Flange 1 outer edge to the Flange 2 outer edge

Tw = Web thickness (real for wall with no opening, or equivalent thickness for wall with openings)

L1C = Flange 1 effective width based on AIJ RC standard equations for beams

L2C = Flange 2 effective width based on AIJ RC standard equations for beams

Revised_Section_Data_for_BBC.in File Data Description

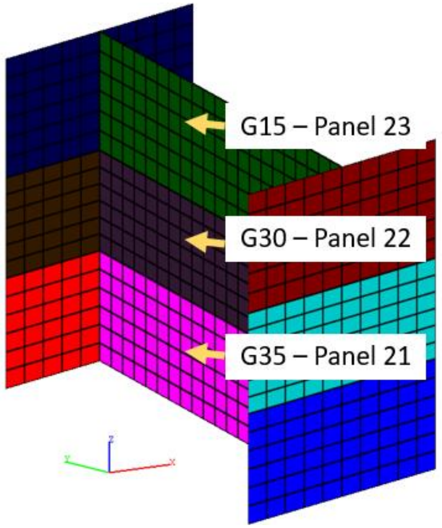
Line 6: NOPN, X0S, X0I, Z0S, Z0I, X1S, X1I, Z1S, Z1I (Openings explicitly defined) where
NOPEN = Total number of openings of the wall
X0S, X1S, … = Superior X coordinates at the top of each wall panel opening
X0I, X1I, … = Inferior X coordinates at the bottom of each wall panel opening
Z0S, Z1S, … = Superior Z coordinates at the top of each wall panel opening
Z0I, Z1I , … = Inferior Z coordinates at the bottom of each wall panel opening
Line 7: PVf1, PVf2, PVw, PHw (Wall Reinforcement Percentage)
PVf1 = Reinforcement percentage for Flange 1 (top)
PVf2 = Reinforcement percentage for Flange 2 (bottom)
PVw = Reinforcement percentage for Web (vertical)
PHw = Reinforcement percentage for Web (horizontal)
Line 8: Ec, Fc, Epsc_y, Epsc_u, Es, Fs, Epss_y, Epss_u
Ec = Concrete E modulus
Fc = Concrete Fc strength
Epsc_y = Concrete Yielding strain
Epsc_u = Concrete Ultimate strain
Es – Steel E modulus
Fs – Steel Fy yielding
Epss_y – Steel Yielding strain
Epss_u – Steel Ultimate strain

These are parameters shall be input by analyst for each wall submodel

Repeat line 3 to line 8 for all the sections of the wall.

Revised_Section_Data_for_BBC.in Input for *BBC_JEAC_4601_2015 Module*

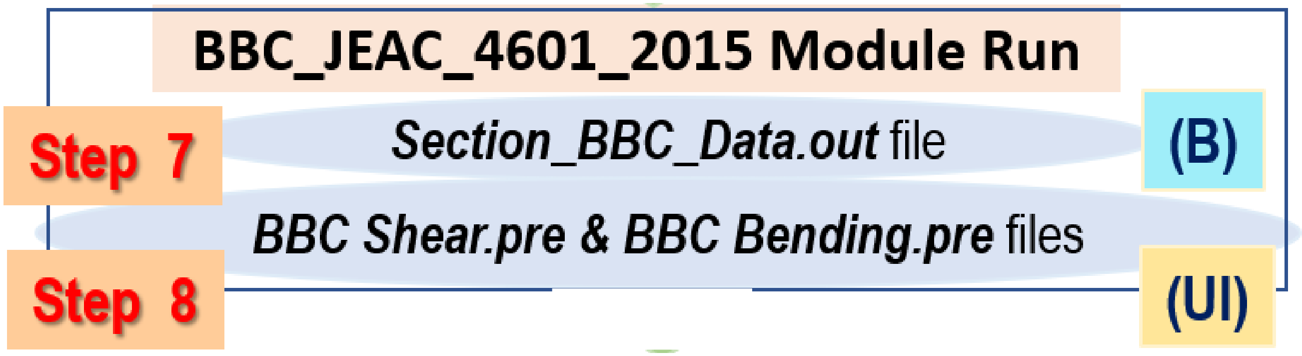
Example for Wall 5 with 3 Floors (and Sections)




```
 3
-8.0264    16.764    40.843
 1
  0.264106E+05   0.409823E+06   0.404182E+05
4.7488    14.441    1.5240    14.441    1.5240    24.079    1.5240    13.801    13.801
 0
1.1950    1.5980    1.2460    0.95300
0.248546E+08   0.3300E+05  0.200E-02  0.400E-02   0.205000E+09   0.3450E+06  0.185E-02  0.500E-01
 2
  0.228232E+05   0.188437E+06   0.358970E+05
11.924    14.441    1.5240    14.441    1.5240    24.079    1.5240    17.650    17.650
 0
1.1950    1.5980    1.2460    0.95300
0.248546E+08   0.3300E+05  0.200E-02  0.400E-02   0.205000E+09   0.3450E+06  0.185E-02  0.500E-01
  3
  0.124042E+05   0.371685E+05   0.215392E+05
19.391    14.441    1.5240    14.441    1.5240    24.079    1.5240    20.946    20.946
 0
1.1950    1.5980    1.2460    0.95300
0.248546E+08   0.3300E+05  0.200E-02  0.400E-02   0.205000E+09   0.3450E+06  0.185E-02  0.500E-01
```

Section data are provided only in International system (kN and m)

BBC_JEAC_4601_2015 Module Run and Files (Step 7 and 8)



Step 7:

Batch *BBC_JEAC_4601_2015* Module_run:

This module computes the shear and bending BBC for each Wall submodel based on JEAC 4601-2015 App.3.7 approaches. For the shear BBC, the ultimate state shear stress is computed for both exterior walls (App.3.7 equations) and internal walls (Ref.App.3.7-14).

Output files for each RC Wall Submodel:

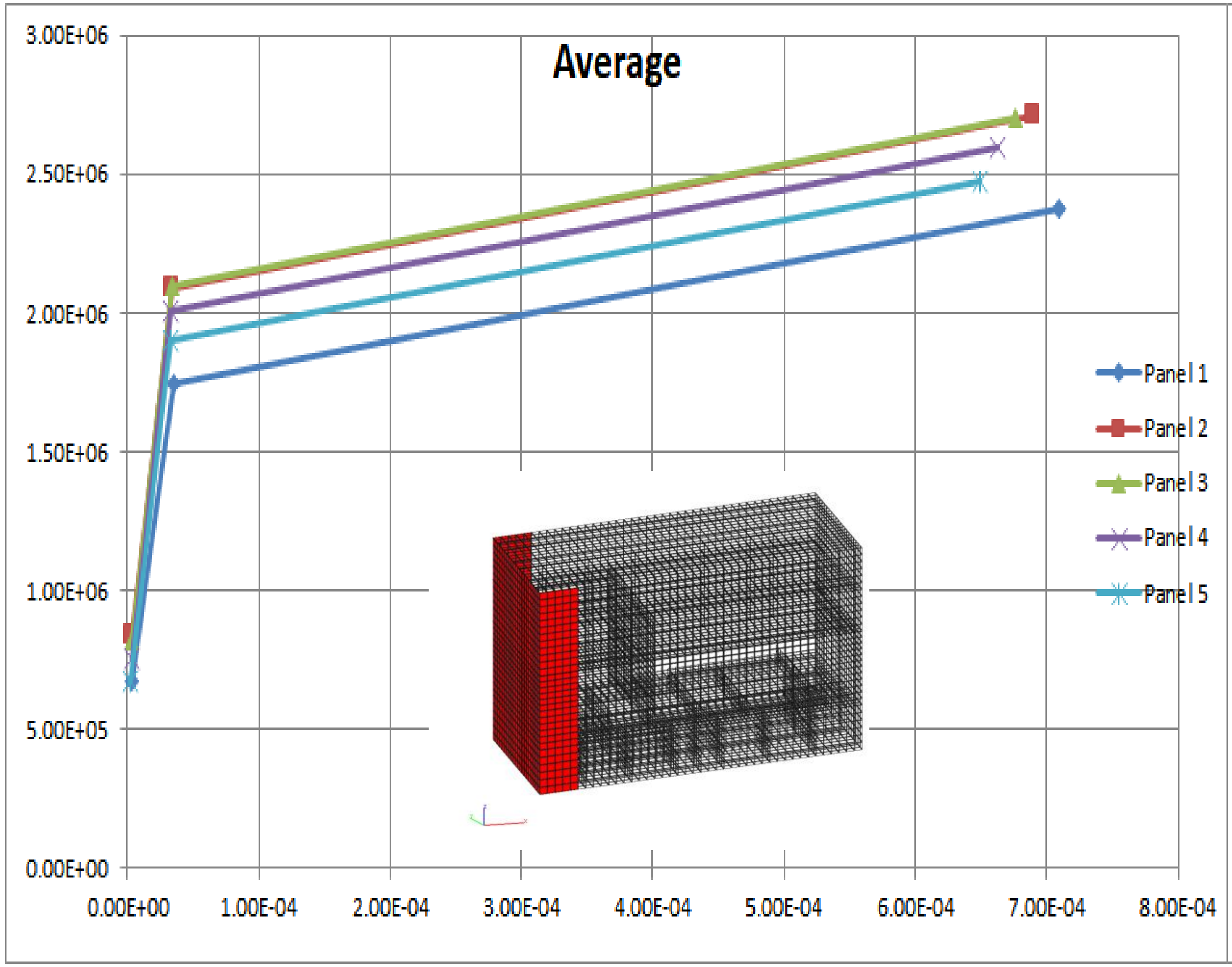
The computed shear BBC are saved in two text files, namely *Modelname_BBC_.out and BBC_Shear.pre.* The units in the output file are N and mm for International units or Kip and ft for British units and it depends on how the 3DFEM model is defined in the .pre input file. The output file contains the computed shear stress in N/mm2, while in the BBC_Shear.pre file the shear force in given kN or Kip.

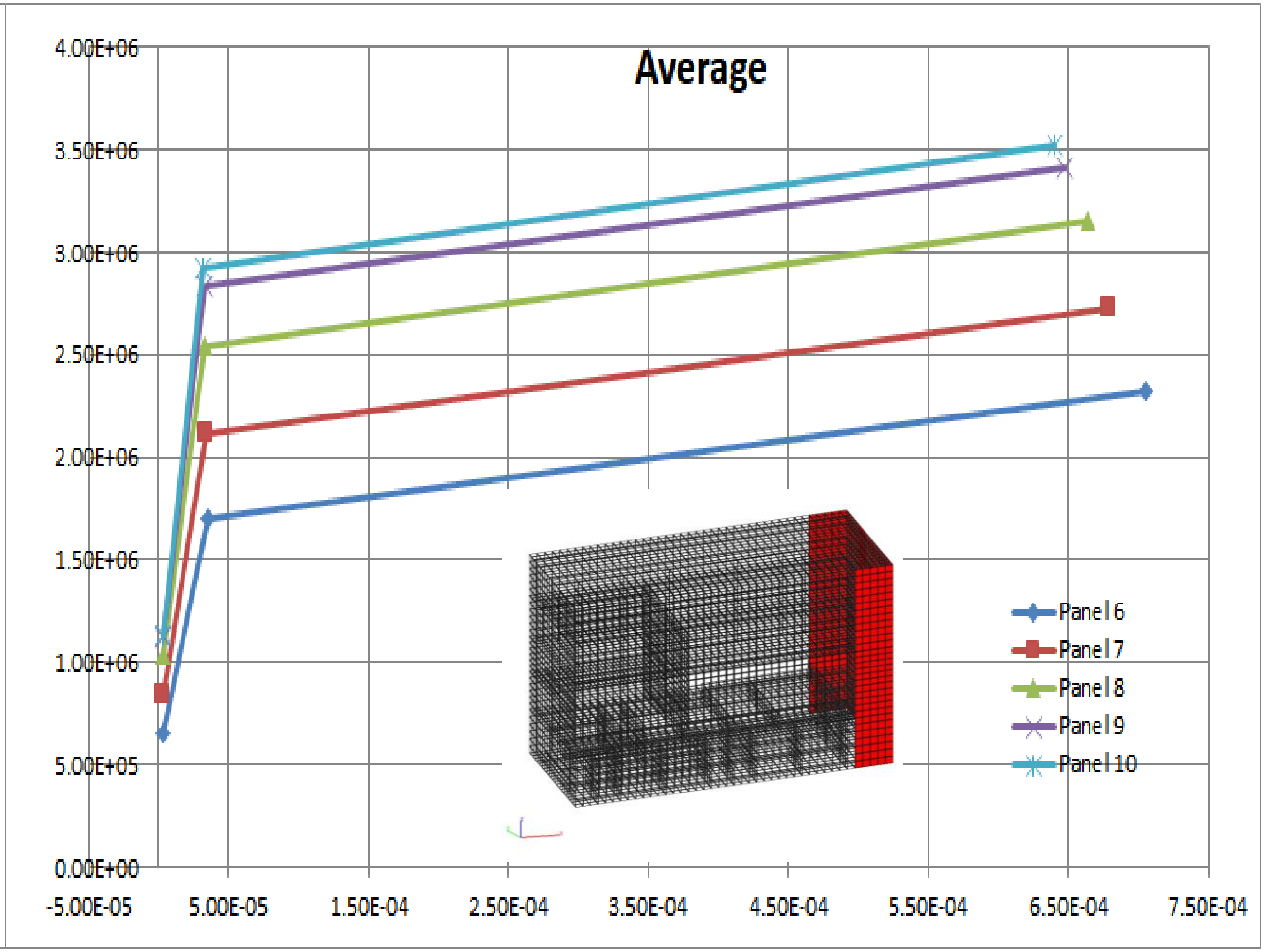
The computed bending BBC are saved in three files, the *BBC_JEAC_4601_Data.out* file *and two BBC_Bending.pre* files, one .pre file for minimum moments and one .pre file for average moments. The minimum and average moments are computed based on two cases: 1) Flange 1 is in compression and 2) Flange 1 is in tension. The moment units in the output file are kN-m, while in the *BBC_Bending.pre files* is given in kN-m or Kip-ft. Analyst has to decide if uses minimum or average moments.

Step 8:

User needs to integrate the computed BBC which are in the shear and bending BBC .pre files with the 3DFEM .pre file, or read directly the BBC .pre files with the UI, and then using AFWRITE to create the .eql file that is the necessary input file for the NONLINEAR module.

Bending BBCs Computed for External and Internal Walls Using BBC_JEAC_4601_2015 Module





Modelname_Wall#.txt File With Section Data Based on JEAC 4601 (Step 7)

Section Geometries and Material Properties

Geometric Input Data:

Z Coordinate of Wall Bottom: -8.026

				Web			North Flange			South Flange		
Section#	Z-Location	Ic	Ie	Dw	Tw	Pvw	L1	T1	Pvf1	L2	T2	Pvf2
		(m4)	(m4)	(mm)	(mm)	(%)	(mm)	(mm)	(%)	(mm)	(mm)	(%)
1	-3.3650	3149.	3444.	24079.	1524.	1.246	5067.	1524.	1.195	5067.	1524.	1.598
2	4.7488	4019.	4400.	24079.	1524.	1.246	7309.	1524.	1.195	7309.	1524.	1.598
3	11.9240	4318.	4728.	24079.	1524.	1.246	8078.	1524.	1.195	8078.	1524.	1.598
4	19.3910	4502.	4931.	24079.	1524.	1.246	8553.	1524.	1.195	8553.	1524.	1.598
5	27.4960	4610.	5050.	24079.	1524.	1.246	8832.	1524.	1.195	8832.	1524.	1.598

Material Properties:

Section#	AS	Fc	Ec	Gc	epsc_y	epsc_u	Fs	Es	Gs	epss_y	epss_u	sigm_v	Pv	Ph
	(m2)	(N/mm2)	(N/mm2)	(N/mm2)	(%)	(%)	(N/mm2)	(N/mm2)	(N/mm2)	(%)	(%)	(N/mm2)	(%)	(%)
1	32.05	33.00	24855.	10356.	0.200	0.400	379.50	205000.	85417.	0.185	5.000	1.821	1.246	0.953
2	32.05	33.00	24855.	10356.	0.200	0.400	379.50	205000.	85417.	0.185	5.000	1.635	1.246	0.953
3	32.05	33.00	24855.	10356.	0.200	0.400	379.50	205000.	85417.	0.185	5.000	1.184	1.246	0.953
4	32.05	33.00	24855.	10356.	0.200	0.400	379.50	205000.	85417.	0.185	5.000	0.574	1.246	0.953
5	32.05	33.00	24855.	10356.	0.200	0.400	379.50	205000.	85417.	0.185	5.000	0.021	1.246	0.953

Shear BBC Information

Shear Force Outputs:

Section#	M/QD	Tao1	Gamma1	Tao2	Gamma2	Tao3 (EX.)	Tao3 (IN.)	Gamma3
		(N/mm2)		(N/mm2)		(N/mm2)	(N/mm2)	
1	0.910	2.5325	0.2445E-03	3.4189	0.7336E-03	5.9927	4.0886	0.4000E-02
2	0.481	2.4665	0.2382E-03	3.3298	0.7145E-03	6.4529	4.1516	0.4000E-02
3	0.322	2.2978	0.2219E-03	3.1020	0.6656E-03	6.5434	4.1287	0.4000E-02
4	0.208	2.0479	0.1977E-03	2.7647	0.5932E-03	6.5666	4.0803	0.4000E-02
5	0.191	1.7914	0.1730E-03	2.4184	0.5189E-03	6.4796	4.0320	0.4000E-02

Section data are provided only in International system (N and mm) per JEAC 4601 App. 3.7

Modelname_Wall#.txt File With Section Data Based on JEAC 4601 (Step 7)

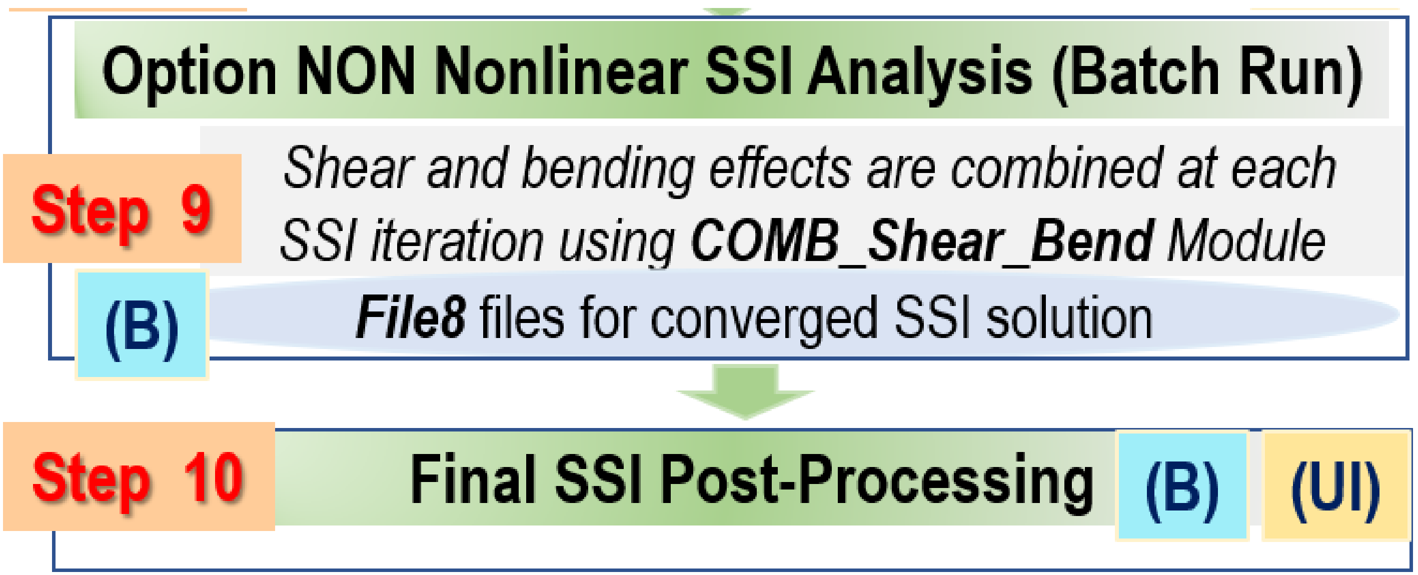
Bending BBC Information

Bending Moment Outputs:

Section#	Load Direction	Cx (mm)	Ze (m3)	M1 Calculation) Mc (KN*M) Value	Mc (KN*M) Average	Mc (KN*M) Minimum	Phi (1/m) Value	Phi (1/m) Average	Phi (1/m) Minimum
1	1	12040.	286.	0.1145E+07			0.1464E-04		
1	2	12040.	286.	0.1145E+07	0.1145E+07	0.1145E+07	0.1464E-04	0.1464E-04	0.1464E-04
2	1	12040.	365.	0.1395E+07			0.1397E-04		
2	2	12040.	365.	0.1395E+07	0.1395E+07	0.1395E+07	0.1397E-04	0.1397E-04	0.1397E-04
3	1	12039.	393.	0.1322E+07			0.1232E-04		
3	2	12039.	393.	0.1322E+07	0.1322E+07	0.1322E+07	0.1232E-04	0.1232E-04	0.1232E-04
4	1	12040.	410.	0.1129E+07			0.1009E-04		
4	2	12040.	410.	0.1129E+07	0.1129E+07	0.1129E+07	0.1009E-04	0.1009E-04	0.1009E-04
5	1	12040.	419.	0.9245E+06			0.8068E-05		
5	2	12040.	419.	0.9245E+06	0.9245E+06	0.9245E+06	0.8068E-05	0.8068E-05	0.8068E-05

M2 Calculation Mc (KN*M) Value	Mc (KN*M) Average	Mc (KN*M) Minimum	Phi (1/m) Value	Phi (1/m) Average	Phi (1/m) Minimum	M3 Calculation Mc (KN*M) Value	Mc (KN*M) Average	Mc (KN*M) Minimum	Phi (1/m) Value	Phi (1/m) Average	Phi (1/m) Minimum
0.2873E+07			0.1119E-03			0.3791E+07			0.2006E-02		
0.2628E+07	0.2751E+07	0.2628E+07	0.1102E-03	0.1110E-03	0.1102E-03	0.3534E+07	0.3662E+07	0.3534E+07	0.2204E-02	0.2105E-02	0.2006E-02
0.3424E+07			0.1083E-03			0.4331E+07			0.2166E-02		
0.3060E+07	0.3242E+07	0.3060E+07	0.1064E-03	0.1073E-03	0.1064E-03	0.3943E+07	0.4137E+07	0.3943E+07	0.2127E-02	0.2147E-02	0.2127E-02
0.3365E+07			0.1052E-03			0.4239E+07			0.2104E-02		
0.2959E+07	0.3162E+07	0.2959E+07	0.1033E-03	0.1042E-03	0.1033E-03	0.3809E+07	0.4024E+07	0.3809E+07	0.2065E-02	0.2085E-02	0.2065E-02
0.3100E+07			0.1017E-03			0.3933E+07			0.2035E-02		
0.2671E+07	0.2885E+07	0.2671E+07	0.9971E-04	0.1007E-03	0.9971E-04	0.3479E+07	0.3706E+07	0.3479E+07	0.1994E-02	0.2014E-02	0.1994E-02
0.2811E+07			0.9840E-04			0.3601E+07			0.1968E-02		
0.2360E+07	0.2586E+07	0.2360E+07	0.9665E-04	0.9752E-04	0.9665E-04	0.3135E+07	0.3368E+07	0.3135E+07	0.1933E-02	0.1950E-02	0.1933E-02

Option NON SSI Analysis and Post-Processing (Steps 9 and 10)



Step 9:

Option NON Nonlinear SSI Analysis Batch Run

The new Option NON includes new hysteretic models (2 JEAC 4601 models and 2 Hybrid models) applicable for both the shear and bending wall in-plane deformation for 3DFEM (Shell models). The shear and bending deformation can be combined using the *COMB_Shear_Bend* module as described in detail in Demo 17.

Step 10:

Post-Processing:

The main results of the nonlinear SSI analysis are the FILE8 and FILE4 (.n4) files for the converged solution that can be post-processed exactly like for a linear analysis to compute structural node displacements and accelerations, and element stresses.

New Hysteretic Models for RC Walls Included In Option NON

The previous Option NON included only four hysteretic models, out of which only three models are usable for RC wall nonlinear modeling, such as Cheng-Mertz Shear (CMS, Model 1) and Cheng-Mertz Bending (CMB, Model 2) and Takeda (TAK, Model 3).

Four New Hysteretic Models:

1) *JEAC 4601 PO Shear (PO, Model 5) – see App 3.7 in JEAC 4601-2015.* No hysteretic damping.

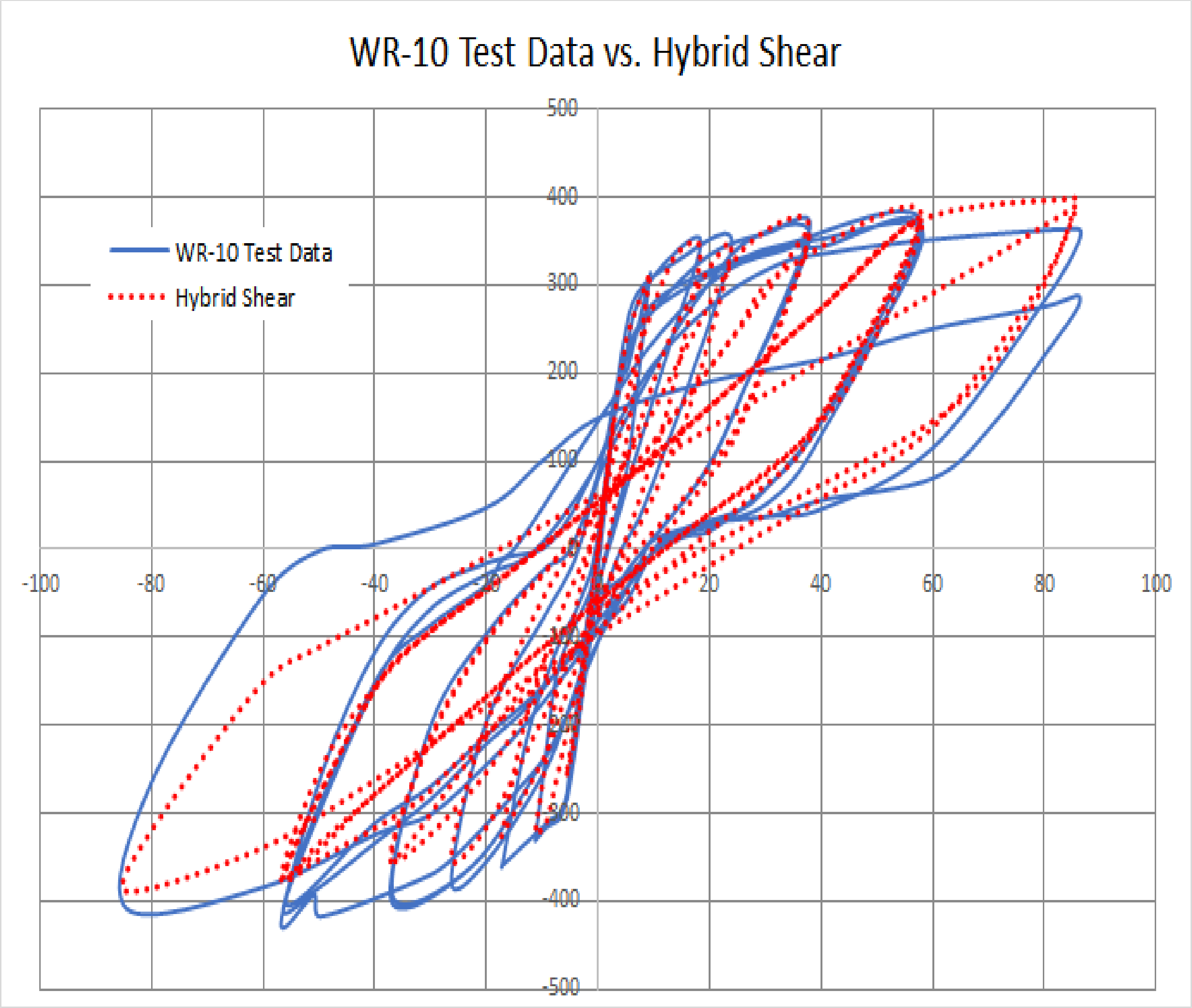
2) *JEAC 4601 PODT Bending (PODT, Model 6) – see App 3.7 in JEAC 4601-2015.* No hysteretic damping before yielding and 15% hysteretic damping at failure.

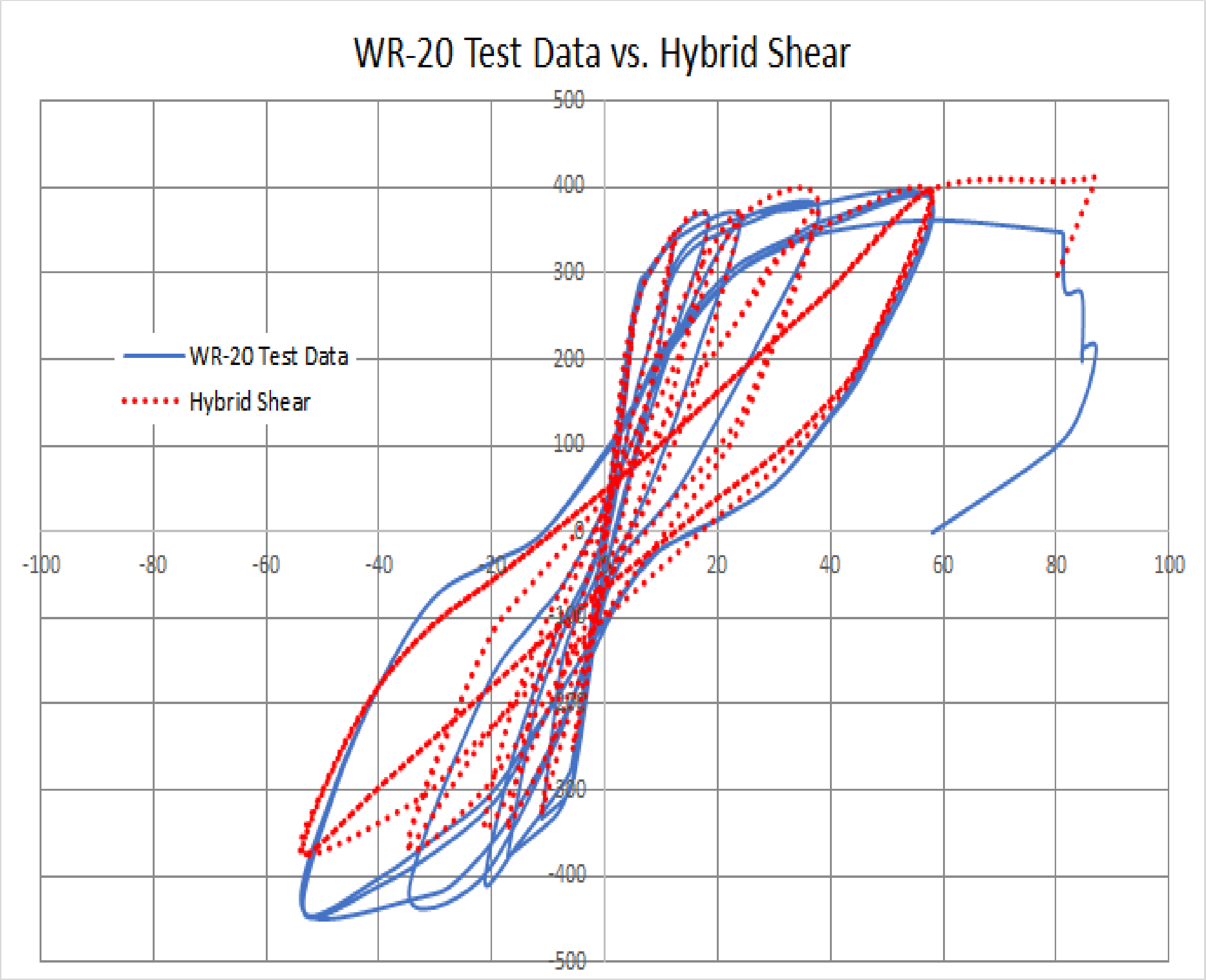
3) *Hybrid Shear (HYS, Model 7).* Is combination of the JEAC 4601 PO Shear and CM Shear models. Less damping than CMS (CMS, Model 1) model and more damping than JEAC 4601 PO Shear model.

4) *Hybrid Bending (HYB, Model 8).* Is a combination of the JEAC 4601 PODT and CMB model. Less damping than CMB (CMB, Model 2) and more damping than JEAC 4601 PODT Bending model.

Validation of Option NON Hysteretic Models vs. Wall Tests [Ref.1]

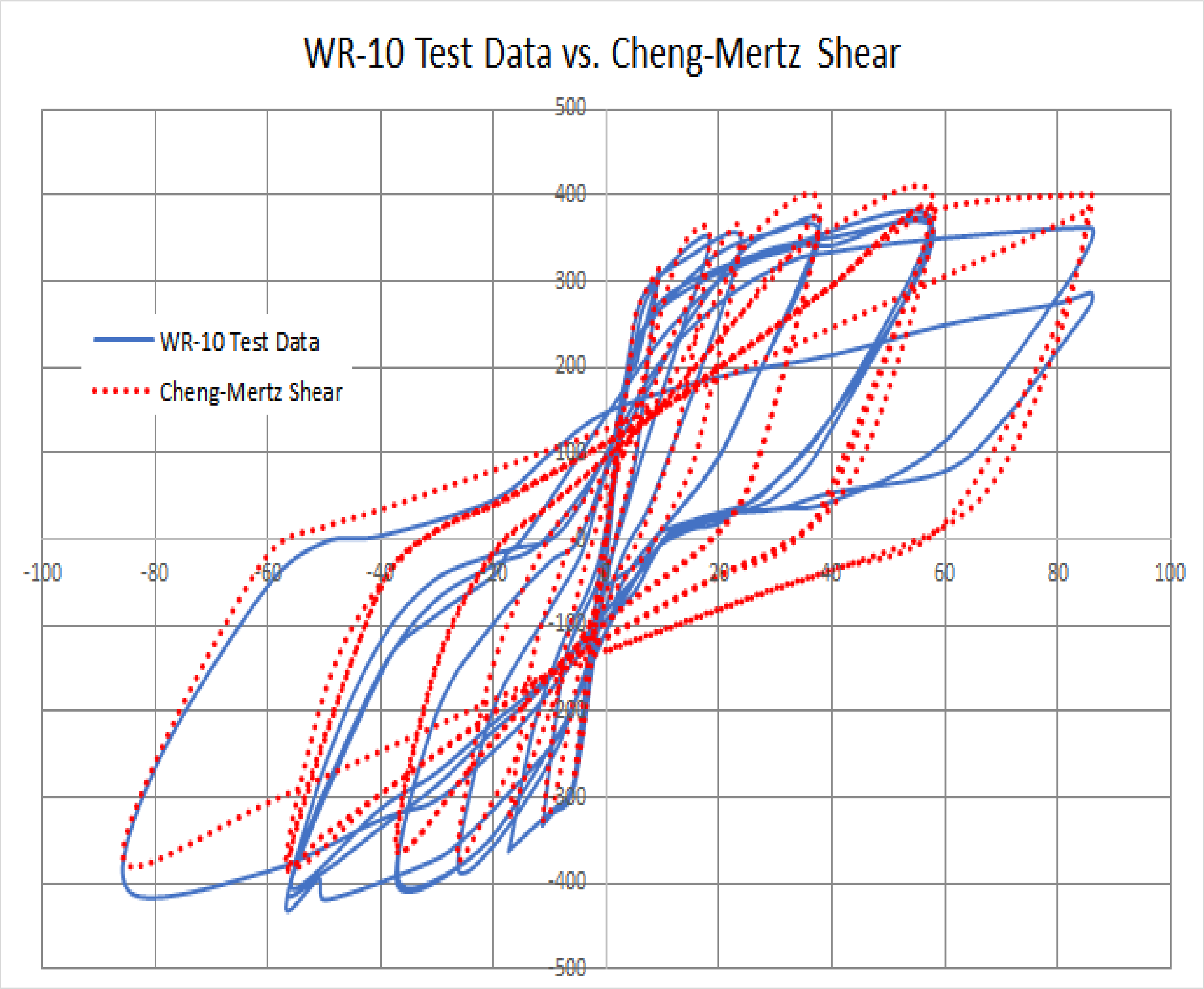
Hybrid Shear Model (Model 7)

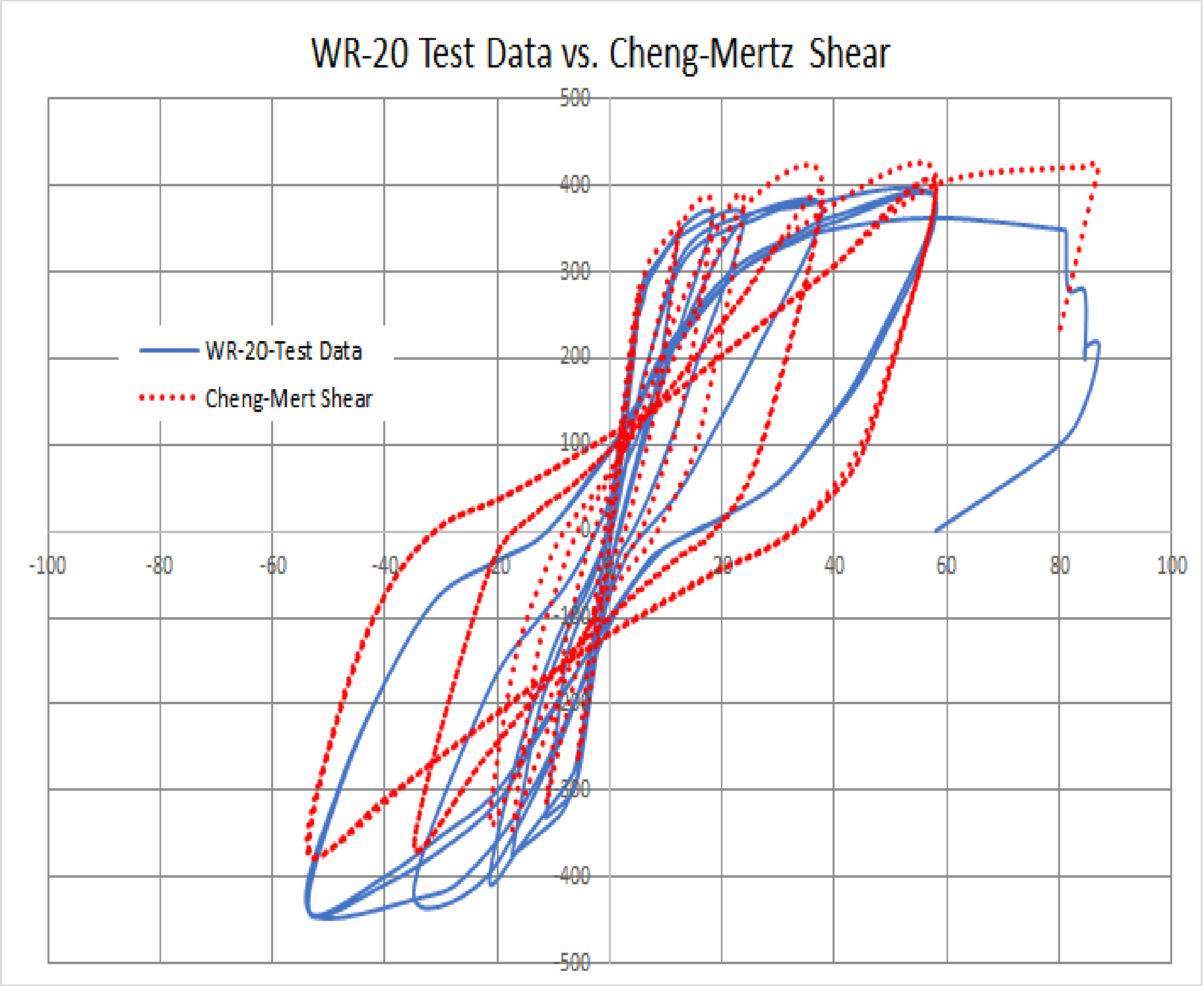




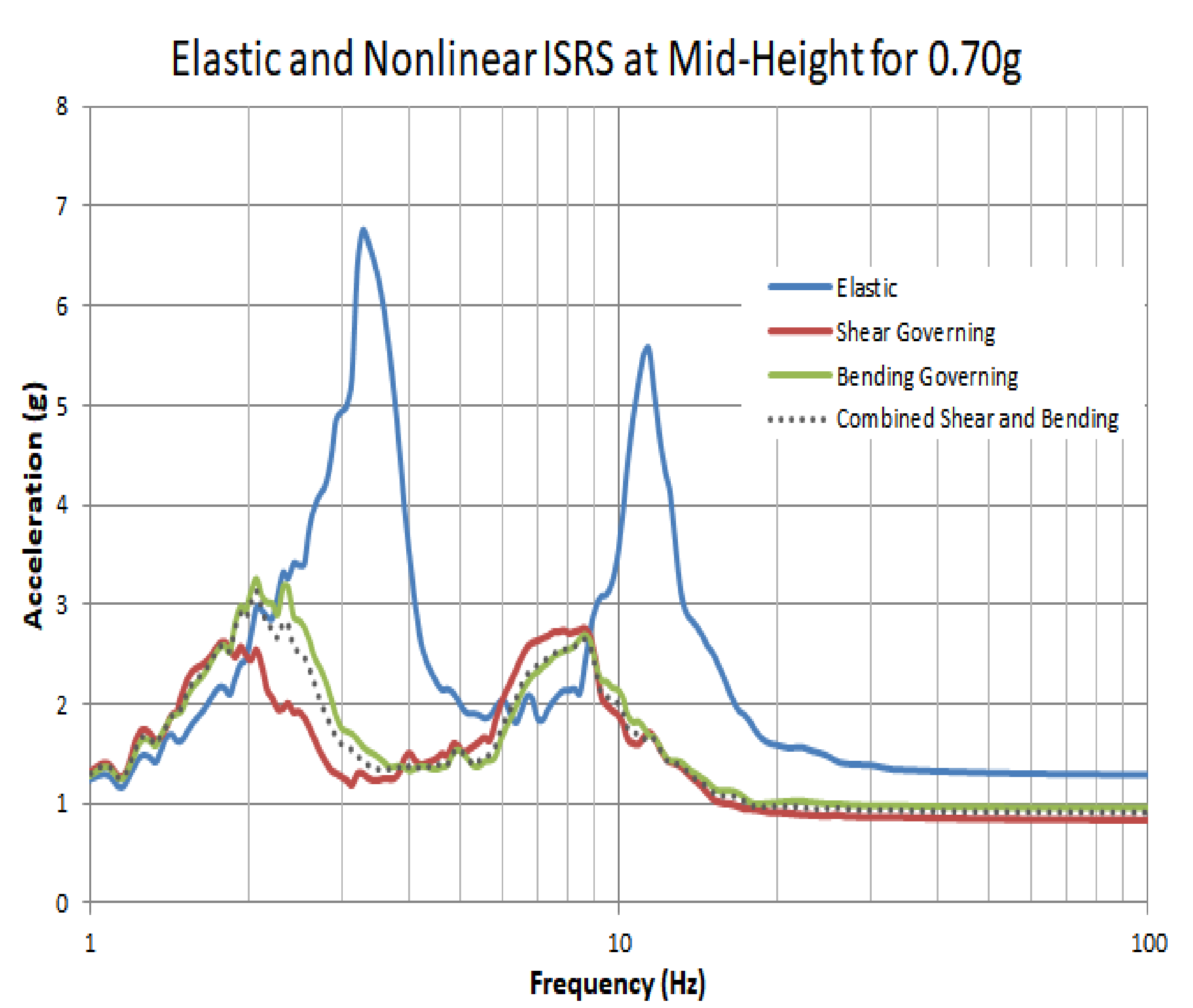
Validation of Option NON Hysteretic Models vs. Wall Tests [Ref.1]

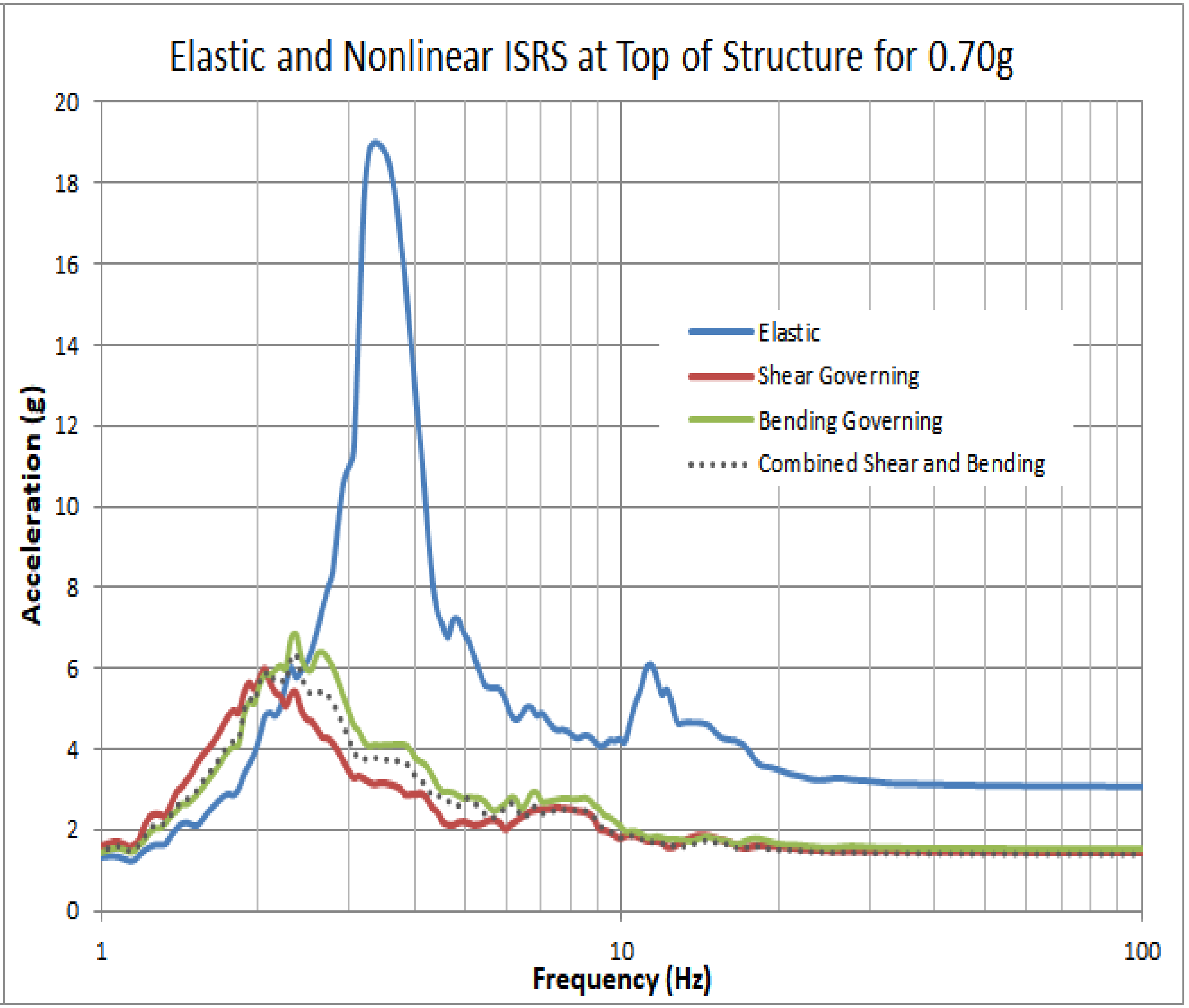
Cheng-Mertz Shear Model (Model 1)





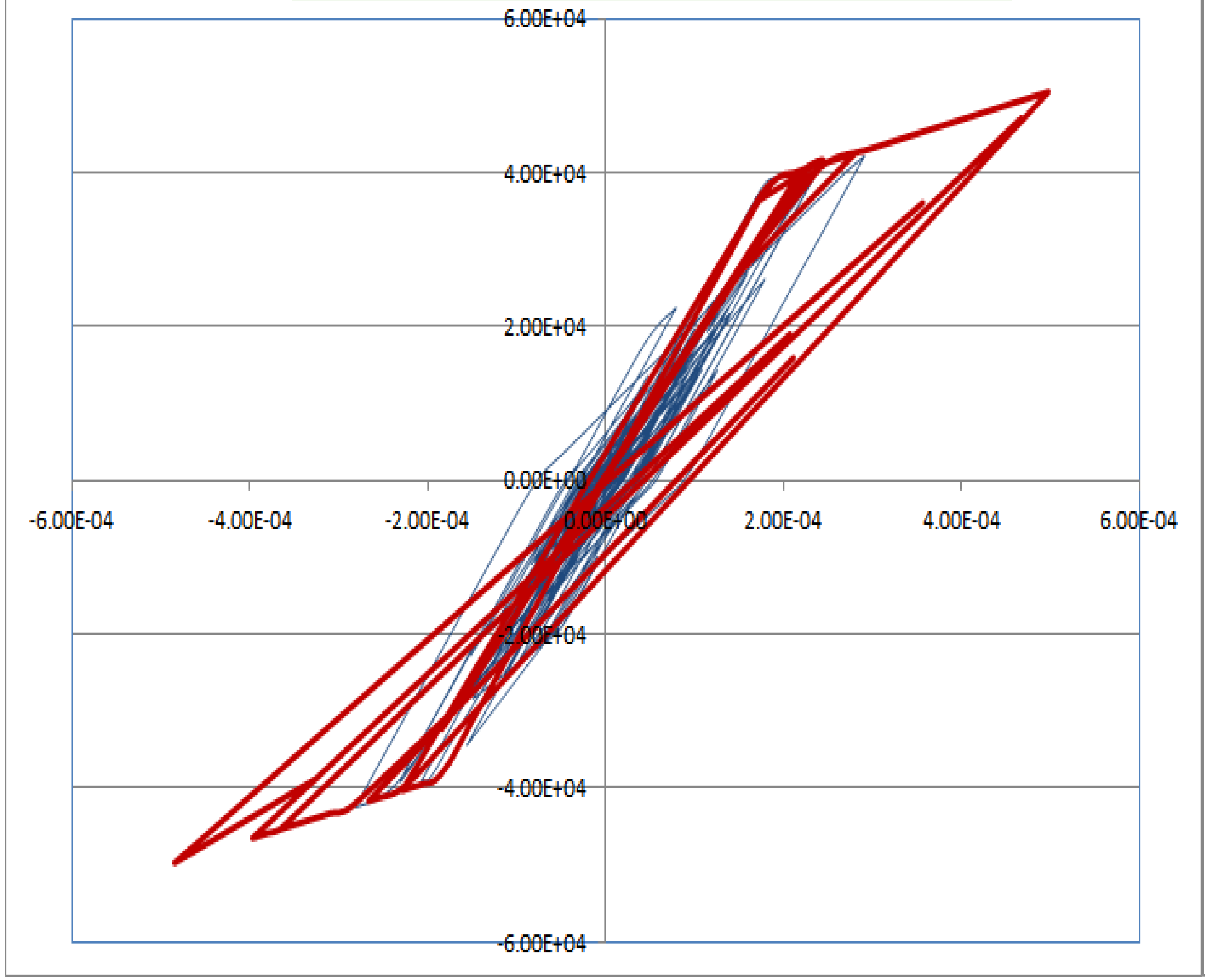
Nonlinear ISRS for CM Hysteretic Model: 1) Shear Governing, 2) Bending Governing and 3) Combined Shear and Bending



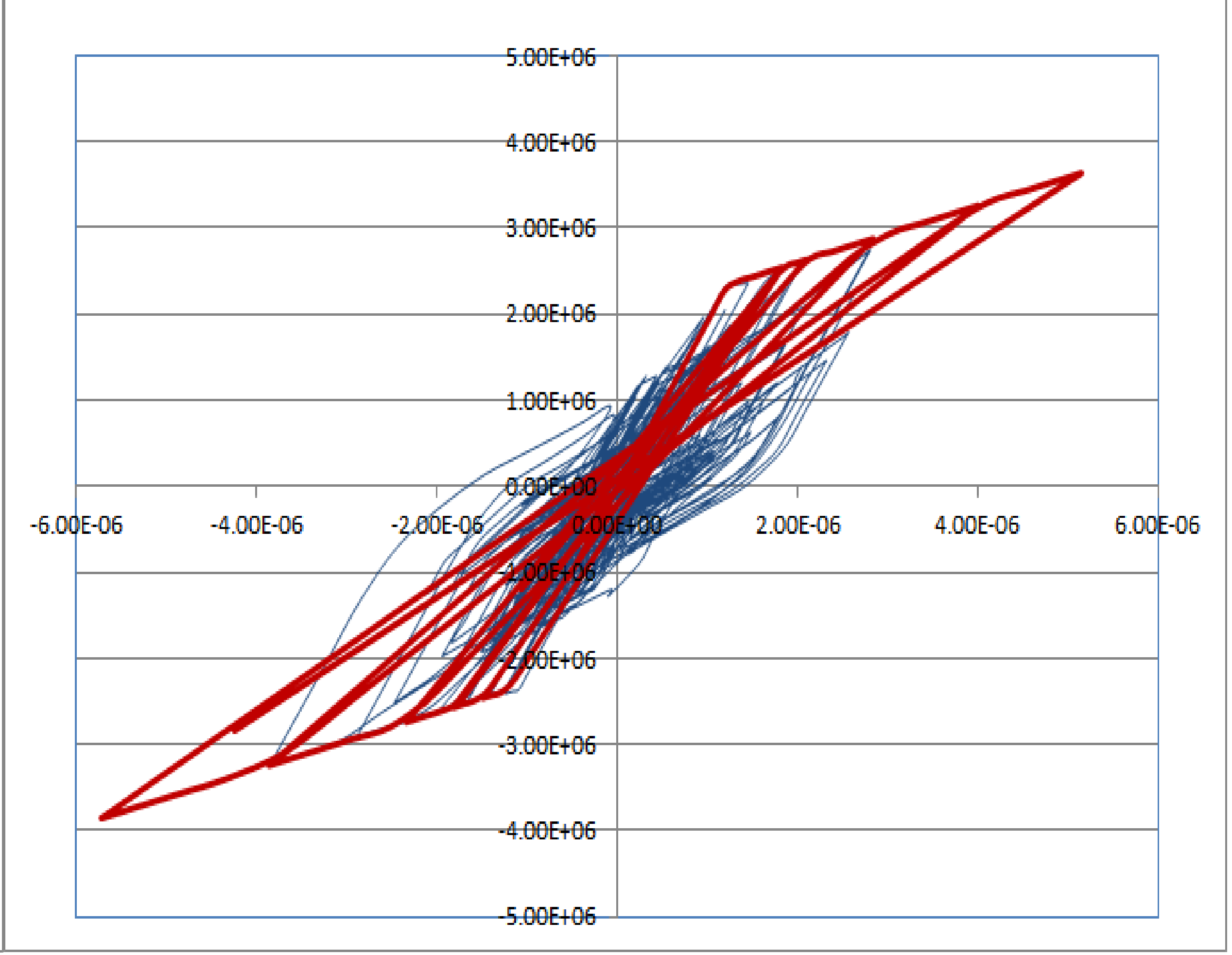


Comparisons of JEAC 4601 Max. PO and Cheng-Mertz Model Hysteretic Responses for Both Shear and Bending Effects

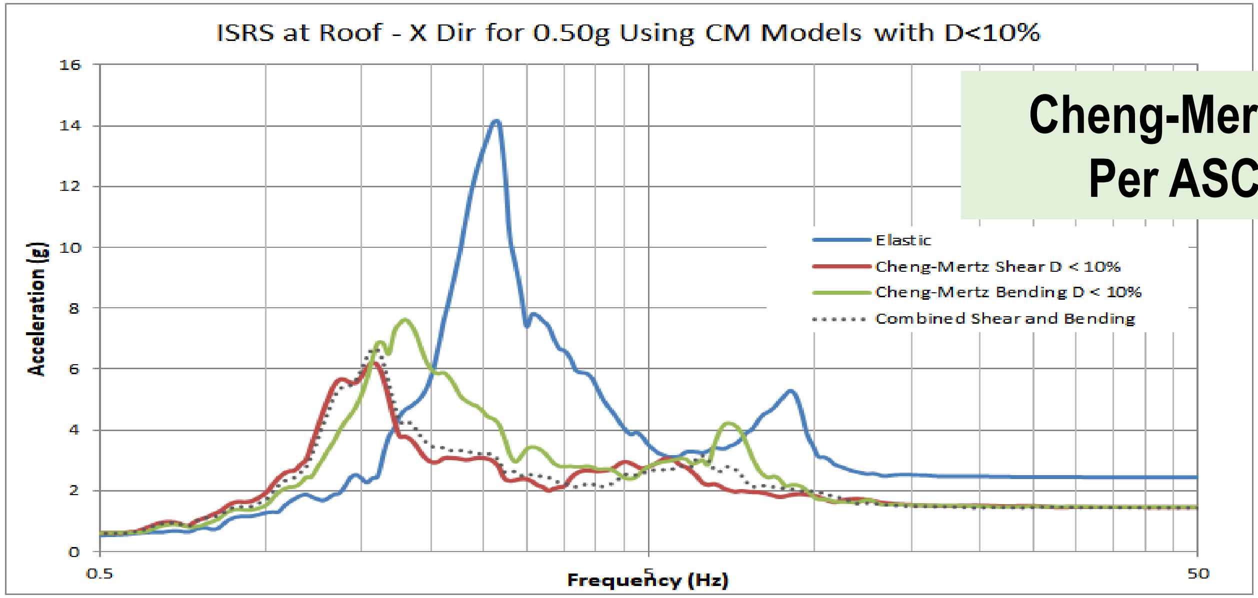
Panel 11 Shear for CMS vs. JEAC PO

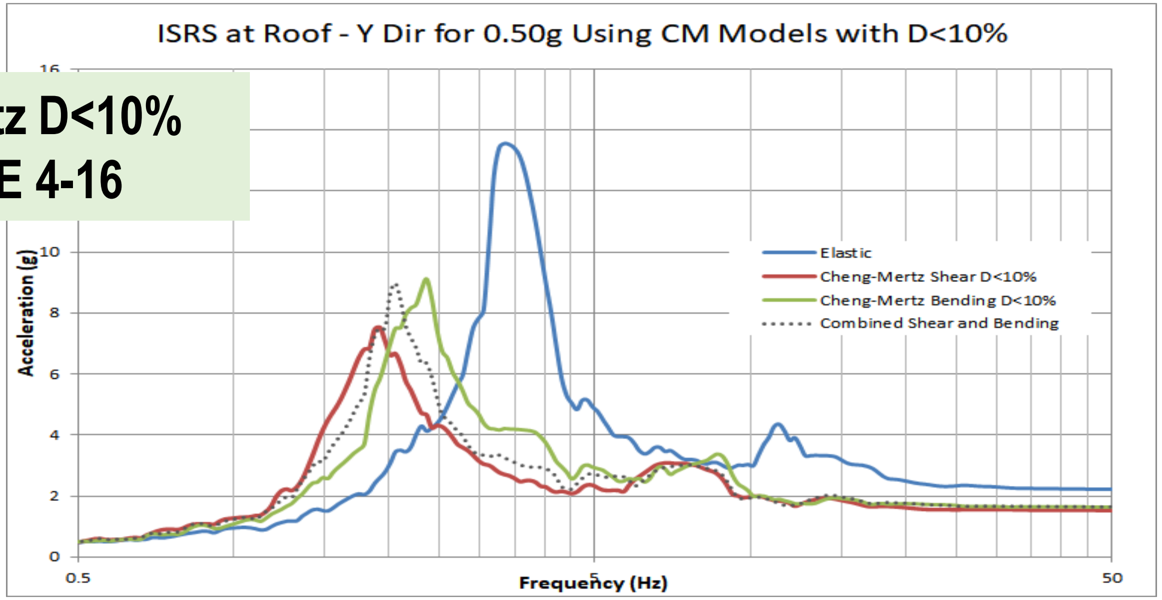


Panel 11 Bending for CMB vs. JEAC PODT

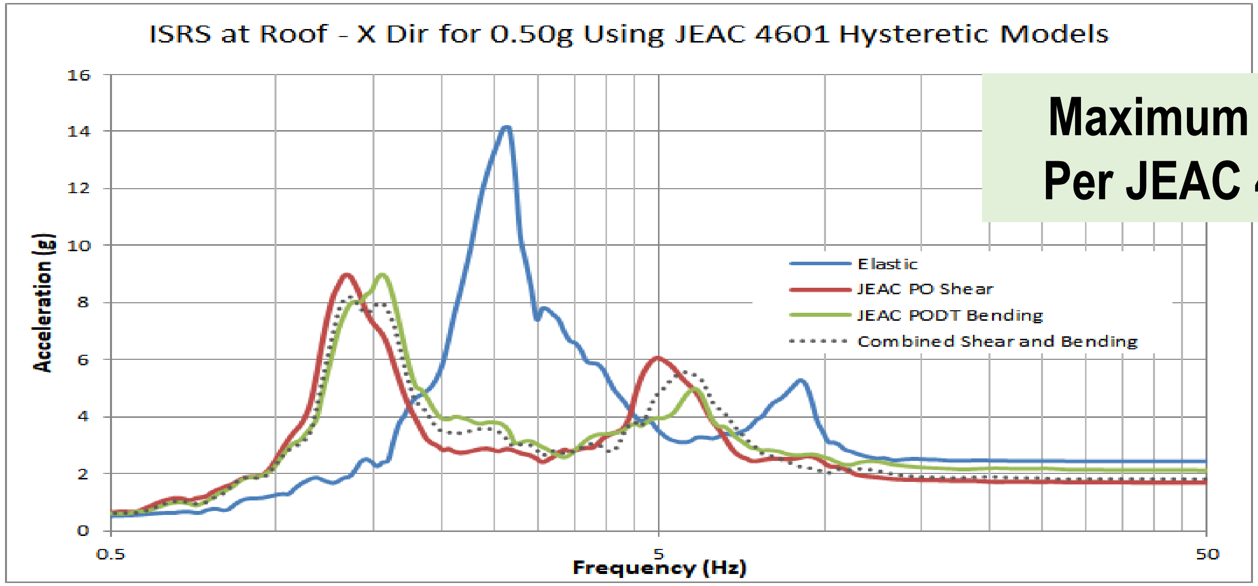


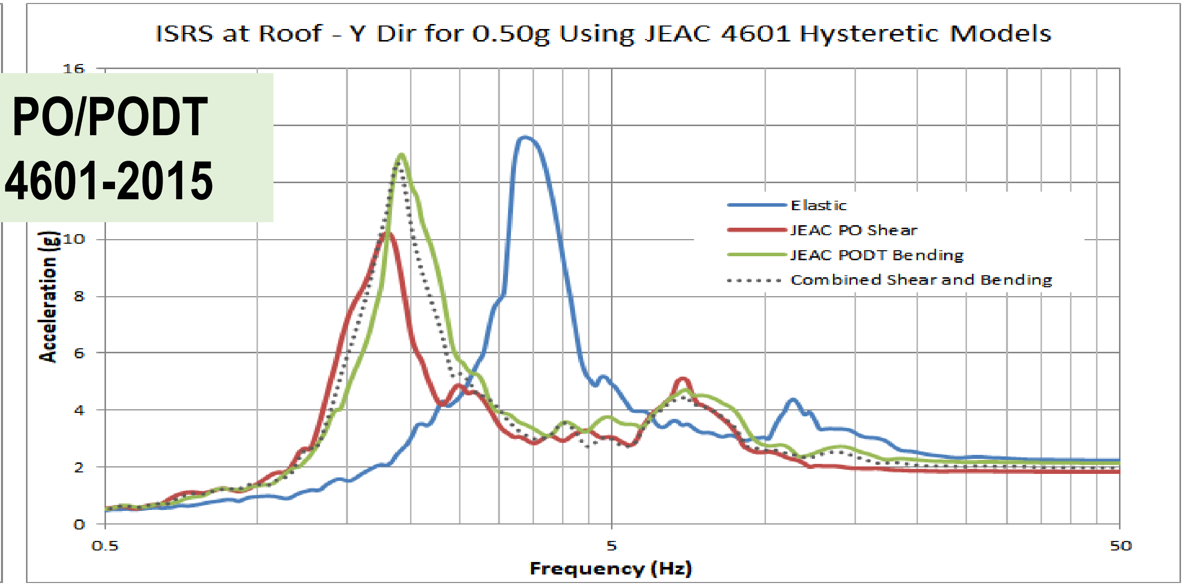
ISRS for CM with D<10% and JEAC 4601 PO Models for 0.50g





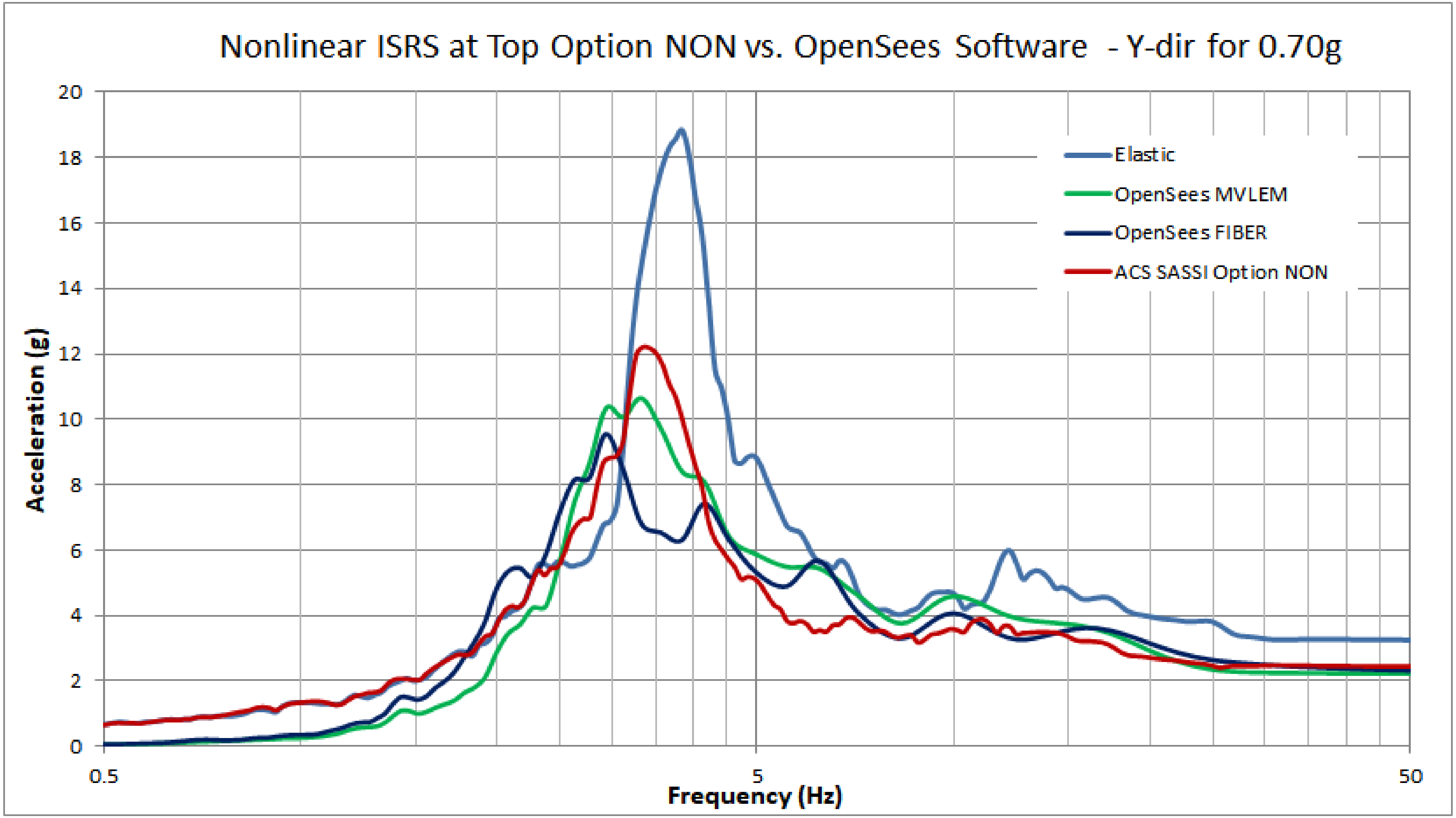
Cheng-Mertz D<10%
Per ASCE 4-16





Maximum PO/PODT
Per JEAC 4601-2015

ISRS Using Option NON with CM vs. OpenSees Software (Ref.4,5)



References

1) Oh, Y. H., Han, S.W. and Lee, L.H. (2002). “Effect of boundary element details on the seismic deformation capacity of structural walls”, J. of Earthquake Engng Struct. Dyn. 2002; 31:1583–1602

2) Cheng, Y. F. (1993).”Coupling Bending and Shear Hysteretic Models of Low-Rise R.C. Walls”.

3) Cheng, Y. F. and Mertz, G. (1989).”Inelastic Seismic Response of R.C. Low-Rise Shear Walls and Building Structures”, Dept. of Civil Engineering, Report 89-30, University of Missouri-Rolla, Rolla, MO

4) Enrico, S.,Ciampi, V., Filippou, F.C. (1992). “A Beam Element for Seismic Damage Analysis”, University of California at Berkeley, Report No. UCB/EERC-92/07. *Reference for FIBER model*

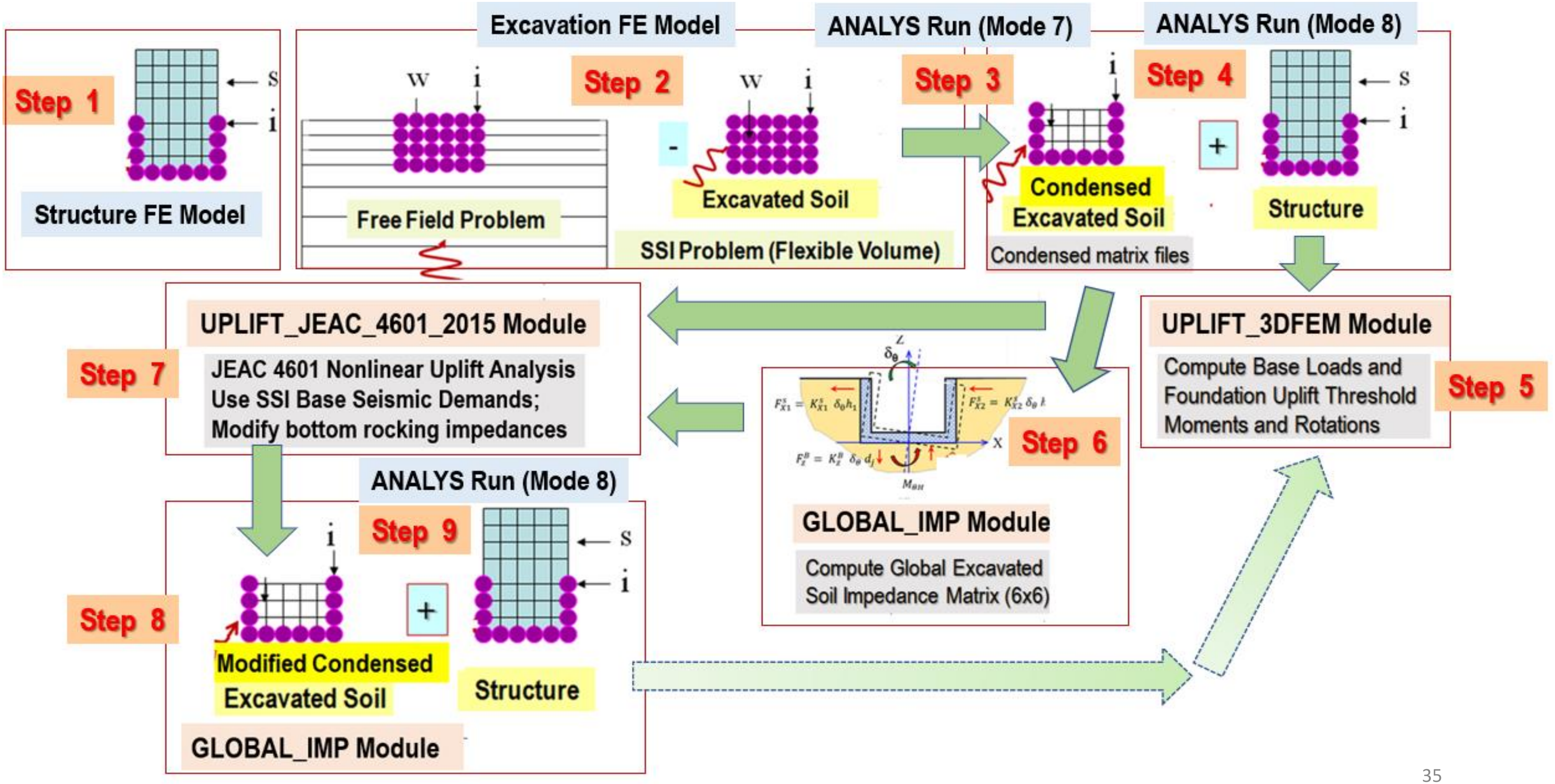
5) Kolozvari K., Orakcal K., and Wallace J. W. (2015). "Shear-Flexure Interaction Modeling of Reinforced Concrete Structural Walls and Columns under Reversed Cyclic Loading", PEER Center, University of California at Berkeley. *Reference for MVLEM*.

6) Park, Y. J., Hoffmayer, C.H. and Costello, J.F. (1994). “Understanding Seismic Design Criteria for Japanese Nuclear Power Plants”, Brookhaven Labs, Report, BNL-NUREG-60885, Upton, NY

3. Foundation Uplift SSI Analysis Using Hybrid Complex Frequency-Time Domain Approach with Reduced-Order Modeling for Foundation-Soil Interface (Option UPLIFT)

Note: Nonlinear uplift SSI approach is developed in compliance with the JEAC 4601-2015 standard recommendations which are applicable to foundation uplift analysis up to 50% of loss-of-contact

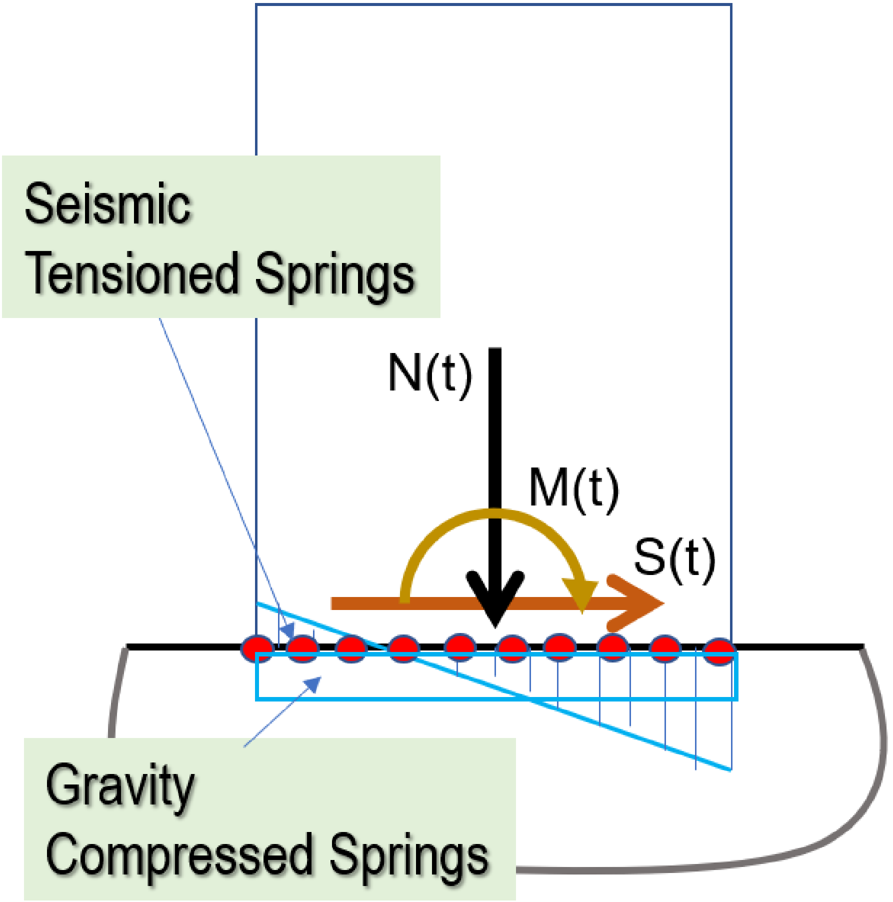
Uplift SSI Approach Based on JEAC 4601-2015 (Option UPLIFT)



Automatic Computation of Uplift Limit Base Moments and Rocking Rotations Under Gravity (Static) and Seismic (Dynamic) Loads

$\eta = \dfrac{A_{contact}}{A_{total}}$ is computed based on the springs in tension

$\gamma = \left| \dfrac{F^{static}}{F^{dynamic}_{max\ tension}} \right|$ Force scaling coefficients



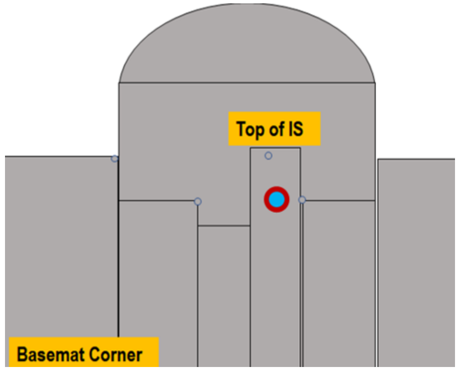
$$M_0 = \sum_j \left(F_j^{static} + \gamma F_j^{dynamic}\right) \cdot d_j$$

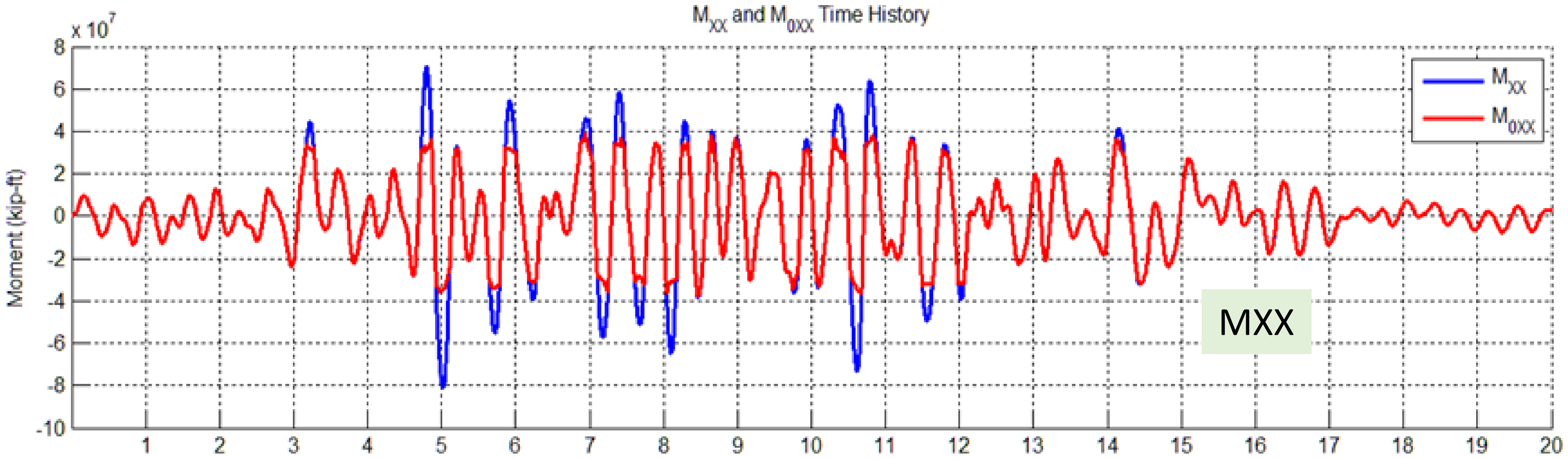
is computed for no-tensile springs

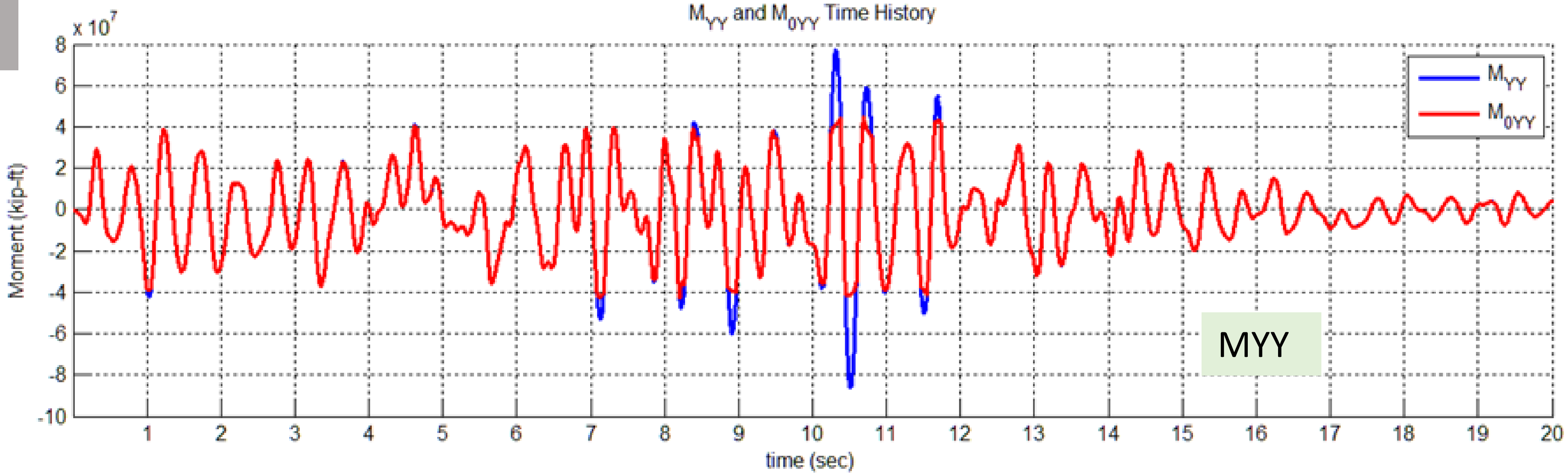
θ_0 is computed by linear regression

Critical spring based on the no-tension force criterion corresponds to the *minimum spring scale factor*.

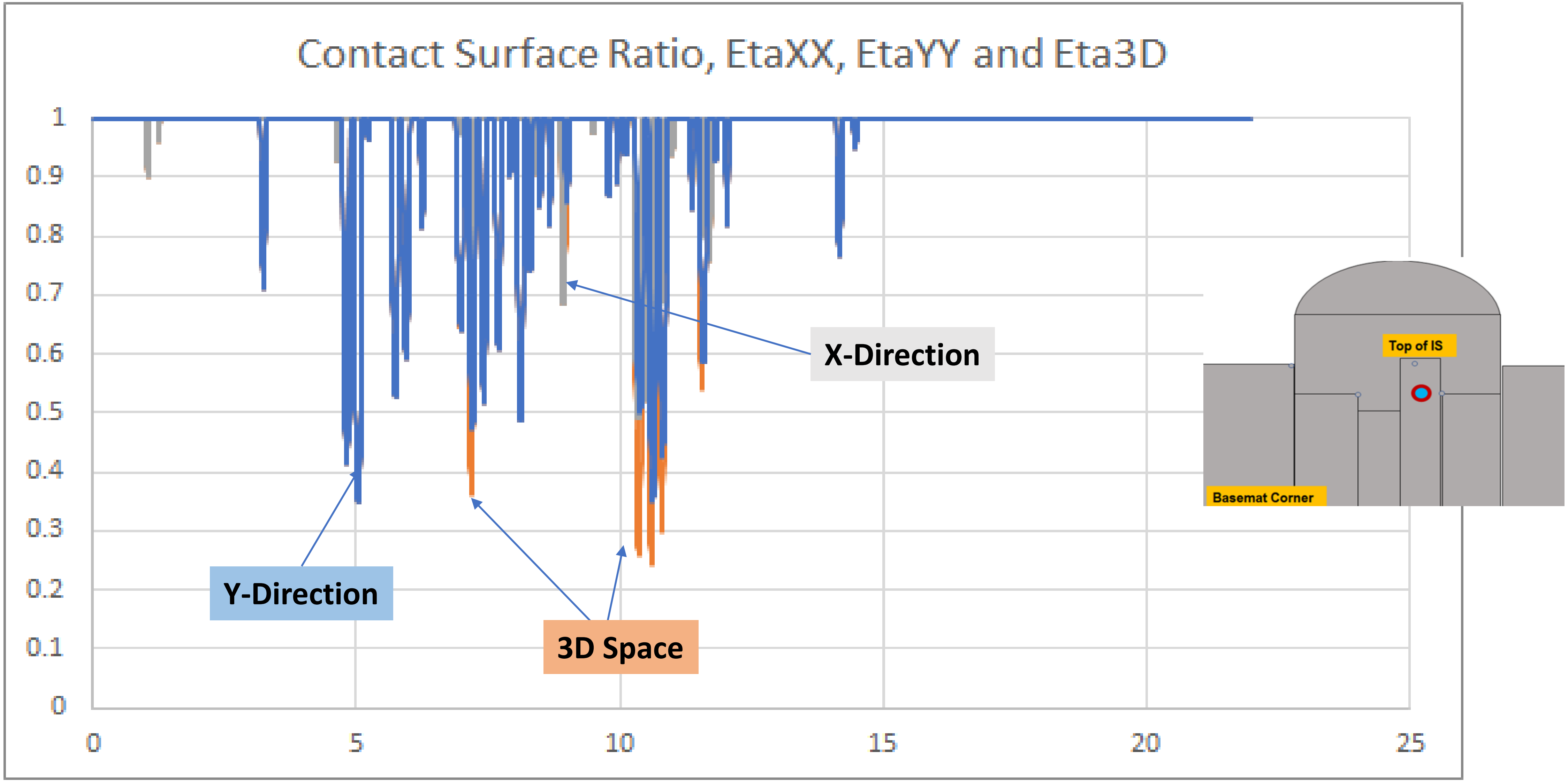
Nonlinear Uplift Limit Base Moments (Mo) for X and Y Directions



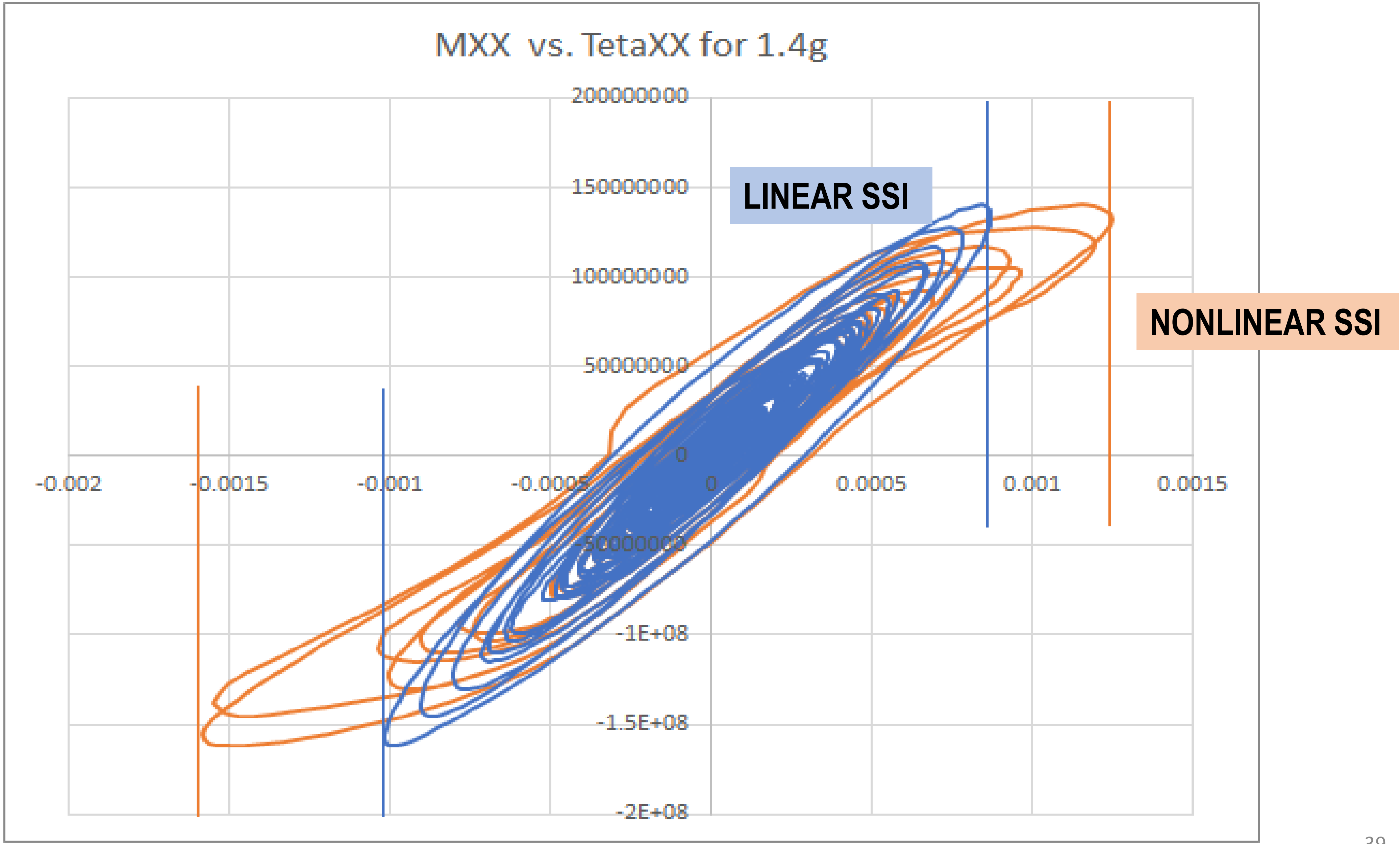




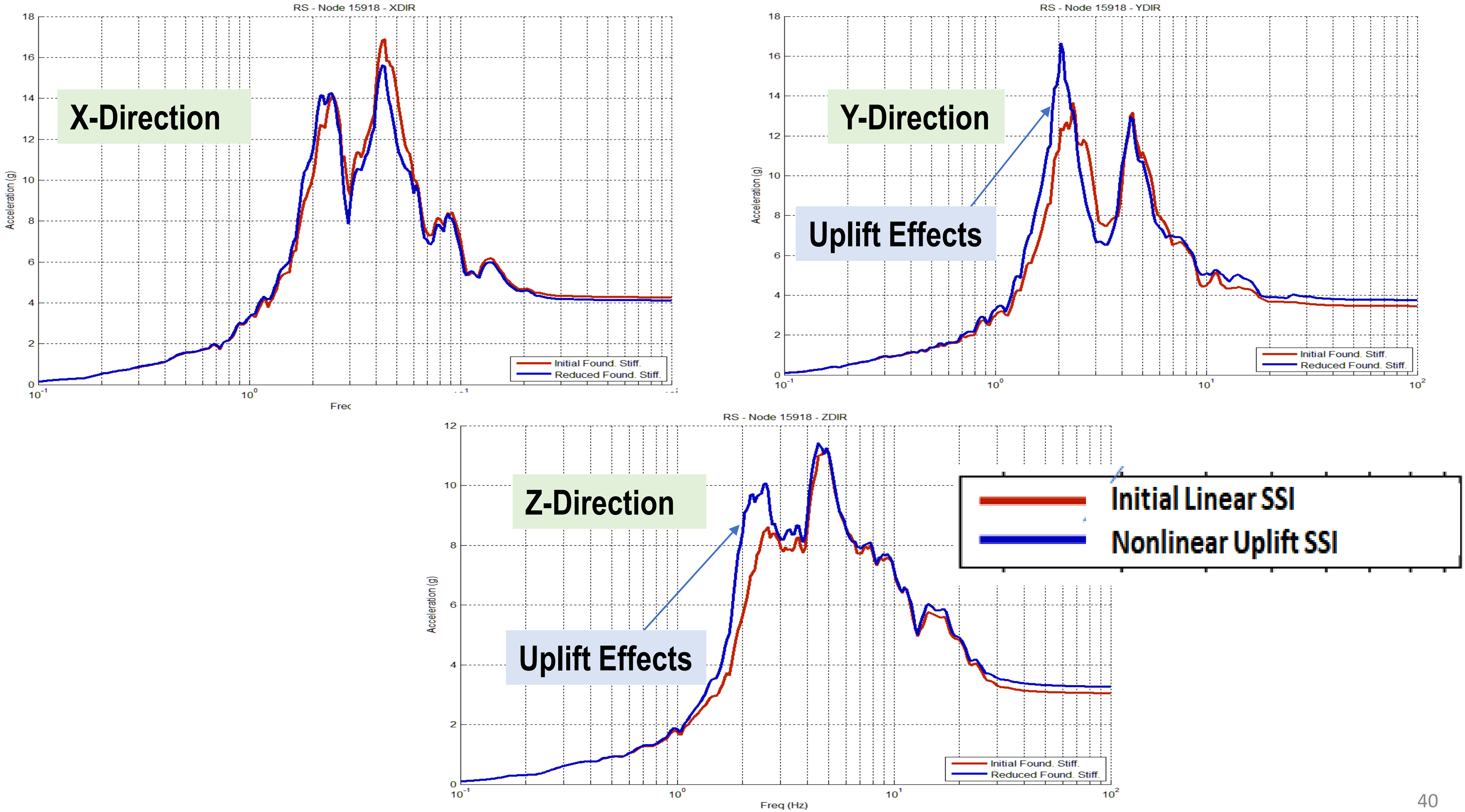
Contact Surfaces for X (Longitudinal) and Y (Transversal) Directions and Combined In 3D Space for 1.4g Seismic Input



Base Uplift Moment-Rotation Curve for Linear SSI vs. Nonlinear SSI



ISRS Computed for Linear SSI vs. Nonlinear Uplift SSI Analysis



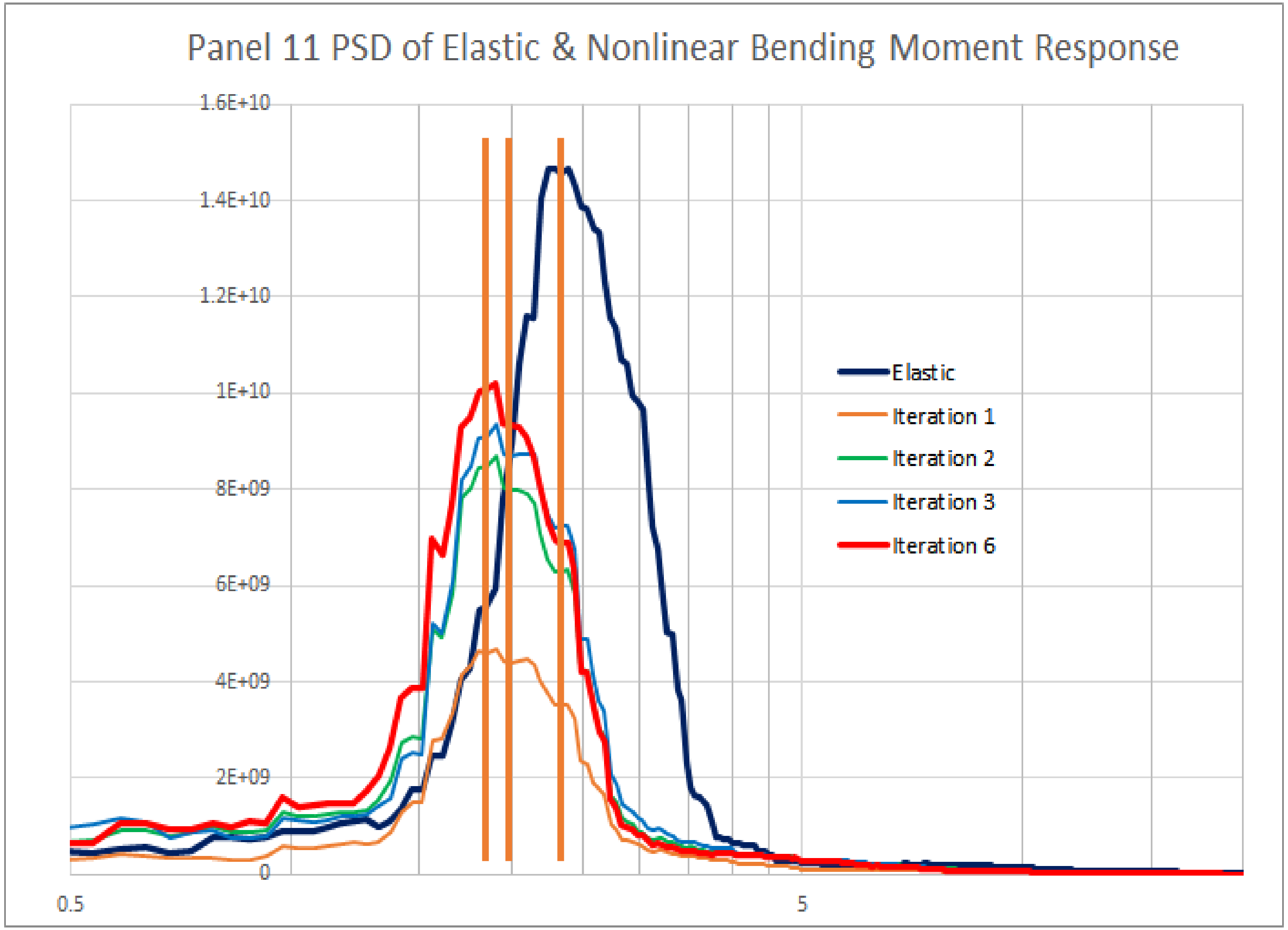
4. Nonlinear Force PSD-Shape Based Iterative Equivalent-Linearization (Option NON)

PSD-Shape Based Variable DRF is Computed Based on the Nonlinear Force PSD for Each Wall at Each Nonlinear Iteration

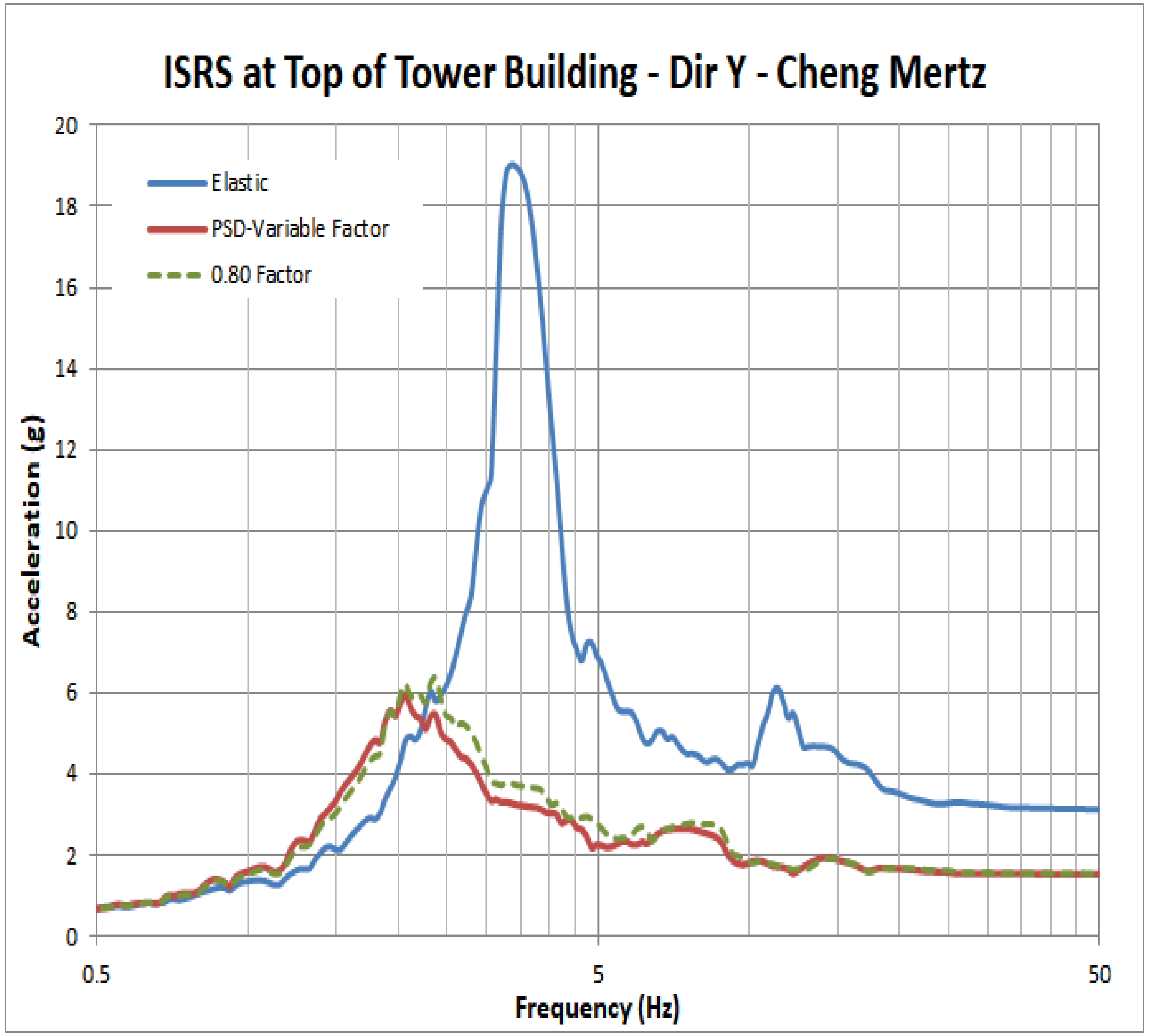
The PSD-based DRF is computed based on the frequency content of the PSD of the nonlinear shear force or the bending moment histories for each wall panel at each nonlinear SSI iteration.

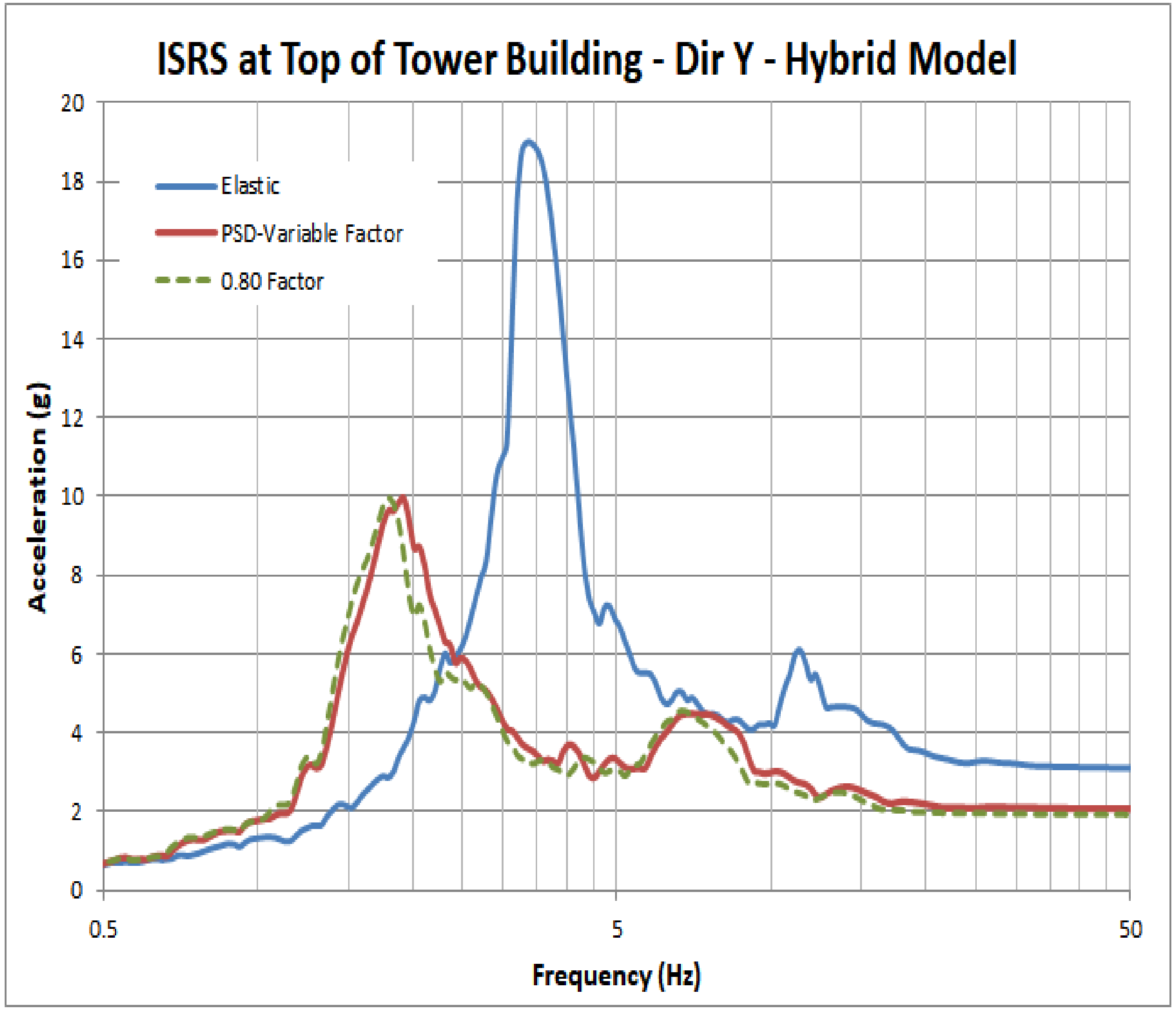
The DRF is computed based the wall nonlinear force PSD dominant frequency shift at each iteration, as shown in the figure.

For iteration j, PSD-variable DRF is DRFj = (Fj/Fj-1)^2



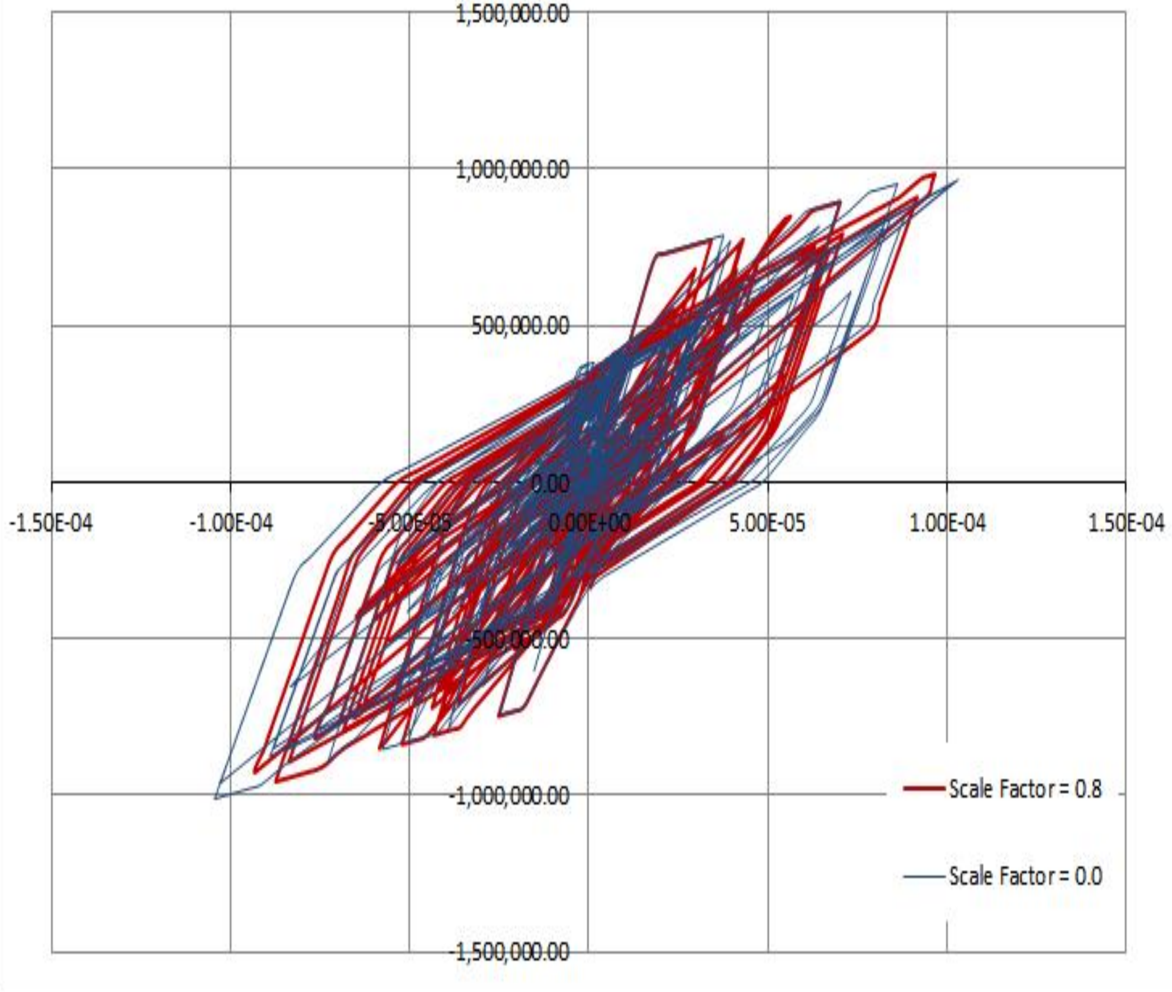
Nonlinear ISRS Computed Using PSD-Shape Based Variable DRF vs. 0.80 Constant DRF for While Performing Nonlinear Iterations



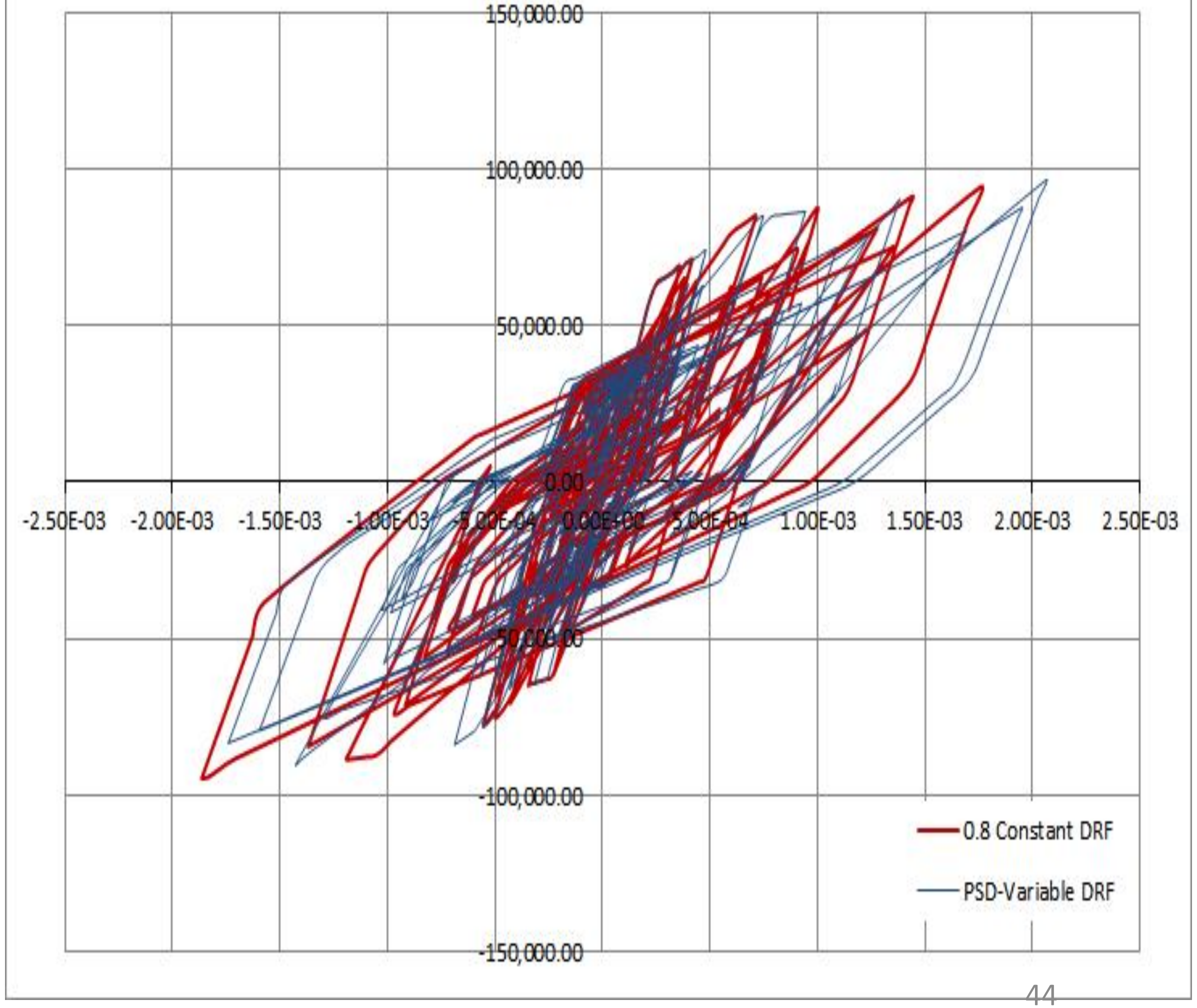


Nonlinear Hysteretic Wall Responses Using PSD-Shape based Variable DRF vs. 0.80 Constant DRF for Nonlinear Iterations

Base Panel 11 Bending CM Hysteretic Loops



Base Panel 11 Shear CM Hysteretic Loops



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Please see the detailed newsletter coming in October!