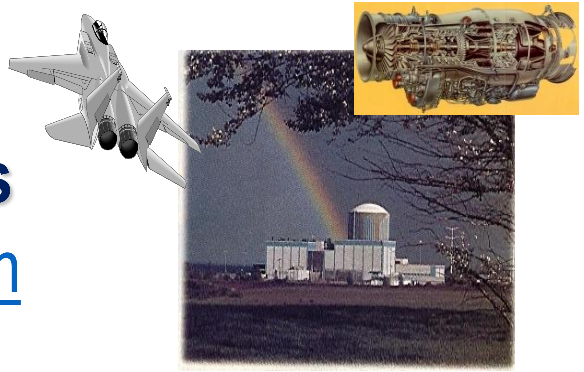
ACS SASSI NQA Advances on Seismic SSI Analysis of NPP Structures Using Best Practices in US and Japan

Ghiocel Predictive Technologies Inc.



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http://www.ghiocel-tech.com

Day 1: 1-Brief Overview of 2021 ACS SASSI NQA V4.3 New SSI Capabilities
2-Nonlinear Seismic SSI Analysis Based on Best Practices in US and Japan

ACS SASSI Workshop, Tokyo
December 2-3, 2021

ACKNOWLEDGEMENT

The development of the new ACS SASSI UPLIFT and NON Advanced and options per Japan JEAC 4601-2015 standard recommendations were developed for almost three years of very intense development effort.

I am very thankful to:

SHIMIZU leading expert structural engineers, especially to Nitta-san and Ikeda-san, for many tens of hours, if not hundreds of hours by now, of precious time during various technical meetings and hundreds of email discussions over these last three years.

TERRABYTE for the great support of many thousands of hours per year for last three years for testing the new UPLIFT and NON Advanced options, helping with our Japanese language understanding, and interacting with Japanese industry users of ACS SASSI, especially to Niwa-san, Horiguchi-san, Sugiyama-san, Kanawabe-san, Shono-san, and many others.

Day 1 Presentation Content:

1-Brief Overview of 2021 ACS SASSI NQA V4.3 New SSI Capabilities

2-Nonlinear Seismic SSI Analysis Based on Best Practices in US and Japan

2.1 ACS SASSI Nonlinear SSI Analysis Based on A Hybrid Frequency-Time Approach Using An Efficient Iterative Procedure

2.2 Nonlinear Modeling Assumptions for RC Walls

2.3 Nonlinear Modelling for Floor Cracking (next release)

2.4 Option NON Simple

2.5 Option NON Advanced

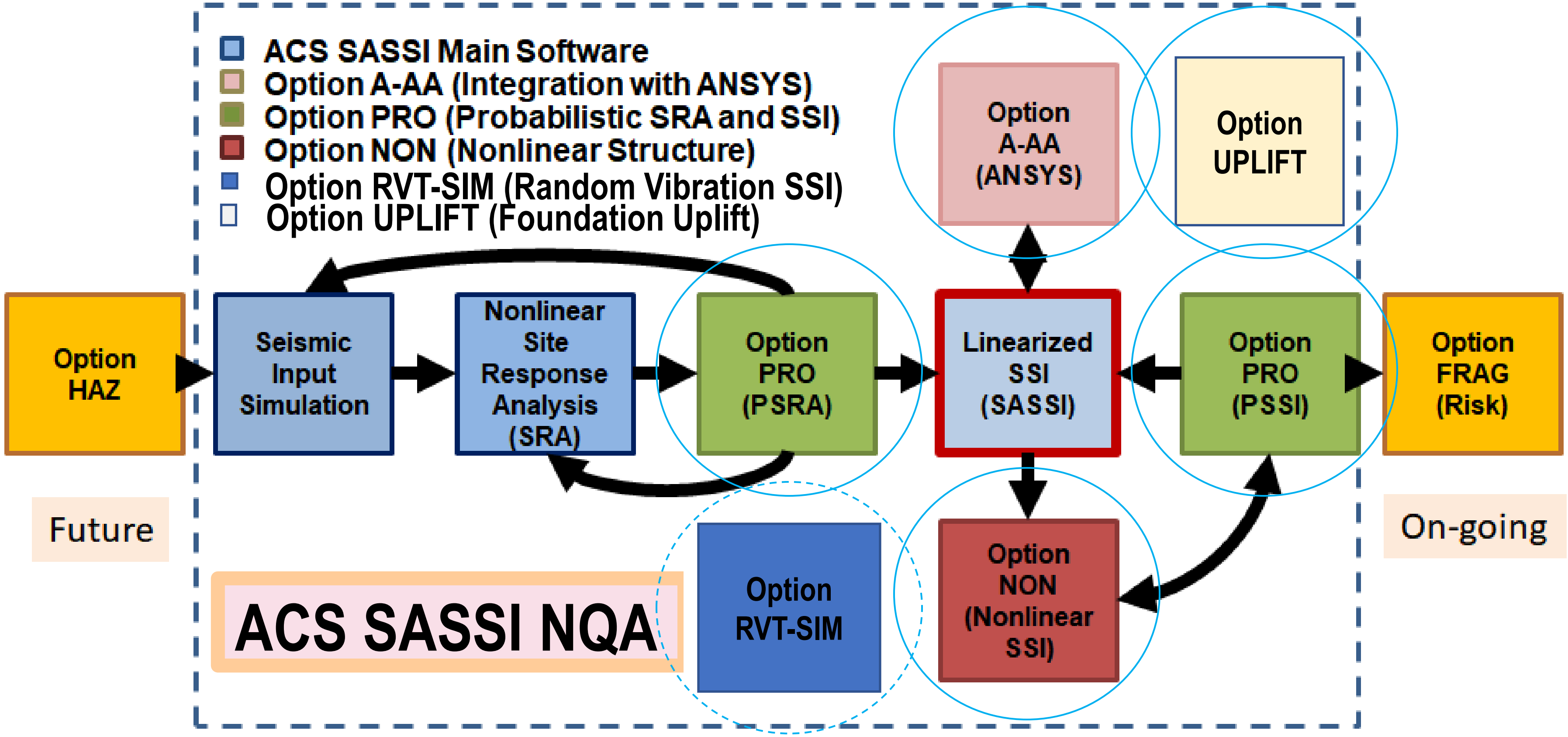
2.6 Nonlinear SSI Analysis Case Studies

2.7 Concluding Remarks

1. Brief Overview of 2021 ACS SASSI NQA V4.3 New SSI Capabilities

ACS SASSI NQA V4.3 Toolboxes

Present/Options A-AA, NON and PRO and UPLIFT
Future/Options HAZ and FRAG



2021 ACS SASSI V4.3 Software Toolboxes

1) **Main Software.** Include advance pre-post processing, nonlinear soil modeling, motion incoherency, others. Plus, includes seismic motion simulation and site response capabilities.

2) **Option A-AA.** Integration with ANSYS. The ANSYS structure FE models can be used directly for the 1st step of the overall SSI analysis in ACS SASSI and/or in the 2nd step for detailed stress analysis using SSI responses as input BCs (Option A) **Option AA-R** extends Option AA to perform SSI analysis in ANSYS using ANSYS model with soil matrix MATRIX50 super-element coming from ACS SASSI.

3) **Options NON Simple & NON Advanced.** Nonlinear structure, applicable to concrete structures and base-isolation using iterative scheme (ASCE 4-16, ACI-318, and JEAC 4601-2015, AIJ RC).

4) **Option PRO.** Probabilistic SRA and SSI analyses (ASCE 4-16 Sections 2 and 5.5, and RG 1.208 E)

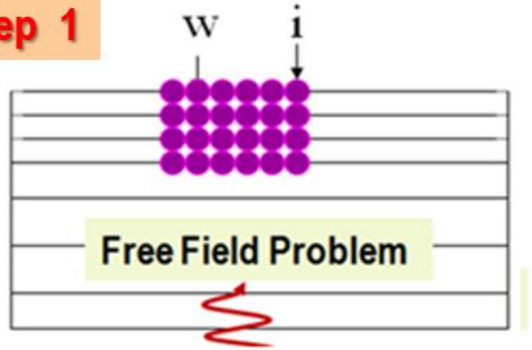
5) **Option RVT-SIM.** No input time histories are required.

New Accurate and Highly Efficient Algorithms for SSI Analysis, Especially Nonlinear Analysis

1. Fast and Accurate SSI Analysis Using Flexible Volume Reduced-Order Modeling (FVROM and FVROM-INT). Applicable to Deeply Embedded SMR Structures
   Main Software and Option AA-R
2. Fast Nonlinear SSI Analysis Via Hybrid Complex Frequency-Time Domain Approach Combined with Reduced-Order Modeling for Nonlinear Structures
   Option NON.
3. Foundation Uplift SSI Analysis Using Hybrid Complex Frequency-Time Domain Approach with Reduced-Order Modeling in Time-Domain
   Option UPLIFT.
4. Nonlinear Force PSD-Shape Based Iterative Equivalent-Linearization
   Option NON.

Fast FVROM-INT SSI Analysis Using Reduced-Order Excavated Soil

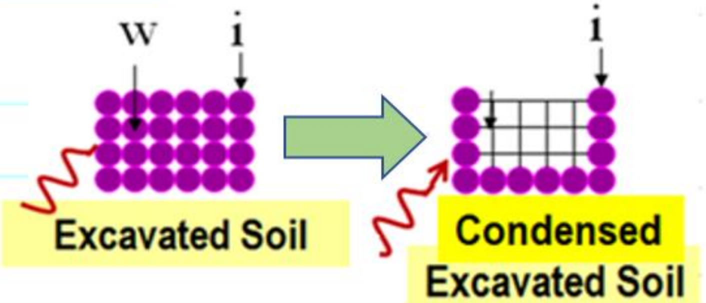
Step 1



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.*

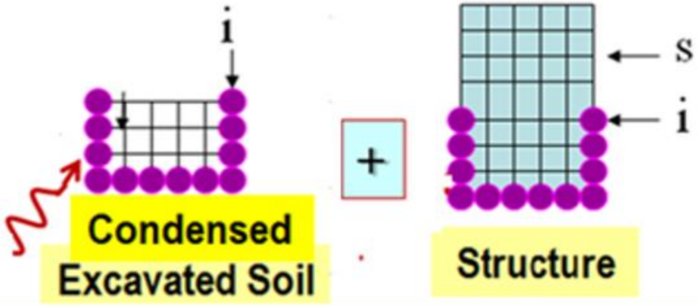
Step 2



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.

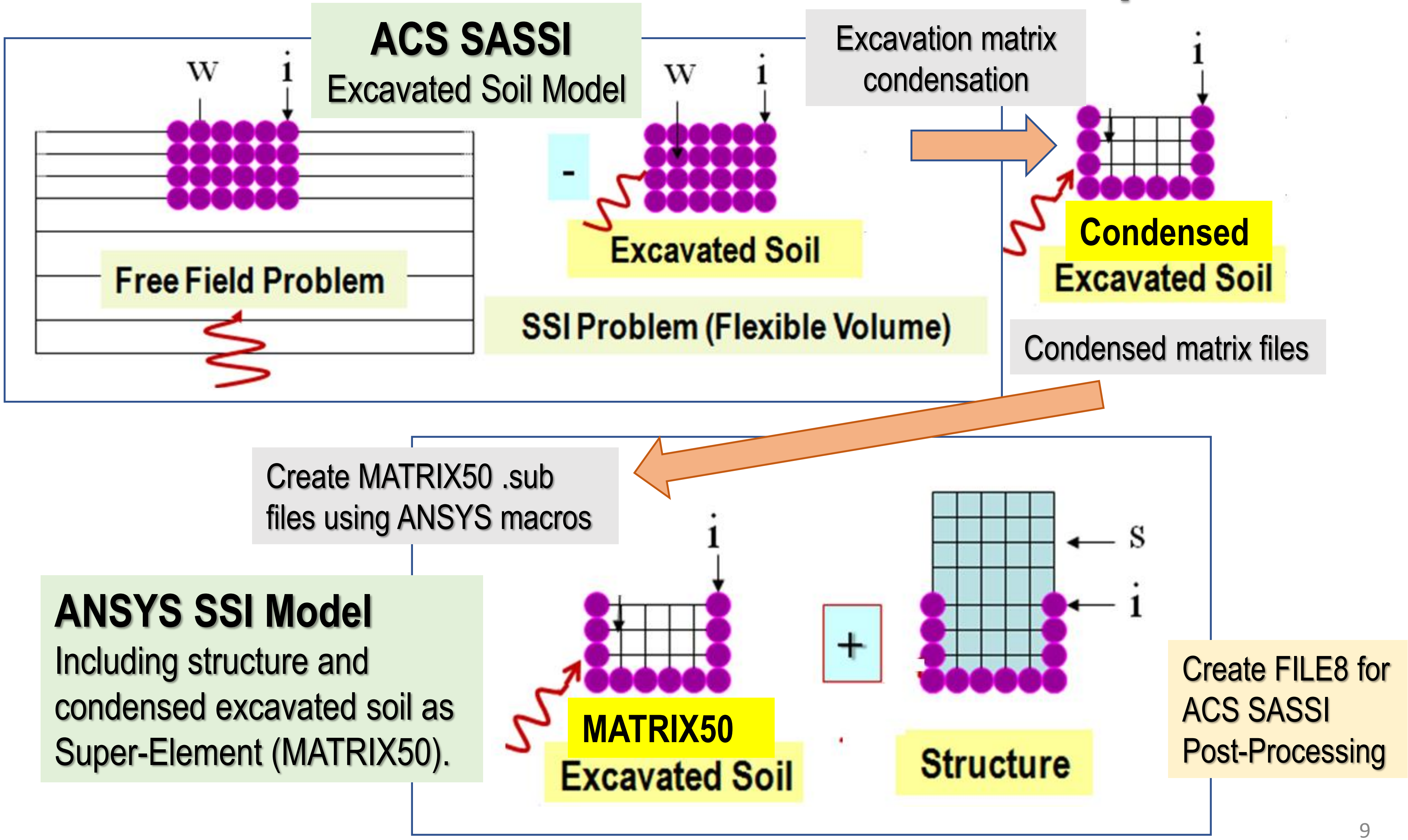
Step 3



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.

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



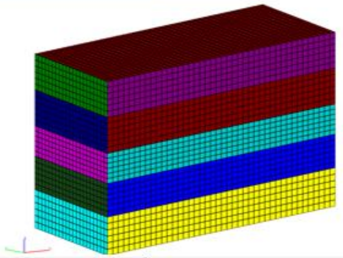
Option NON Nonlinear SSI Analysis per US and Japan Standards

Build SSI Model

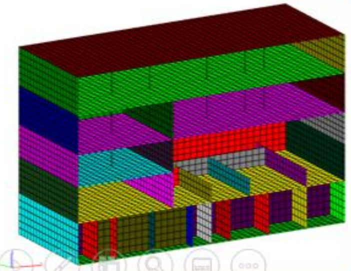
Analyst creates a 3DFEM for with element groups for each wall.

AB_Shearwall.pre Input File

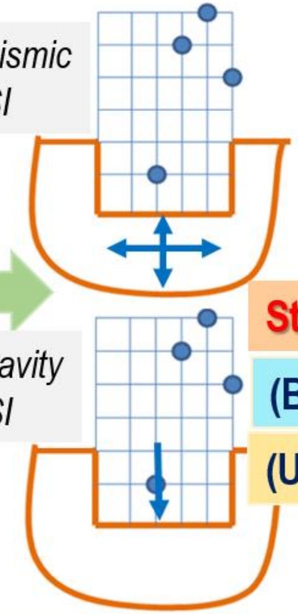
Step 1 **(UI)**



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



ACS SASSI SSI Analysis



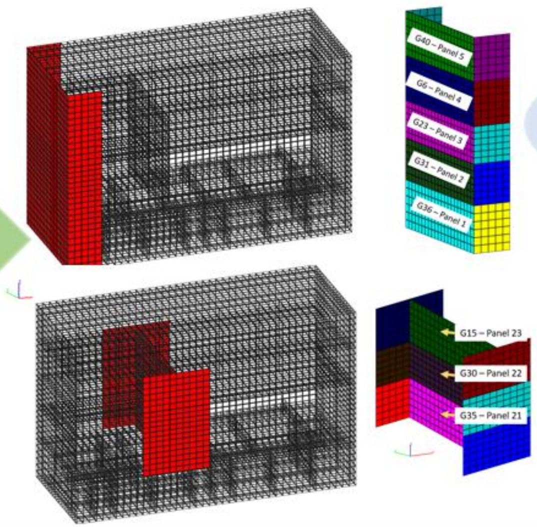
STRESS Module Runs

STRESS Binary DB *for combined X, Y and Z Seismic inputs*

Step 3 **(B)** **(UI)**

Step 4 **(B)** **(UI)**

STRESS Binary DB *for Gravity load in Z direction*



AB_ShearWall _Wall1.pre

⋮

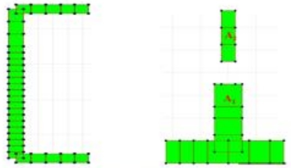
AB_ShearWall _Wall5.pre

Step 2 **(UI)**

Compute Shear and Bending BBCs

AB_Submodels_for_BBC.in file

Section_Cut_for_BBC Module Run



Automatic and sectio identi

Options for Flanges:
1) Japan AIJ RC
2) US ACI 318

Step 5 ***Section_Data_for_BBC.out*** file **(B)**

User Section Review Adding RC Material Inputs

Step 6 ***Revised_Section_Data_for_BBC.in*** file **(EIF)**

Step 7 **BBC_JEAC_ACI_Fiber2D R**
BBC Shear.pre & BBC Bending.p

Step 8 **Create_Flange_Materials F**
AB_ShearWall_New.pre file

Options for BBCs:
1) Japan JEAC 4601
2) US ACI 318/ASCE 4

Step 9 **UI is Used to AFWRITE New Inputs**
Generate New .Hou and .Eql Input Files **(UI)**

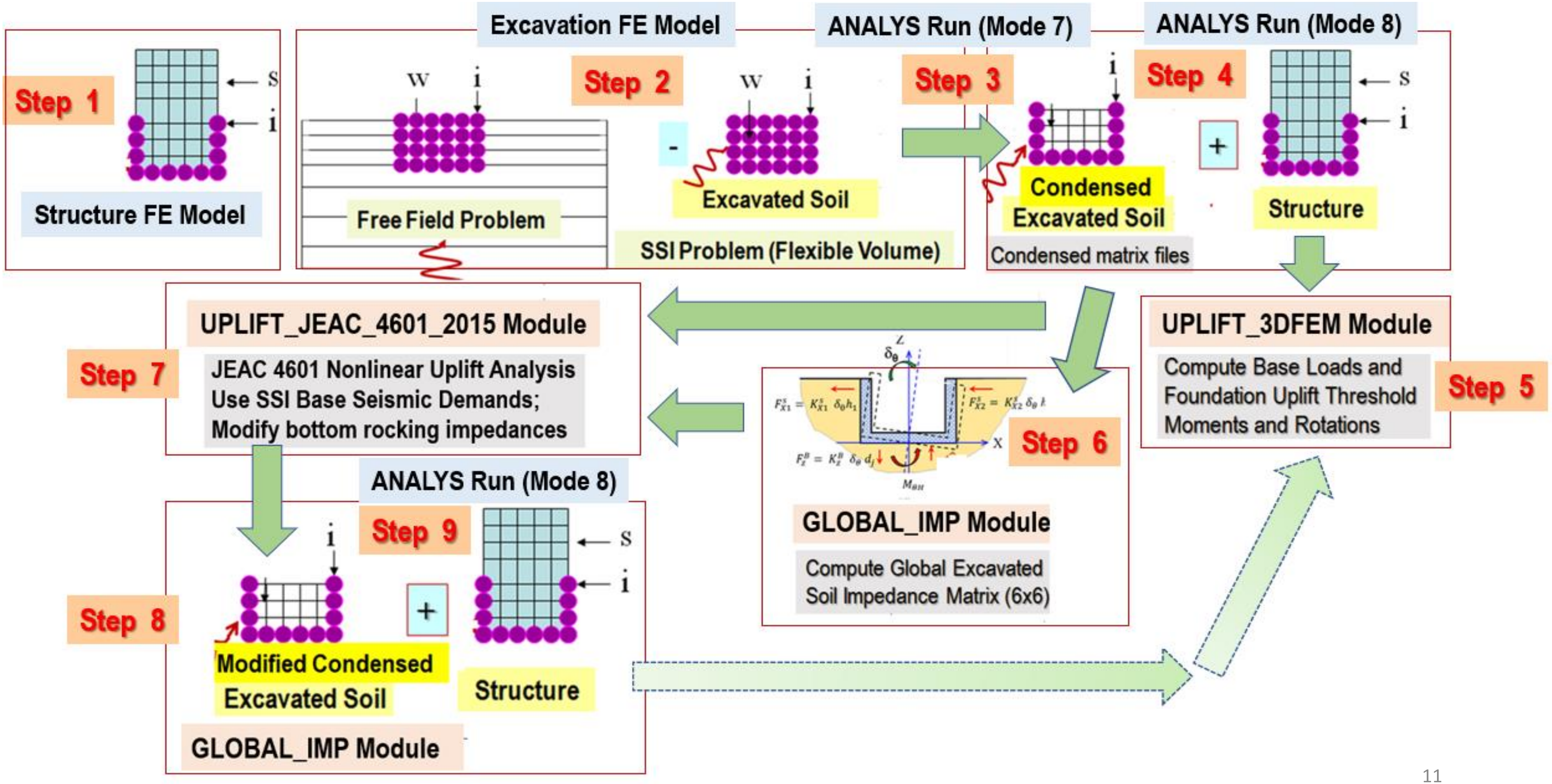
Option NON Nonlinear SSI Analysis (Batch Run)

Step 10 *Shear and bending effects are combined at each SSI iteration using **COMB_Shear_Bend** Module*

(B) ***File8*** files for converged SSI solution

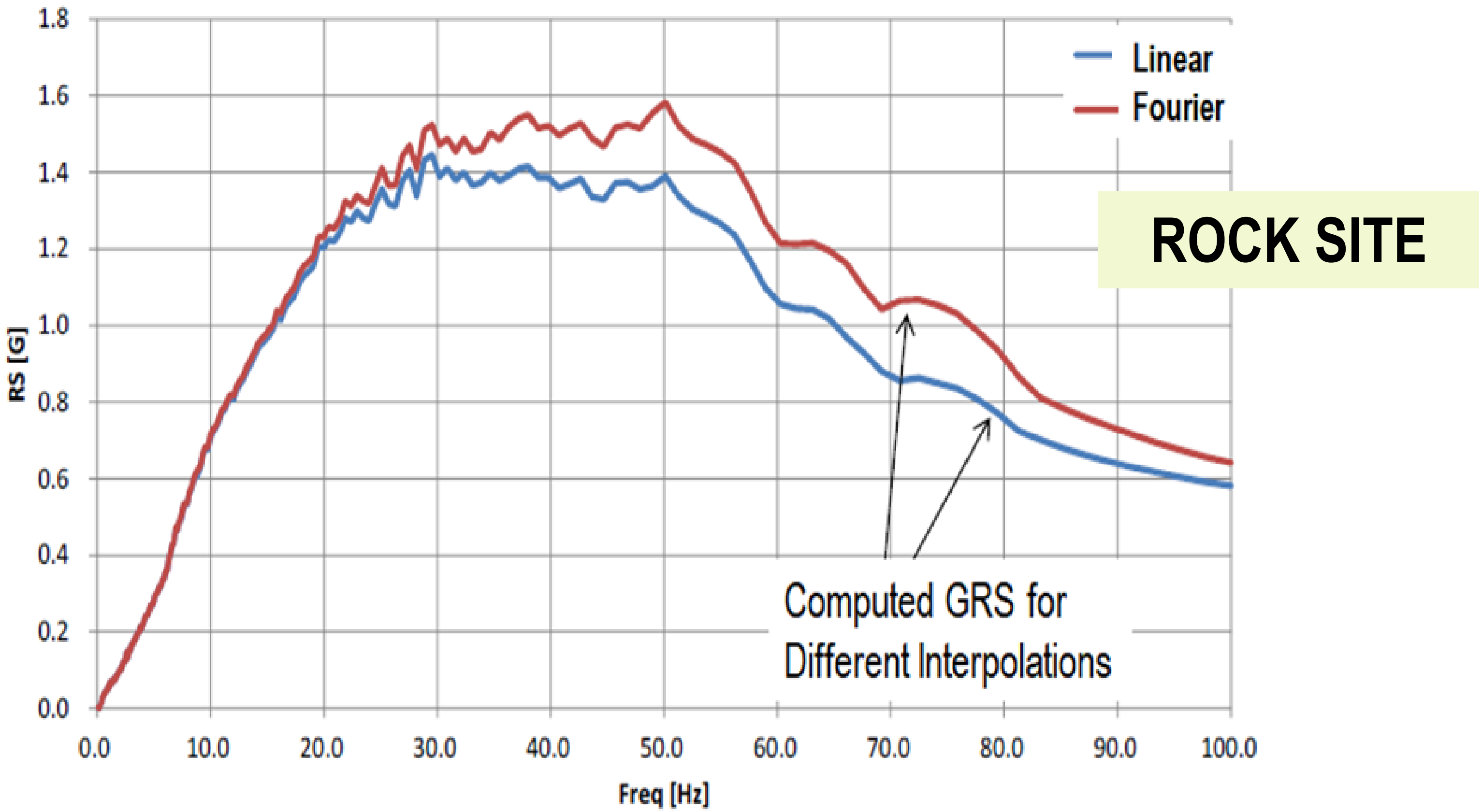
Step 11 **Final SSI Post-Processing** **(B)** **(UI)**

Option UPLIFT SSI Approach Based on JEAC 4601-2015

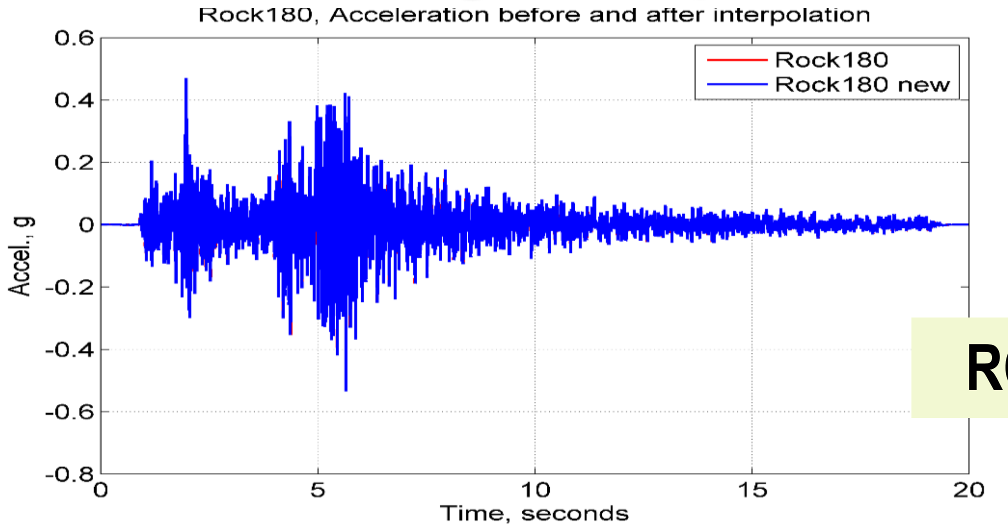


New Fourier Acceleration Interpolation for High-Frequency RS

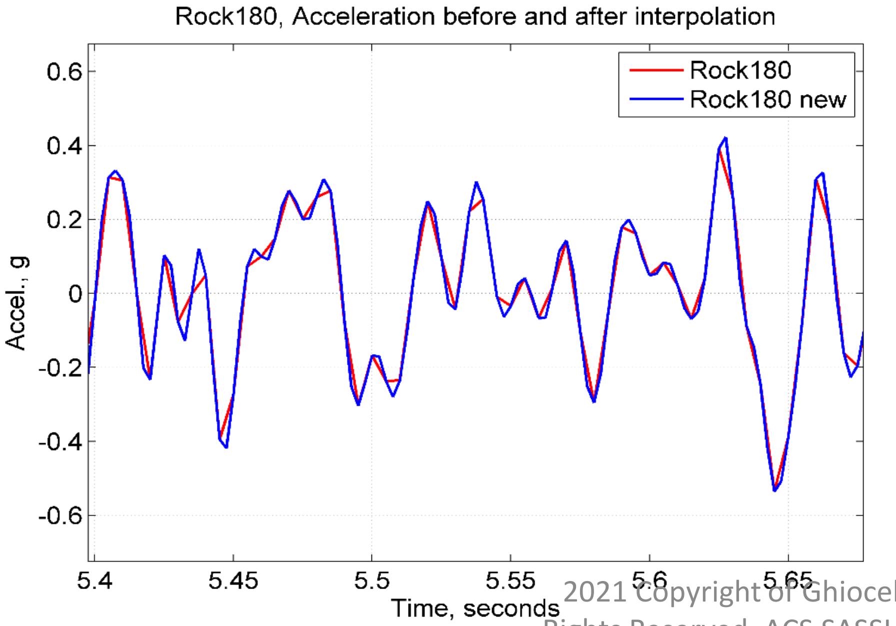
ACS SASSI V4.3 includes the *Fourier zero-padding interpolation (FZPI) for acceleration histories* for computing the response spectra in the high-frequency range per new ASCE 43-19 requirements. FZPI can be used for a 0.005 sec time step for high-frequency RS up to 50 Hz with an error less than 10%. Linear interpolation error is about 30% at 50Hz.

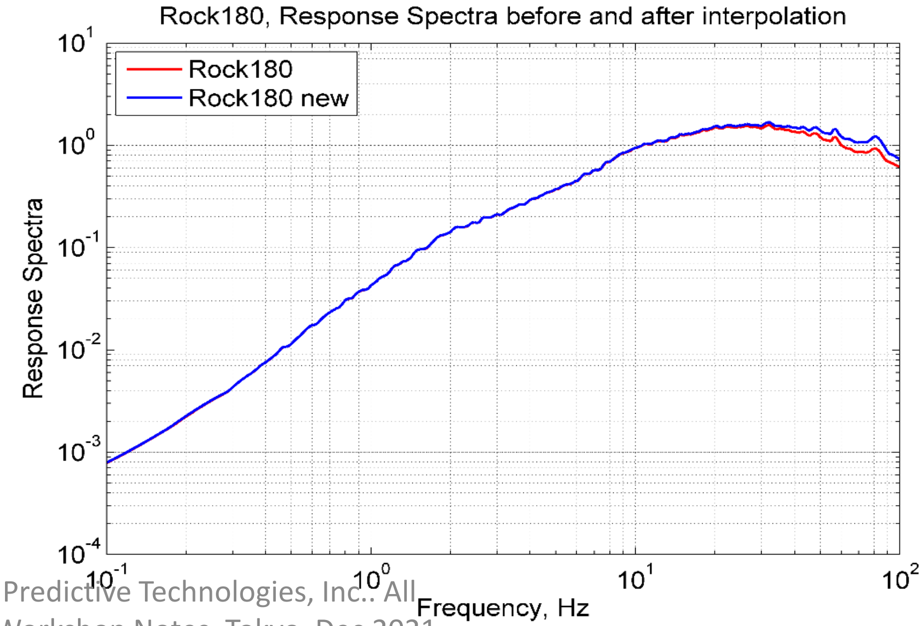


Computing High-Frequency RS Using EQUAKE Fourier Zero-Padding Interpolation Example



ROCK SITE





Single Workstation License USB *Green* Key (HL) or *No* Key (SL)
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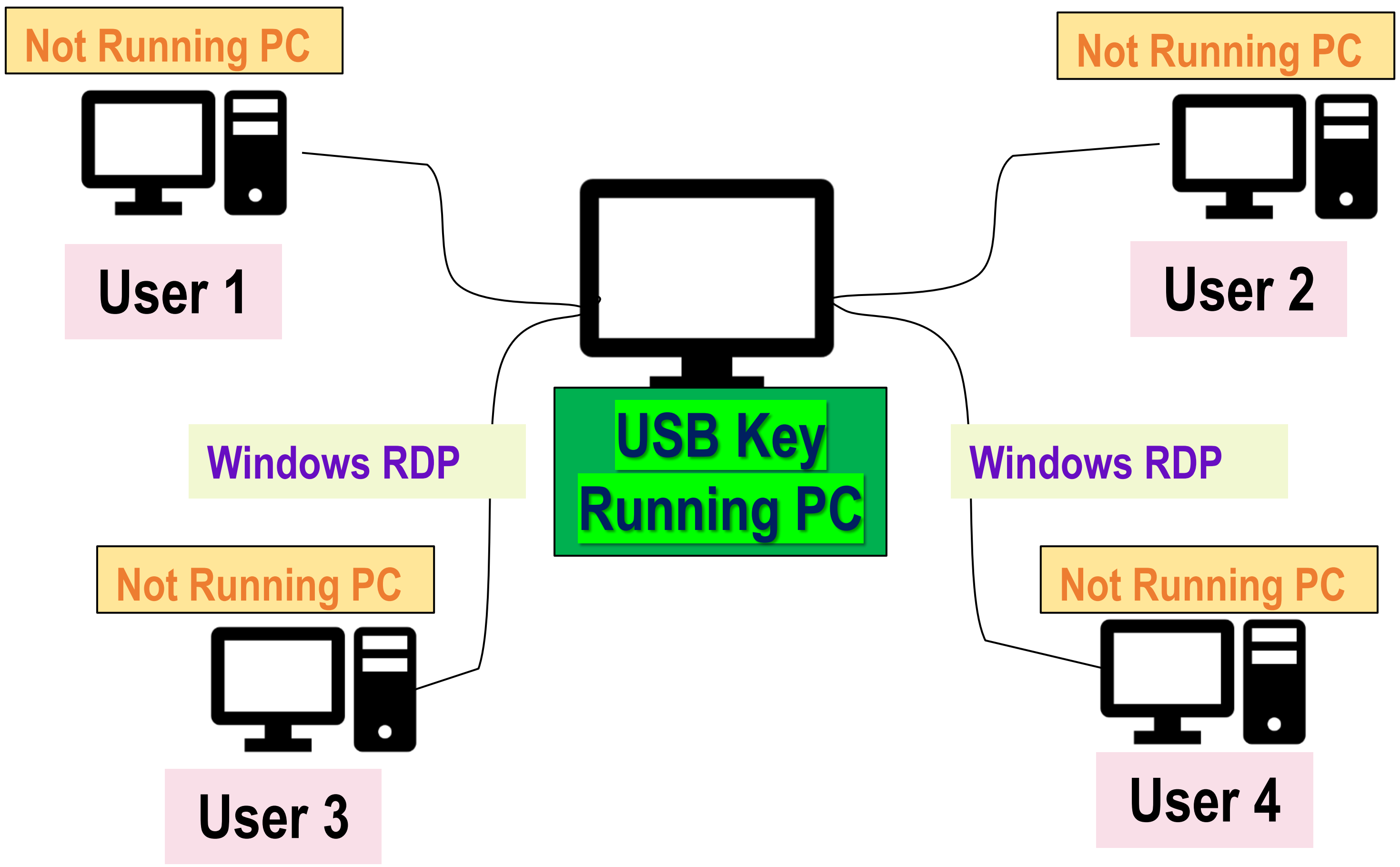

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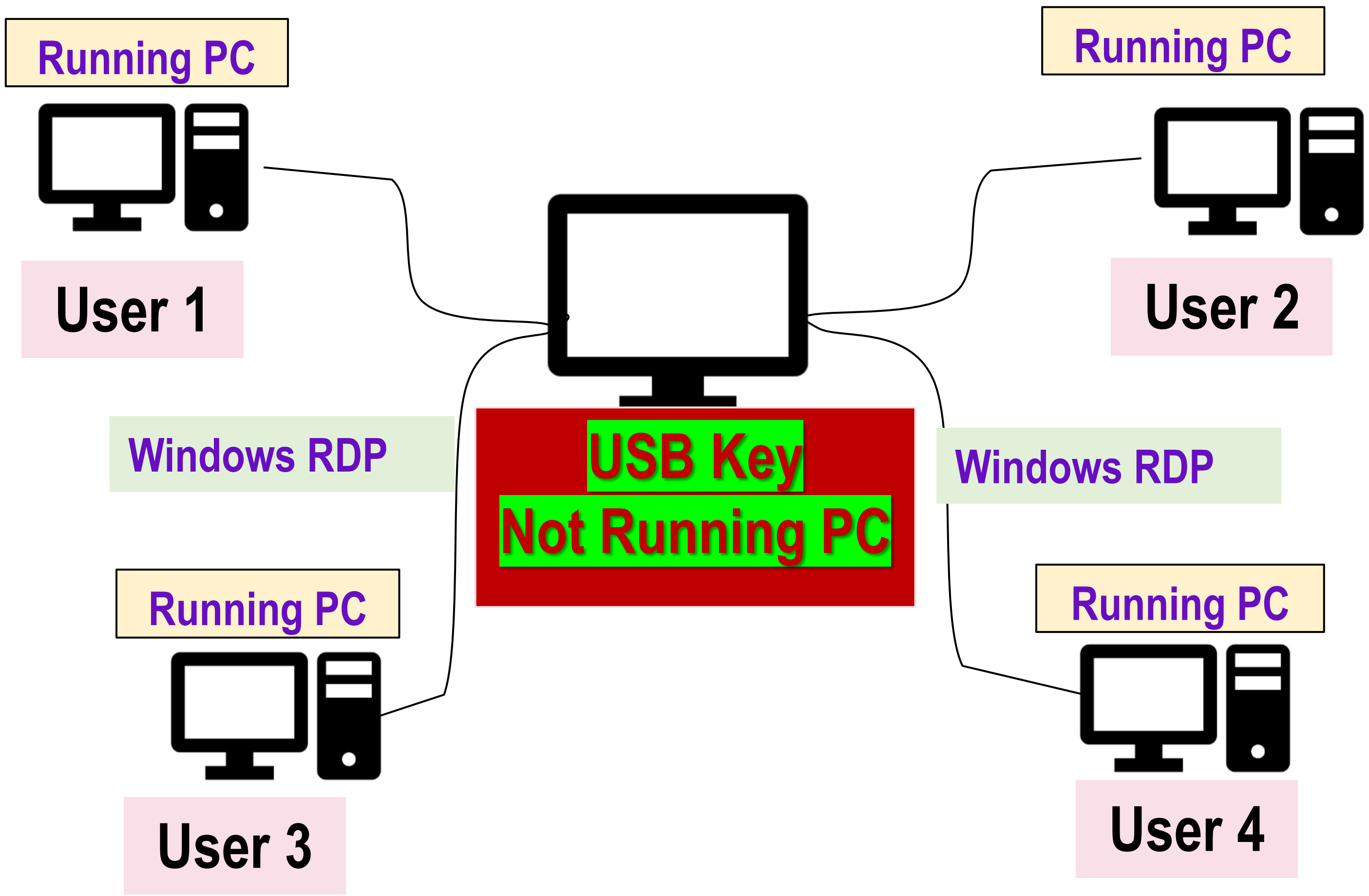


2. Nonlinear Seismic SSI Analysis Based on Best Practices in US and Japan

2.1 ACS SASSI Nonlinear SSI Analysis Based on A Hybrid Frequency-Time Approach Using An Efficient Iterative Procedure

2. 1 ACS SASSI Nonlinear SSI Analysis Based on A Hybrid Frequency-Time Approach Using An Efficient Iterative Procedure

The implemented SSI hybrid approach uses an iterative procedure. Each iteration i includes two coupled analysis steps using two structural models, as follows:

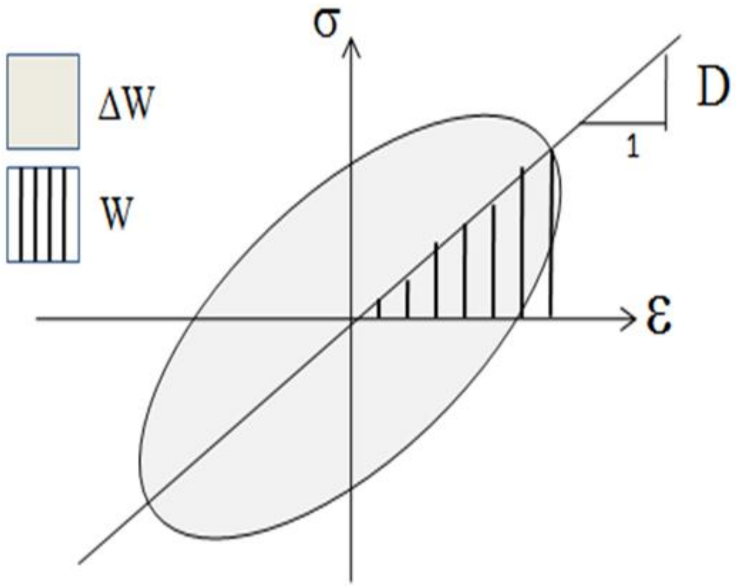
<u>Step i1</u>: Uses an iterated *"equivalently-linear*" structural model, based on equivalent-linear hysteretic components, for performing a ***global seismic SSI analysis (full model)*** in ***complex frequency*** to compute deformation of all components, and then,

<u>Step i2:</u> Uses nonlinear models for hysteretic components ***(reduced-size models)***, for performing ***local "true" nonlinear component analyses*** in ***time domain*** based on boundary displacements computed in Step i1.

The iterations are converged when the nonlinear responses in Step 2 do not change, or change only negligibly, from an iteration to the next iteration. Typically, 4-8 iterations are required depending on the nonlinearity level (2-4 linear SSI runtime).

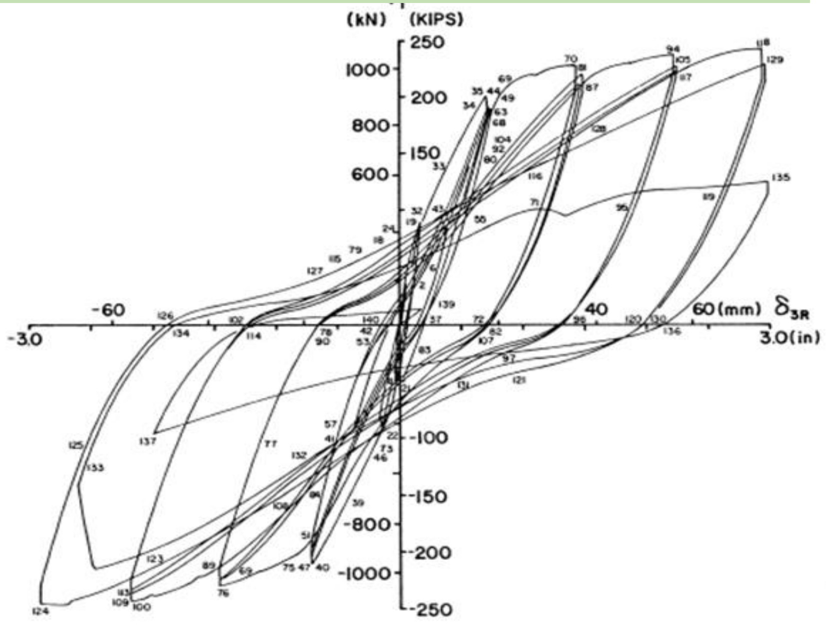
Frequency and Time Domain Hysteretic Systems

Frequency Hysteretic Model



Frequency Domain
Linearized Hysteretic Model

Time-Domain Hysteretic Model

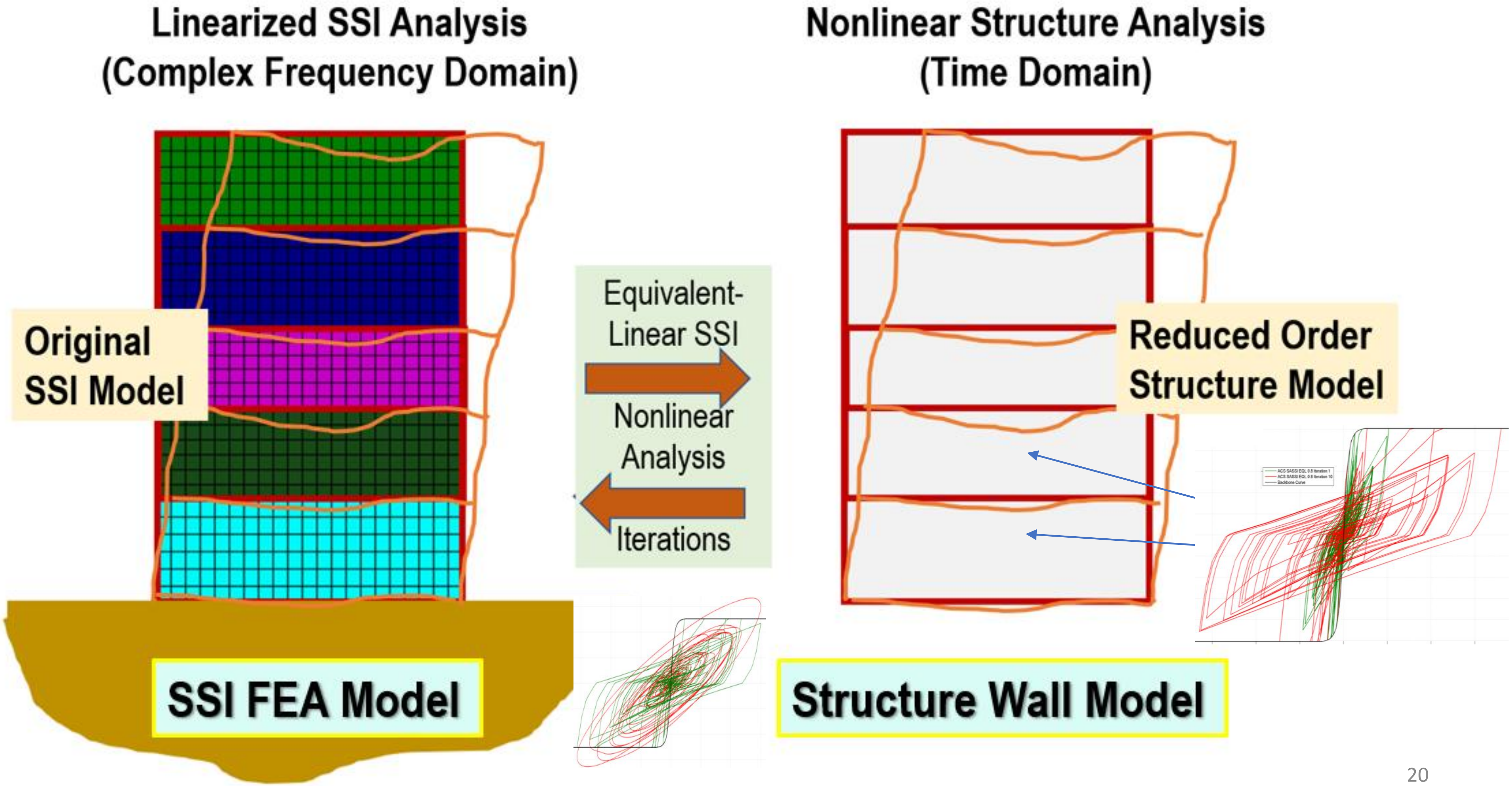


Time Domain
Degrading Hysteretic Model

Hybrid Approach with Reduced-Order Modeling for Structure:

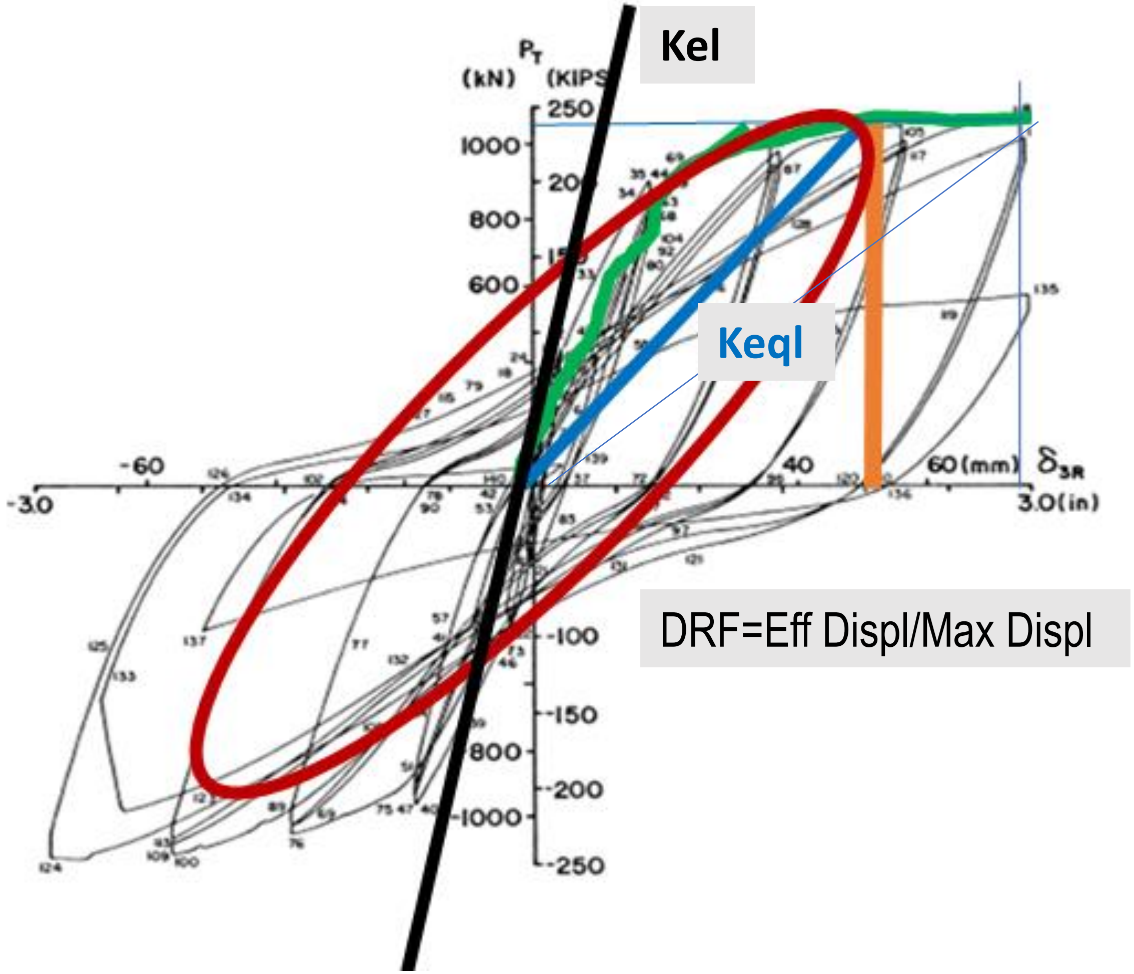
- *Fast and accurate* nonlinear SSI analyses at small time fractions (<< 1%) of time domain nonlinear analyse
- *More robust than nonlinear time integration approaches to numerical noise, damping effects*
- *<u>Made compliant with standard and regulatory requirements</u> based on experimental test data.*

Nonlinear Structure SSI Analysis Using A Hybrid Frequency-Time Domain Approach (Iterative Coupled Global-Local Iterations)

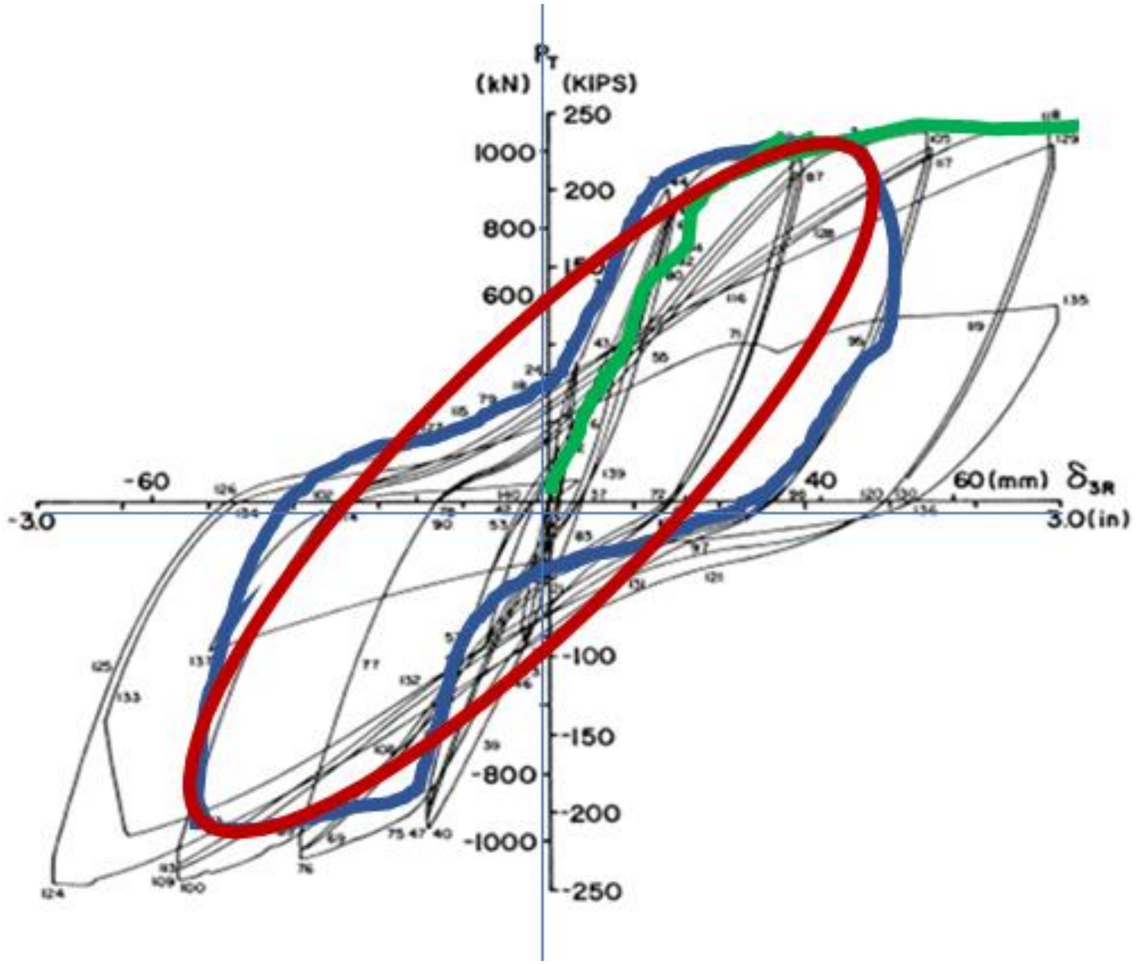


Computing Equivalent-Linear Dynamic Stiffness and Damping

Computing Equivalent Stiffness (Eeql)

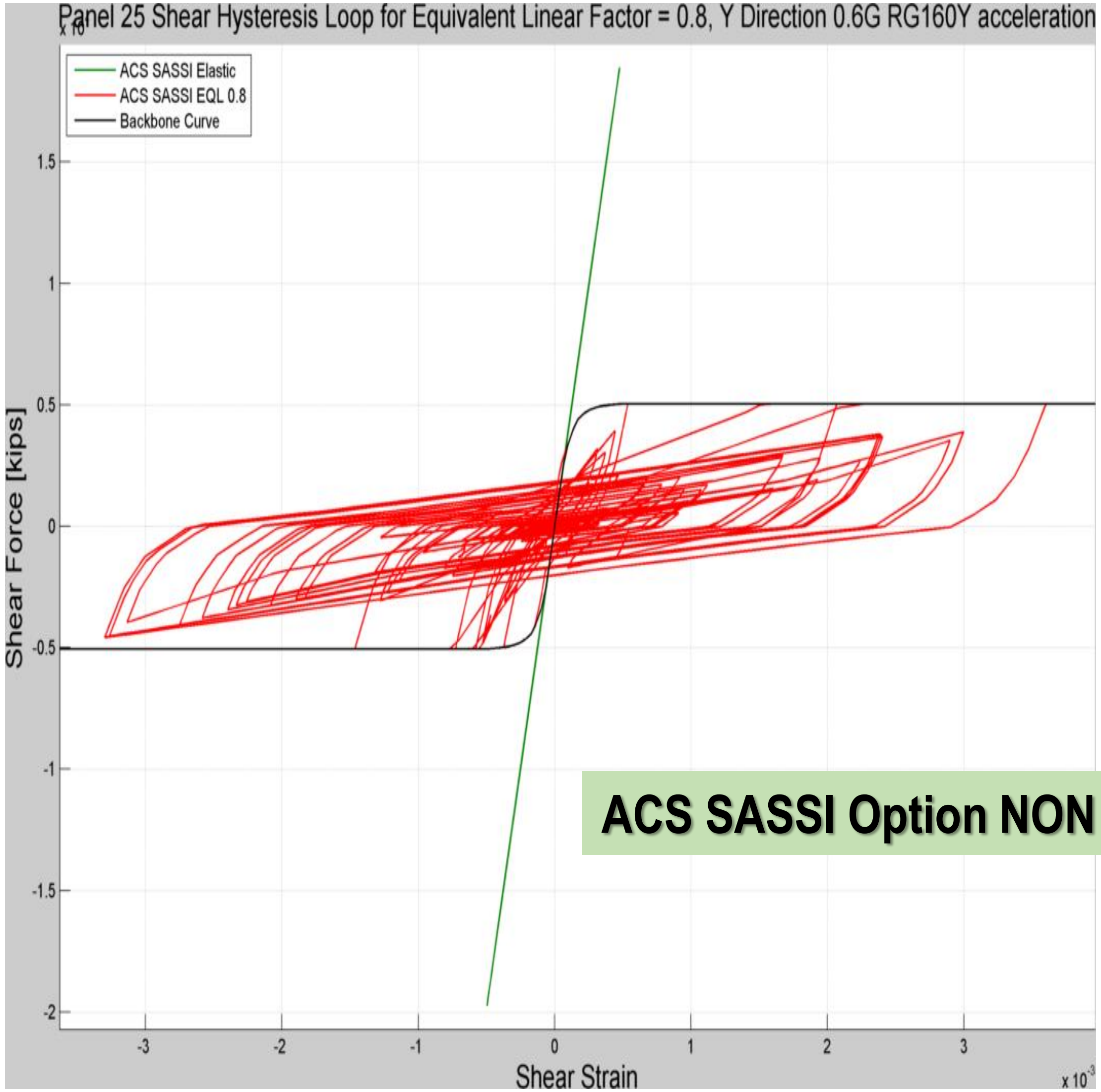


Computing Equivalent Damping (Deql)



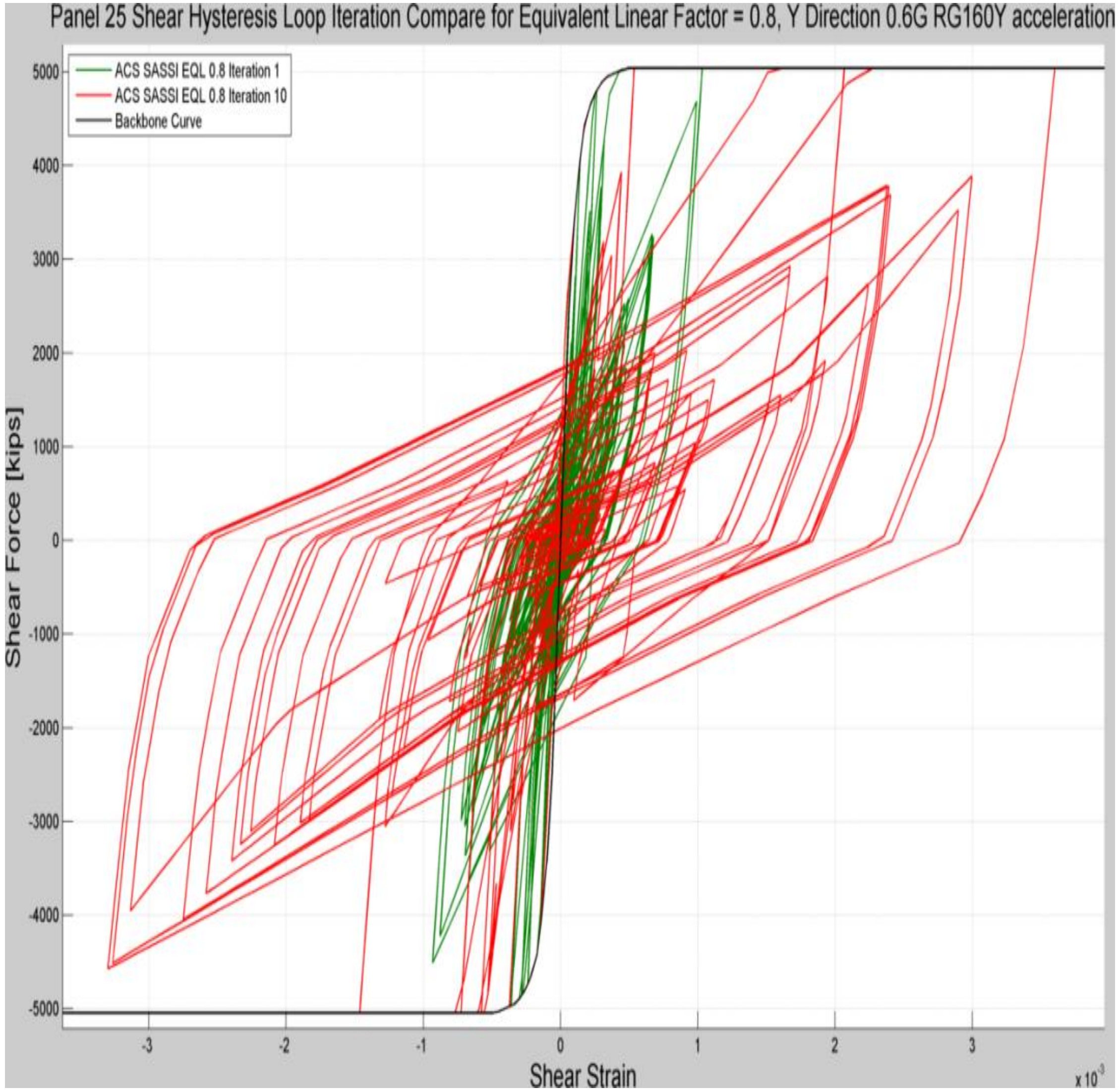
Applied to Structure Nonlinear SSI Analysis (up to 3-8 iterations)

Elastic vs. Nonlinear

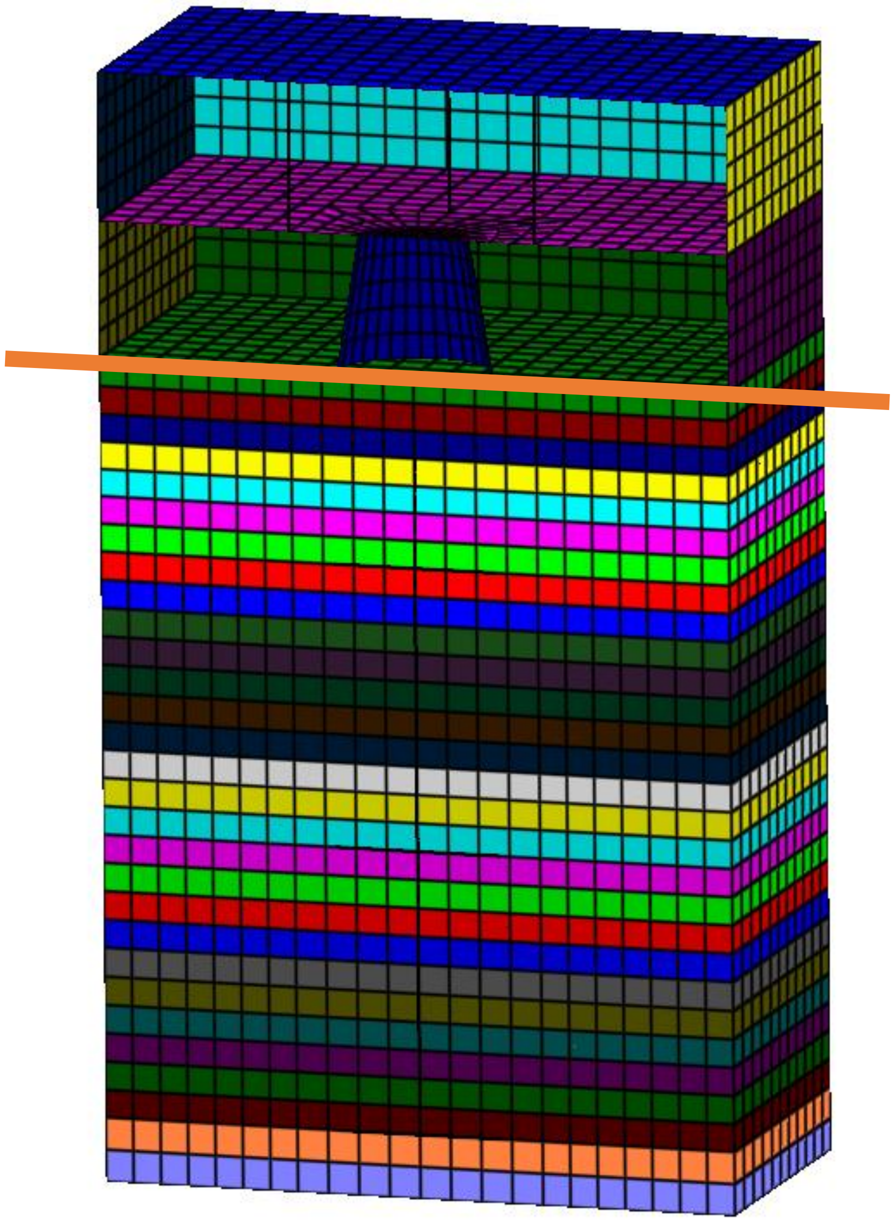


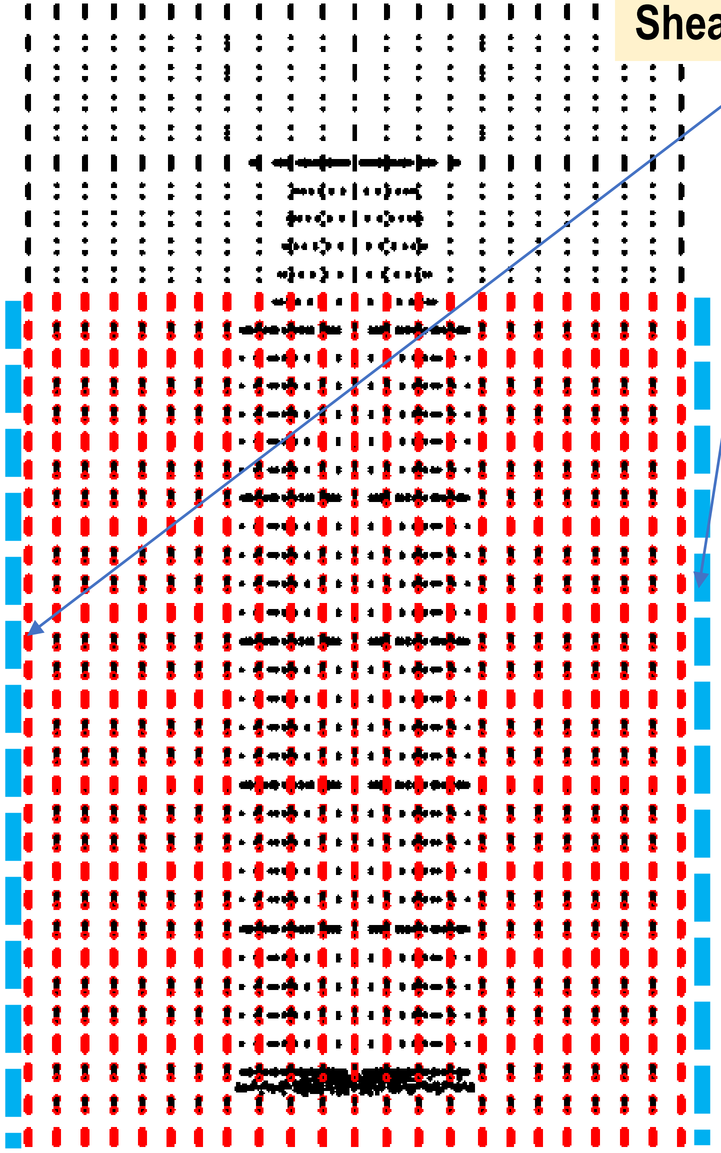
ACS SASSI Option NON

1st Iteration vs. 8th Iteration



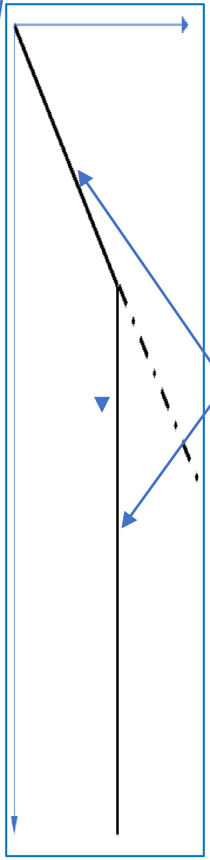
Applied to Embedded SMR with Wall-Soil Friction Interface





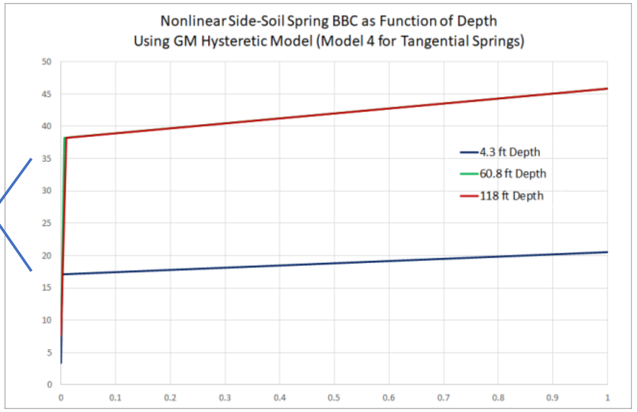
Nonlinear Shear Springs

Yielding Point



Side-soil interface friction modeled using nonlinear springs:

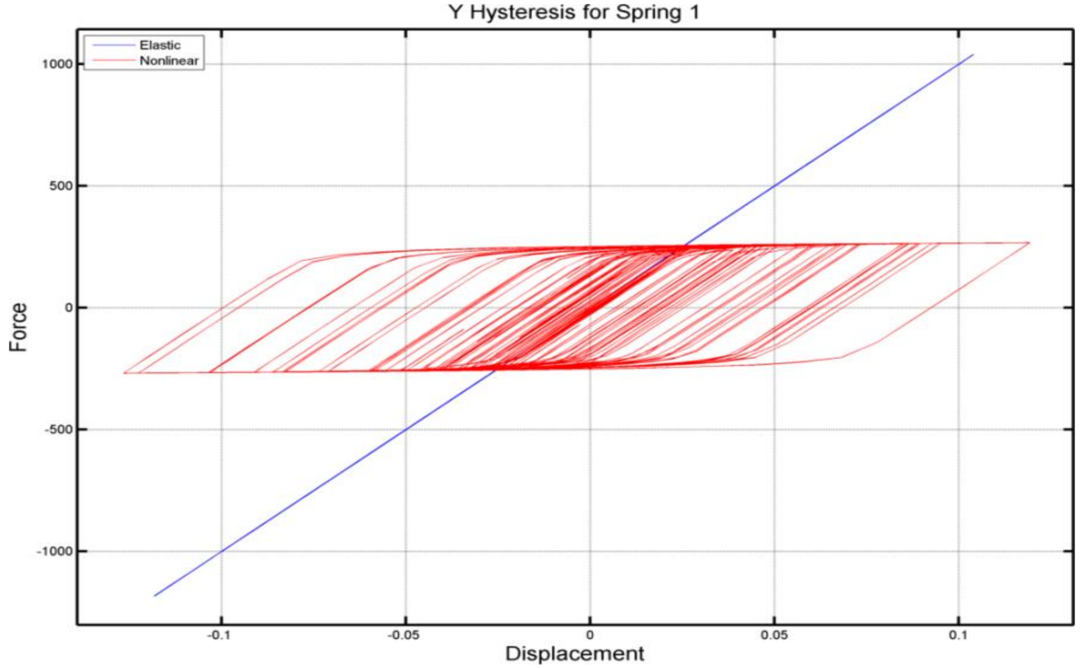
Nonlinear interface
Rigid springs in normal directions X, Y and Z, and nonlinear springs in tangential directions X, Y and Z. Friction forces vary with depth.



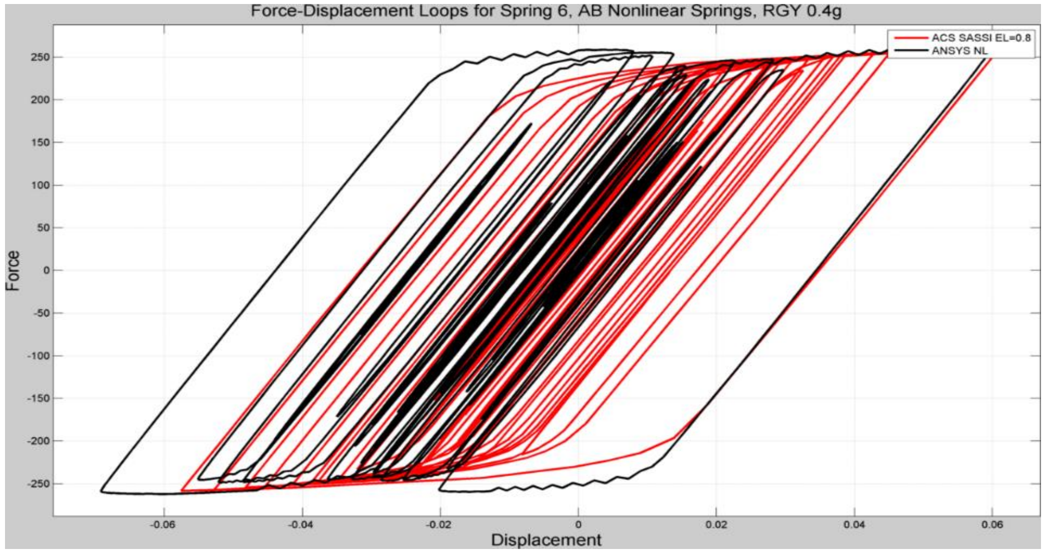
BBCs are computed based on the increasing static soil pressure on the lateral wall down to the layer for which the interface shear stress is above 2ksf (API standard).

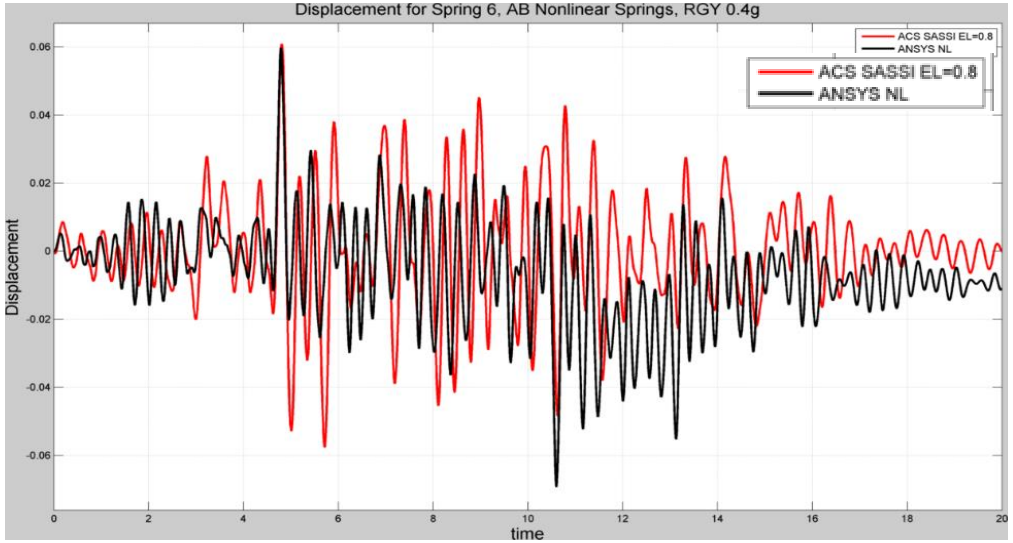
Applied to Base-Isolators, Wall-Soil Slip, or Checking Sliding

Hysteretic Base-Isolators



Reduced Foundation Sliding





Nonlinear RC Structure SSI Methodology Using Two-Step Iterations

The nonlinear RC structure SSI analysis based on the hybrid iterative scheme includes two separate coupled analysis steps at each iteration, as follows:

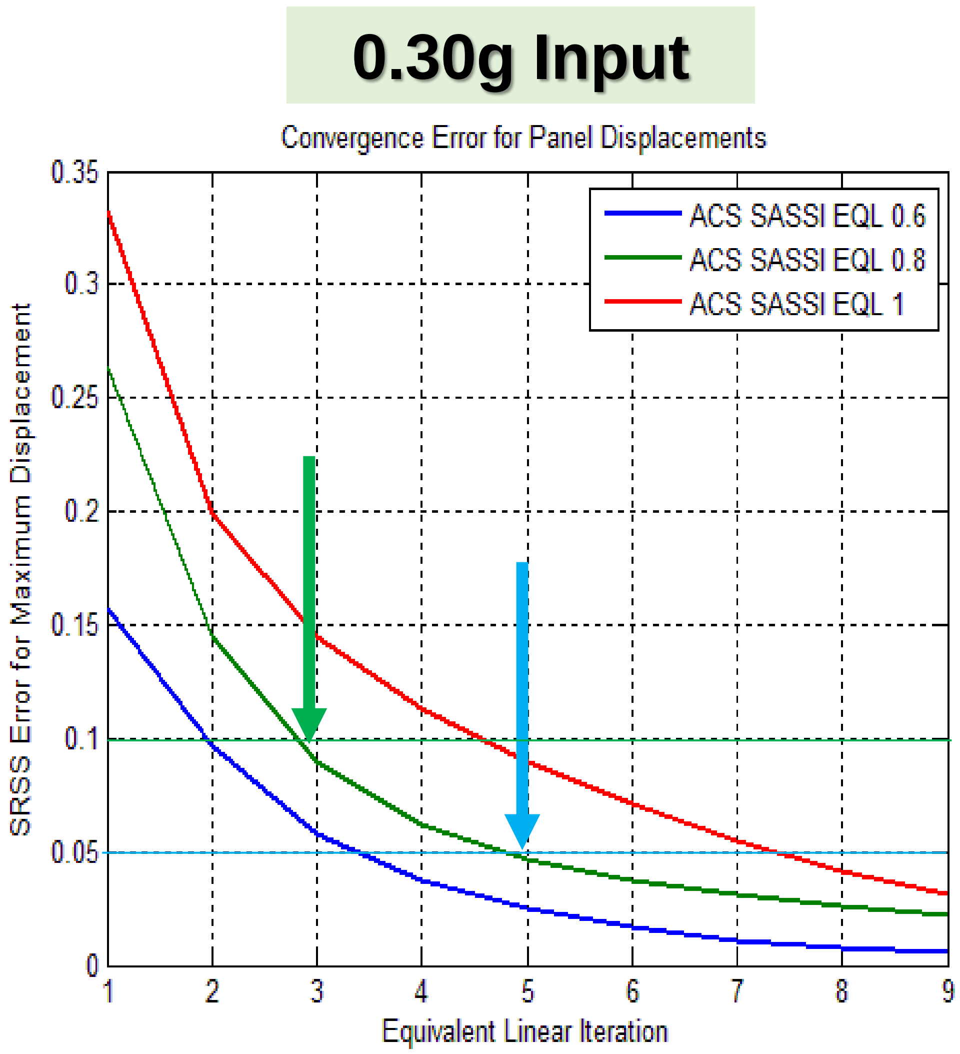
- Step 1: Perform an *equivalent-linear SSI analysis* in complex frequency via SASSI approach to compute the structural displacements for each nonlinear RC wall and spring, and then,

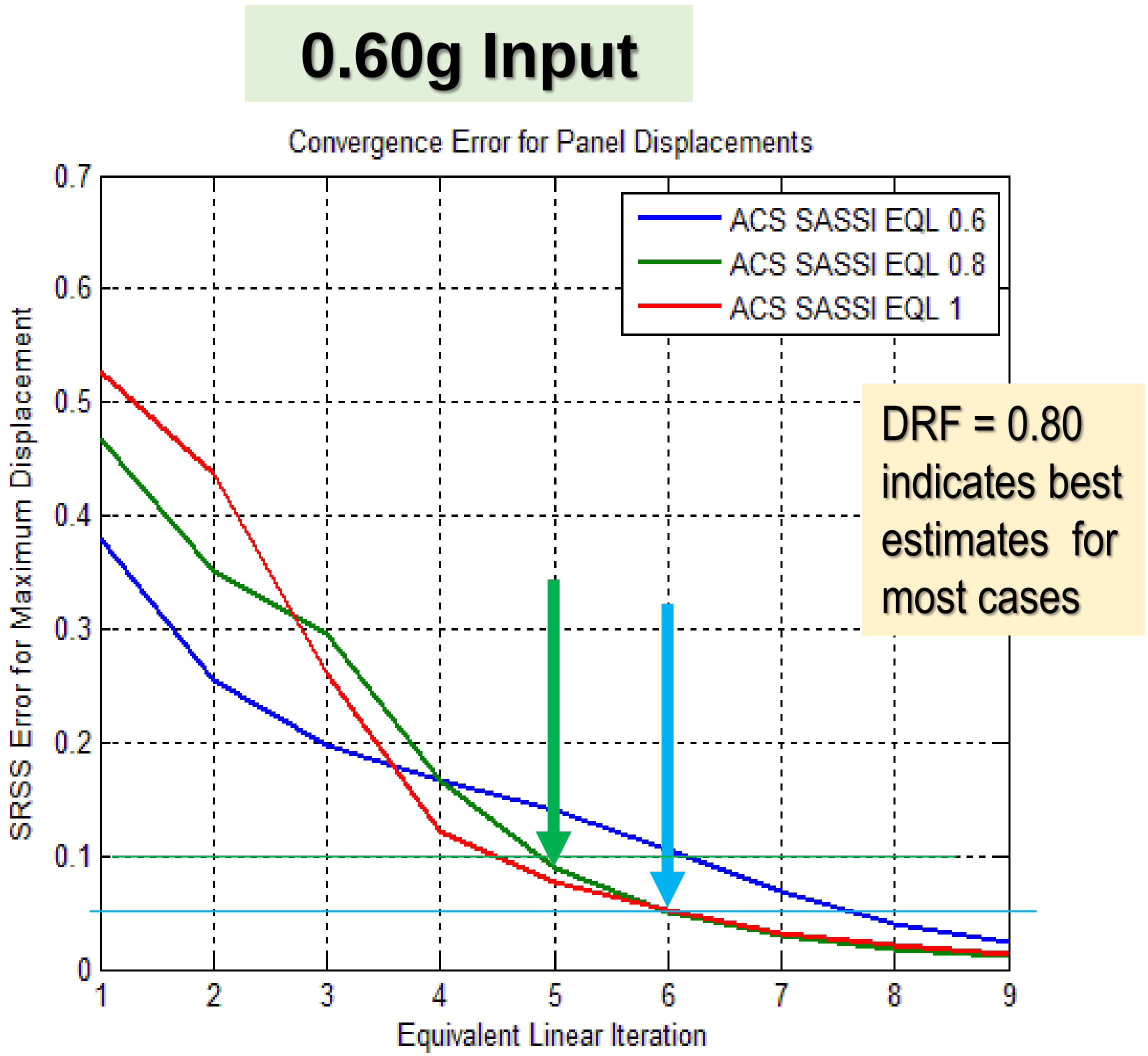
- Step 2: Perform a *nonlinear time-integration analysis* for each RC wall and spring loaded with the SSI displacements from Step 1, to compute the in-plane shear and bending nonlinear wall responses using *standard-equation BBCs* and *selected hysteretic models calibrated based on test data*.
  The *equivalent-linear stiffness and damping for each wall or spring* are computed based on time domain nonlinear responses using either a constant or a variable DRF applied to each SSI iteration.

REMARKS:

1) Step 1 uses the *original, refined FE SSI model*, while Step 2 uses a *reduced-order structural model* composed by nonlinear RC walls (macro-mechanics models). Therefore, the Step 2 “true” nonlinear time-domain integration analysis is extremely fast. For DES, the *condensed soil impedance matrix solution (via FVROM-INT)* could be used for the SSI iterations to speed up the analysis runtime.
2) The *iterative nonlinear SSI methodology* has been *verified* against CSI PERFORM3D code, ANSYS, OpenSees 3D FIBER and 2D MVLEM software, XTRACT and LS-DYNA. Not sufficient to detail here.

Typical Nonlinear SSI Solution Convergence in 3-8 Iterations for 5% or 10% Overall Accuracy Tolerance (for DRF=0.80)





PANEL_EQL_MATL_PROP_IT# Text Files; Iteration 1,4,6

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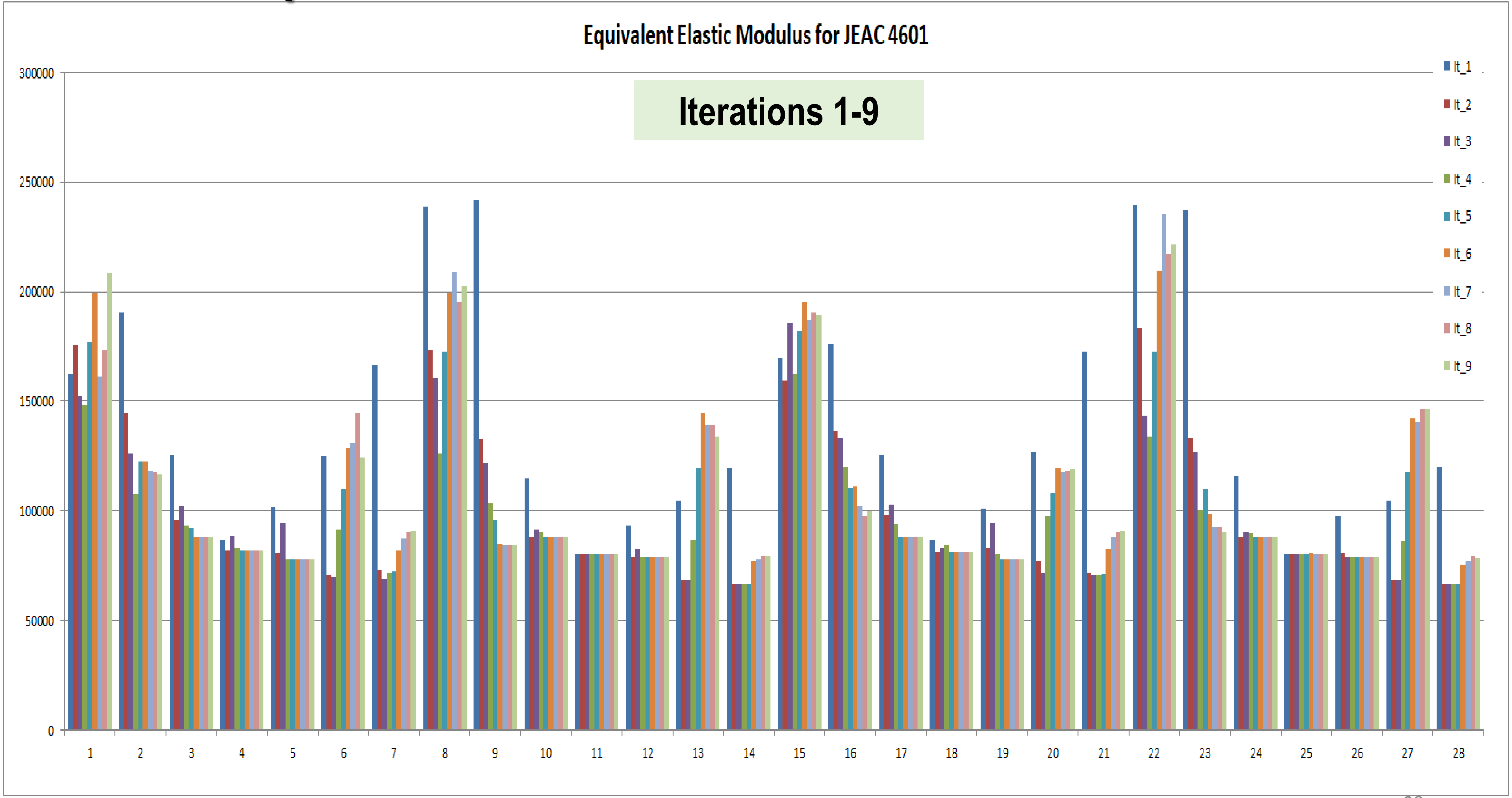
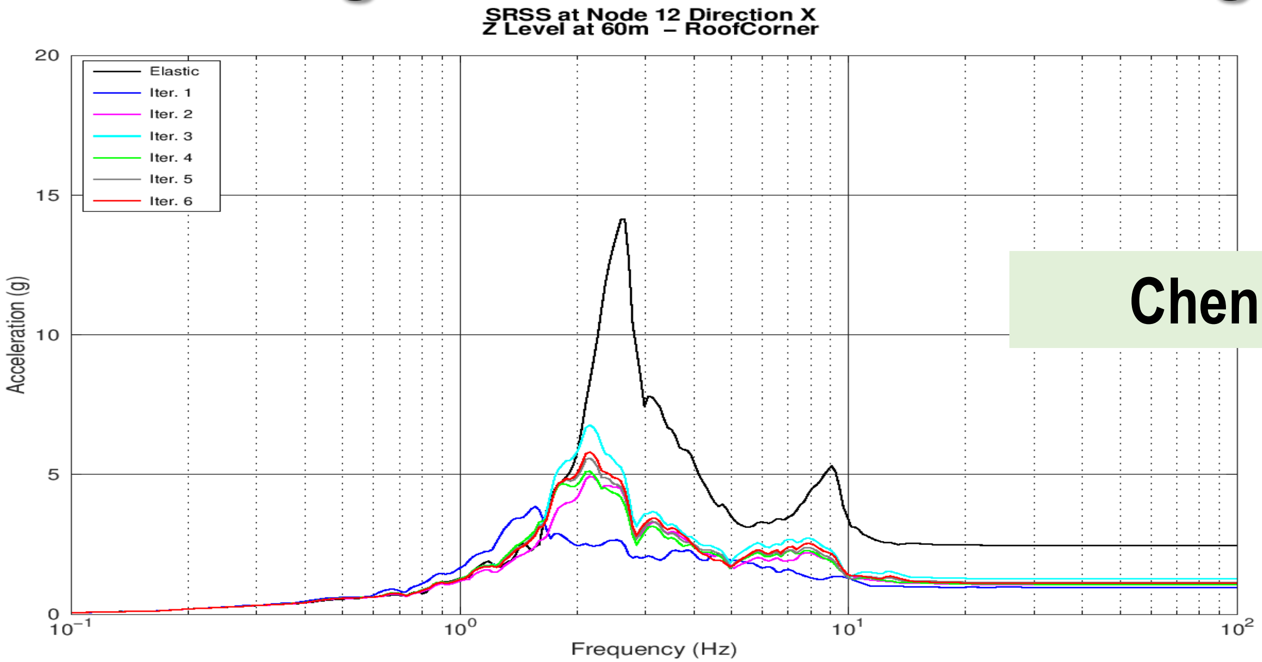
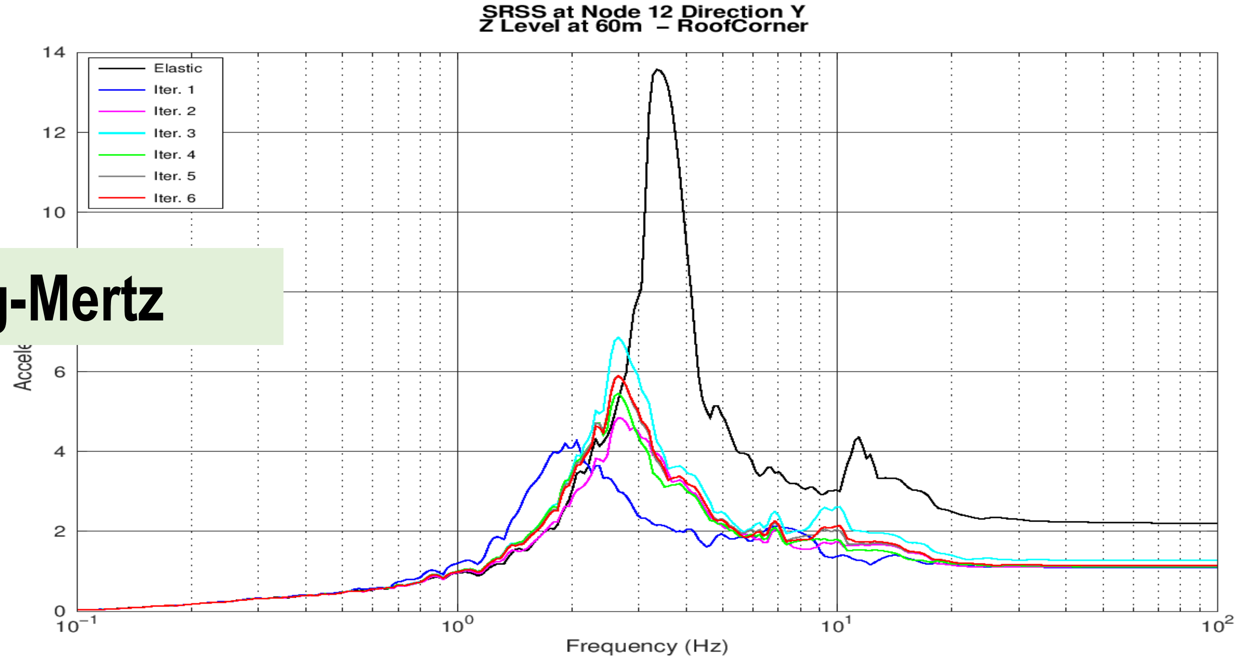
00084	457948	0.066831

Iterative Equivalent E Modulus Due to in Embedded SMR Walls

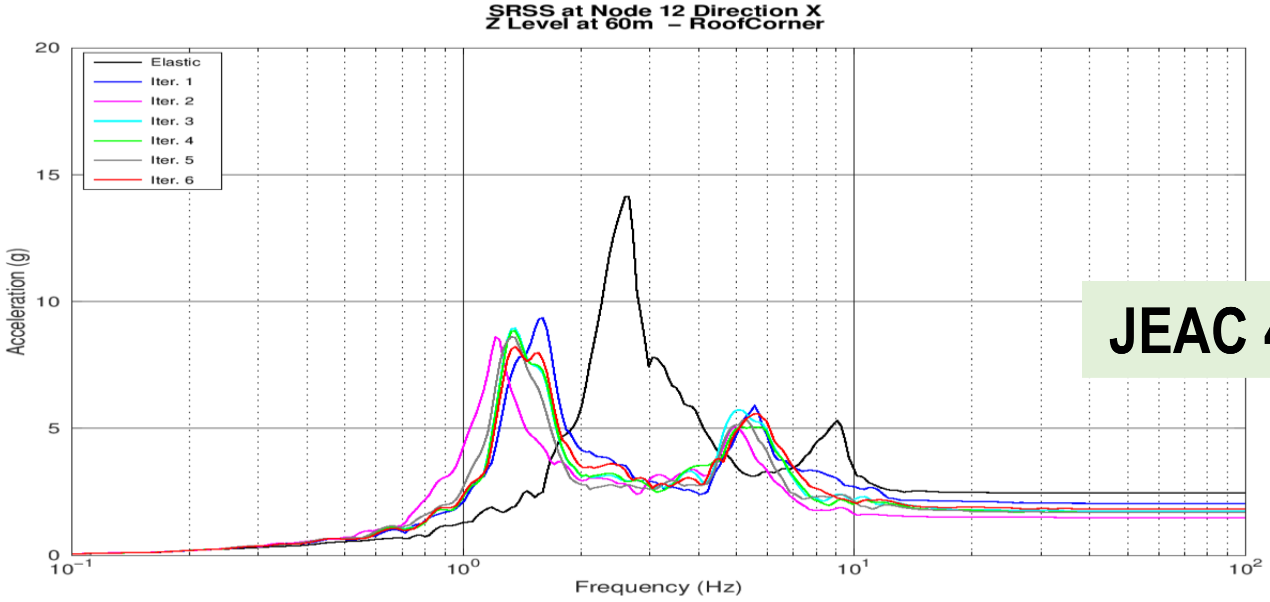


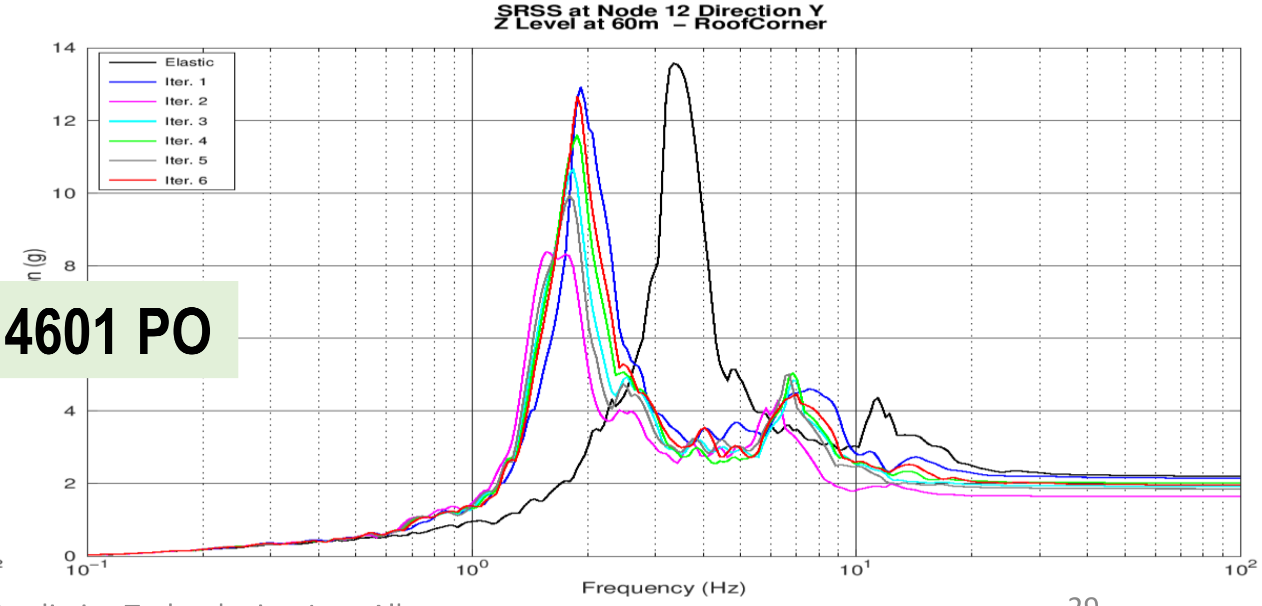
Convergence of ISRS for Cheng-Mertz and JEAC 4601 PO Models





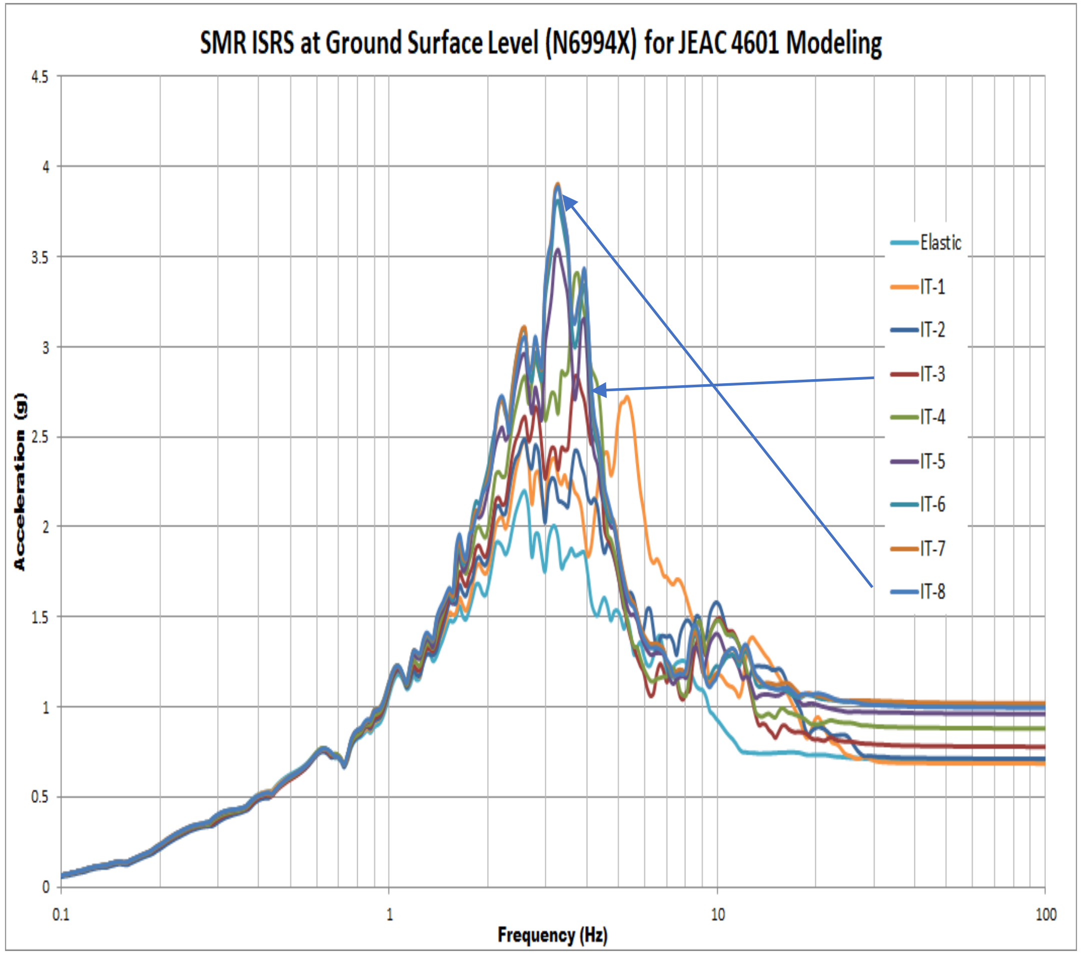
Cheng-Mertz





JEAC 4601 PO

Embedded SMR SSI Response Convergence for Nonlinear RC Walls (Panels) and Nonlinear Wall-Soil Interface (Springs) for 0.60g



*Nonlinear-Response-Convergence-Checking - Notepad

File Edit Format View Help

Convergence File

```
Number of Iteration =    1
Elastic E modulus relative difference between current and previous iteration =    70.738%
Damping ratio relative difference between current and previous iteration =    2.883%

Number of Iteration =    2
Elastic E modulus relative difference between current and previous iteration =    42.549%
Damping ratio relative difference between current and previous iteration =   17.882%

Number of Iteration =    3
Elastic E modulus relative difference between current and previous iteration =    54.342%
Damping ratio relative difference between current and previous iteration =   16.987%

Number of Iteration =    4
Elastic E modulus relative difference between current and previous iteration =    27.948%
Damping ratio relative difference between current and previous iteration =   11.733%

Number of Iteration =    5
Elastic E modulus relative difference between current and previous iteration =    15.903%
Damping ratio relative difference between current and previous iteration =    9.445%

Number of Iteration =    6
Elastic E modulus relative difference between current and previous iteration =    13.246%
Damping ratio relative difference between current and previous iteration =    6.800%

Number of Iteration =    7
Elastic E modulus relative difference between current and previous iteration =     7.132%
Damping ratio relative difference between current and previous iteration =    5.197%

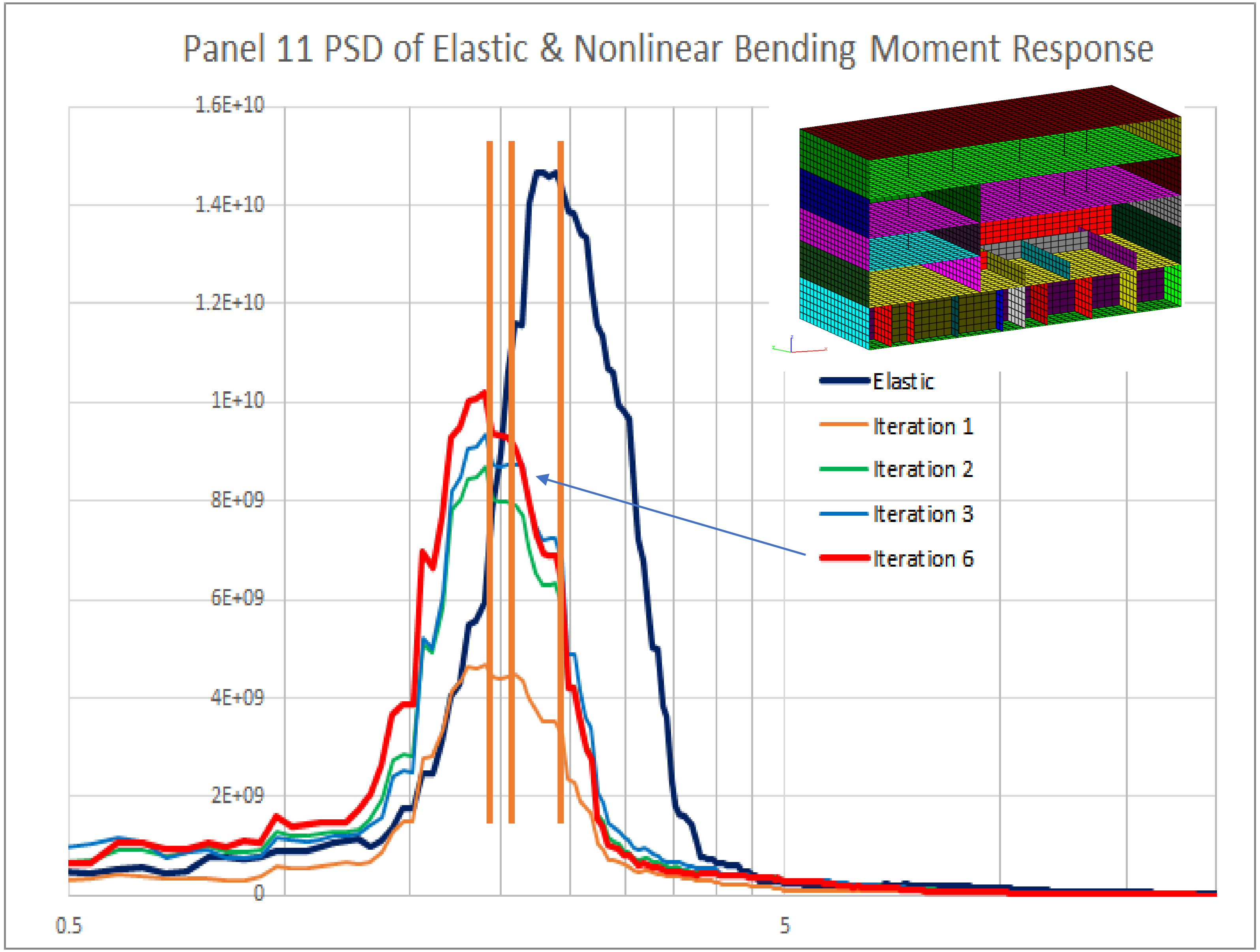
Number of Iteration =    8
Elastic E modulus relative difference between current and previous iteration =     4.837%
Damping ratio relative difference between current and previous iteration =    3.408%

Number of Iteration =    9
Elastic E modulus relative difference between current and previous iteration =     4.251%
Damping ratio relative difference between current and previous iteration =    0.838%
```

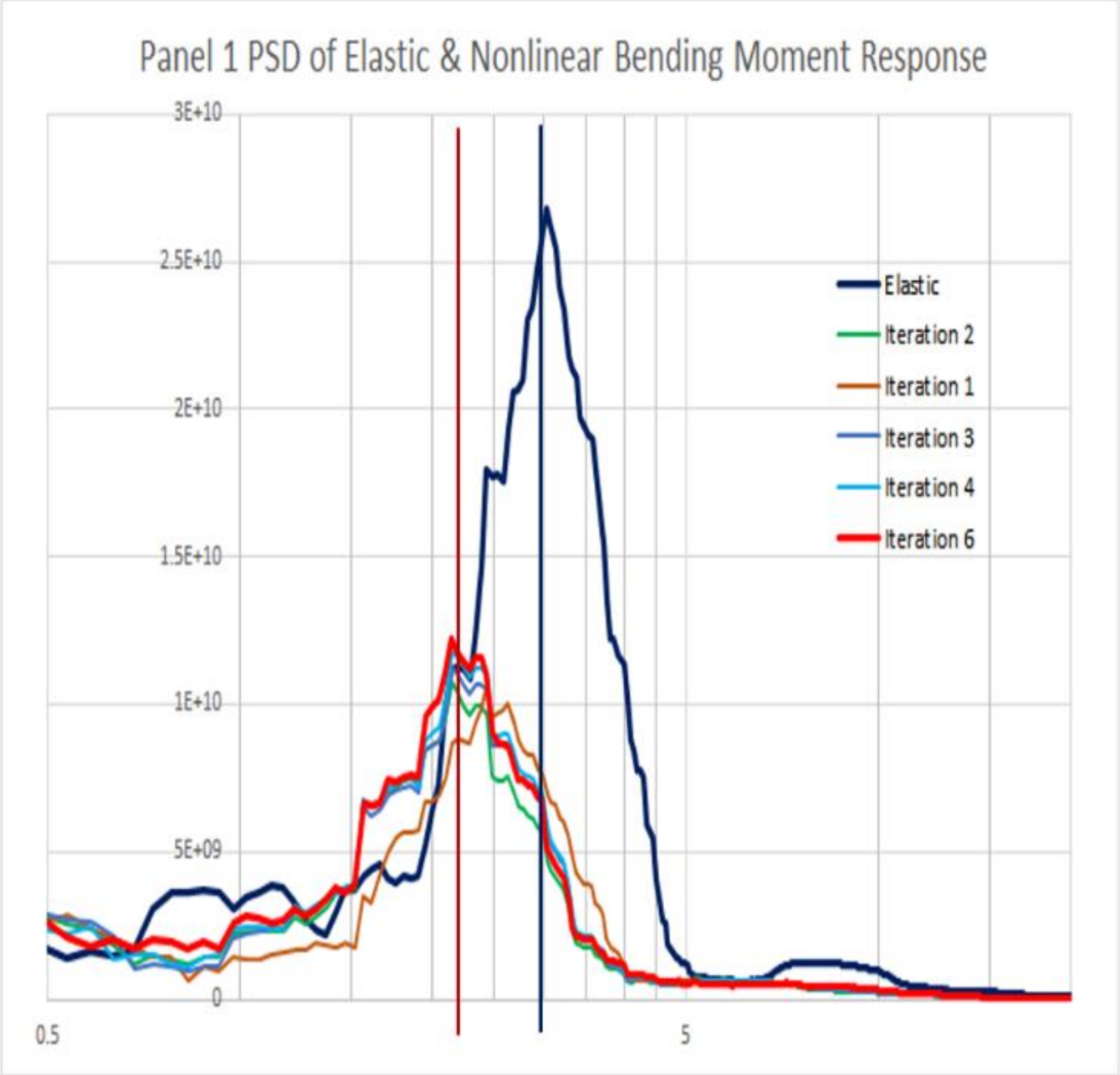

Iterative Equivalent Linearization Using PSD-Based Variable DRF

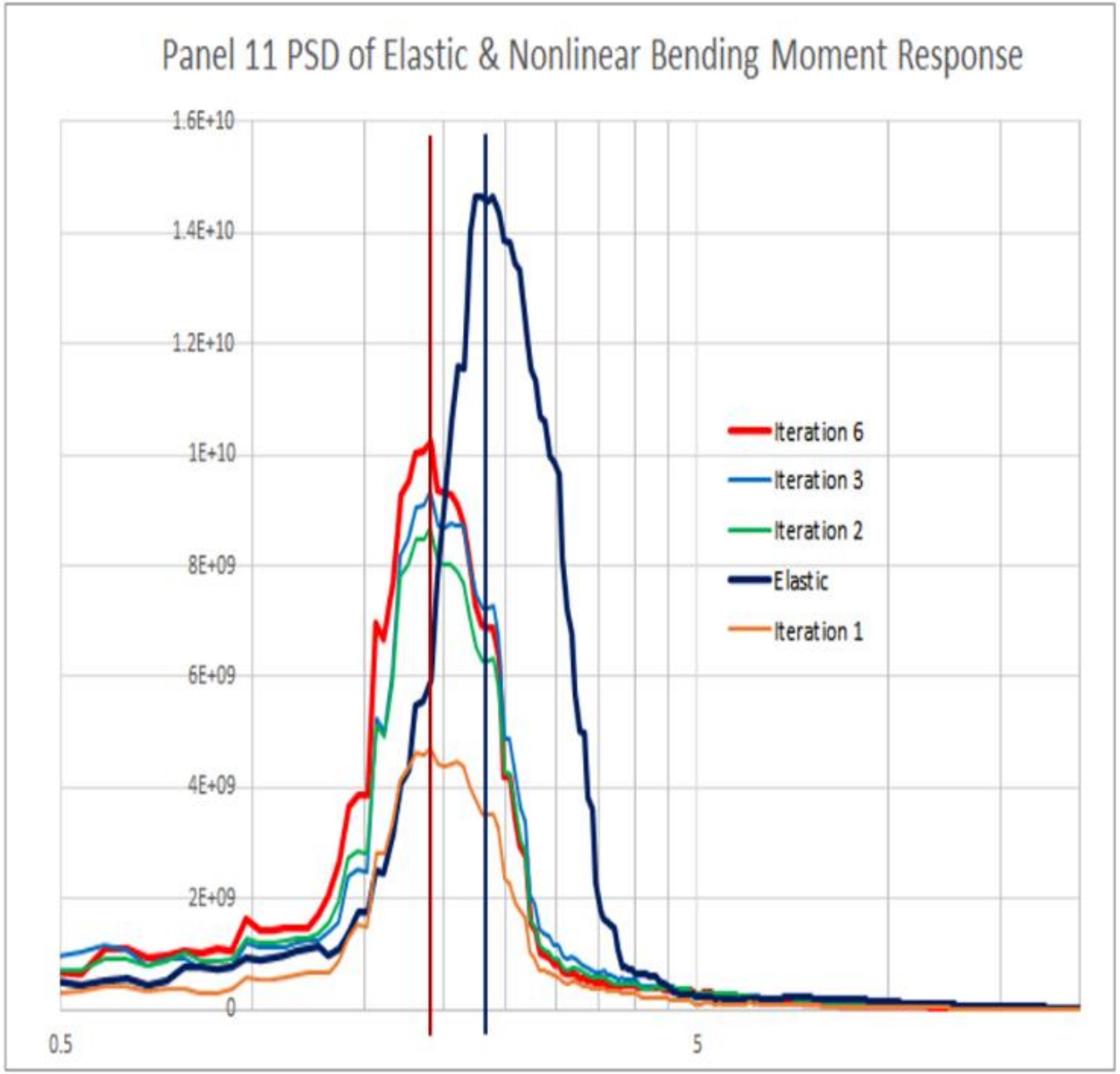
The *PSD-based DRF* is computed based on the frequency content of the PSD frequency computed for the nonlinear shear force or bending moment for each wall at each floor level and each iteration.

The DRF is computed based the PSD dominant frequency shifts at each iteration, as shown in the right-side figure.

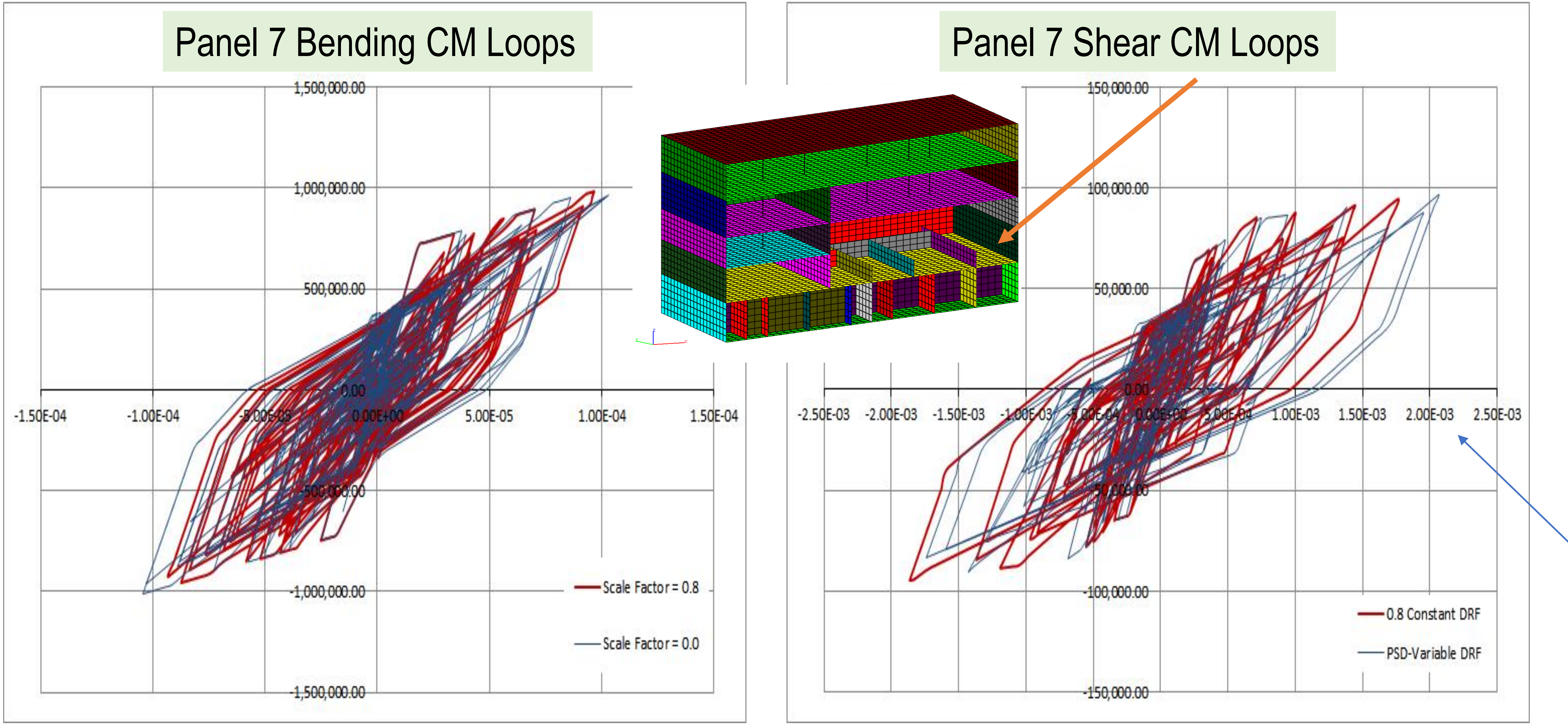


Convergence Using PSD-Based Variable DRFs

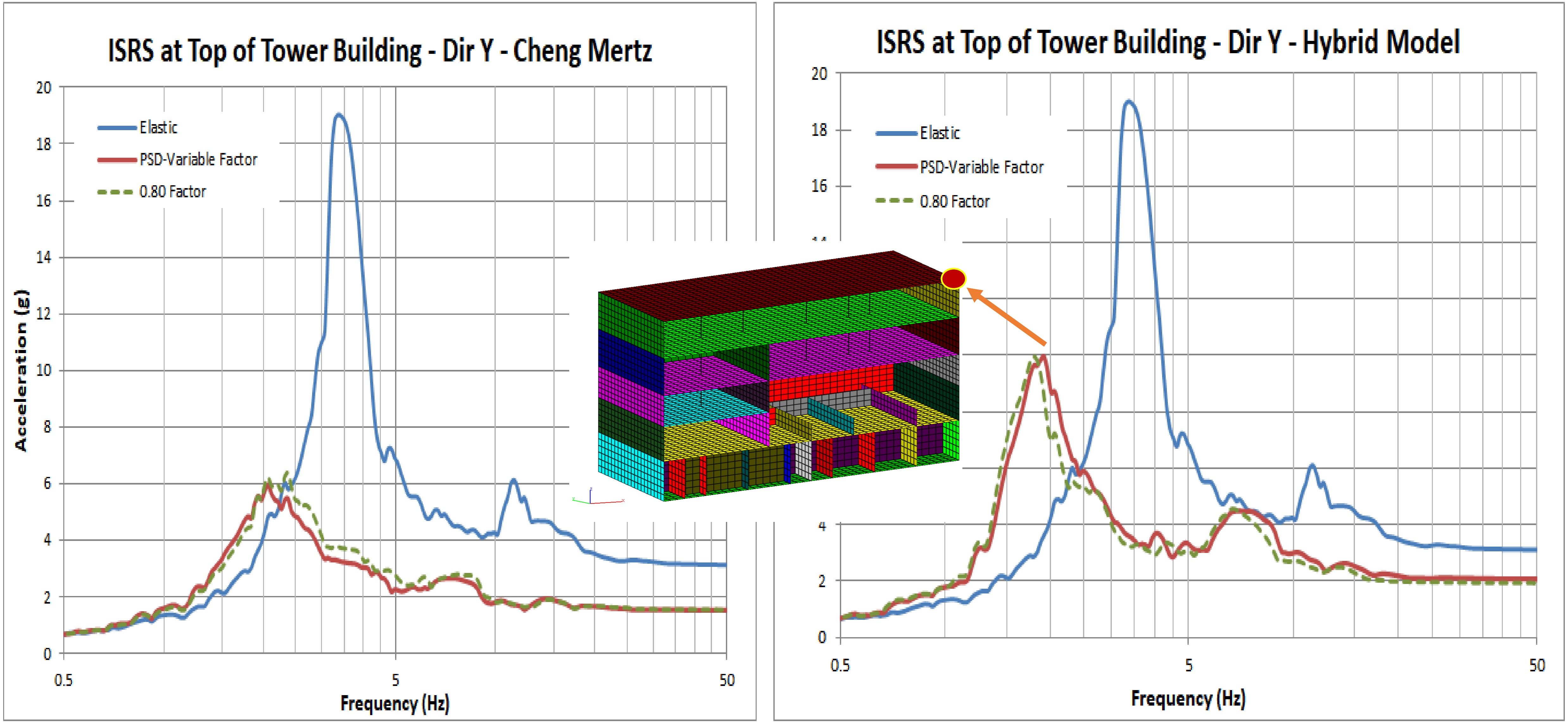




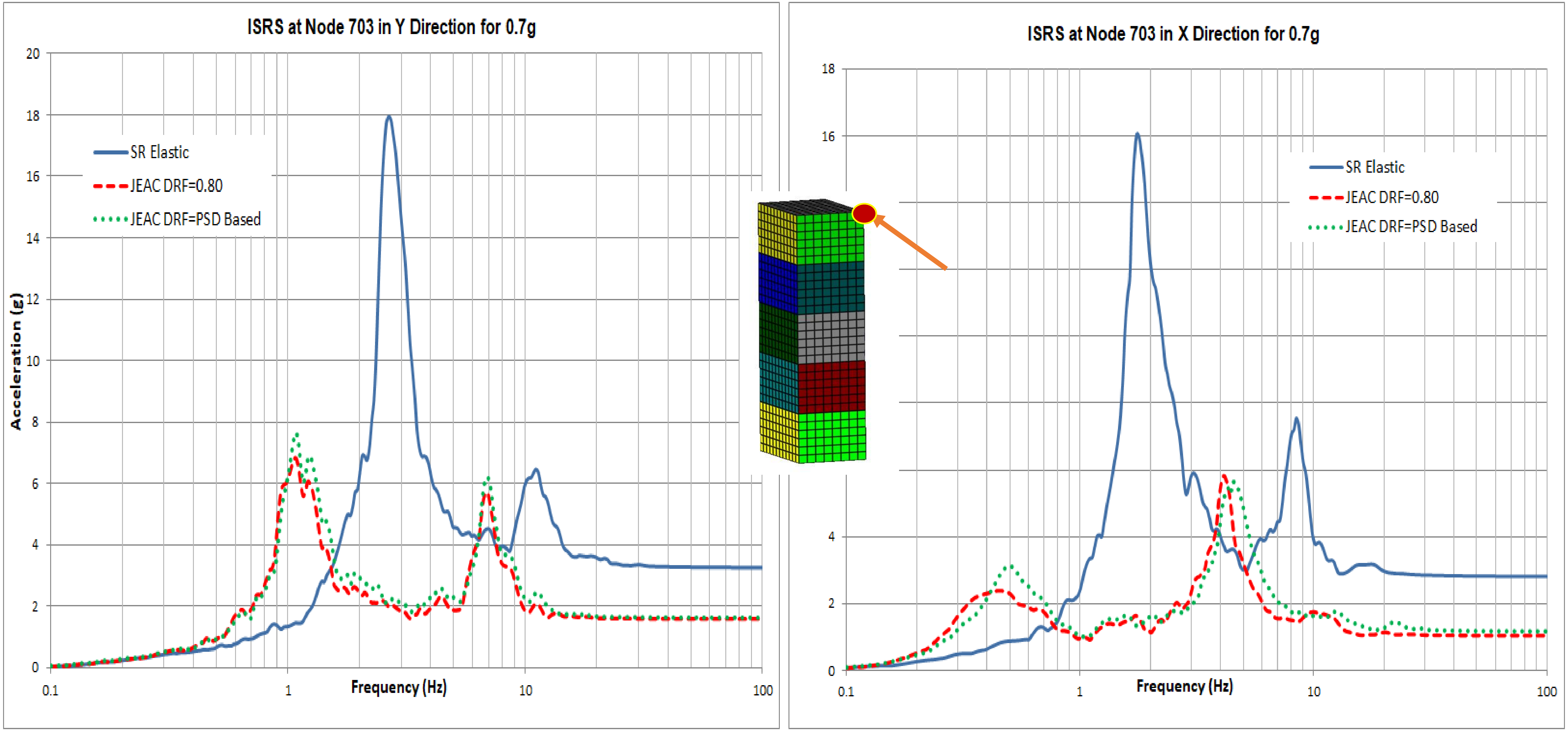
CM Hysteretic Responses for PSD-Variable DRF vs. 0.80 DRF



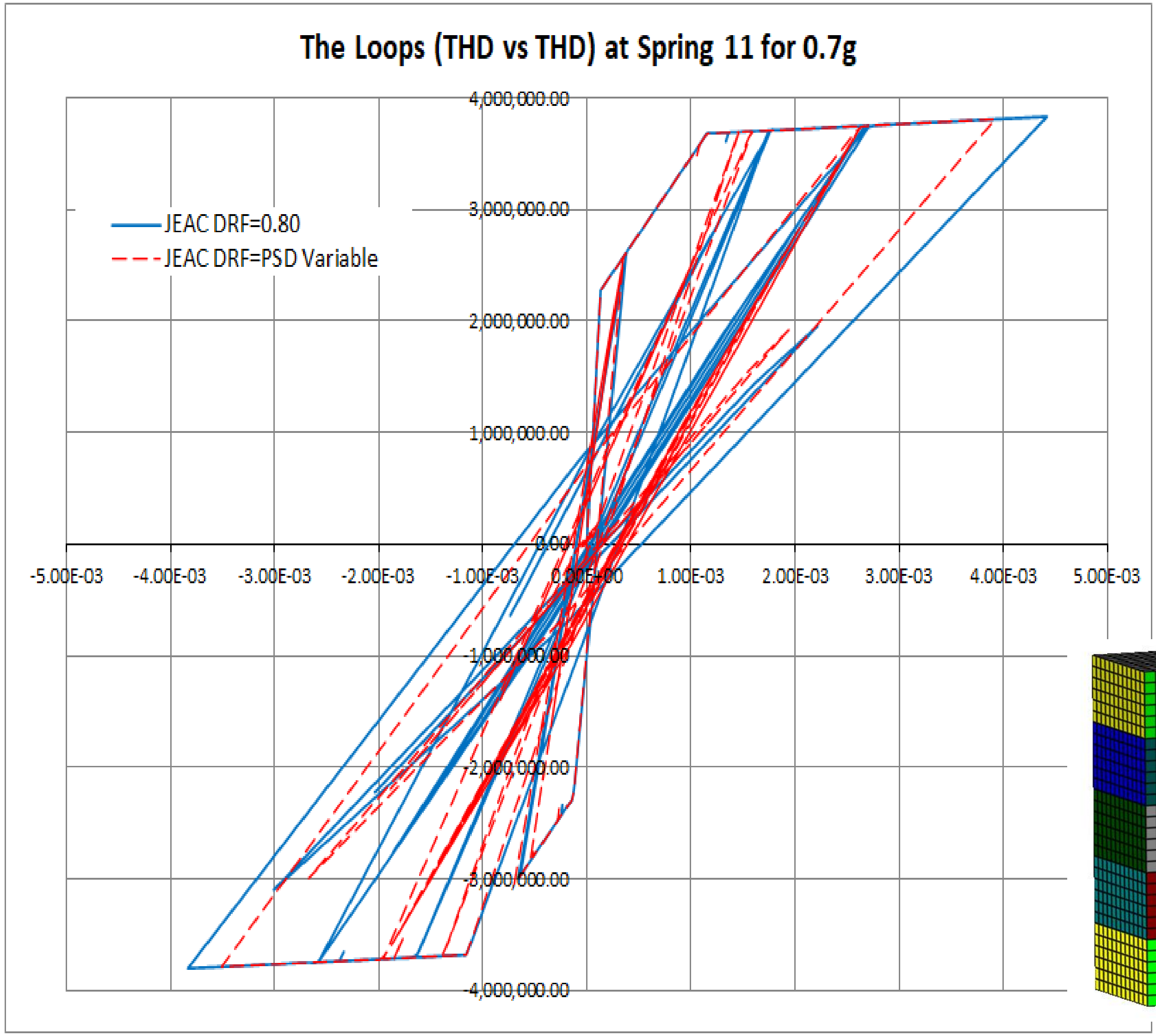
CM Nonlinear ISRS Computed Using PSD-variable DRF vs. 0.80 DRF

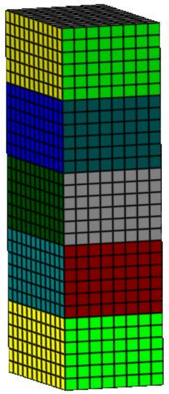


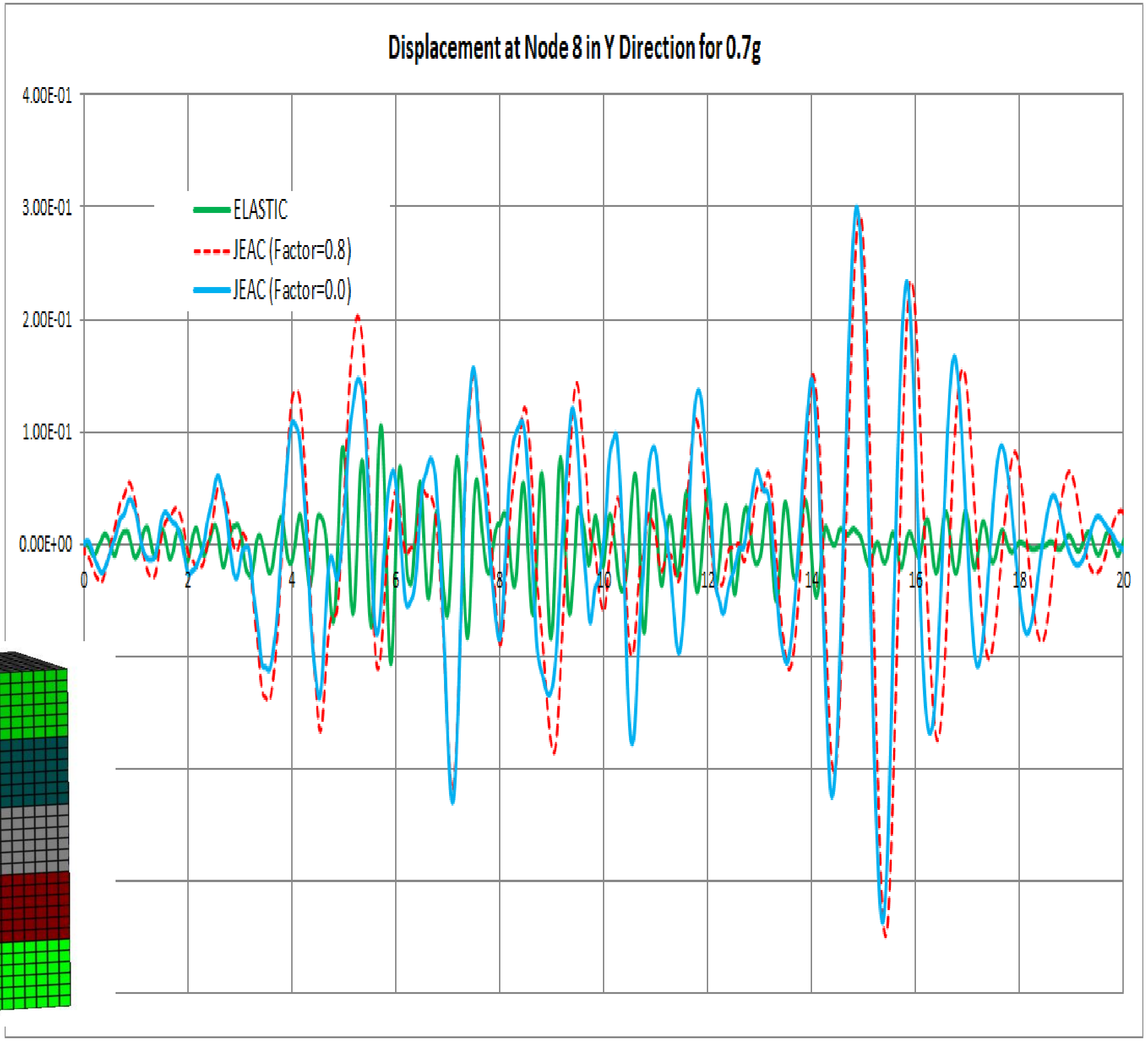
CM Nonlinear ISRS Computed Using PSD-variable DRF vs. 0.80 DRF



Based Wall Responsew & Top Displacements for PSD-variable DRF vs. 0.80 DRF







2.2 Nonlinear Modeling Assumptions for RC Walls

Nonlinear Modeling Assumptions for RC Wall Deformation

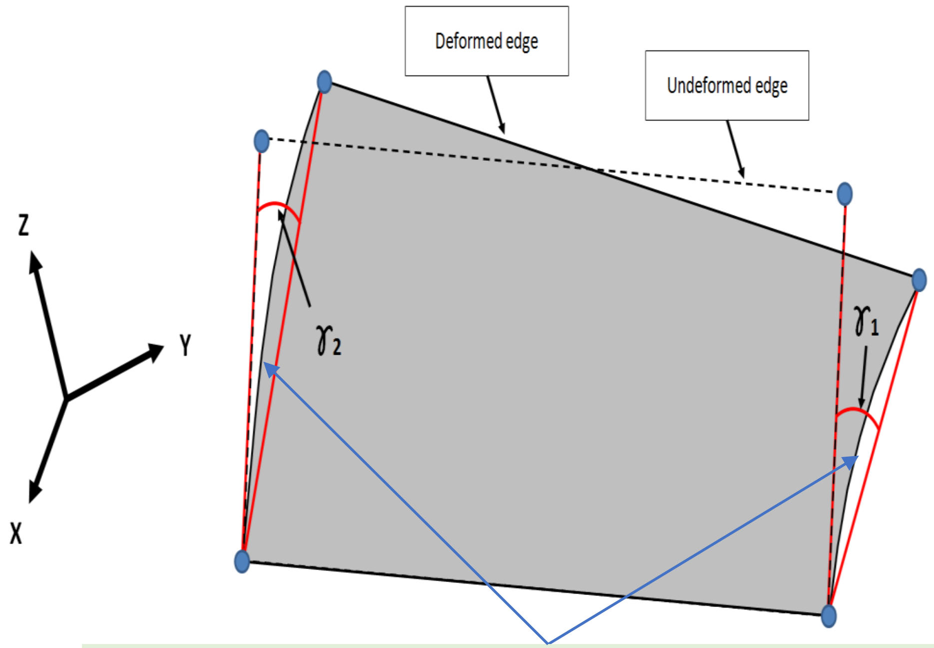
Option NON is applicable to the reinforced concrete structures for simulating the concrete cracking and post-cracking behavior in the shearwalls for the design-level and/or beyond-the-design-level seismic inputs.

Option NON is applicable to *low-rise* reinforced concrete shearwall buildings that fail primarily due to the *in-plane shear deformation via* ***Option NON Simple****.*

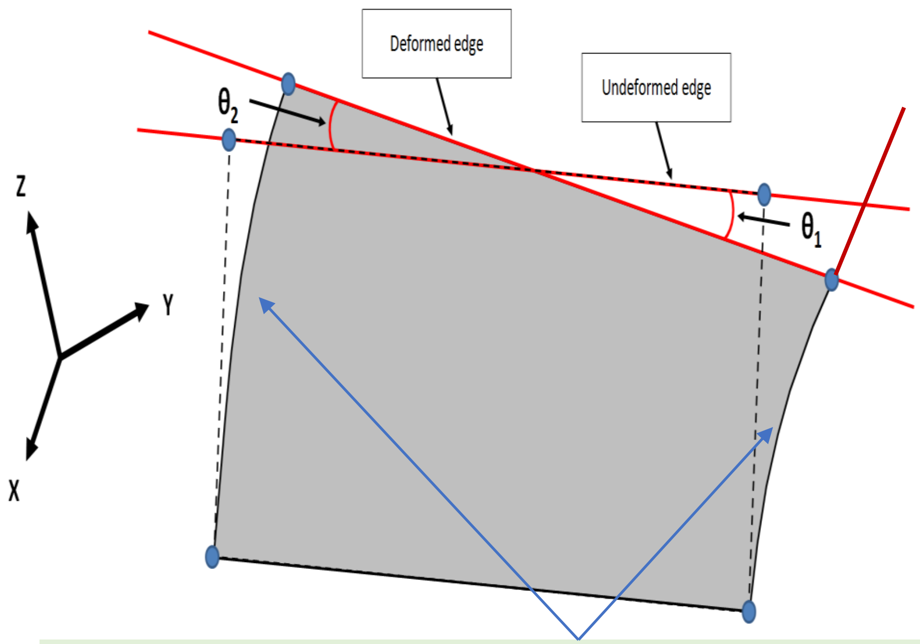
Option NON is also applicable to *general case* of reinforced concrete shearwall buildings for which both *in-plane shear and in-plane bending deformation* is significant via ***Option NON Advanced****.* Option NON Advanced includes automatic BBC generation algorithms based on US or Japan standards requirements and guidelines. It follows an implementation *inspired* from the Japanese nonlinear structure modeling practice for seismic analysis as explained hereafter.

Option NON versions:
Shear deformation only: *Option NON Simple*
Shear & Bending deformation: *Option NON Advanced*

Wall Shear and Bending Deformation Are Computed for Each Wall, at Each Floor Level at Each SSI Iteration



Shear Deformation (vertical edges)
(shear strain assumed constant per height, wall vertical edge displacements are linear)

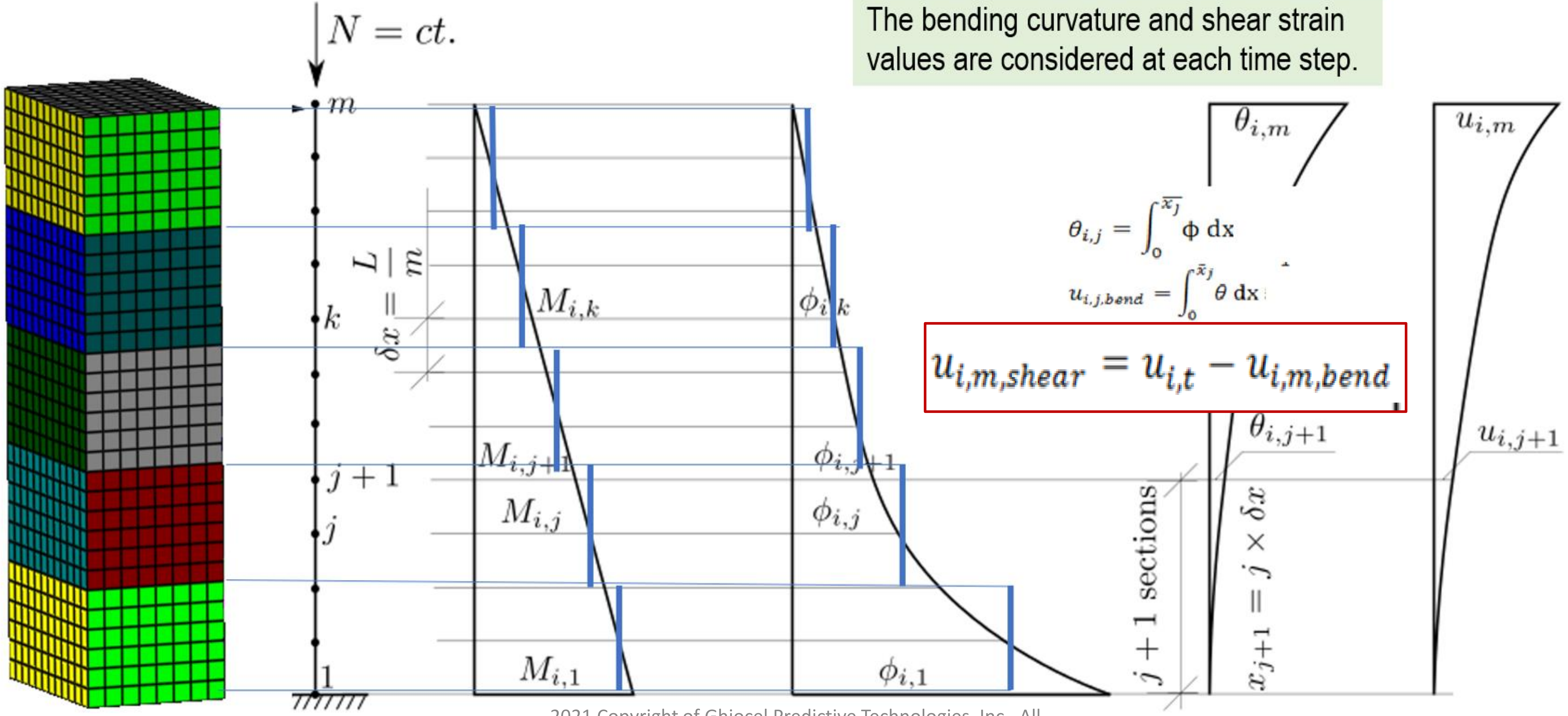


Bending Deformation (horizontal edges)
(curvature assumed constant per height, wall vertical edge displacements have quadratic variation)

Remark: Rigid body motion is removed. Very important.

Nonlinear Shear and Bending Responses Are Computed Based on Each Floor Structural Displacements at Each SSI Iteration

The bending curvature and shear strain values are considered at each time step.



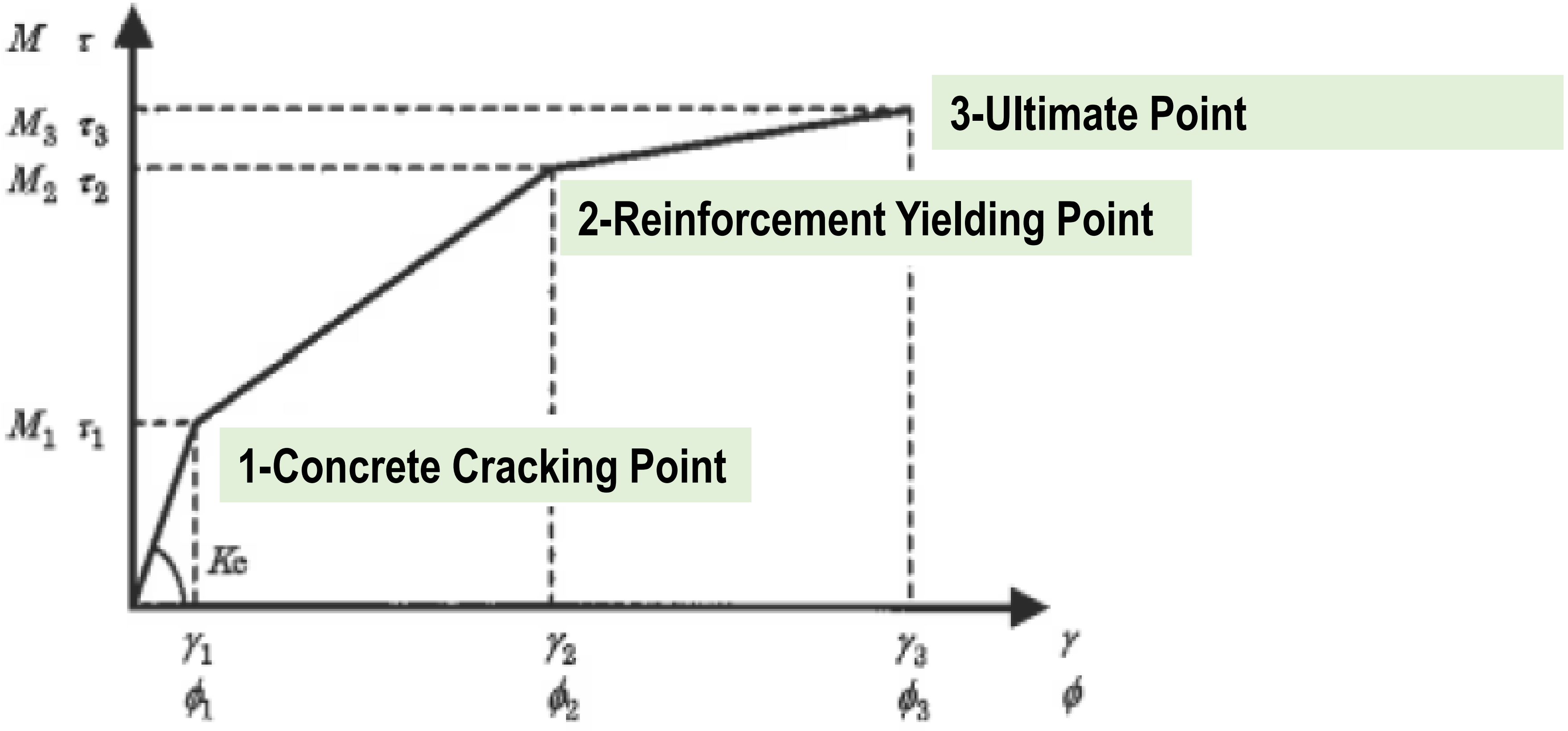
$$\theta_{i,j} = \int_0^{\overline{x_j}} \phi \, dx$$

$$u_{i,j,bend} = \int_0^{\bar{x}_j} \theta \, dx$$

$$\boxed{u_{i,m,shear} = u_{i,t} - u_{i,m,bend}}$$

Nonlinear Modeling Wall Behavior Based on US & Japan Practice. Trilinear Back-Bone Curves (BBC) and Selected Hysteretic Models

BBC Curves: Are trilinear BBCs for both the shear and bending deformation following typical engineering practice, also recommended by the JEAC 4601-2015 Sect.3.5.6 (See figure below)



Exp. Figure 3.5.6-1 Trilinear skeleton curve.

Shear BBCs Computed per JEAC 4016-2015 Standard App.3.6

***SHEAR BBC** (Shear stress τ vs. Shear Strain γ)*

Point 1 for Cracking:

$$\tau_1 = \sqrt{0.31\sqrt{Fc}\,(0.31\sqrt{Fc} + \sigma_v)}$$

$$\gamma_1 = \frac{\tau_1}{G}$$

Shear BBC at each floor level depends on the axial compression stress from gravity and the seismic bending moment by M/Q ratio (shear span ratio)

Point 2 for Yielding:

$$\tau_2 = 1.35 * \tau_1$$

$$\gamma_2 = 3 * \gamma_1$$

Point 3 for Ultimate:

Exterior Wall (Appendix 3.7)

$$\tau_3 = \begin{cases} \left(1 - \dfrac{\tau_s}{1.4 * Fc}\right) * \tau_0 + \tau_s & if\ \ \tau_s \le 1.4\sqrt{Fc} \\ 1.4\sqrt{Fc} & if\ \ \tau_s > 1.4\sqrt{Fc} \end{cases}$$

$$\gamma_3 = 0.004$$

where

$$\tau_0 = (0.94 - 0.56 * M_{QD}) * Fc$$

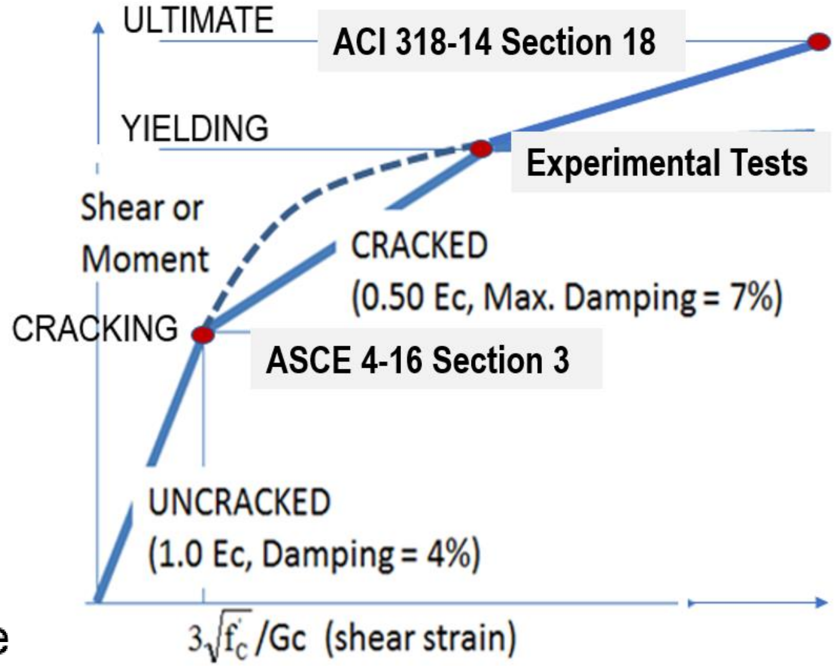
$$\tau_s = \frac{Pvw + Phw * Fs}{2} + \frac{\sigma_v + \sigma_h}{2}$$

Interior Wall (Ref. 14 in Appendix 3.7)

$$\tau_3 = \frac{0.068 p_{te}^{0.23}(Fc + 18)}{\sqrt{M_{QD} + 0.12}} + 0.85\sqrt{\sigma_{wh} * P_{wh}} + 0.1 * \sigma_0$$

Shear BBCs Computed per ACI 318/ASCE 4-16

SHEAR BBC (Shear stress τ vs. Shear Strain γ)



Point 1 for Cracking:

$\tau_1 = 3\sqrt{f'c}$ (ASCE 4-16)

$\gamma_1 = \frac{\tau_1}{G}$

Does no depend on axial force or bending effects!

Point 2 for Yielding:

$\tau_2 = s * \tau_3$ where s is user defined reduction factor based on te

$\gamma_2 = \gamma_1 * (1 + 2\left(\frac{\tau_2}{\tau_1} - 1\right))$ (ASCE 4-16)

Point 3 for Ultimate:

$\tau_3 = \left(\propto \sqrt{f'c} + P_h f_y\right) \leq 10\sqrt{f'c}$ (ACI 318-19), with ∝ varying as a function of plane wall sizes

$\gamma_3 = 0.008$

Bending BBCs Computed per JEAC 4601-2015 App. 3.6

BENDING BBC (Bending moment M vs. Curvature φ)

Point 1 for Cracking:

$$M_1 = Ze * (ft + \sigma_v)$$

$$\emptyset_1 = \frac{M_1}{Ec * Ie}$$

Shear BBC at each floor level depends on the axial compression stress from gravity

Point 2 for Yielding:

$$M_2 = M_y$$
$$\emptyset_2 = \emptyset_y$$

Point 3 for Ultimate:

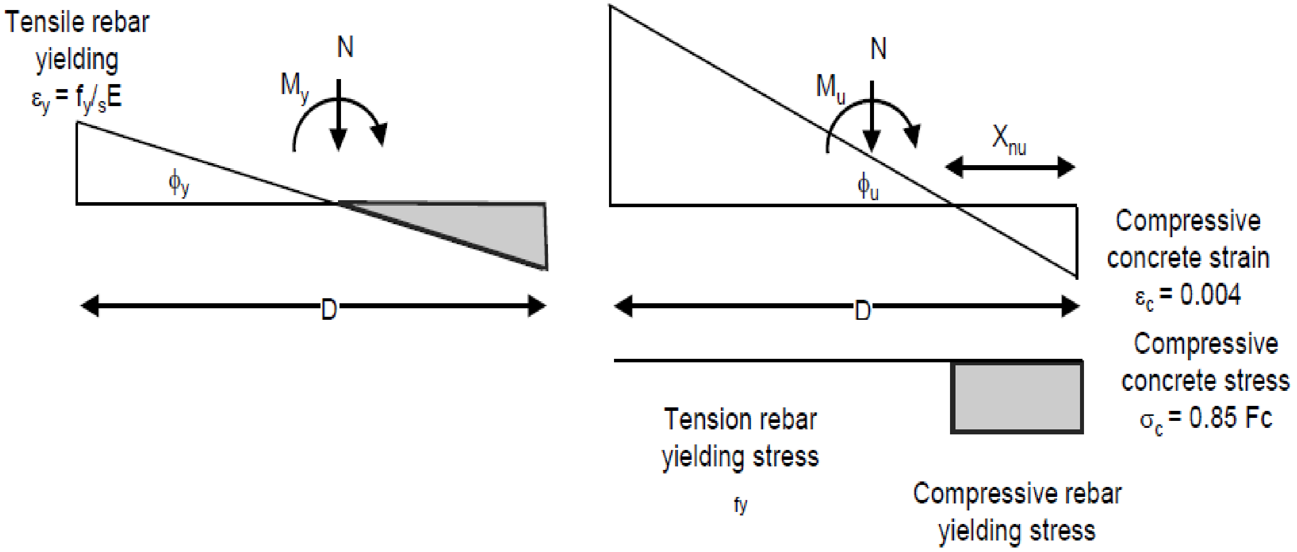
$$M_3 = M_u$$

$$\emptyset_3 = \frac{0.004}{X_{nu}}$$

if $\emptyset_3 > 20\,\emptyset_2$, then $\emptyset_3 = 20\,\emptyset_2$

2- Yielding Point

3-Ultimate Point



Bending BBCs Computed per ACI 318/ASCE 4-16

BENDING BBC (Bending moment M vs. Curvature φ)

<u>Point 1 for Cracking:</u>

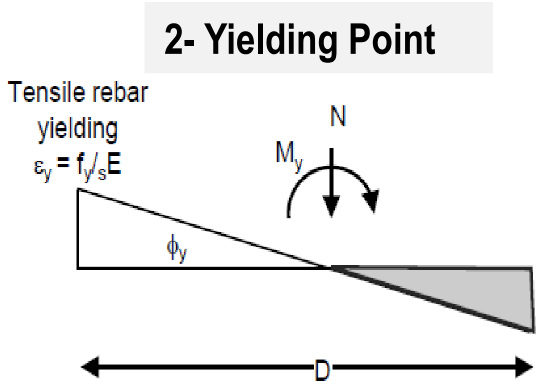
$$M_1 = 7.5 * Ze\sqrt{f'c} \quad \text{(ASCE 4-16)}$$

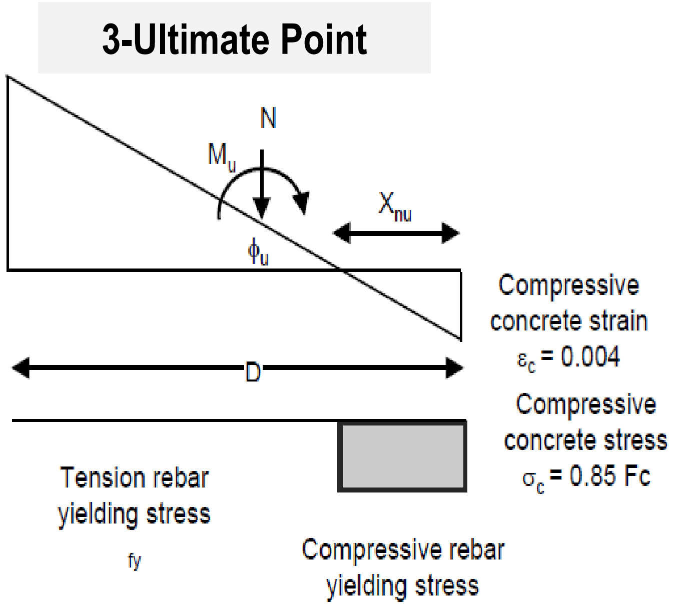
$$\emptyset_1 = \frac{M_1}{Ec * Ie}$$

where Ie and Ze are effective section moment of inertia and modulus (including rebars).

<u>Point 2 for Yielding:</u>

$$M_2 = M_y$$
$$\emptyset_2 = \emptyset_y$$

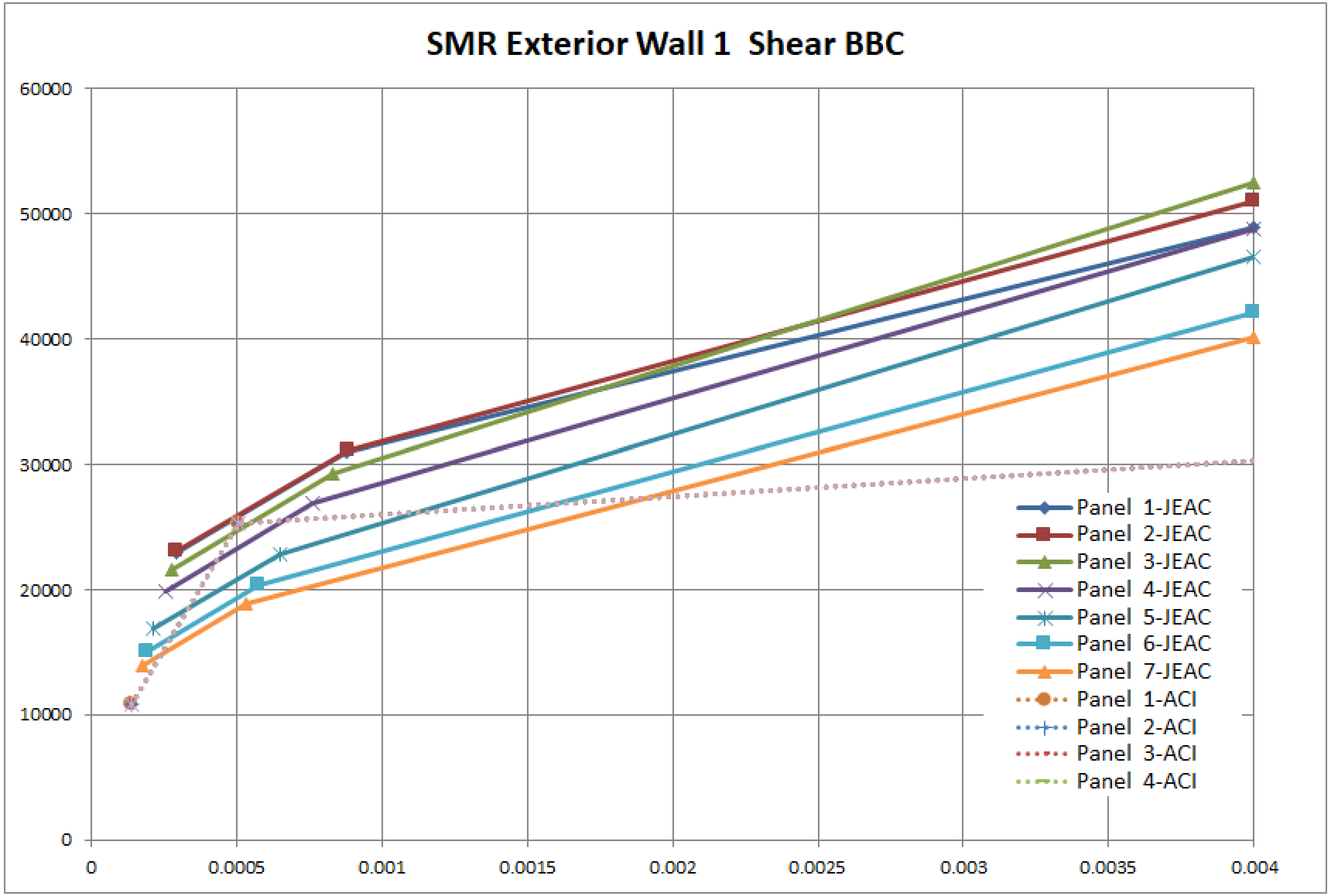




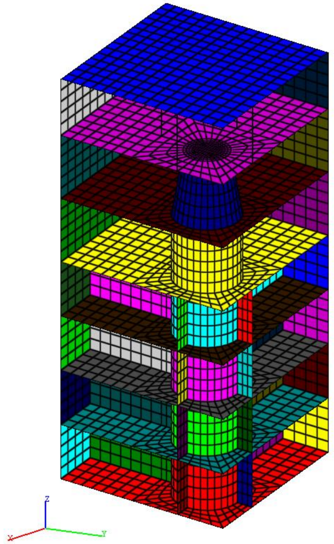
<u>Point 2 for Ultimate:</u>

$$M_3 = M_u$$
$$\emptyset_3 = \emptyset_u$$

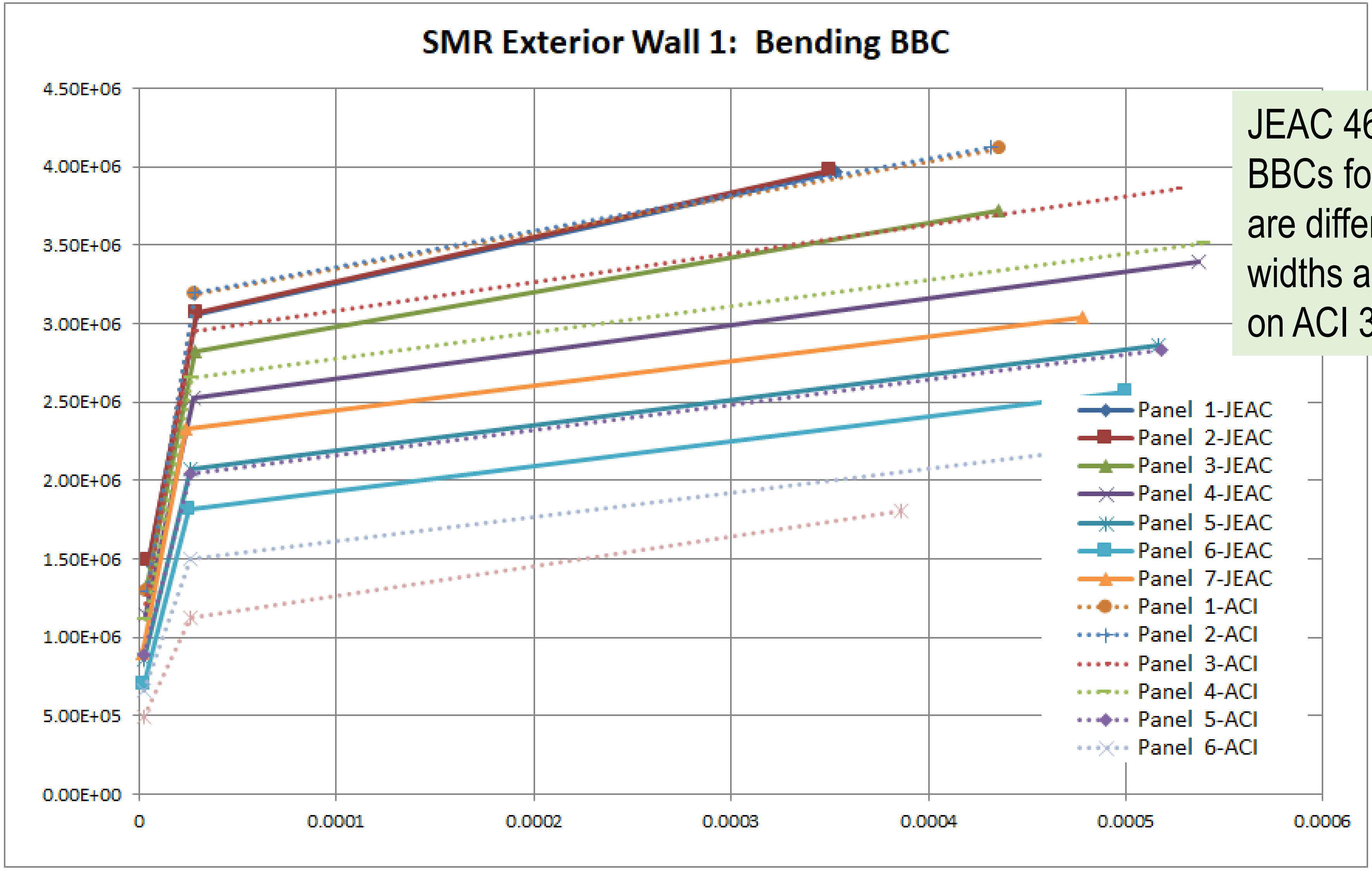
Computed Shear BBCs for SMR RC Exterior Wall



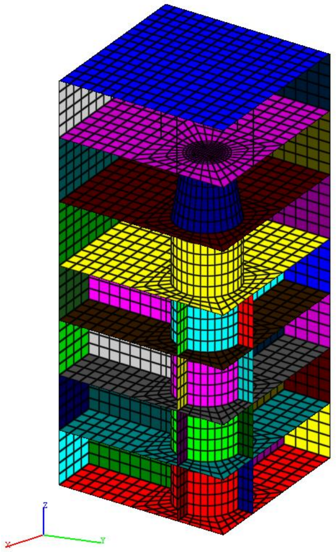
JEAC 4601 ultimate shear forces include significant flange effects; larger than ACI 318 ultimate shear wall strengths.



Bending BBCs for SMR RC Exterior Wall



JEAC 4601 and ACI 318 bending BBCs for each wall at each floor level are different since the effective flange widths are differently computed based on ACI 318 and AIJ RC standards.



Effective Flange Size Calculations Implemented in Option NON

ACI 318 Option 1 in NON

The first ACI 318 option (Section 18.10.5.2) is recommended by the standard for modeling the RC walls, and the effective wall flange widths computation is based on the shear lag effects on the stress distribution in perpendicular walls at the intersection with the parallel walls. The shear lag effect is larger for larger nonlinear story drifts and axial loads.

ACI 318 Option 2 in NON

The second ACI 318 option (Section 6.3.2.1) is not recommended by the standard for modeling the RC walls. This option uses the effective wall flange width equations for the effective beam flange widths, basically, assuming that the beams represent the verticall RC walls. This assumption is conceptually consistent with the Japanese AIJ RC standard requirements for computing the effective wall flange widths.

JEAC 4601 Option in NON

Per the JEAC 4601-2015 standard implementation in practice based on the SR/Stick models and the Case 4 directional approach, the effective wall flange widths are determined using the effective beam flange widths computed per the AIJ RC standard equations. The effective flange widths conceptually reflect the variation with height of the effective bending stiffneses for RC wall parallel to the input direction.

Effects of Effective Flange Sizes on Nonlinear SSI Responses

The new Option NON implementation uses three calculation options per JEAC 4601 and ACI 318:

ACI 318-19 for Wall Effective Flange Widths Per Section 18.10.5.2 (ACI recommended)

ACI 318 Option 1

For the two-*sided* wall flanges, B1 and B2, then, the effective wall flanges are computed based on the side clearances, AR and AL, at each floor level I, as follows:

$$B1_i = min \begin{cases} \frac{1}{2} ARi \\ 0.25\,(H - Zsect, i) \end{cases}$$

$$B2_i = min \begin{cases} \frac{1}{2} ALi \\ 0.25\,(H - Zsect, i) \end{cases}$$

Where H-Zsect, i is the height of the structure above the i section level, Zsect,i

$$L1C_i = B1_i + Tw_i + B2_i$$

$$L2C_i = L1C_i$$

The above equations are also used for the one-sided wall flanges.

JEAC 4601-2015/AIJ RC Standard:

JEAC 4601/AIJ RC

$$B1_i = \begin{cases} \left(0.5 - 0.3 * \left(\frac{AR}{L_i}\right)\right) * AR, & if\ AR < L_i \\ 0.2 * L_i, & else \end{cases}$$

$$B2_i = \begin{cases} \left(0.5 - 0.3 * \left(\frac{AL}{L_i}\right)\right) * AL, & if\ AL < L_i \\ 0.2 * L_i, & else \end{cases}$$

$$L1C_i = B1_i + Tw_i + B2_i$$

$$L2C_i = L1C_i$$

ACI 318-19 for Wall Effective Flange Widths Per Section 6.3.2.1 (conceptually similar to AIJ RC modeling requirements, but not ACI recommended)

ACI 318 Option 2

a. If the panel i has *two side* flanges, B1i and B2i.

$$B1_i = min \begin{cases} \frac{1}{2} AR \\ 8\,Tw_i \end{cases}$$

$$B2_i = min \begin{cases} \frac{1}{2} AL \\ 8\,Tw_i \end{cases}$$

Check also $B1_i + B2_i \le \frac{1}{4} L_i$

b. If the panel has only *one side* flange`

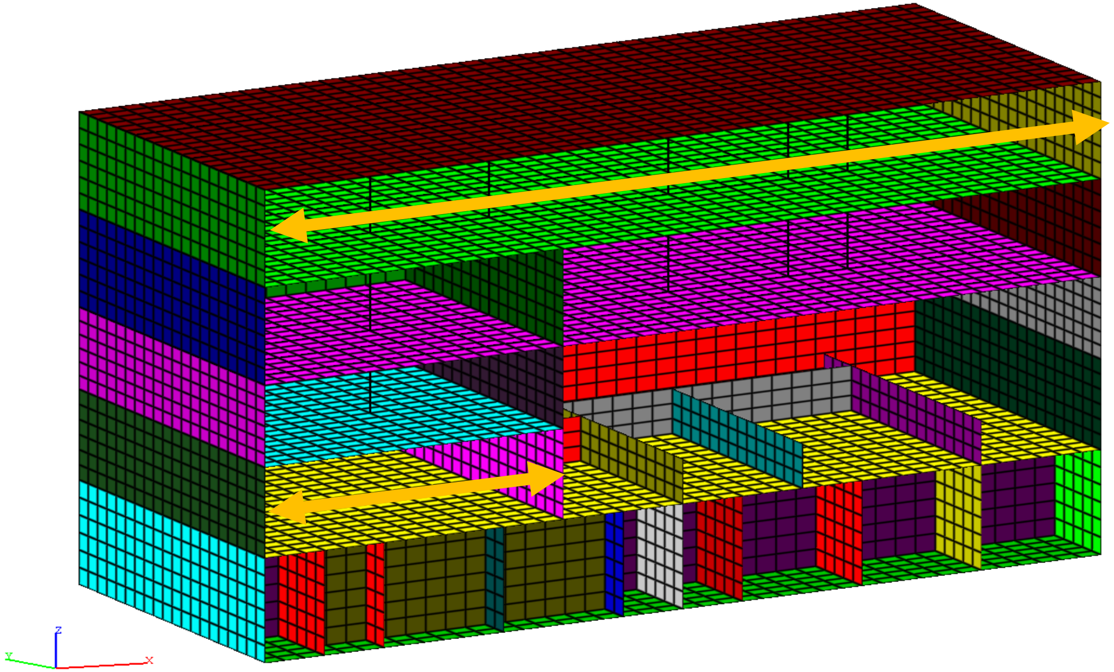
$$B1_i = min \begin{cases} \frac{1}{12} L_i \\ 6\,Tw_i \\ \frac{1}{2} AR \end{cases}$$

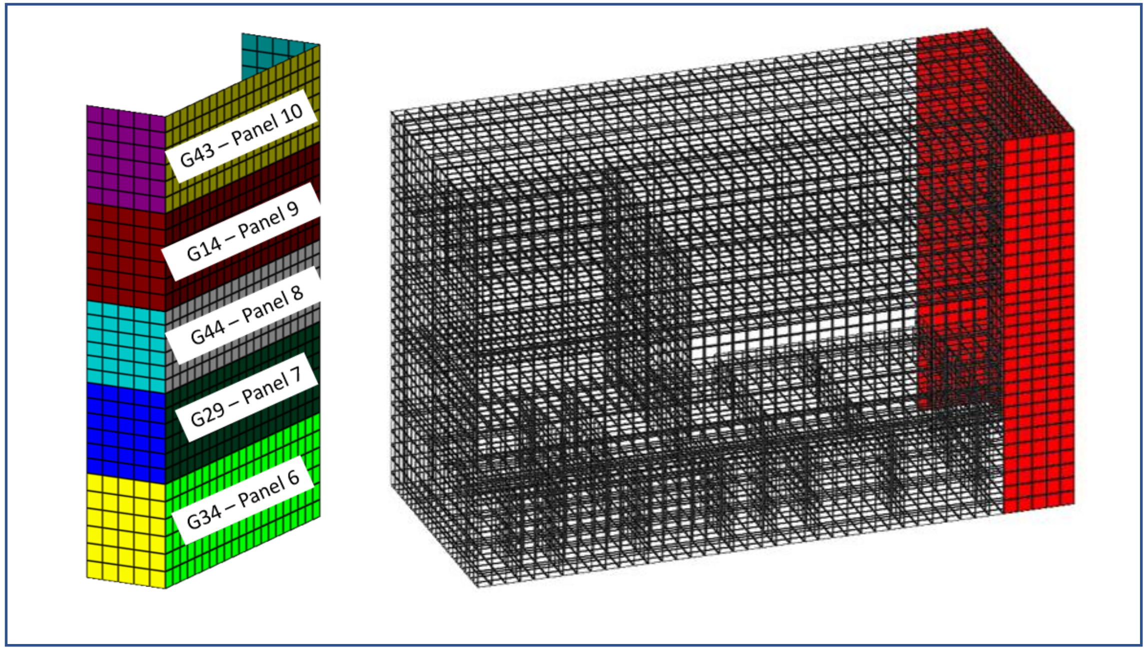
$$B2_i = min \begin{cases} \frac{1}{12} L_i \\ 6\,Tw_i \\ \frac{1}{2} AL \end{cases}$$

$$L1C_i = B1_i + Tw_i + B2_i$$

$$L2C_i = L1C_i$$

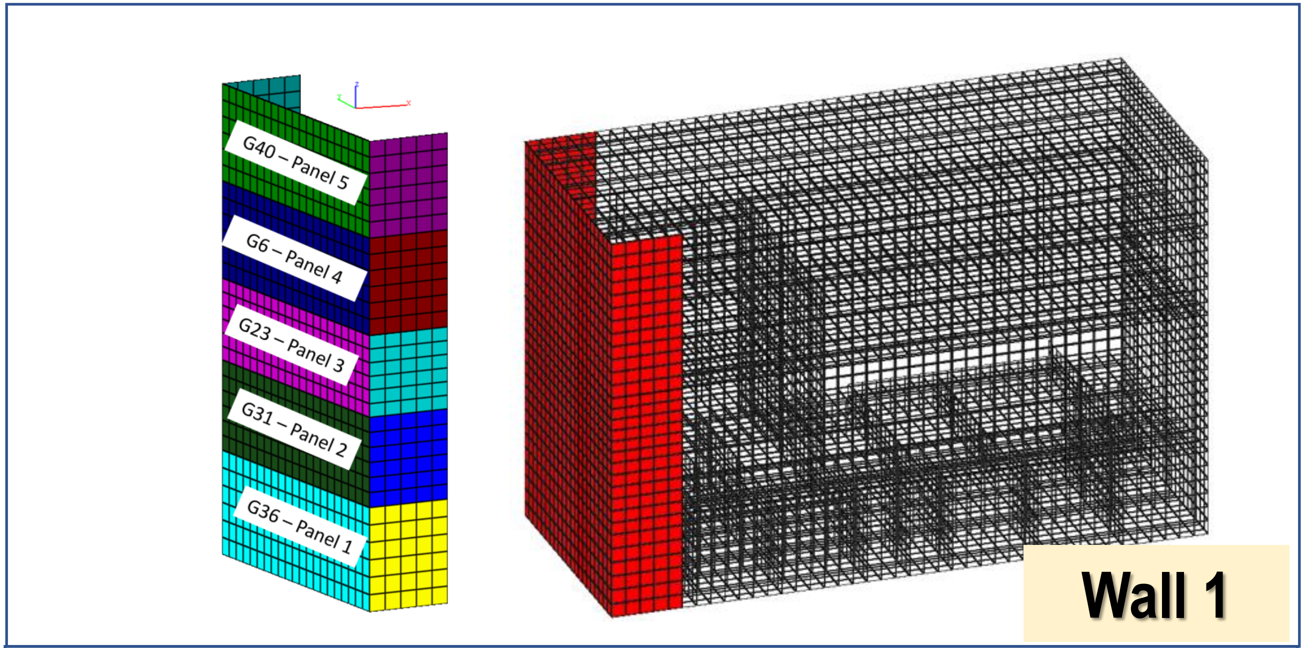
Effective Flange Sizes Can Be Computed Using Variable Clearances per Building Height

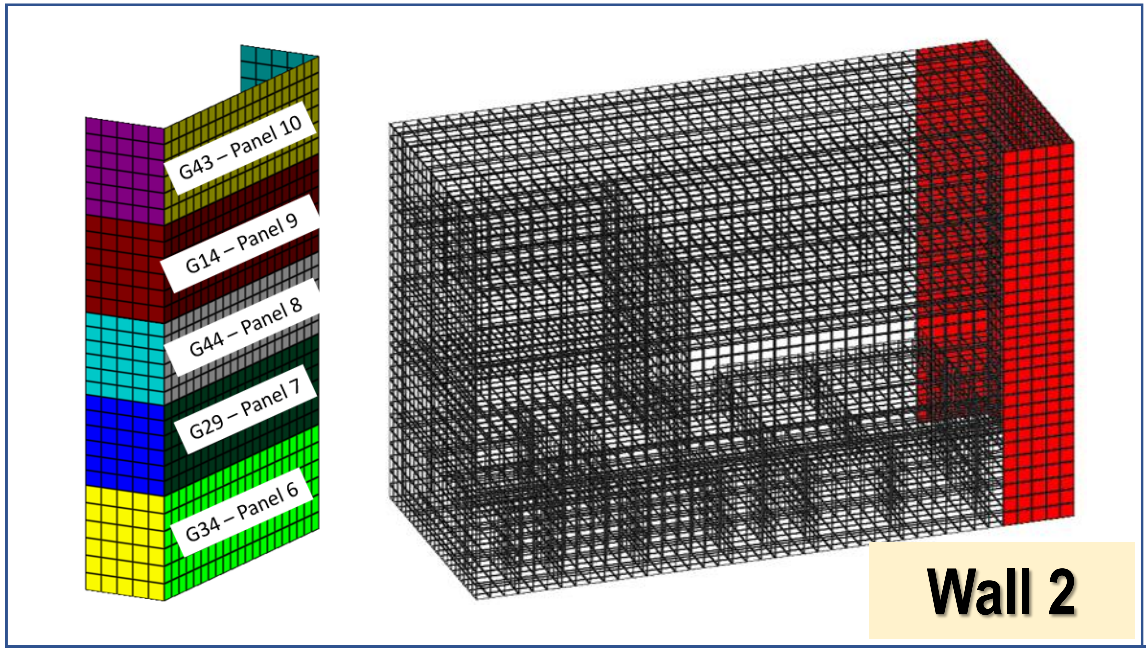


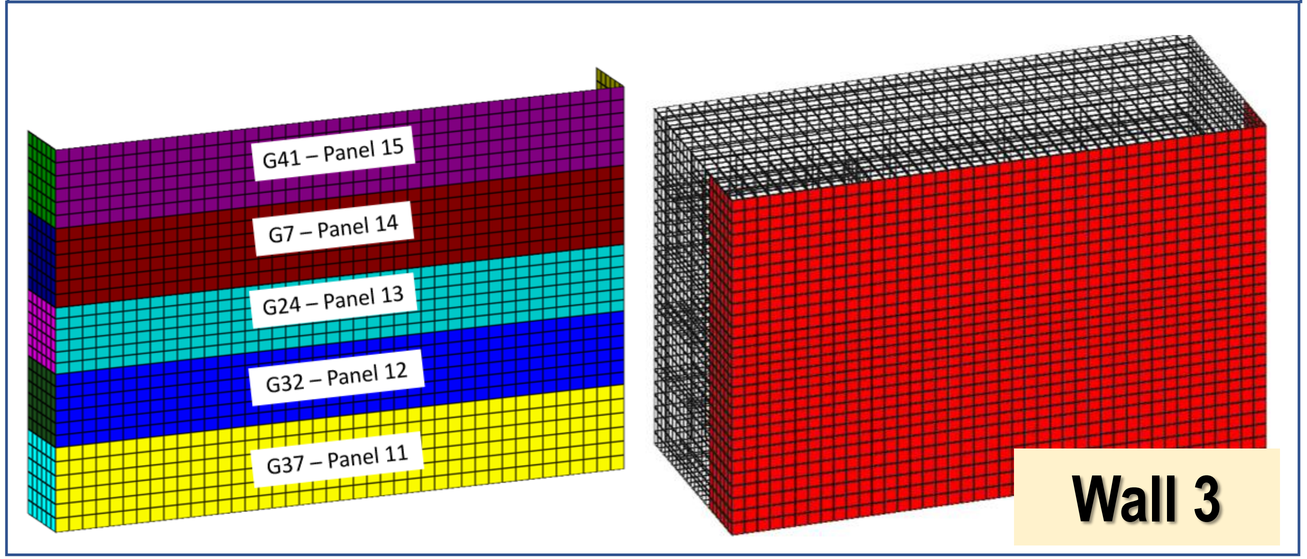


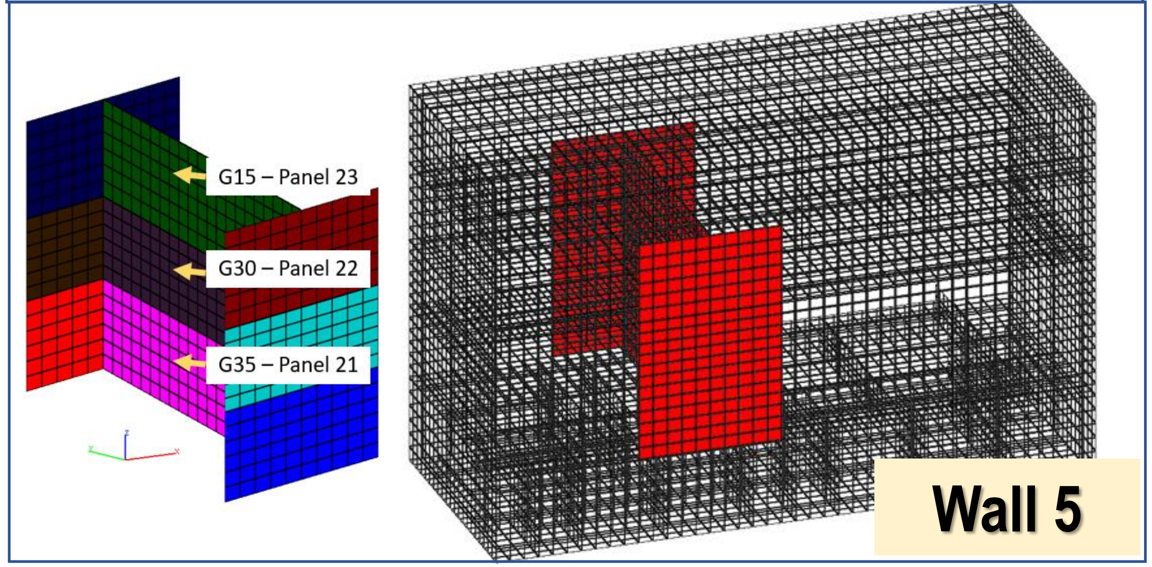
User can include variable clearances per height. The clearance input is at each floor level.

FE Model Split in RC Wall Submodels Based on Max Flange Sizes





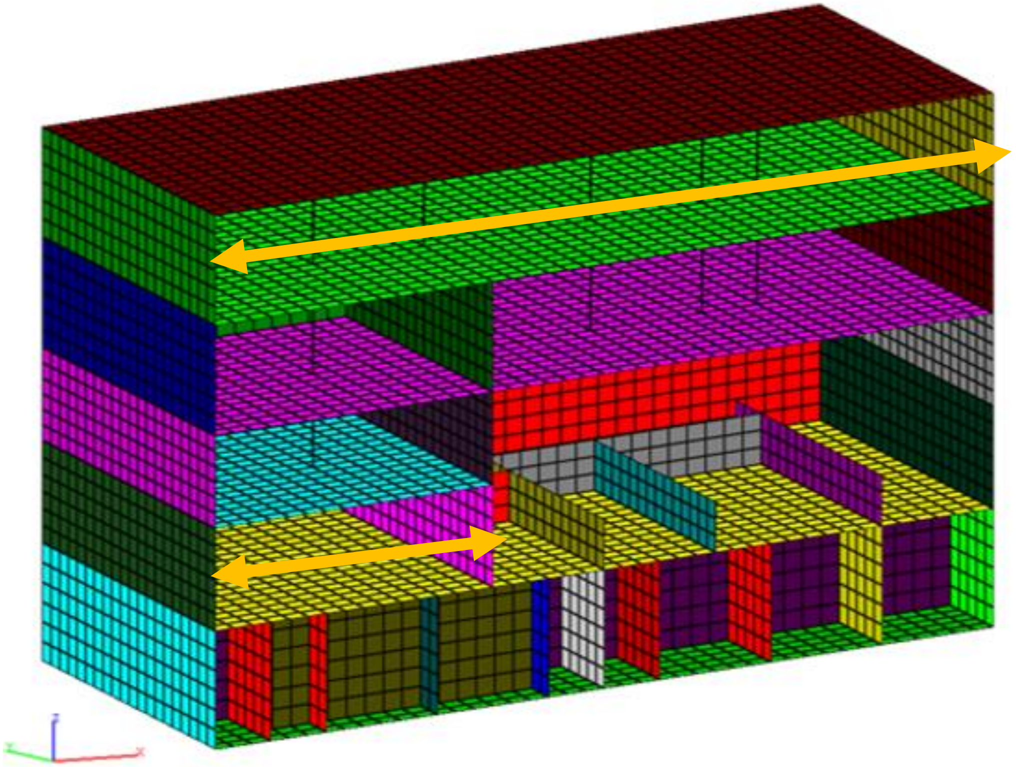


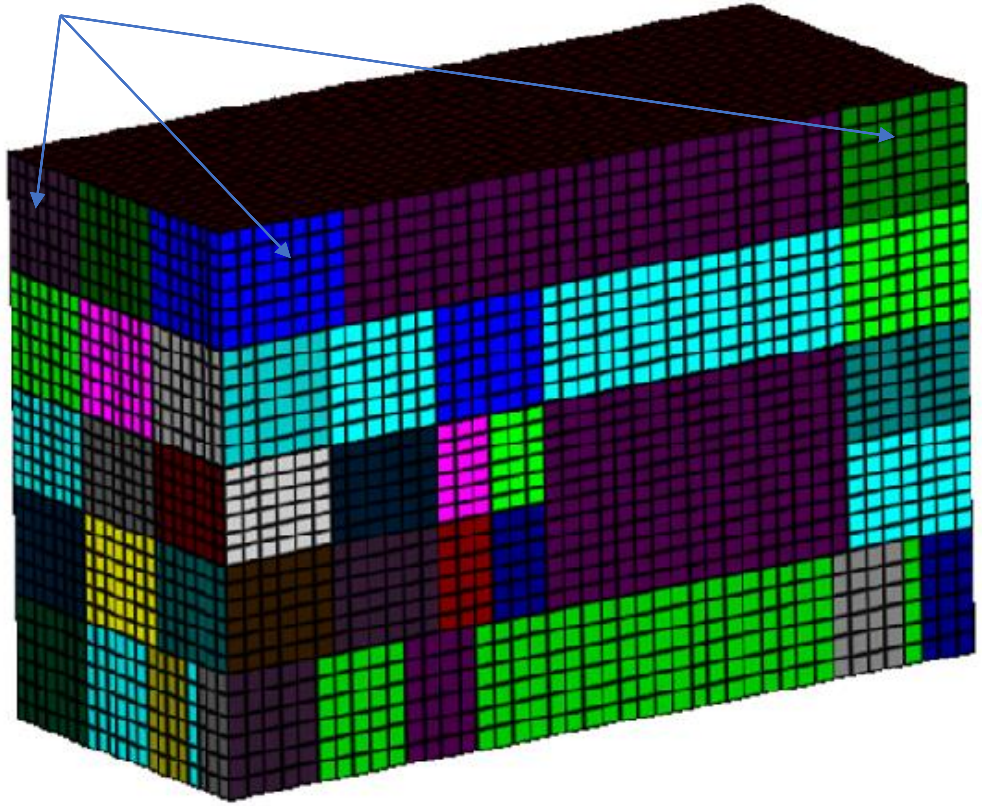


Effective Flange Sizes Based on ACI 318 or AIJ RC Standards

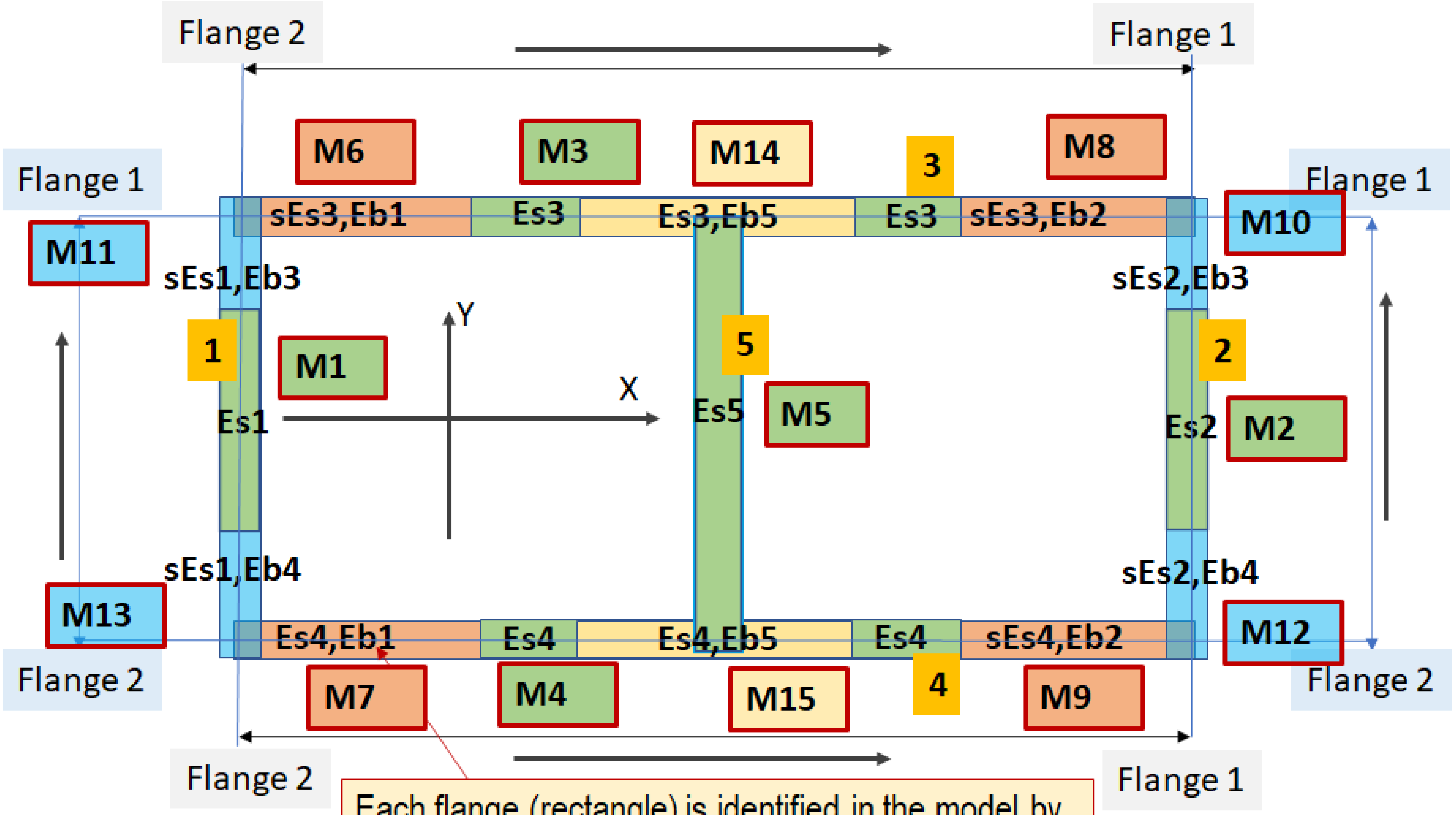
Original FE Model with No Wall Flanges Defined

Modified FE Model for Including New Nonlinear Materials for Flanges





New Flange Materials Are Added for Nonlinear Modeling



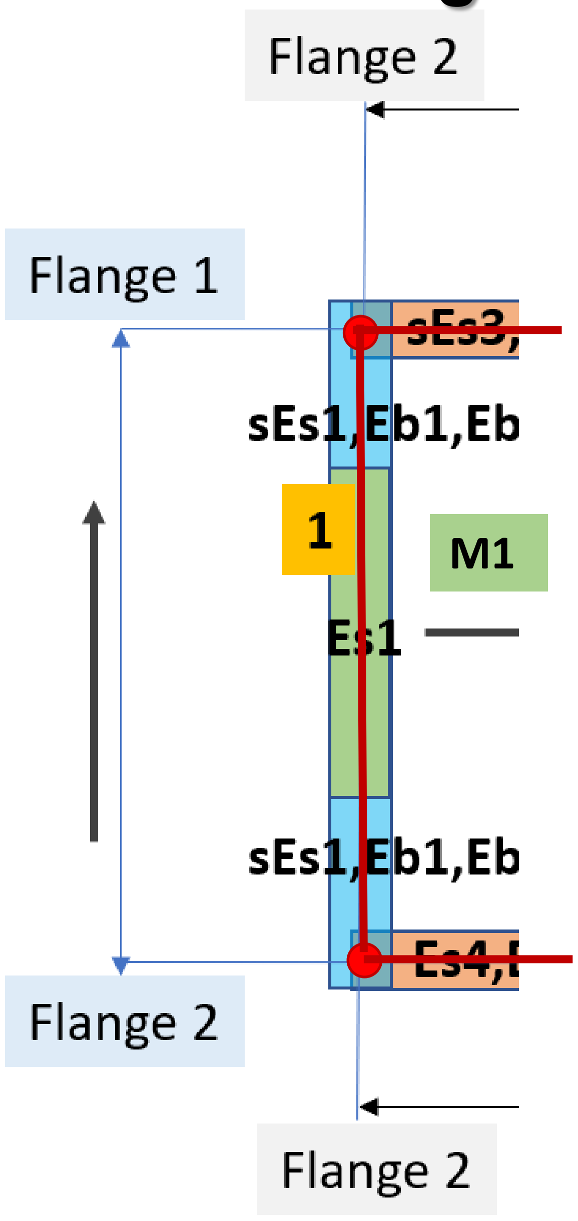
S =1 is for including shear effective Es for corner flanges (exterior walls)

S = 0 (default) is for not including Es for corner flanges.

For separate inputs, the wall perpendicular to input direction remain elastic (M3, M4 for Y input, and M1, M2 for X input)

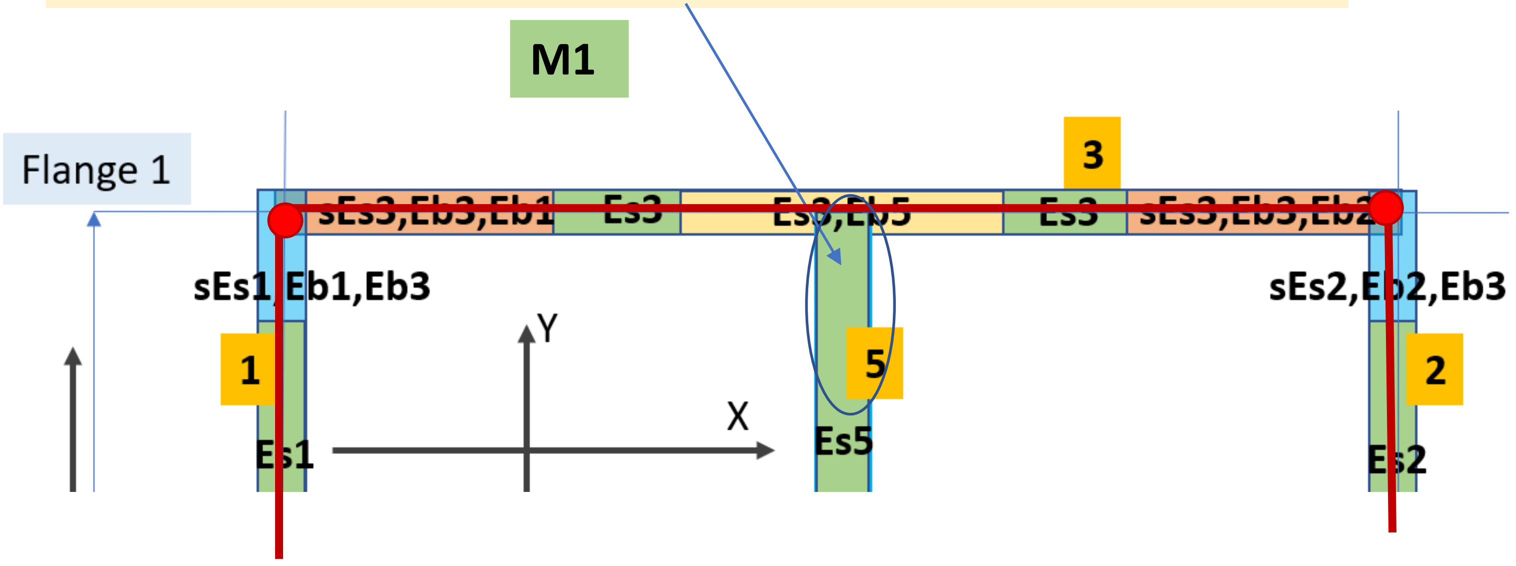
Each flange (rectangle) is identified in the model by the group # and the new assigned material # (to be used to change HOUSE input after each iteration)

E & D Material Changes For Flanges 1 & 2 Are at Two Wall Web Ends



Nodes of elements of Flanges 1 and 2 which are the two web ends should include the Panel 4 corner nodes!

This criterion was used to eliminate any other intermediate flanges in the middle of the web (not at the two ends) that should not be included for the E material shear-bending combination in COMB_SHEAR_BEND.



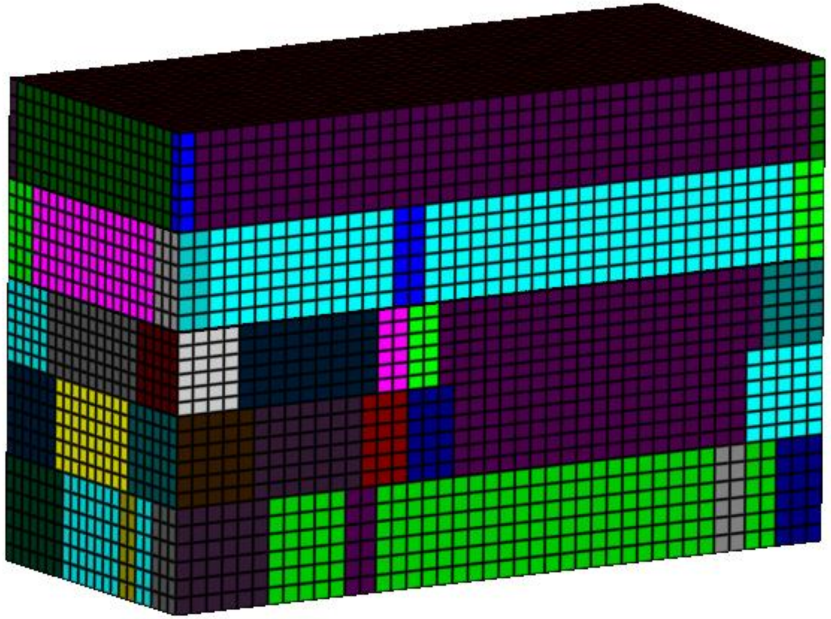
Effective Flange Sizes Based on ACI 381 and AIJ RC Standards

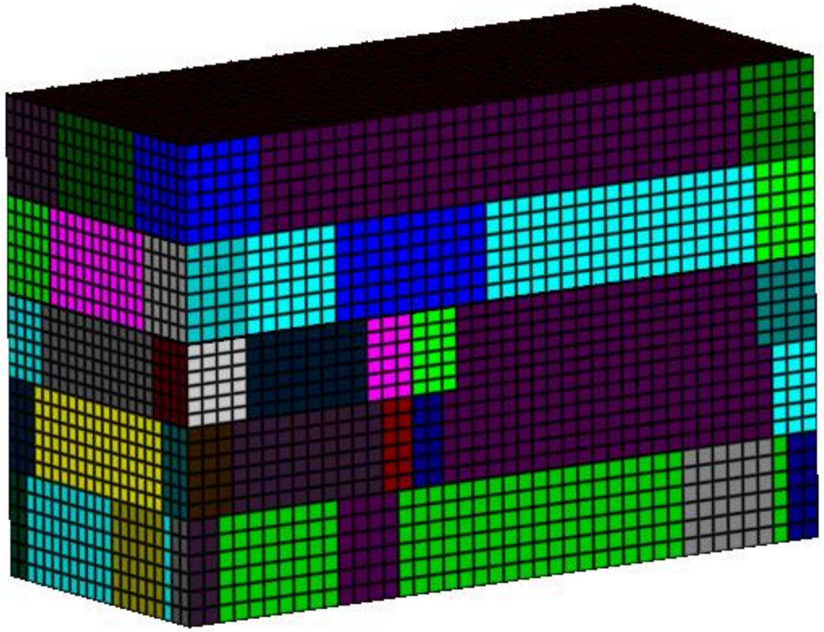
ACI 318-19 Sections 18 and 6

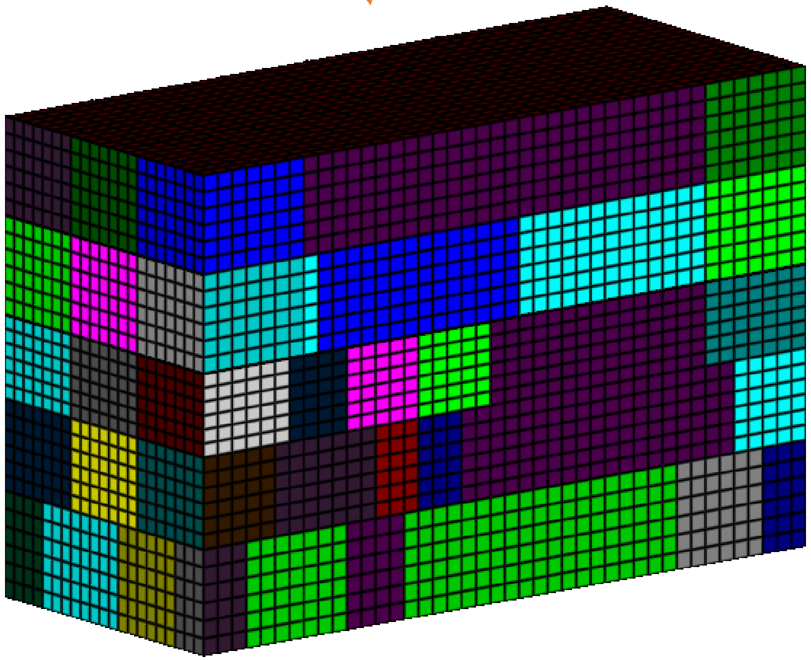
JEAC 4601-2015/AIJ RC

Option 1

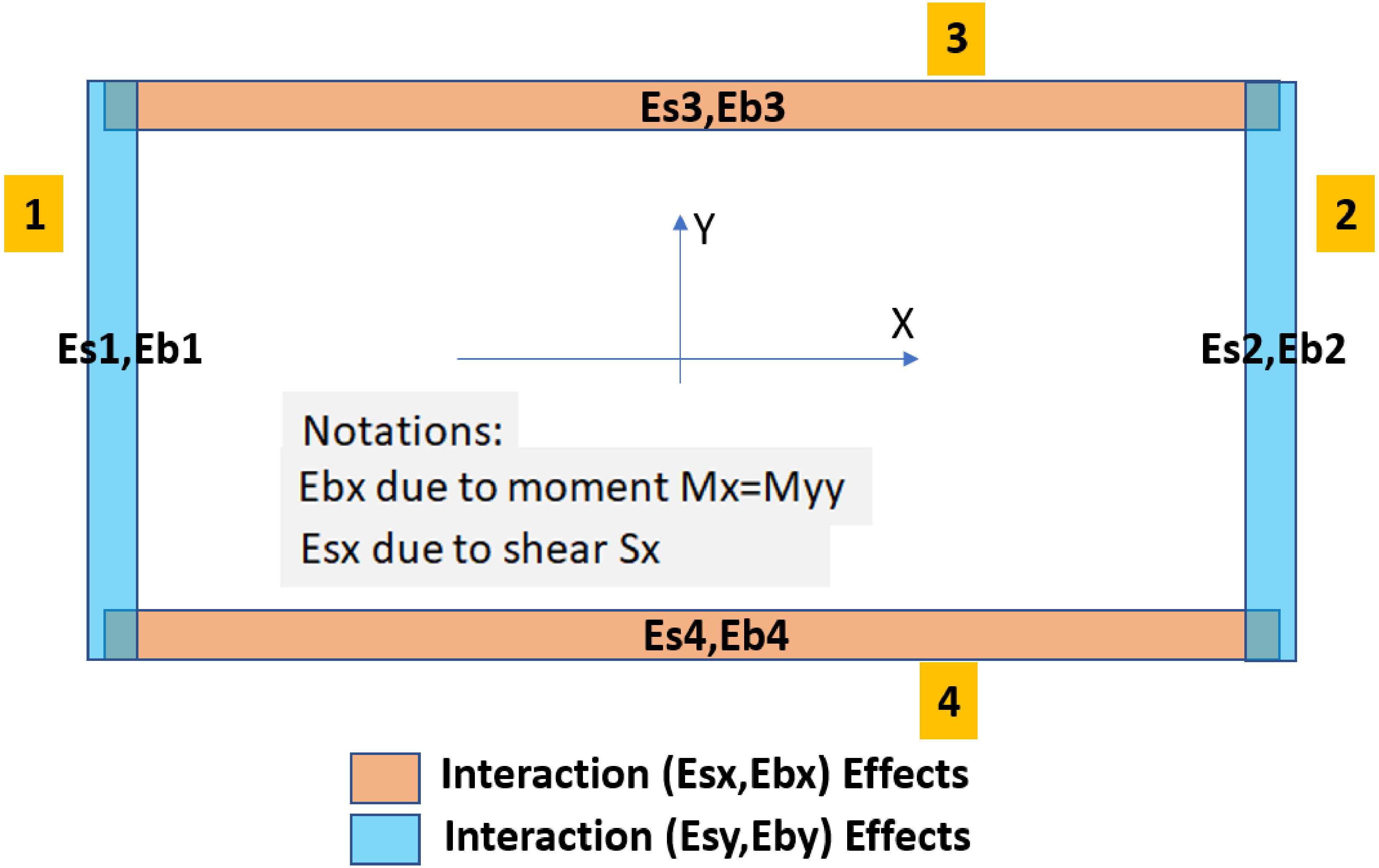
Option 2



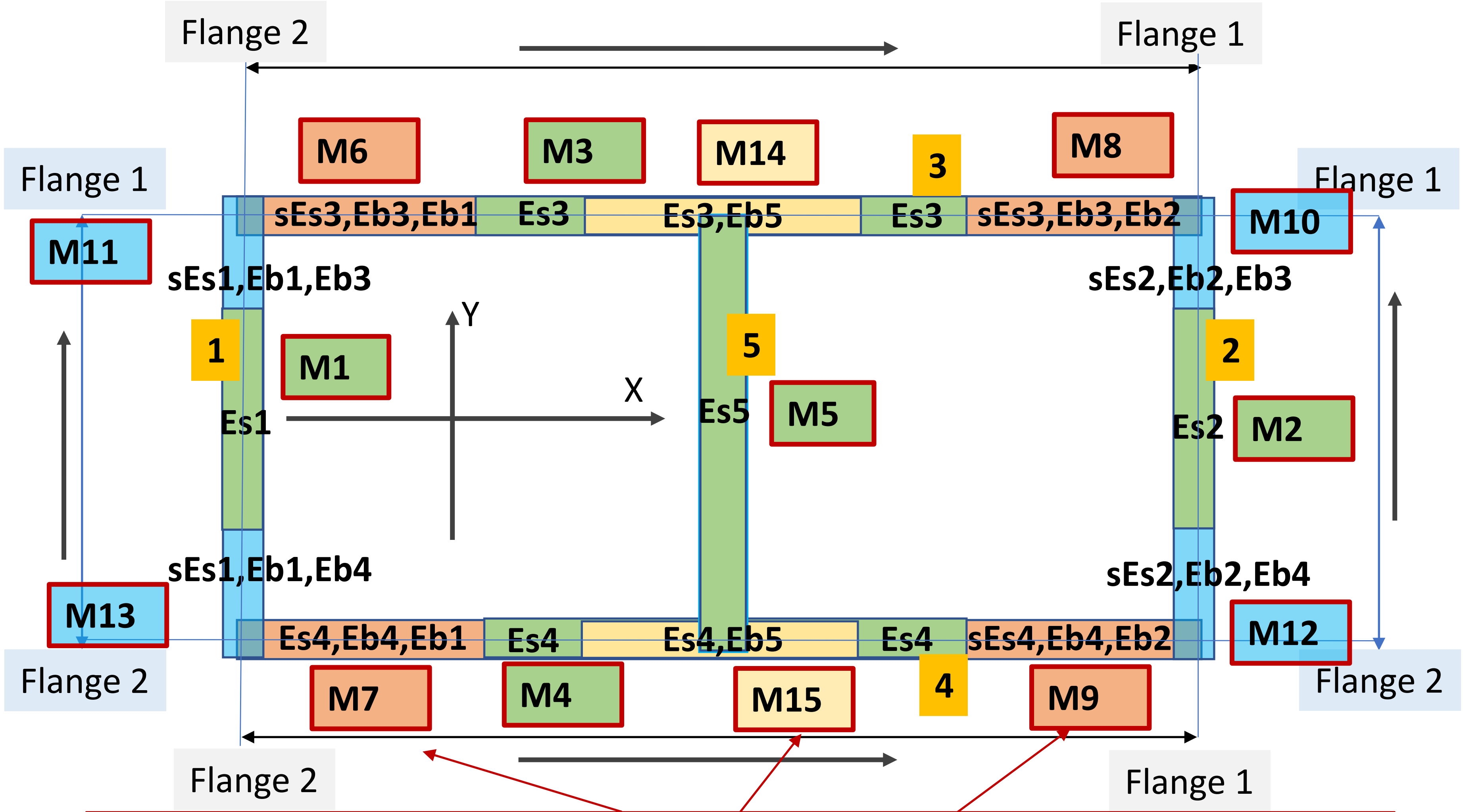




Case 1 (Simplified) Based on Original Model (no wall submodels)



Case 2 (Refined) Material Changes. Example with 5 RC Nonlinear Wall Submodels (3 Transversal and 2 Longitudinal)



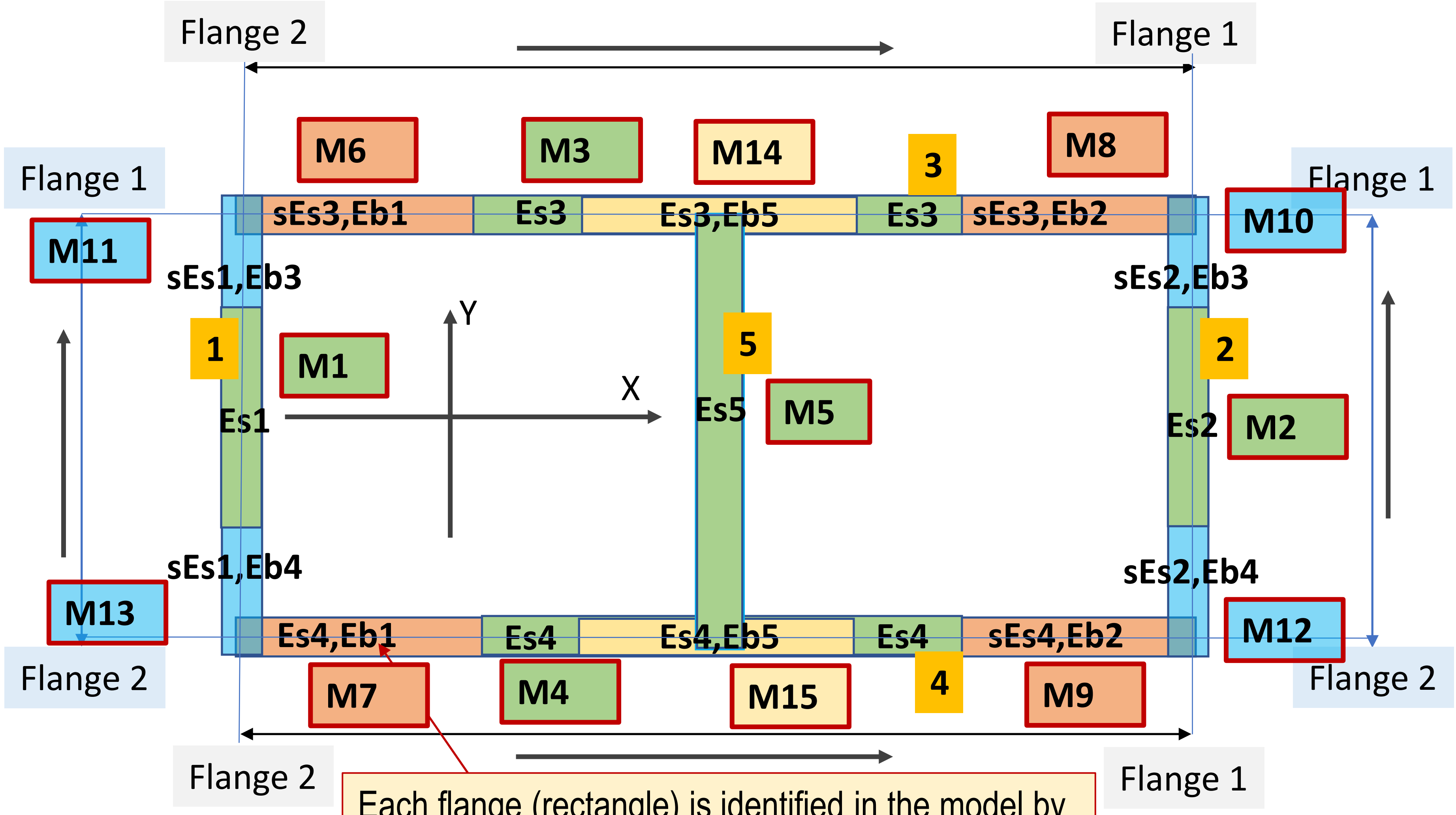
S =1 is for including shear effective Es for corner flanges (exterior walls)

s = 0 (default) is per JEAC, per SHIMIZU comments. (no M-Q interactions for flanges)

NOTE:
Only the two end wall flanges are considered. This comes automatically from using new materials when changing the flange materials in the wall submodels .pre files.

Each wall flange is identified in the FE model by the group # and the new materials are be added to create a FE new model with appended "_New" .pre to file name using *Change_Flange_Materials module*

Case 3 (Refined) Material Changes. Example with 5 RC Nonlinear Wall Submodels (3 Transversal and 2 Longitudinal)



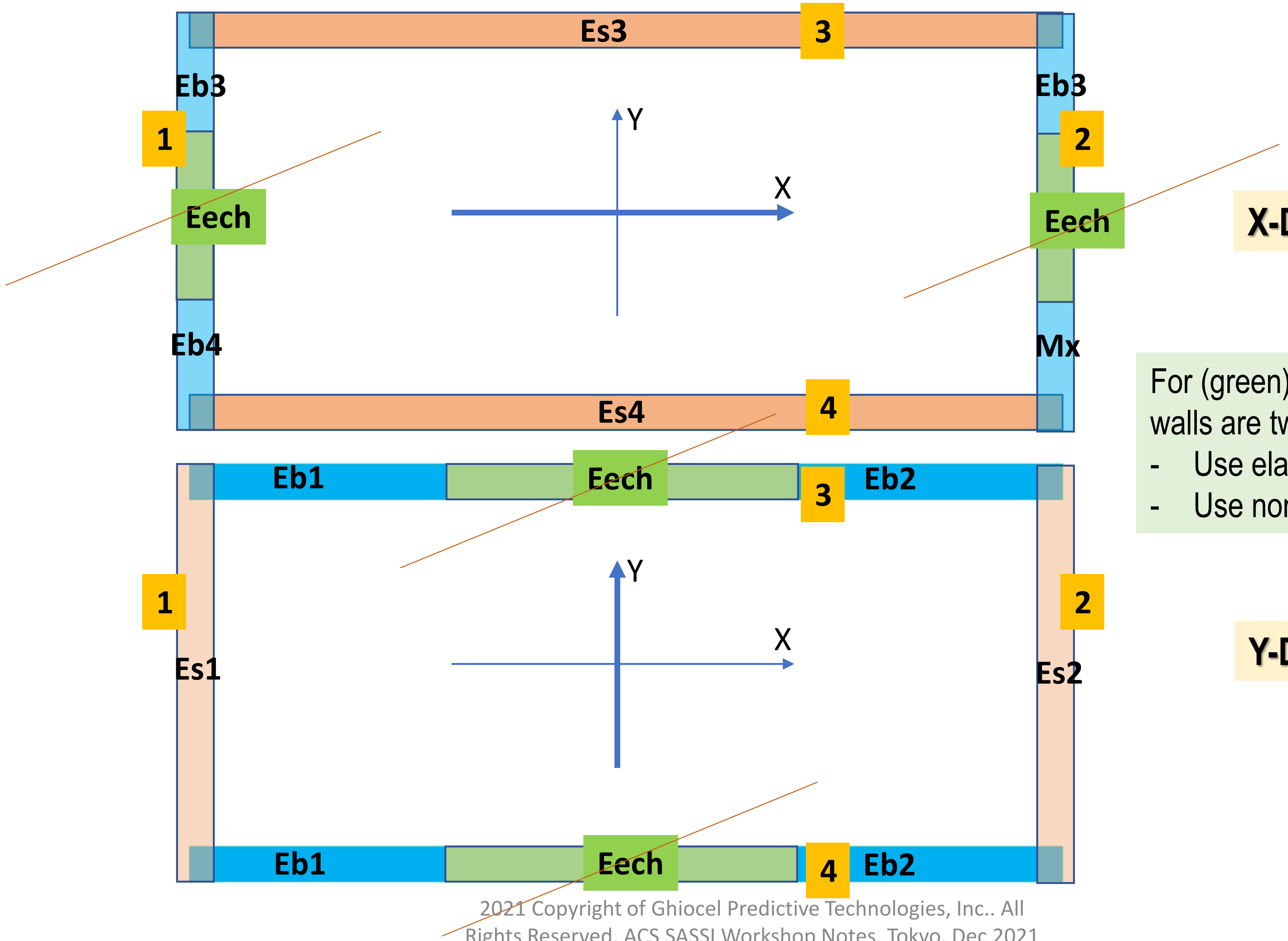
Each flange (rectangle) is identified in the model by the group # and the new assigned material # (to be used to change HOUSE input after each iteration)

S =1 is for including shear effective Es for corner flanges (exterior walls)

S = 0 (default) is for not including Es for corner flanges.

NOTE:
Only the end wall flanges are considered. This comes automatically from using new materials when changing the flange materials in the wall submodels .pre files.

Directional 3DFEM Models for X and Y Direction Using Case 3 (S=0)



X-Direction Model

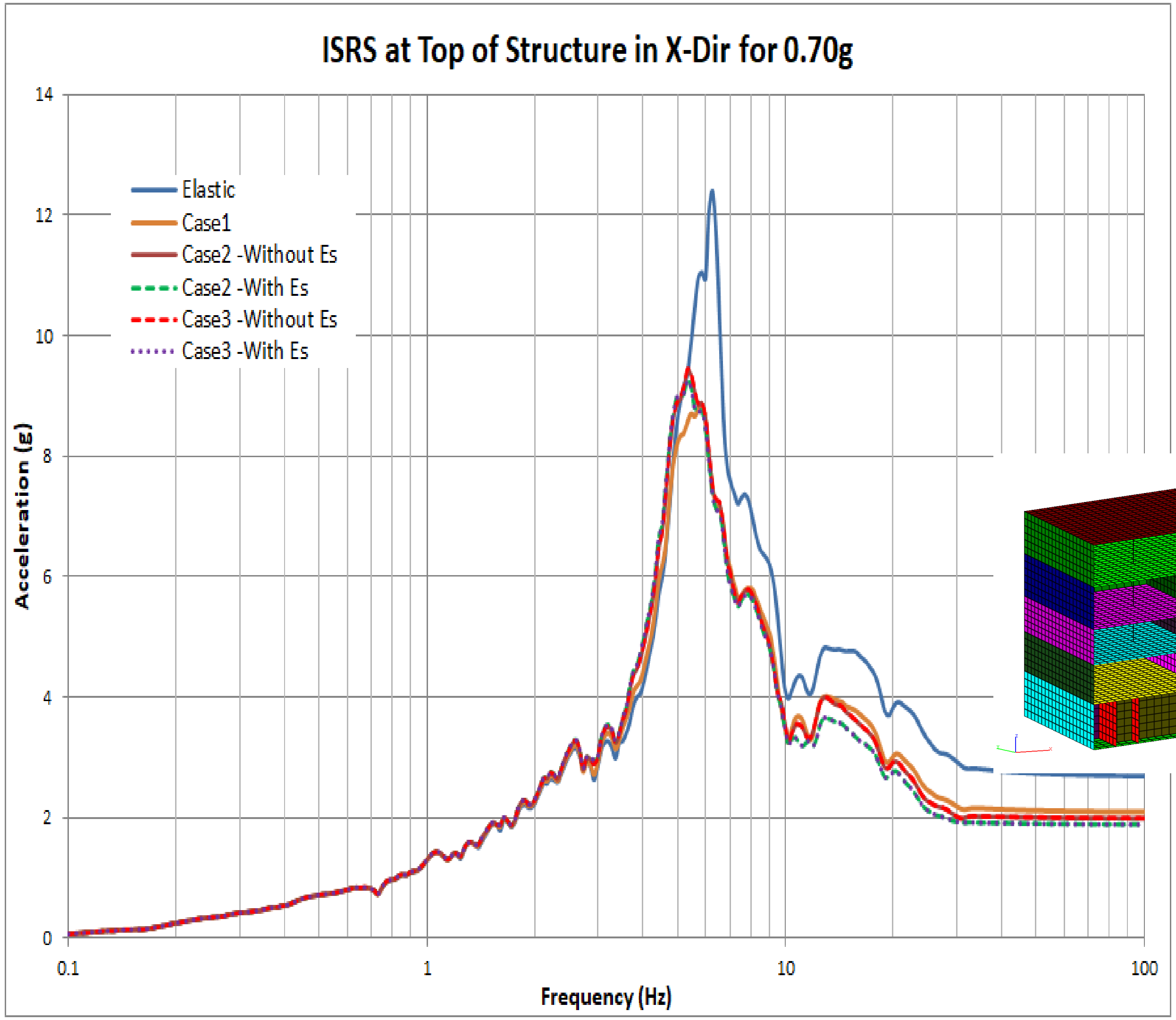
For (green) web material in perpendicular walls are two options:

- Use elastic stiffness
- Use nonlinear iterated flange stiffness

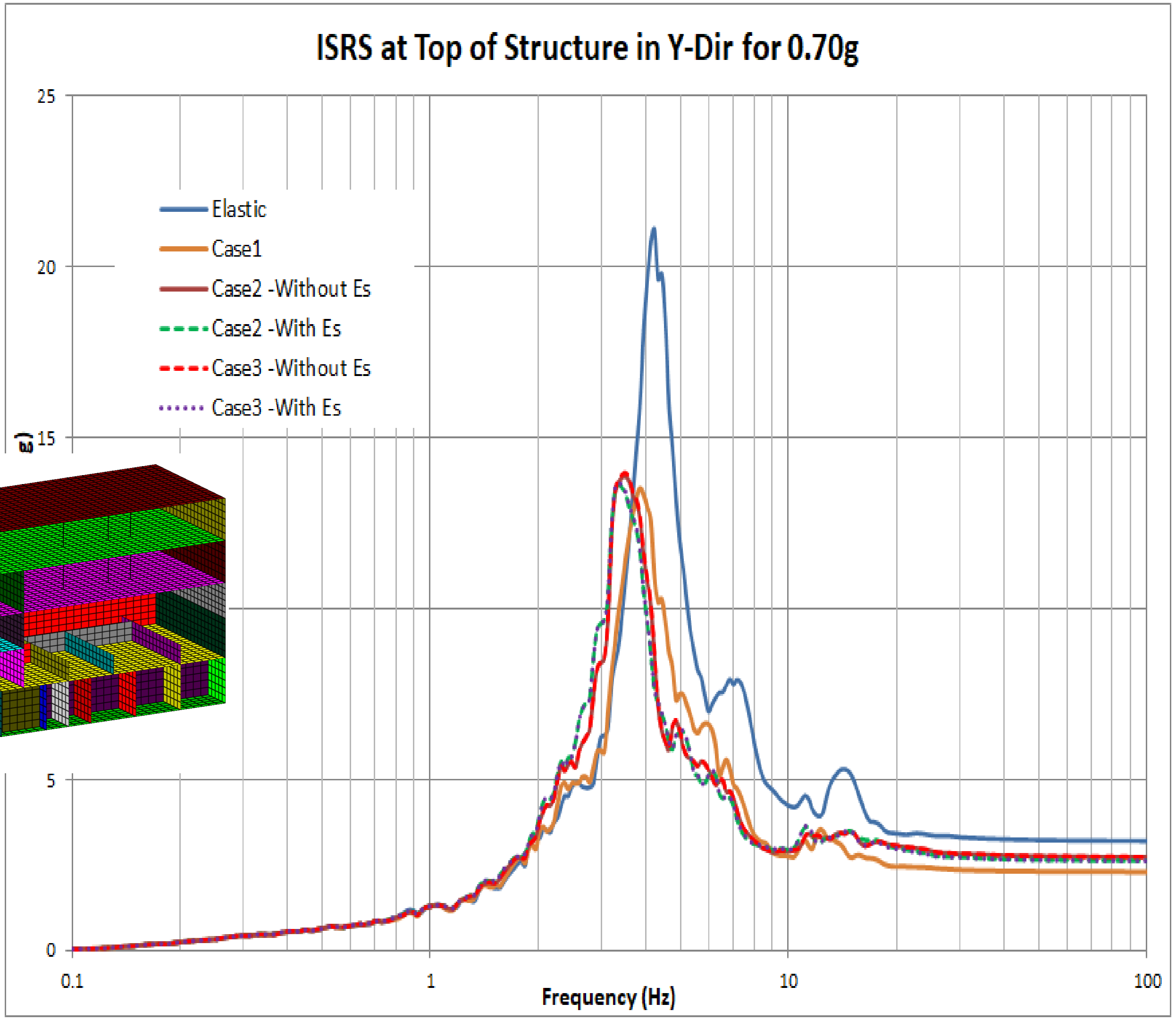
Y-Direction Model

US Standards - ISRS at Top of Structure for Cases 1, 2 and 3

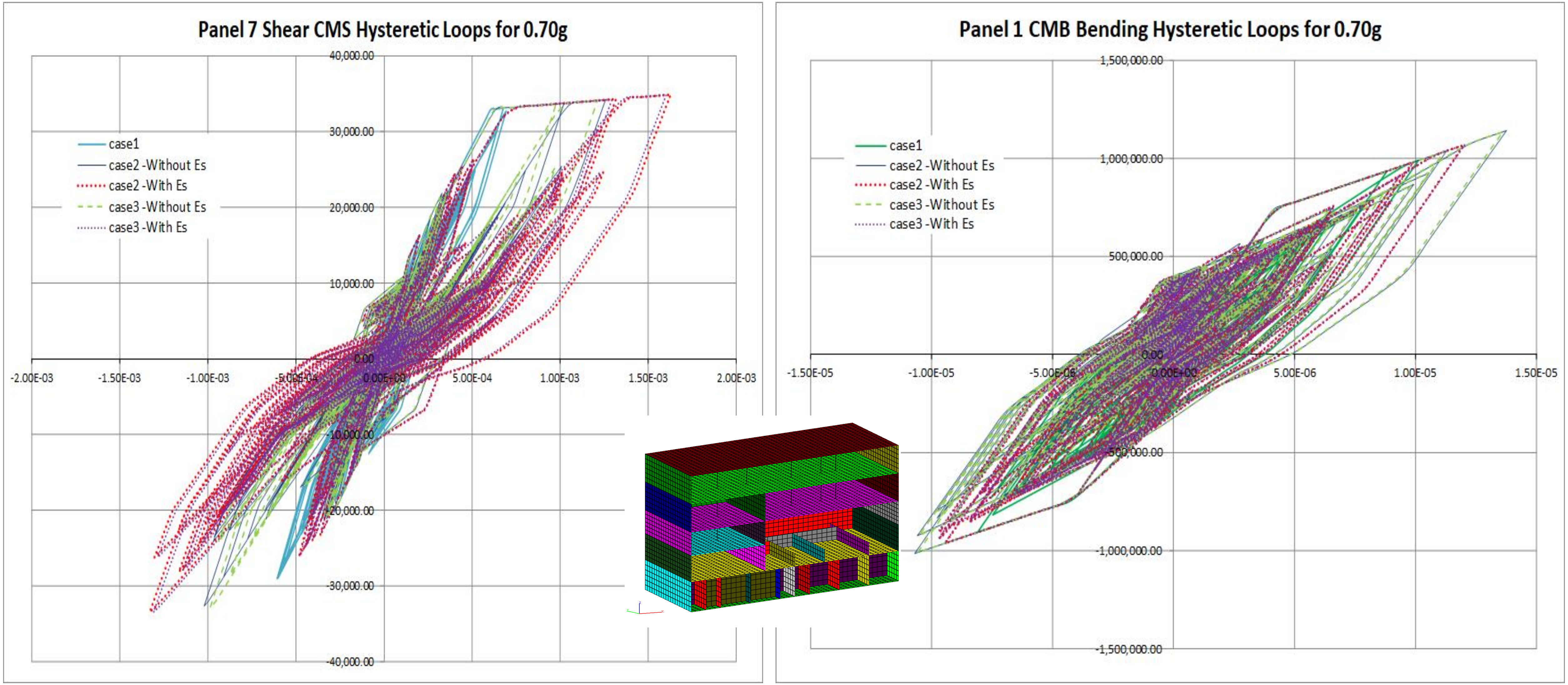
X-Direction



Y-Direction

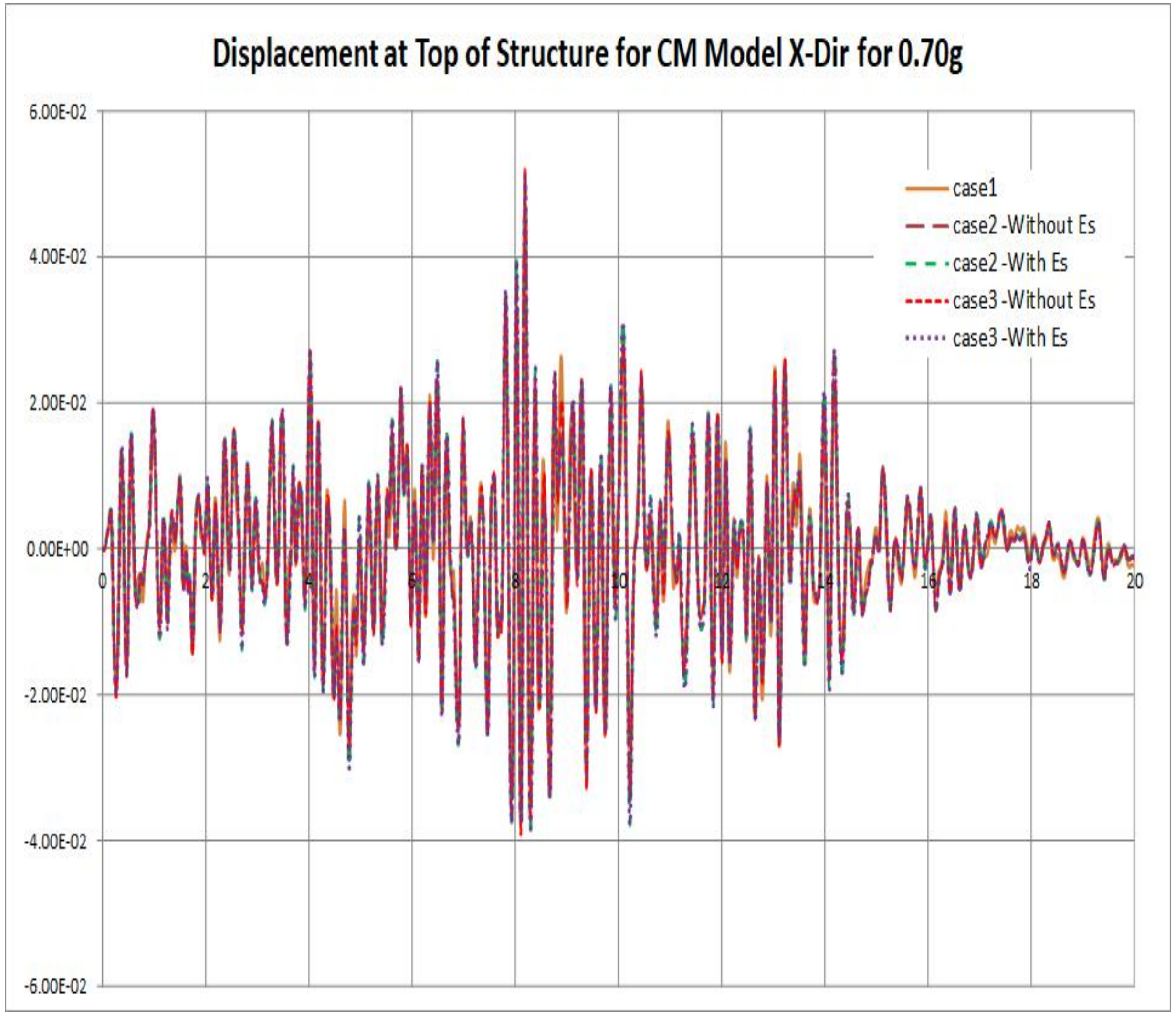


US Standards - Panels 7 and 21 Shear Hysteretic Loops for Cases 1, 2 and 3

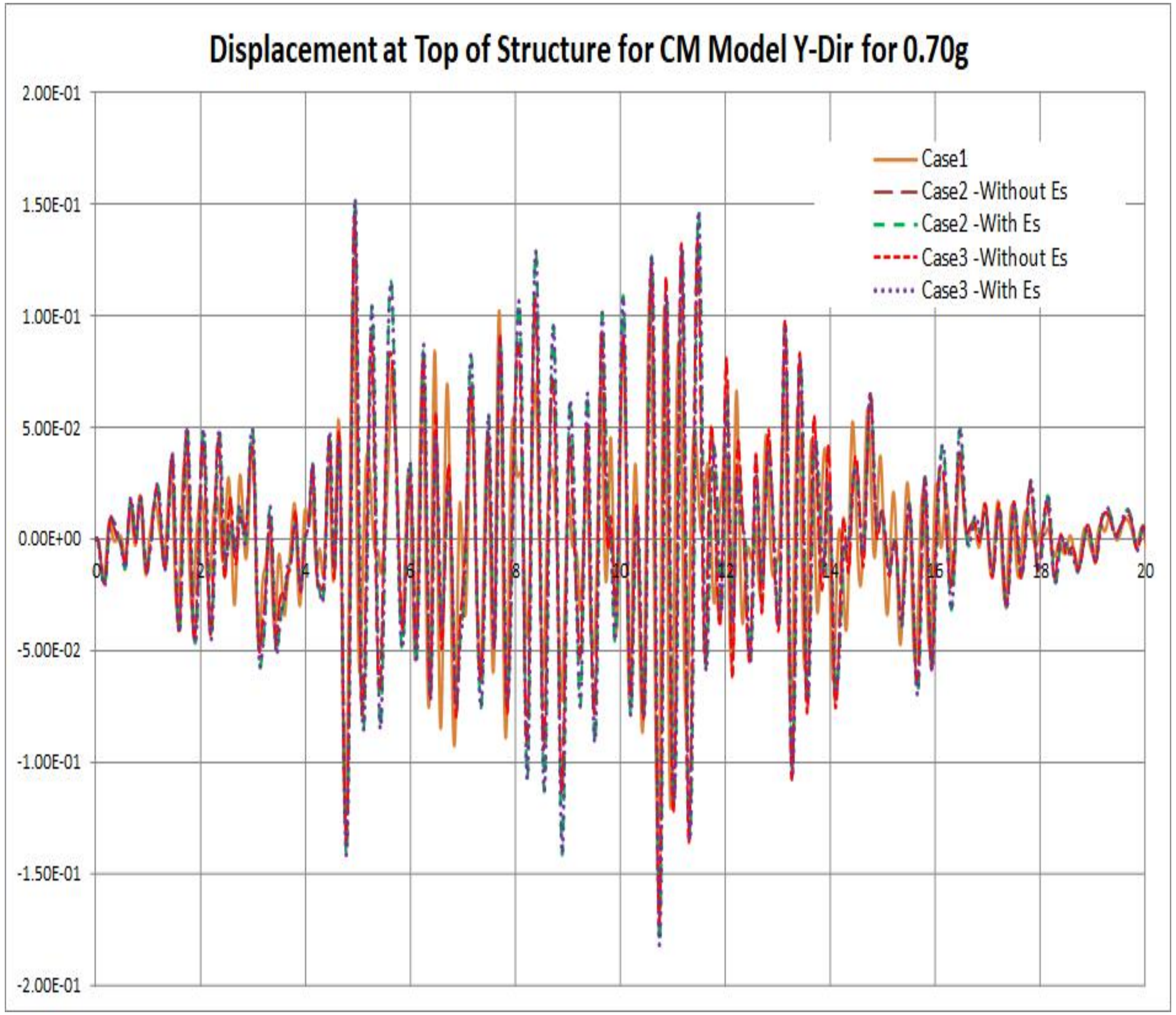


US Standards - Displacement at Top for Cases 1, 2 and 3

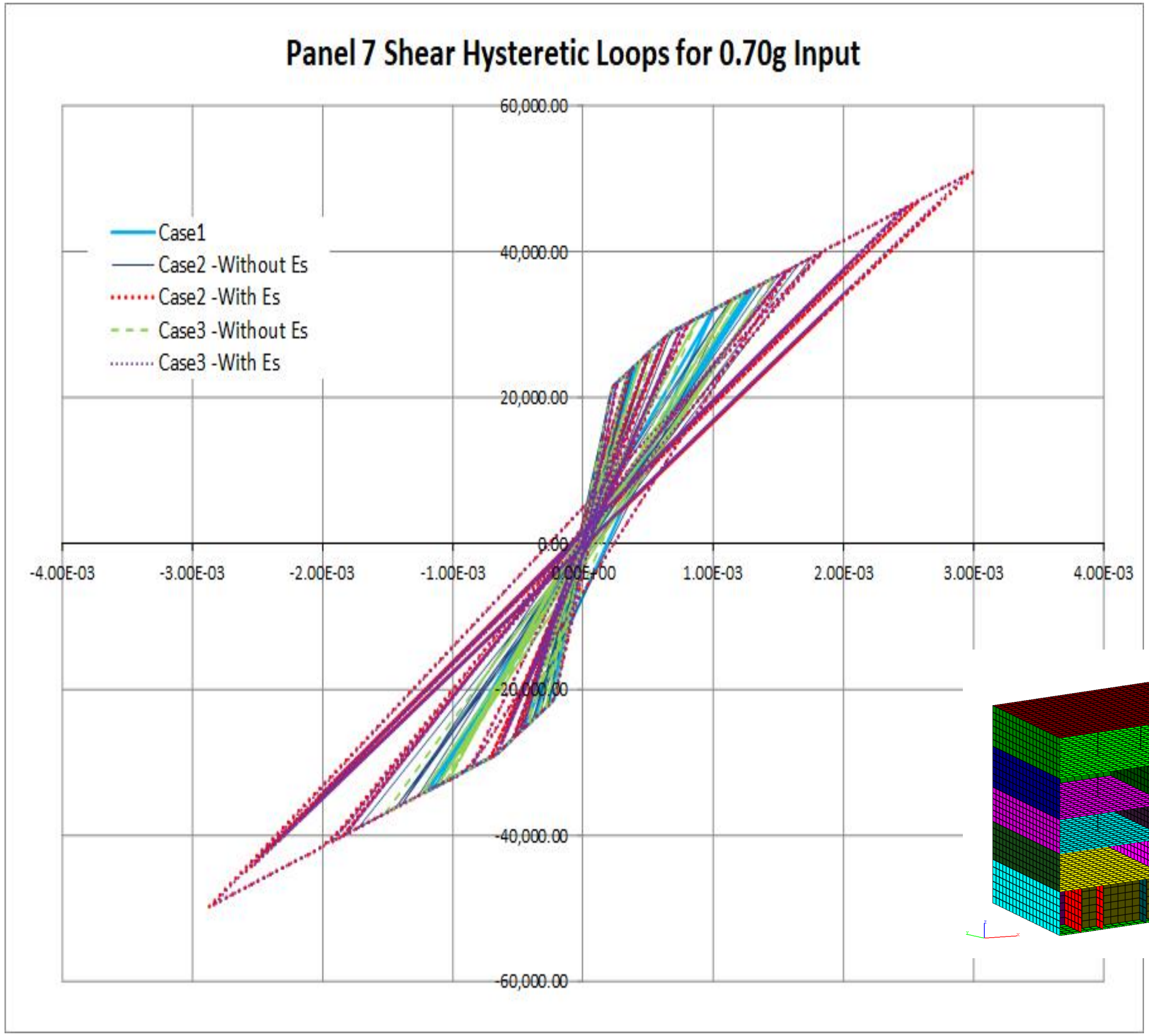
X-Direction

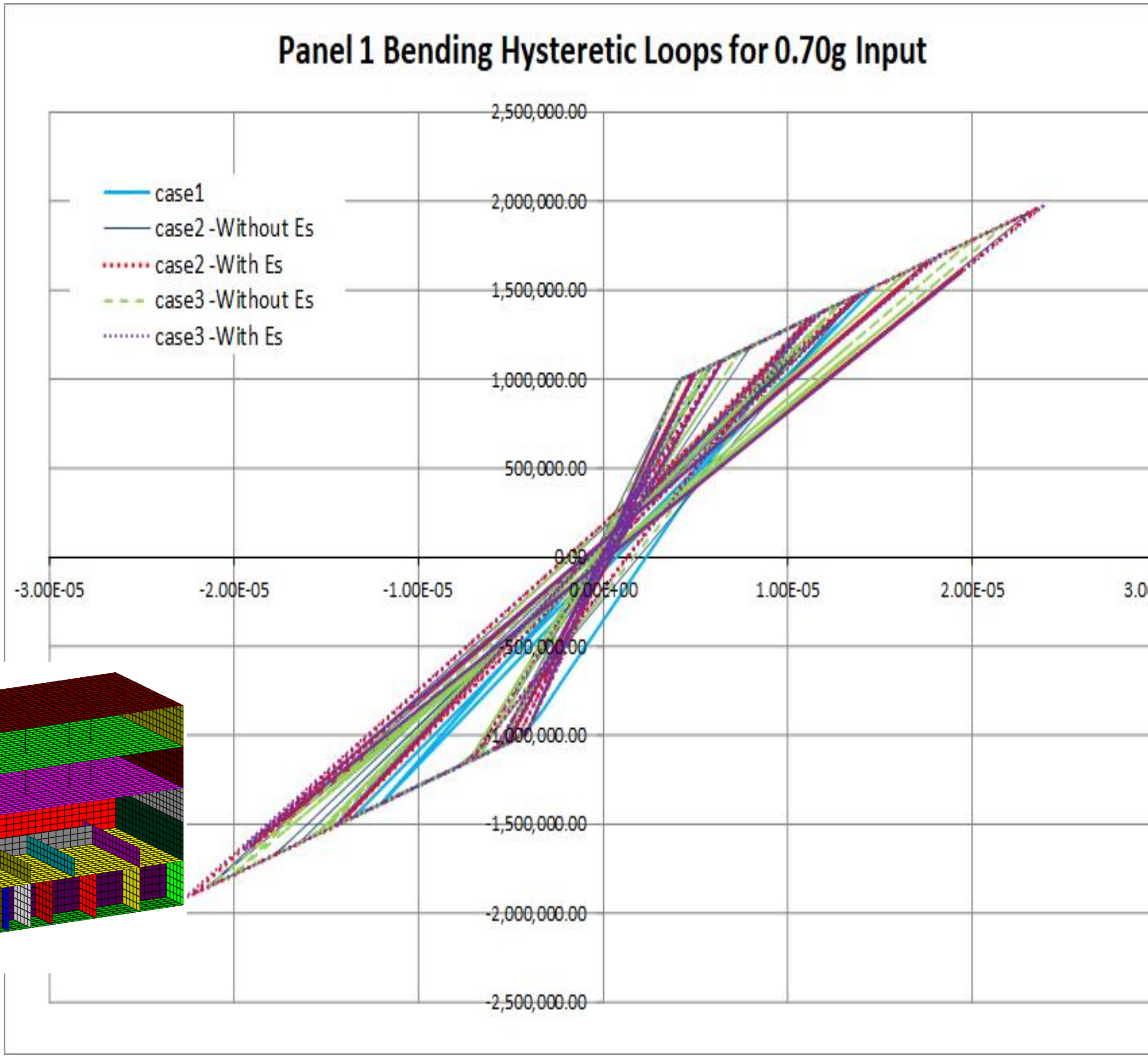


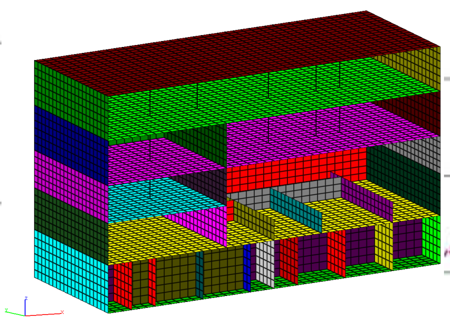
Y-Direction



Japan Standards - Panels 7 Hysteretic Loops for Cases 1, 2 and 3

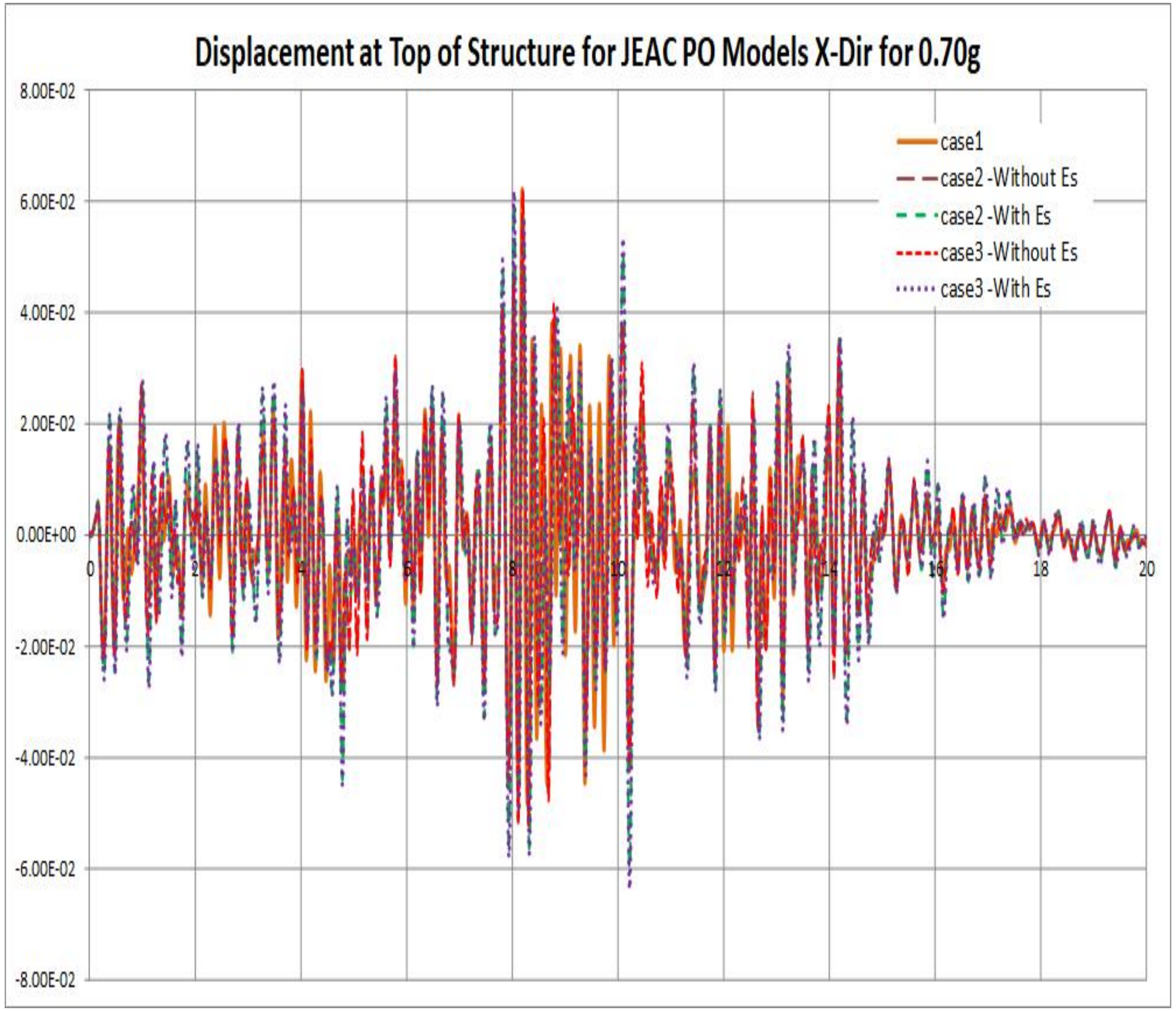




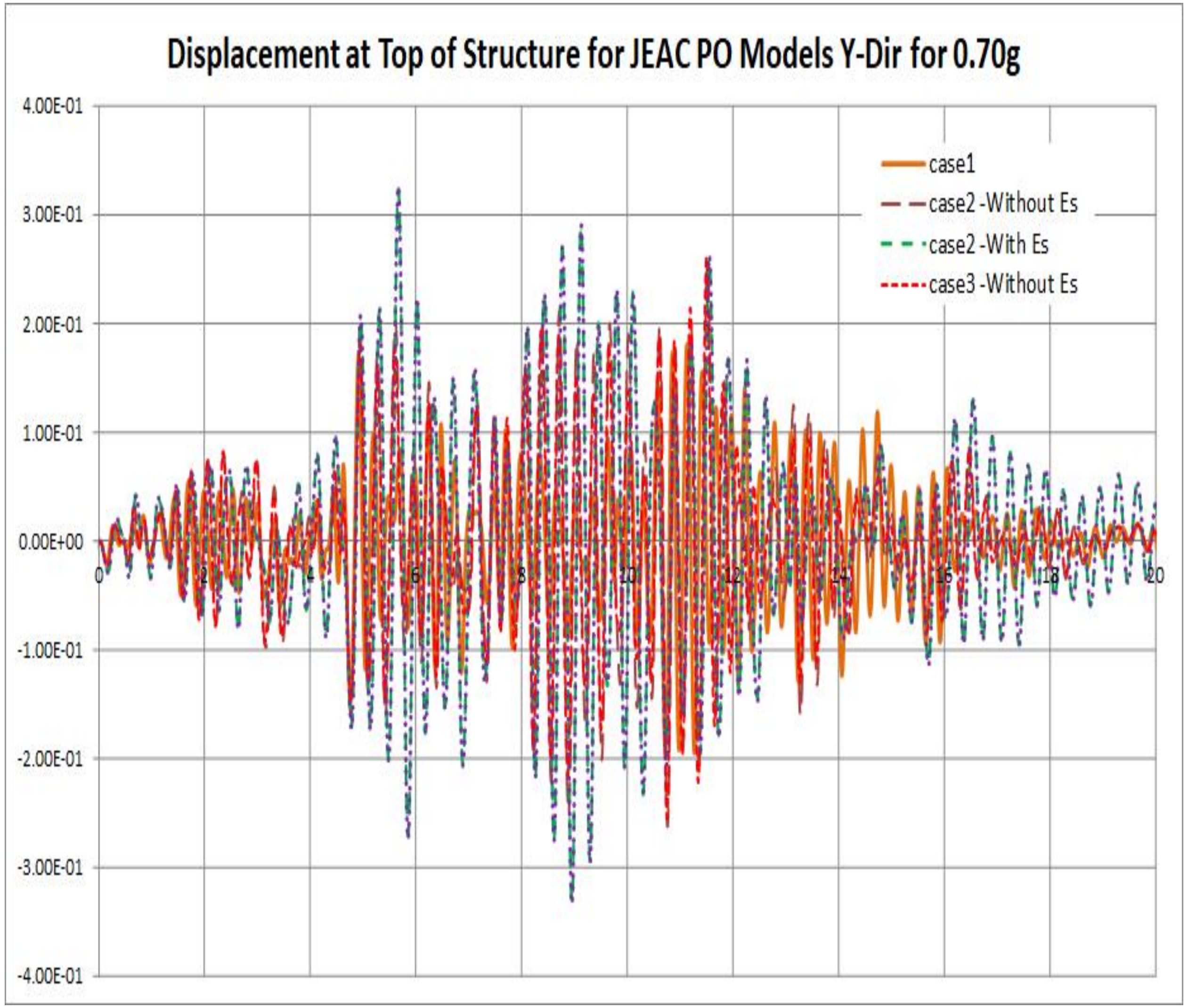


Japan Standards - Displacement at Top for Cases 1, 2 and 3

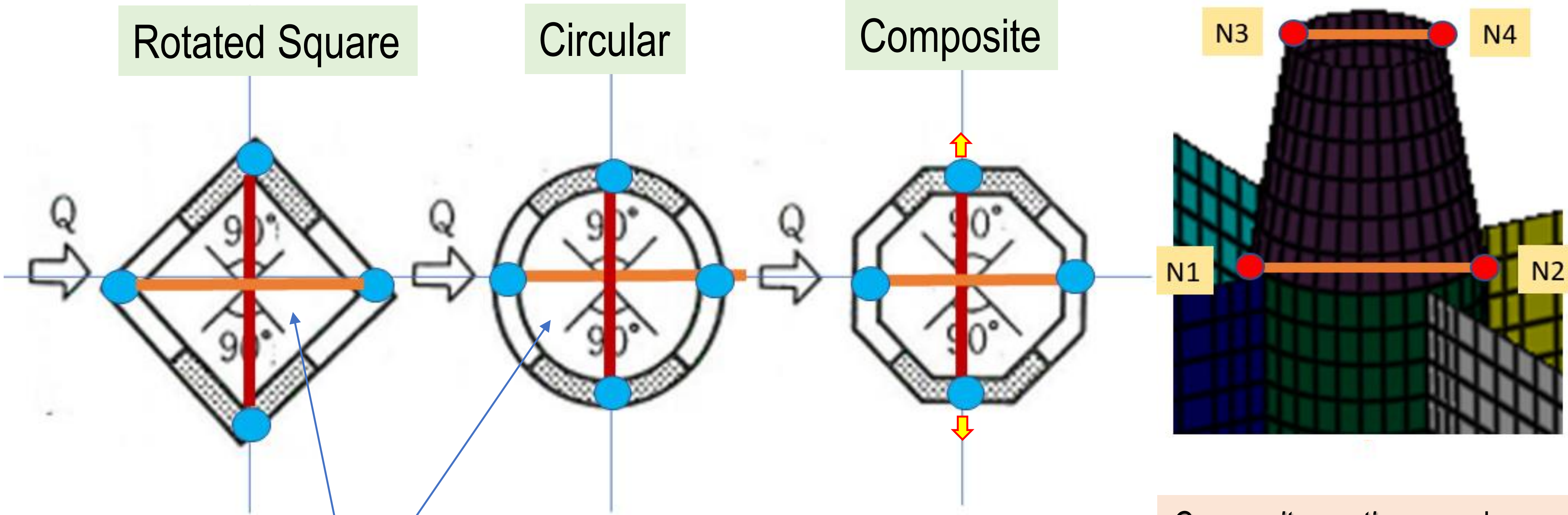
X-Direction



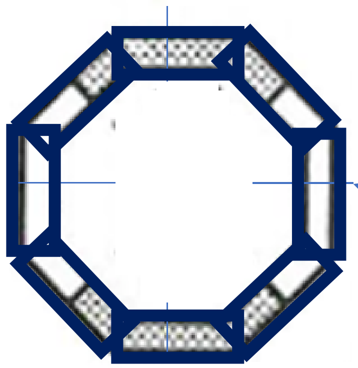
Y-Direction



Non-Planar RC Wall Section and Composite Shapes



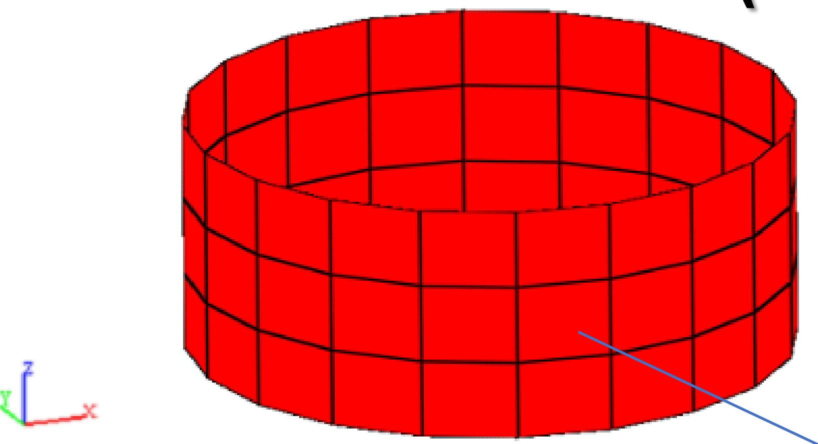
For *simple sections*, the corner nodes are automatically determined for each direction by the NONLINEAR module.



Composite sections can be decomposed by users as shown hereafter..

Composite sections can be automatically decomposed in a series of rectangular objects – in V.4.3.3

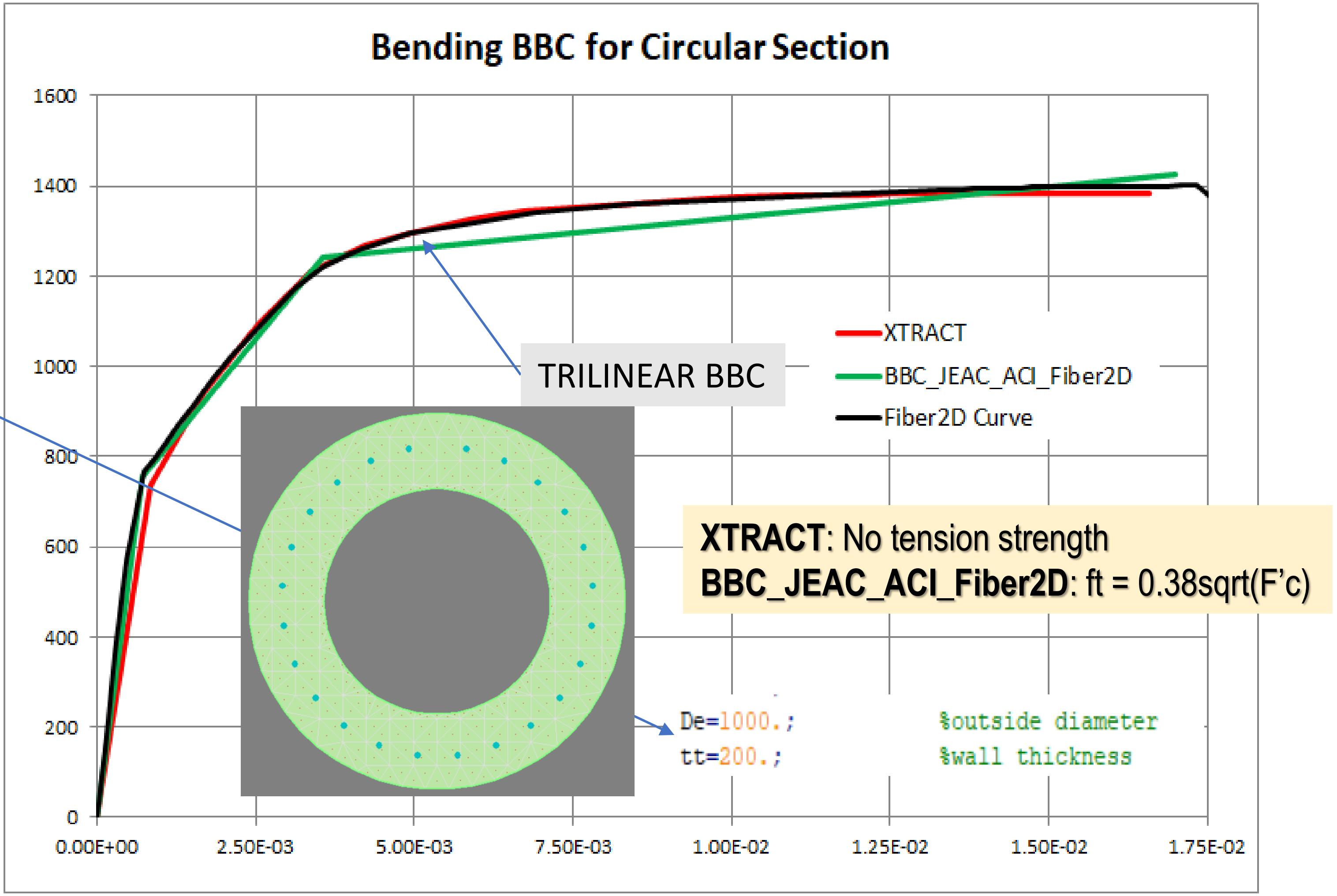
Circular Section Shape Verification of 2DFiber Model vs. XTRACT (BBC_JEAC_ACI_Fiber2D.exe)



Shear Wall Reinforcement:
Vertical Rebar Ratio = 1%
Horizontal Rebar Ratio = 1%

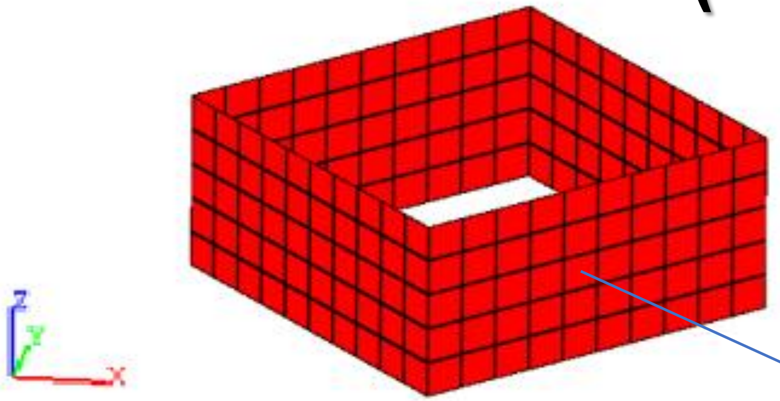
Concrete Material Properties:
Elastic Modulus = 24400000 (kN/m2)
Compression Strength = 30000 (kN/m2)
Yield Strain = 0.002
Ultimate Strain = 0.0035

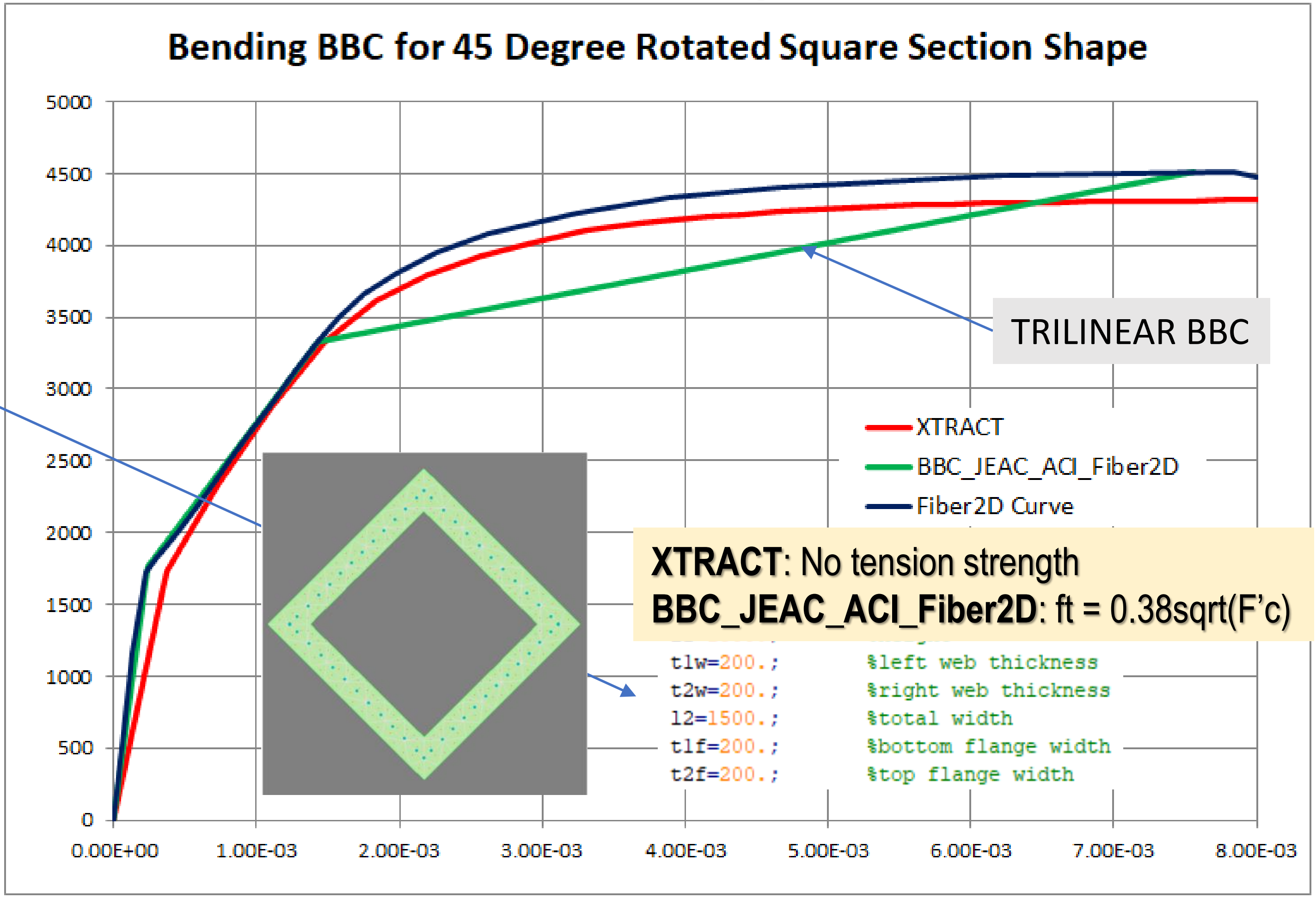
Rebar Material Properties:
Young modulus = 200,000,000. (kN/m2)
Yield Strength = 345000. (kN/m2)
Yield strain = 0.001725
Ultimate strain = 0.10



Axial force N=2500 KN, with mesh_size=50mm.

Rombic Section Shape Verification of 2D Fiber Model vs. XTRACT (BBC_JEAC_ACI_Fiber2D.exe)





XTRACT: No tension strength
BBC_JEAC_ACI_Fiber2D: ft = 0.38sqrt(F'c)

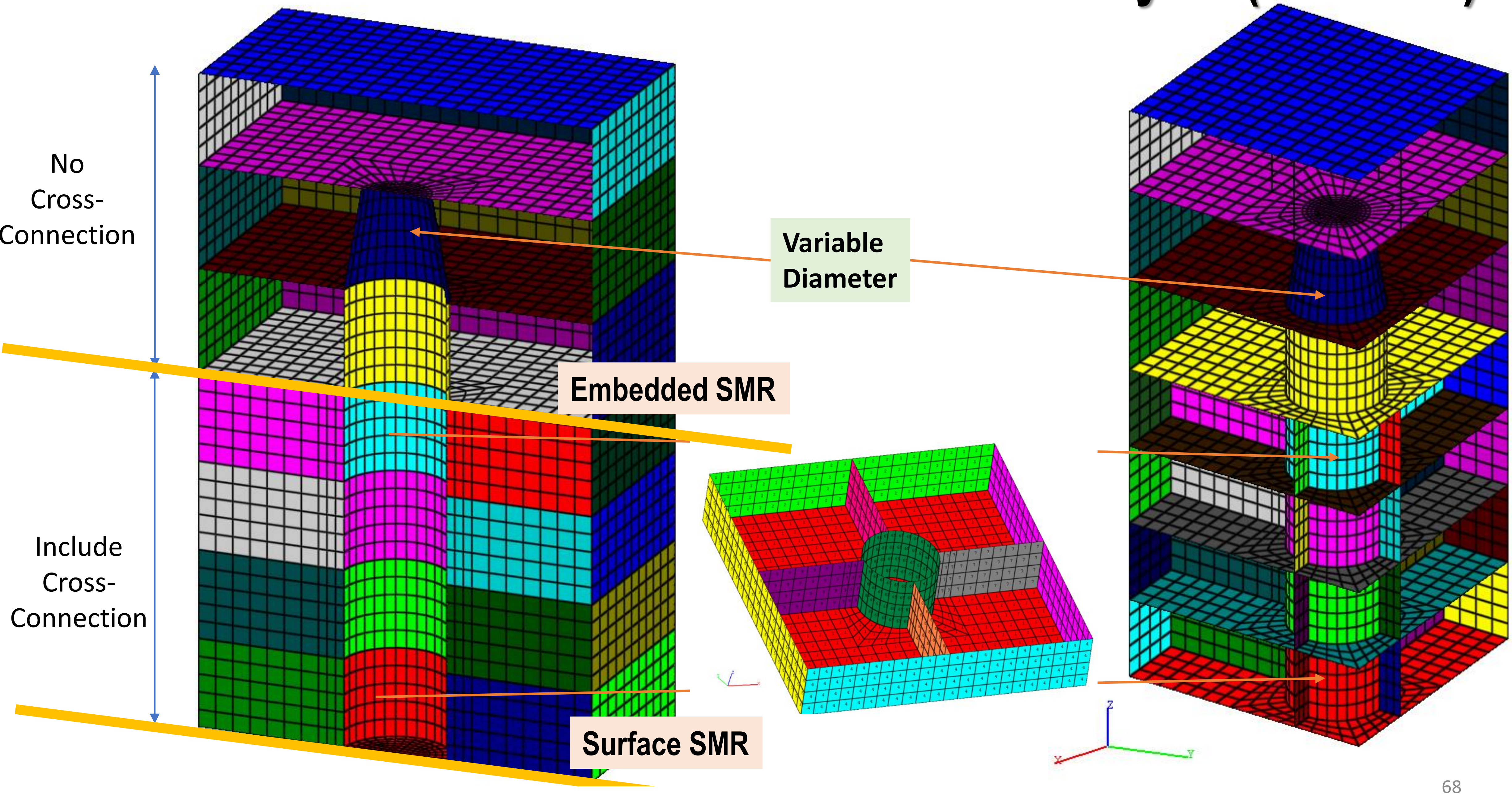
Shear Wall Reinforcement:
Wall 1 Vertical Rebar Ratio = 0.6%
Wall 2 Vertical Rebar Ratio = 0.6%
Wall 3 Vertical Rebar Ratio = 1%
Wall 4 Horizontal Rebar Ratio = 1%

Concrete Material Properties:
Elastic Modulus = 24400000 (Kn/m2)
Compression Strength = 30000 (Kn/m2)
Yield Strain = 0.002
Ultimate Strain = 0.0035

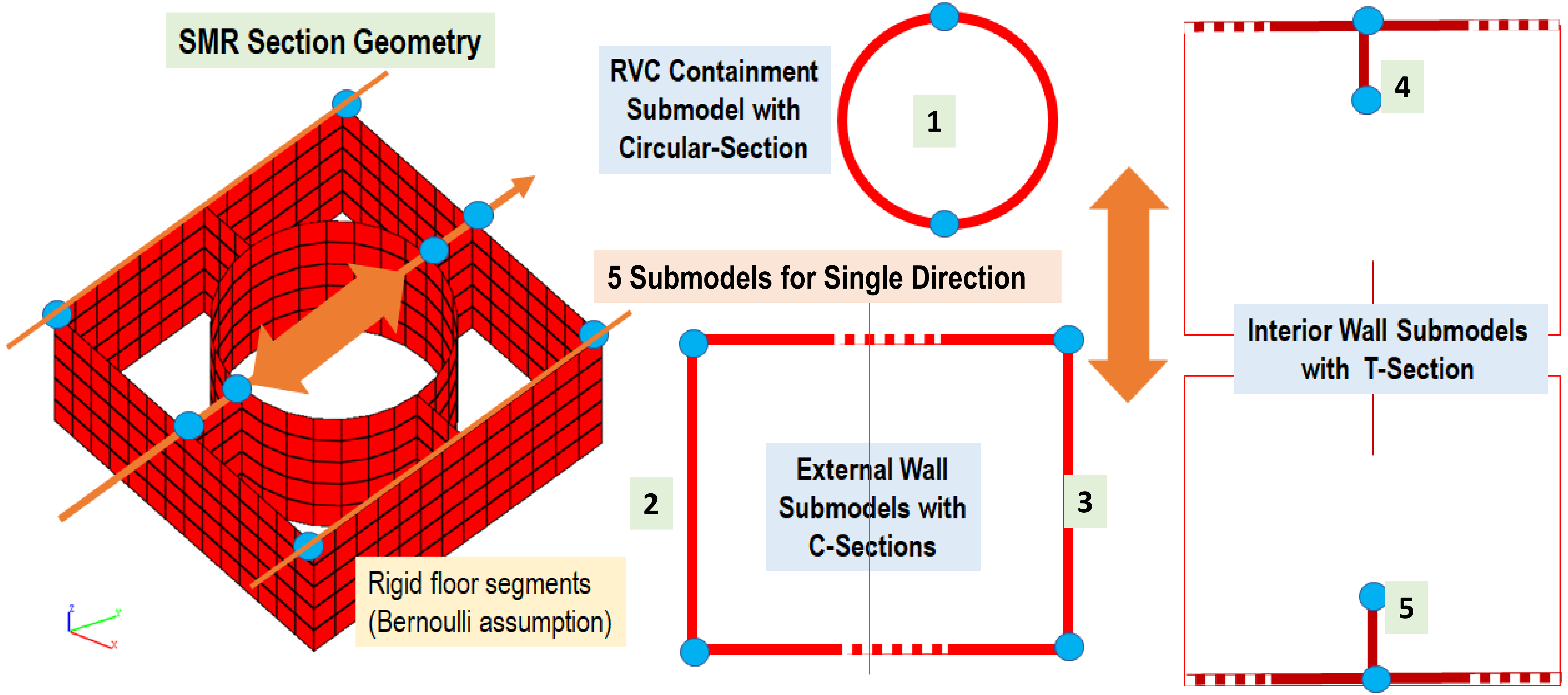
Rebar Material Properties:
Young modulus = 200000000. (Kn/m2)
Yield Strength = 345000. (Kn/m2)
Yield strain = 0.001725
Ultimate strain = 0.1

Axial force N=2500 KN, with mesh_size=40mm.

SMR Structural Model for Nonlinear SSI Analysis (Demo 19)



Composite Section Decomposition in Elementary Shapes



Splitting SMR Model in 9 Wall Submodels Using UI Commands

SMR_SURF_cuts - Notepad

File Edit Format View Help

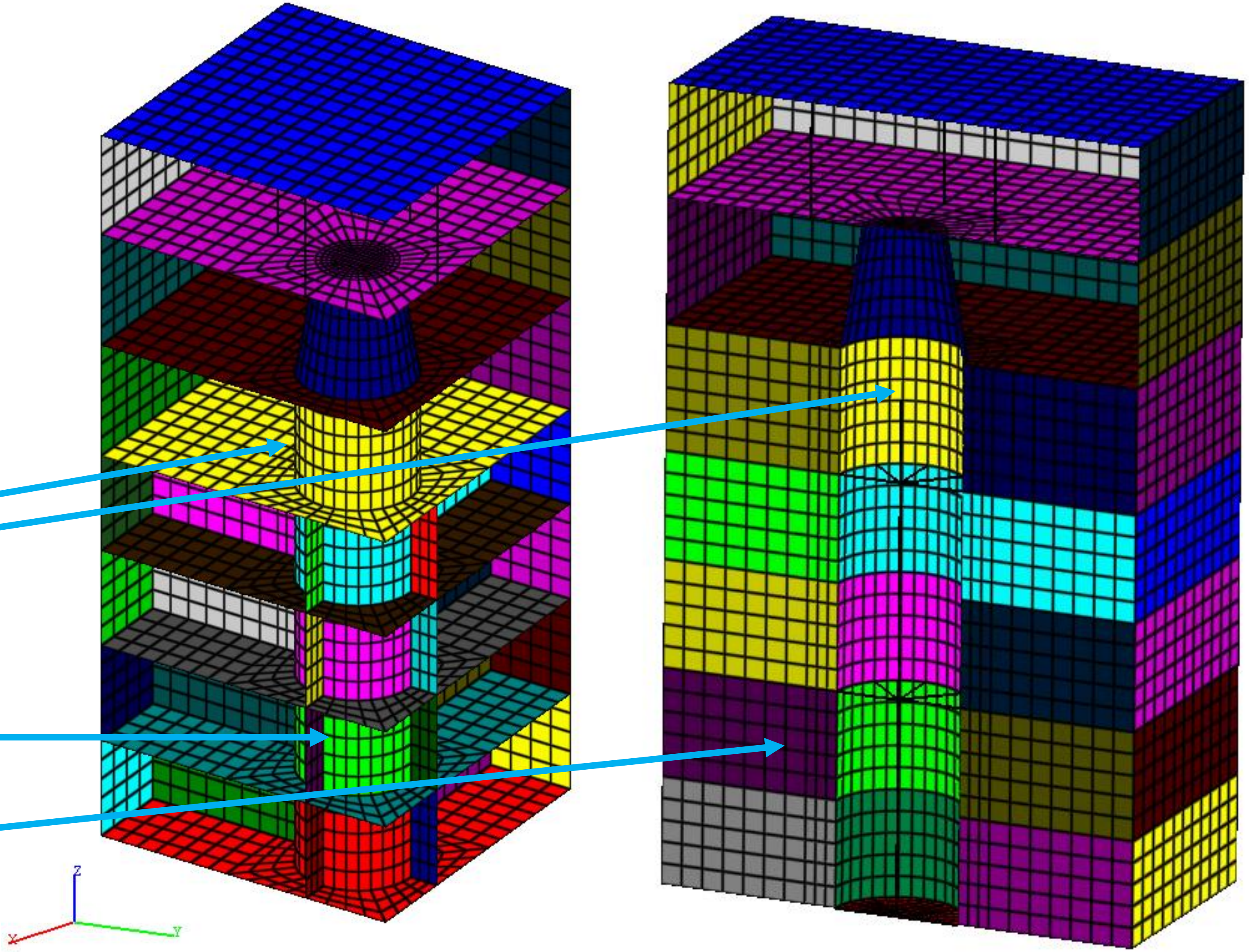
```
var,PATH,C:\SSI\SMR2021\Model-Pre-files\
var,MODELNAME,SMR_SURF_Final
DMODEL,0
DMODEL,1
DMODEL,2
DMODEL,3
DMODEL,4
DMODEL,5
DMODEL,6
DMODEL,7
DMODEL,8
DMODEL,9
CUTCLR,1,9,1
ACTM,0

INP,@PATH[1]\@MODELNAME[1].pre

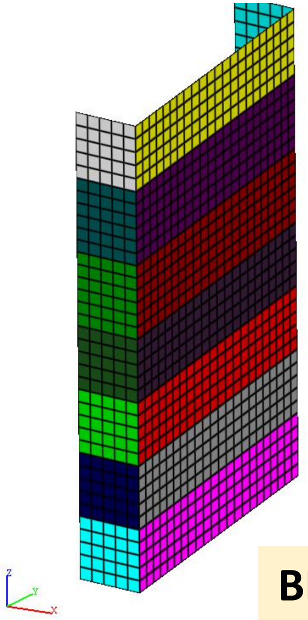
**************************************************
* CIRCULAR MIDDLE SECTION
CUTADD,1,65,RANGE,1,160,1
CUTADD,1,66,RANGE,1,160,1
CUTADD,1,67,RANGE,1,160,1
CUTADD,1,68,RANGE,1,160,1
CUTADD,1,69,RANGE,1,192,1
CUT2SUB,1,1
ACTM,1
WRITE,@PATH[1]\@MODELNAME[1]_circular.pre
ACTM,0

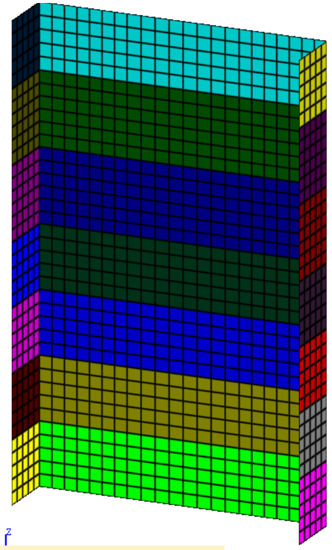
**************************************************
* INTERIOR MIDDLE WALLS 1
CUTADD,2,6,RANGE,1,50,1
CUTADD,2,15,RANGE,1,50,1
CUTADD,2,24,RANGE,1,50,1
CUTADD,2,33,RANGE,1,50,1
CUTADD,2,42,RANGE,1,60,1
CUTVOL,2,-25,25,50,50,-118,-4.3
CUT2SUB,2,2
ACTM,2
WRITE,@PATH[1]\@MODELNAME[1]_interior1.pre
ACTM,0

**************************************************
```

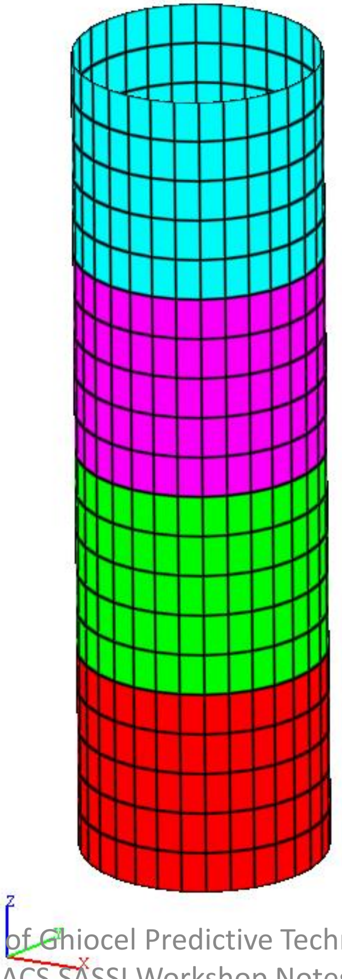


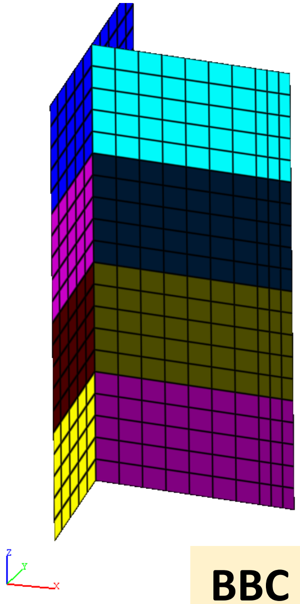
SMR Wall Submodels (4 Exterior, 1 Circular, 4 Connections)

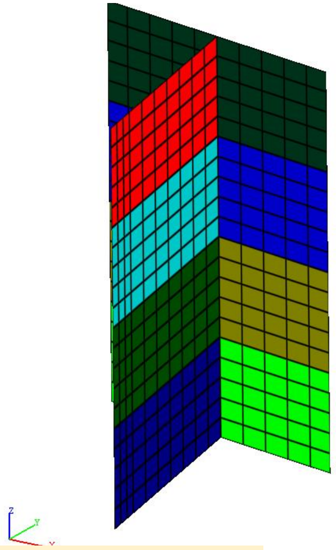




BBC_2DFiber
Dw=0

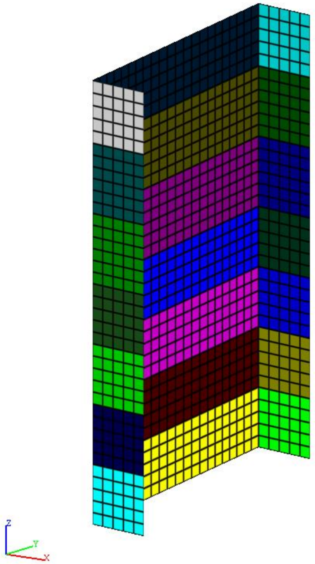


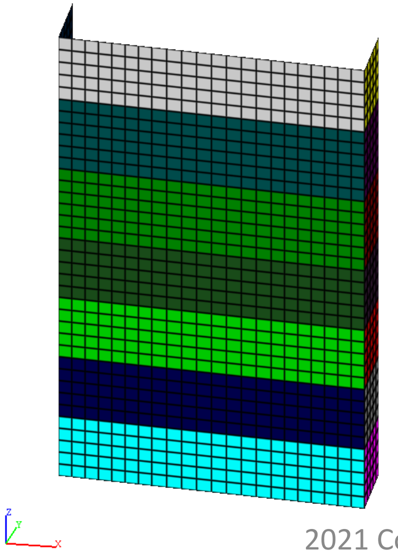


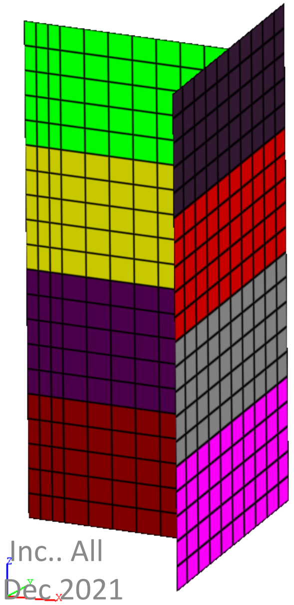


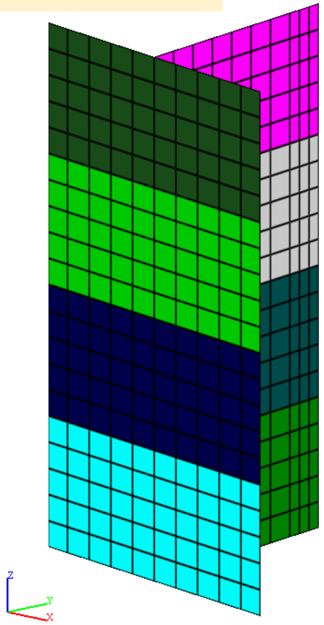
BBC_JEAC_ACI (Dw>0)
BBC_2DFiber (Dw<0)

BBC_JEAC_ACI (Dw>0)
BBC_2DFiber (Dw<0)





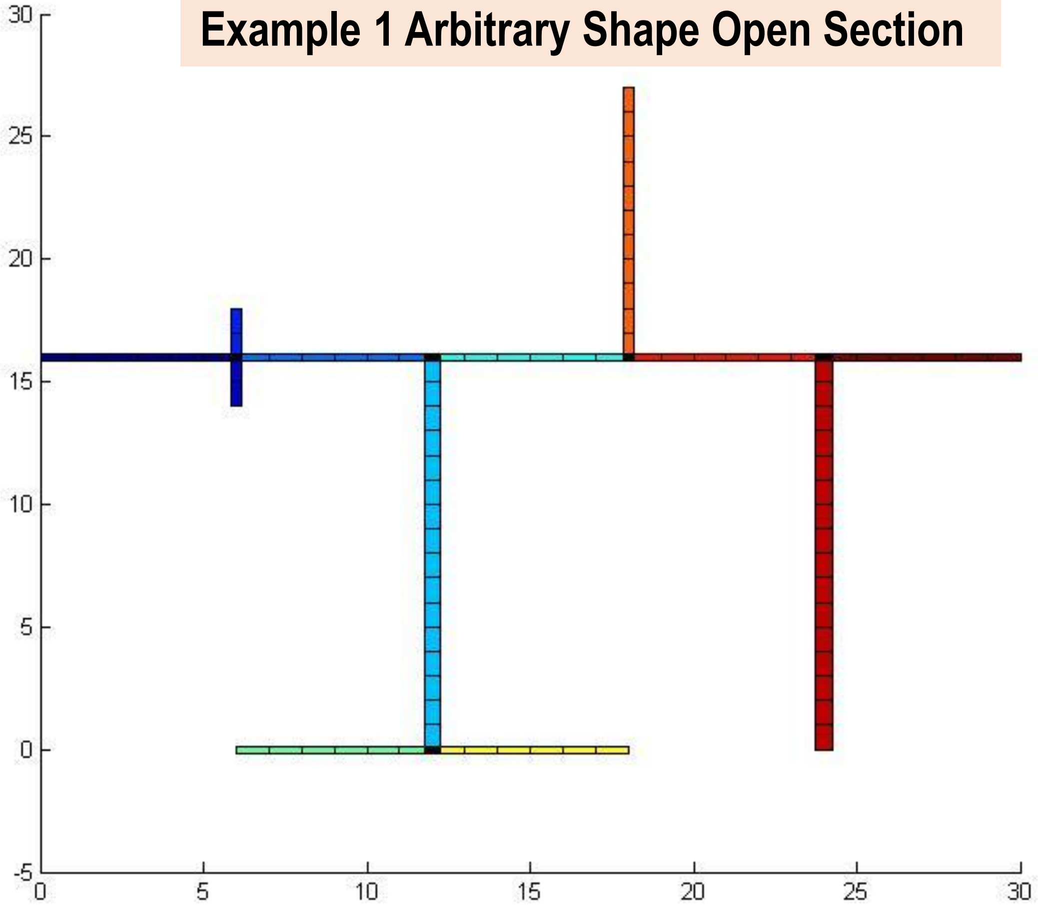




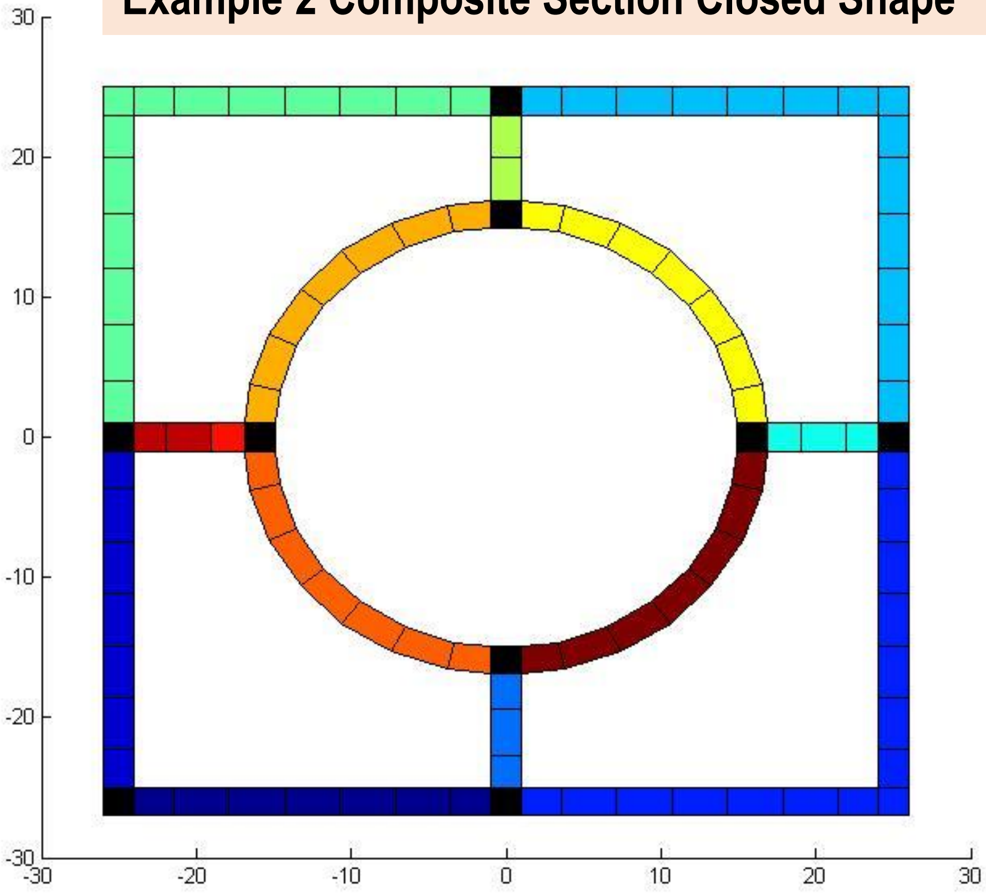
Arbitrary Sections Defined with Different Reinforcement Ratios (See Colors Below) Using Option NON 2DFiber Model (V4.3.3)

Reinforcement ratios considered as material parameters via the M and MSET commands, ***MSET,<e1>,[<e2>],[<inc>],<index>***

Example 1 Arbitrary Shape Open Section

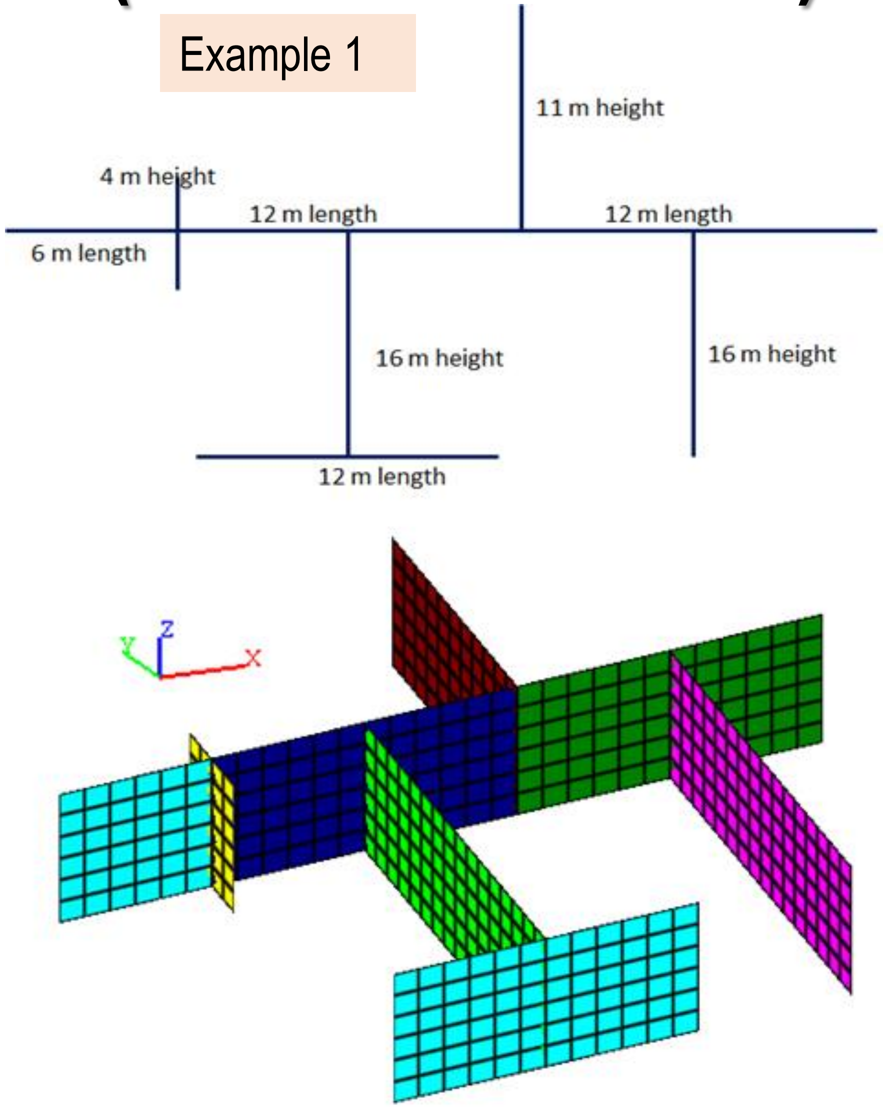


Example 2 Composite Section Closed Shape

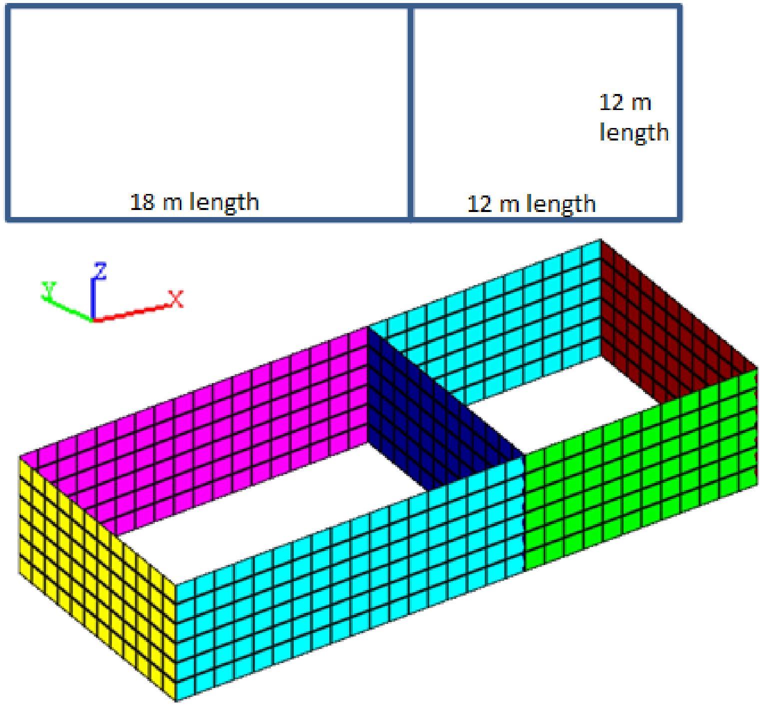


Arbitrary Sections Defined with Different Reinforcement Ratios (See Colors Below) Using Option NON 2DFiber Model (V4.3.3)

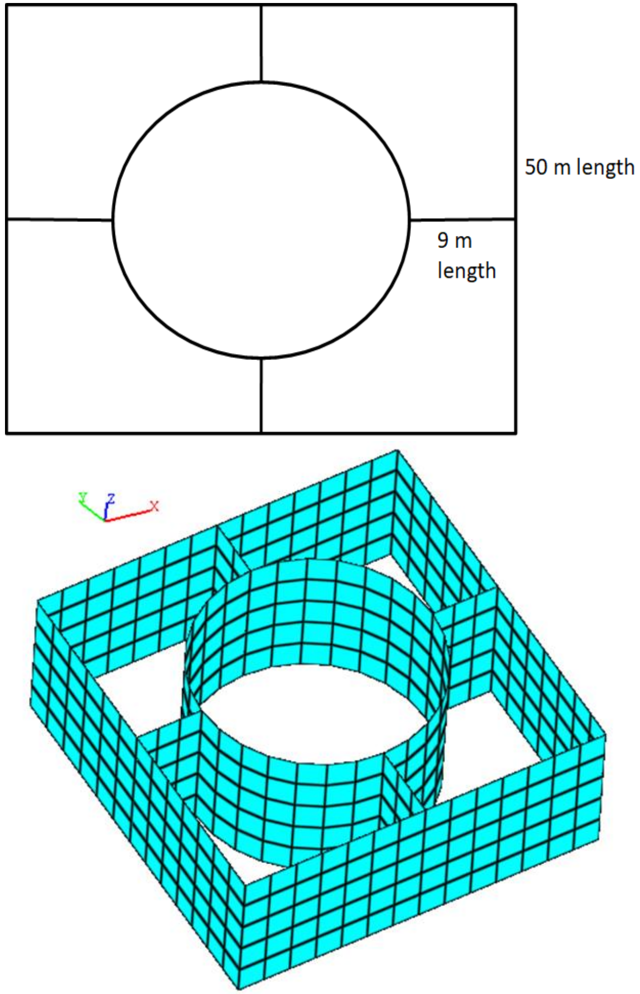
Example 1



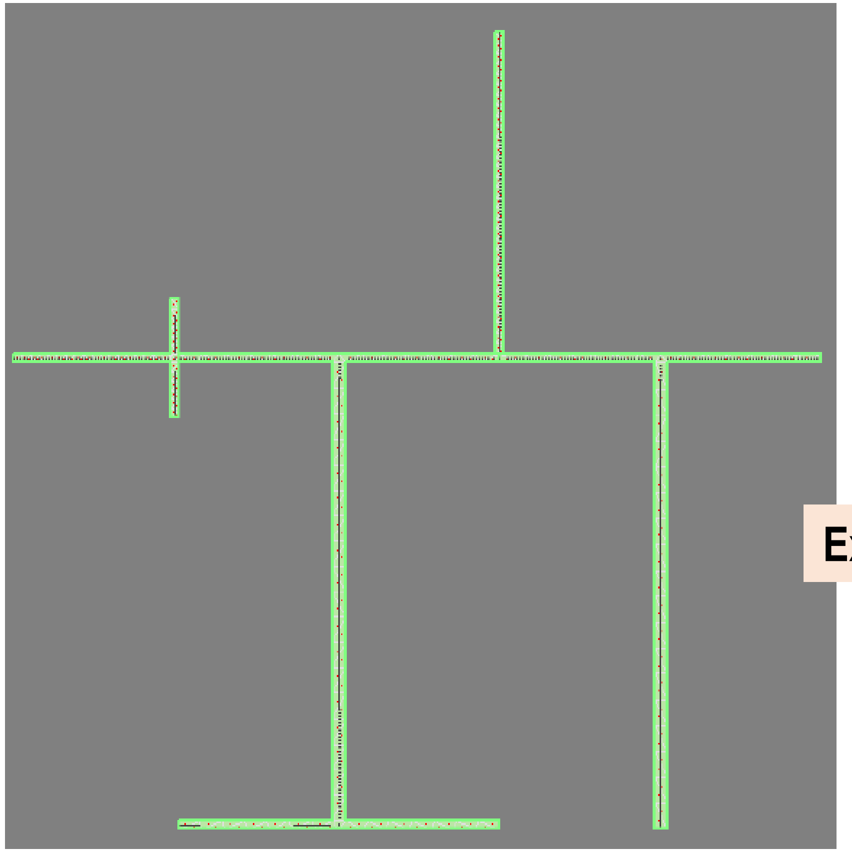
Example 2



Example 3



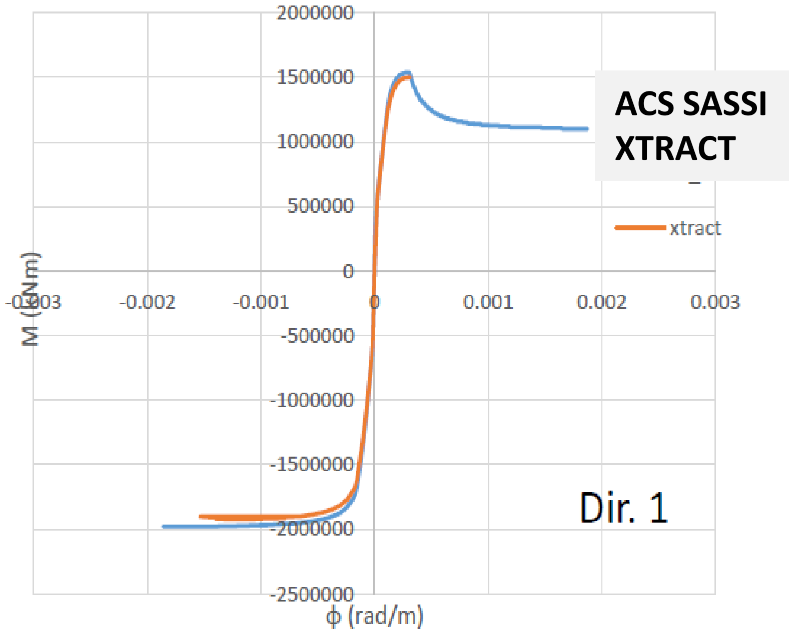
Arbitrary Shape Verification Against XTRACT

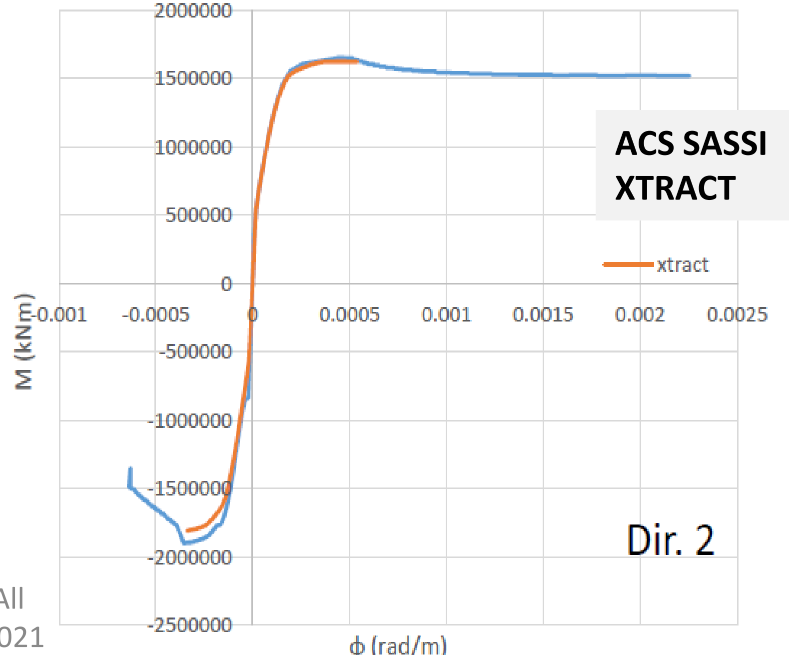


Example 1

Axial force N=70000 KN, with mesh_size=300mm.

Same reinforcement ratio for all elements: 1%.





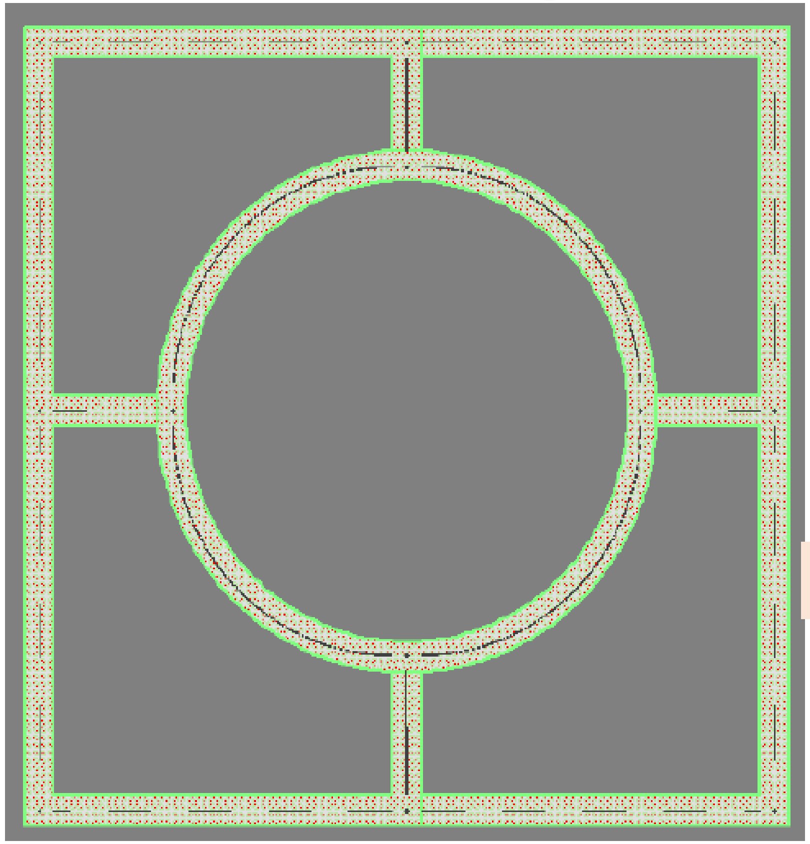
Concrete:

fck=30.; compression strength <N/mm^2>
fct=0.; no tension strength
Ec=2.440e+04; <N/mm^2>
eco=0.002; strain at maximum force <mm/m>
ecu=0.0035; maximum strain <mm/m>
Mander with zero tension

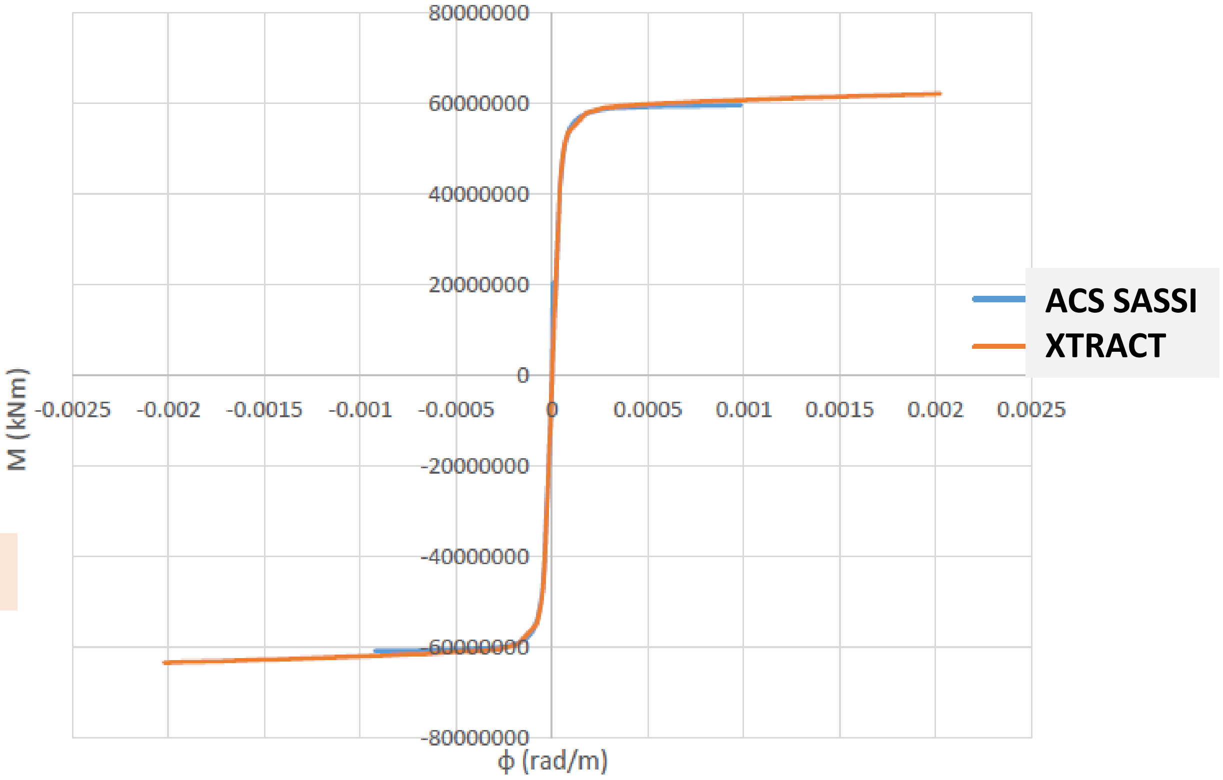
Reinforcement:

fy = 345.; yield strength of longitudinal rebars <N/mm^2>
E = 200000.; elastic modulus
epsu=0.10; maximum strain <mm/m>
Bilinear with no hardening

Arbitrary Shape Verification Against XTRACT



Example 2



Axial force N=100000 KN, with mesh_size=500mm.

Same reinforcement ratio for all elements: 1%.

Concrete:
fck=30.; compression strength <N/mm^2>
fct=0.; no tension strength
Ec=2.440e+04; <N/mm^2>
eco=0.002; strain at maximum force <mm/m>
ecu=0.0035; maximum strain <mm/m>
Mander with zero tension

Reinforcement:
fy = 345.; yield strength of longitudinal rebars <N/mm^2>
E = 200000.; elastic modulus
epsu=0.10; maximum strain <mm/m>
Bilinear with no hardening

Hysteretic Models Library Available for Nonlinear RC Walls

The hysteretic model library includes 8 types of models applicable to the structure RC walls:

1-Cheng-Mertz Shear (CMS)

2-Cheng-Mertz Bending (CMB)

3-Takeda (TAK)

4-General Massing Rule (GMR)

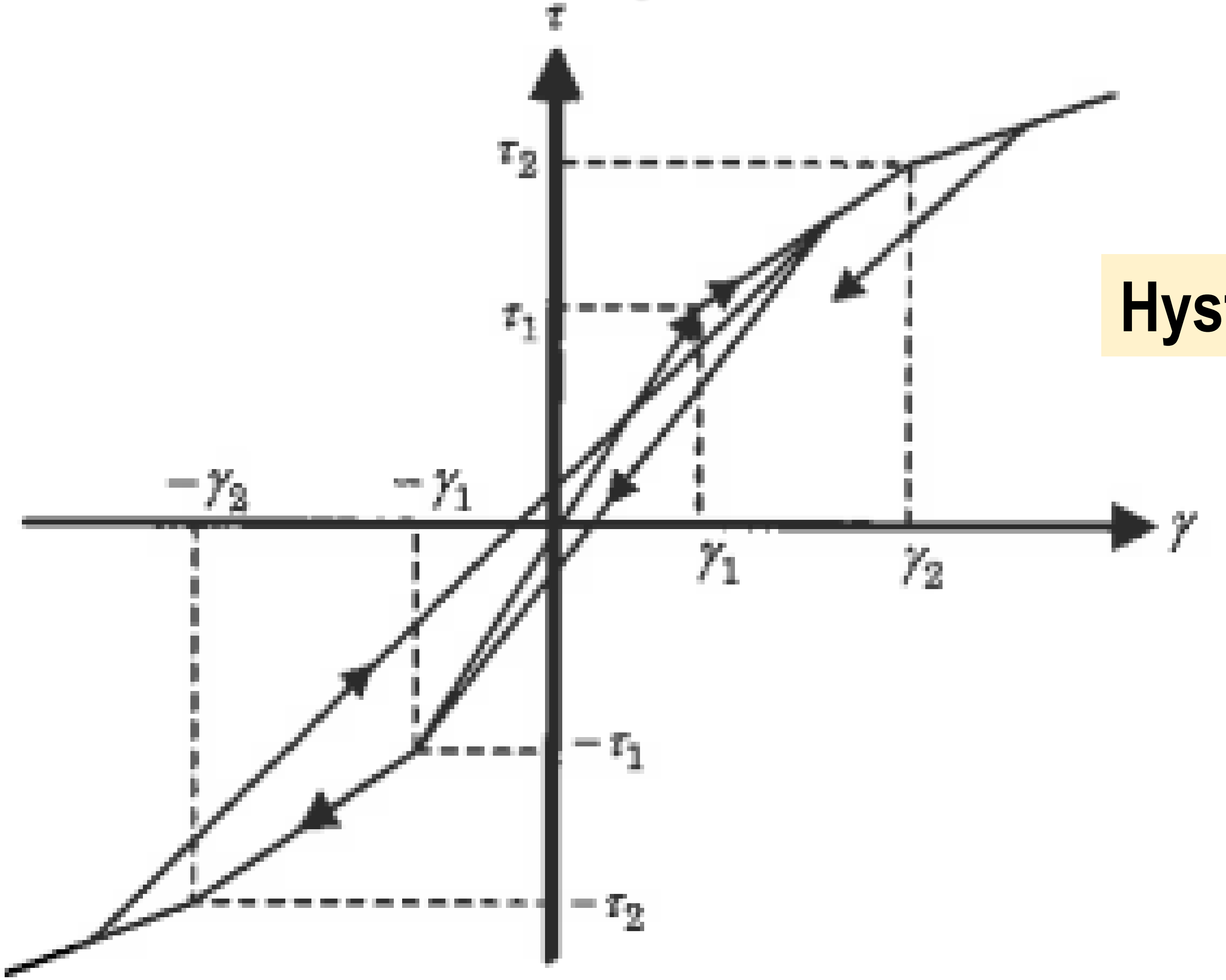
5-Maximum Point-Oriented (PO) for Shear - per JEAC 4601 App. 3.6

6-Maximum Point-Oriented Degrading Trilinear (PODT) for Bending - per JEAC 4601 App. 3.6

7-Hybrid Shear (HYS) – obtained by combining PO Shear and CMS models

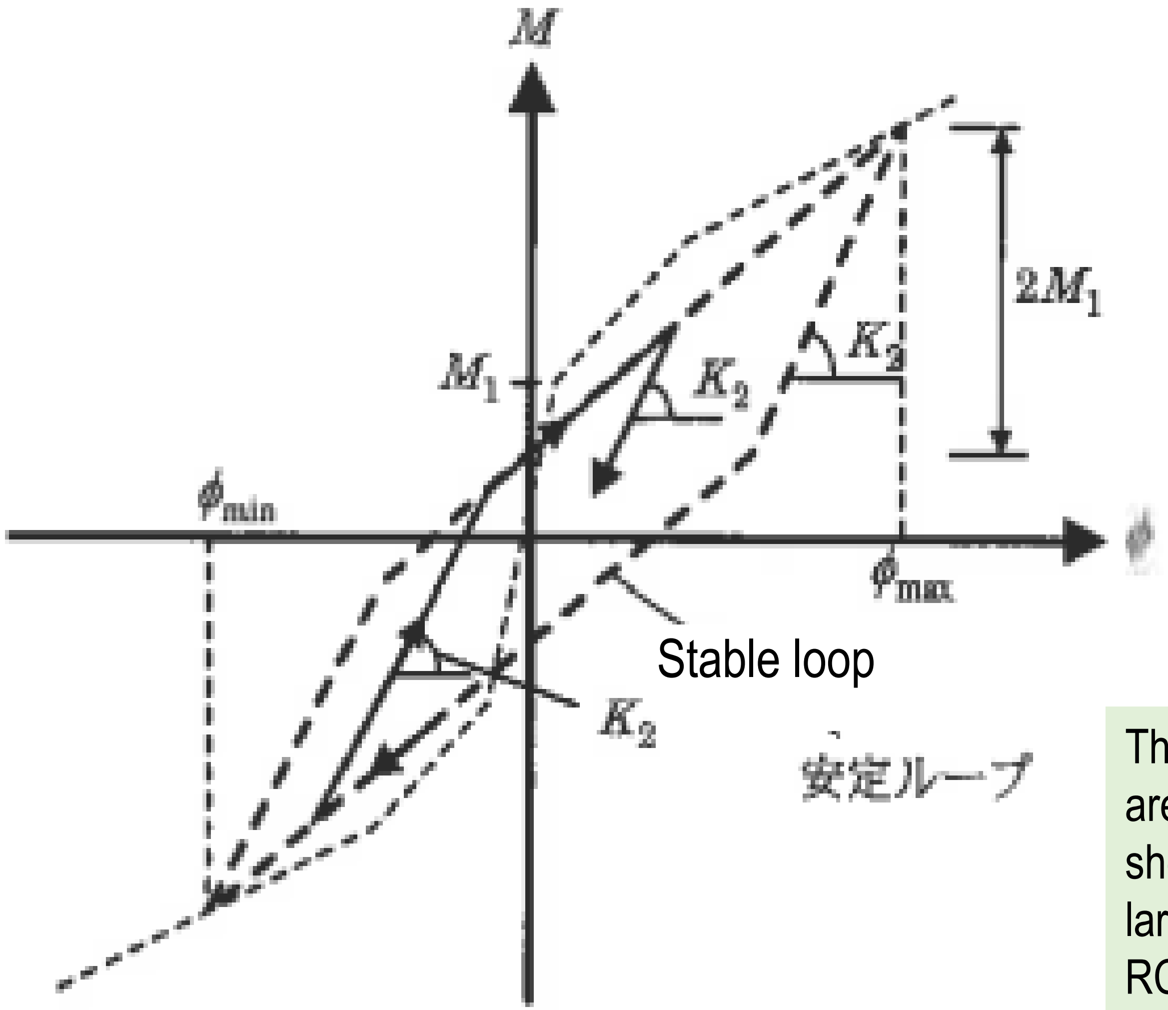
8-Hybrid Bending (HYB) - obtained by combining PODT Bending and CMB models

Remarks for JEAC 4601 Max Point-Oriented (PO) Shear Hysteretic Model

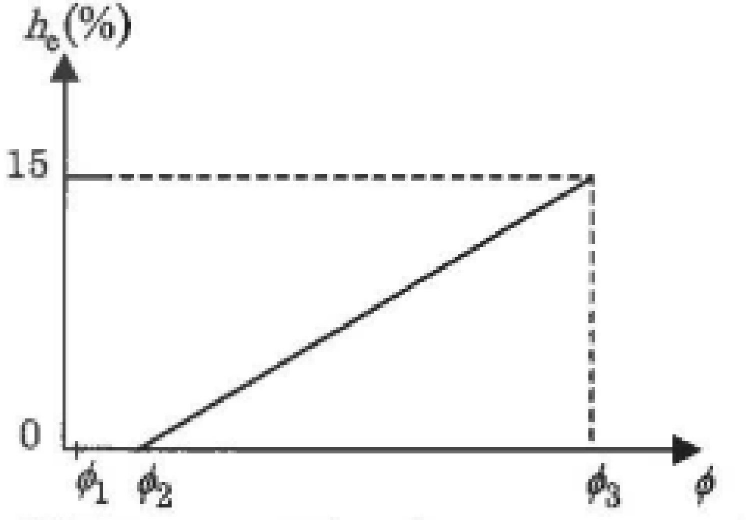


Hysteretic Damping is zero!

Remarks for JEAC 4601 Max Point-Oriented-Degraded-Trilinear (PODT) Bending Hysteretic Model

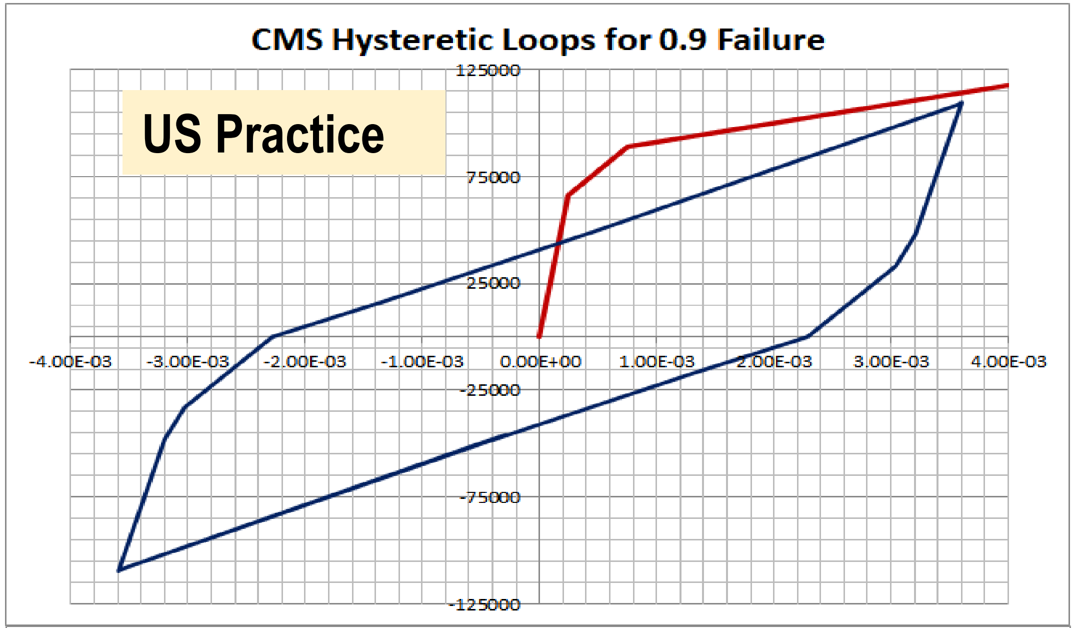


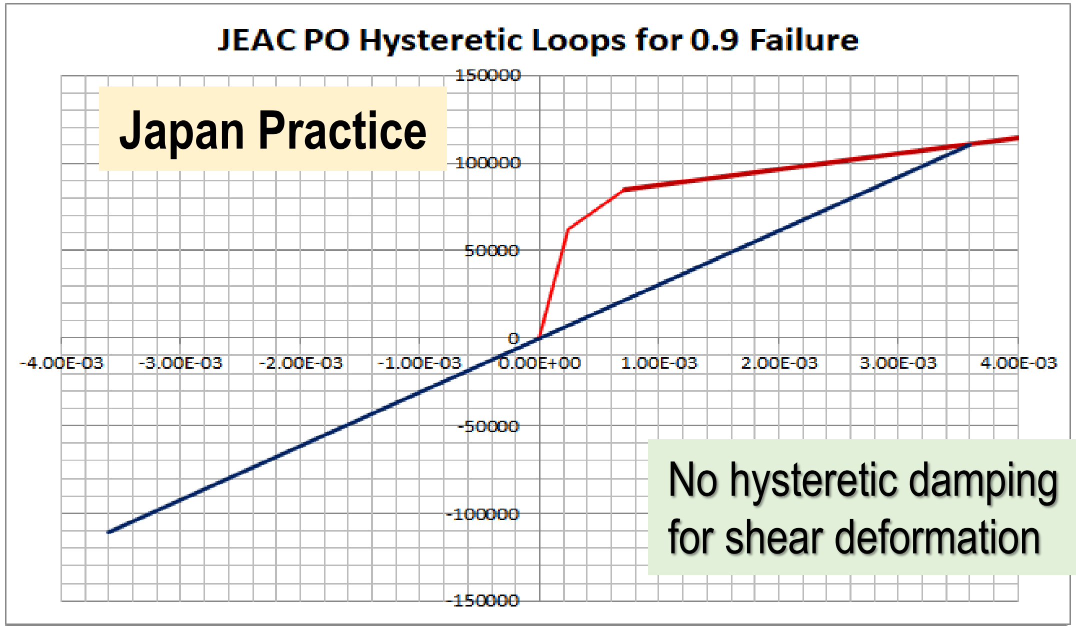
Hysteretic Damping varies from 0% to 15%; 0% at yielding and 15% at failure (ultimate).



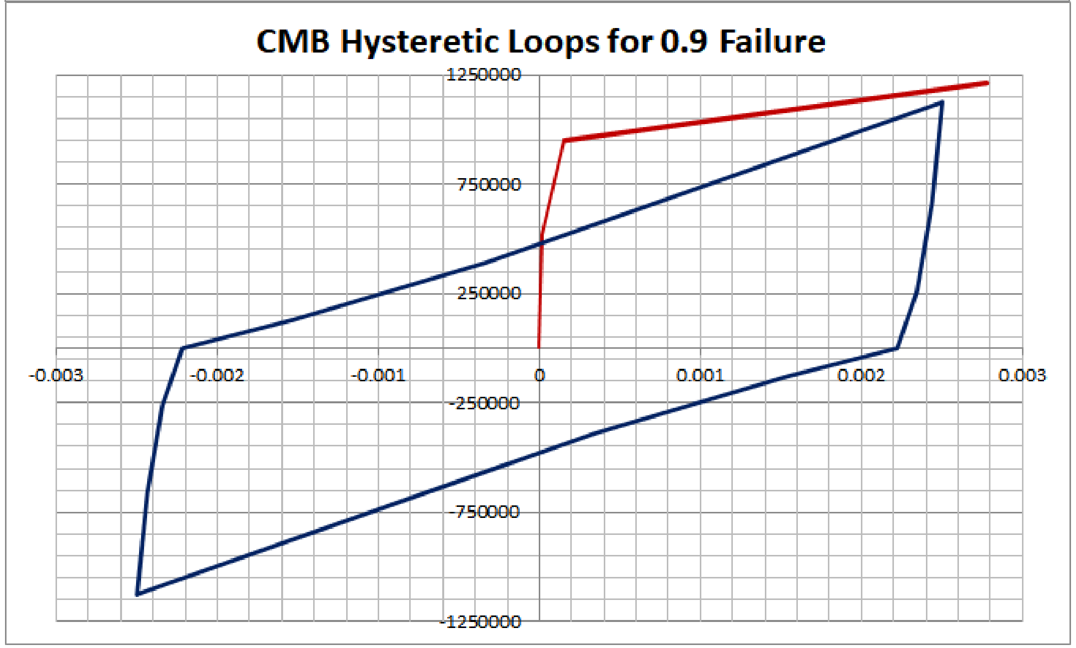
The low hysteretic damping values recommended in the JEAC 4601 are based on a series of experimental tests done for various shearwall configurations and typical NPP structure RC walls with larger thicknesses and reinforcement percentages than those of the RC walls in conventional structures (Taitokui report, 1987). These damping values are lower than those computed using FEA codes.

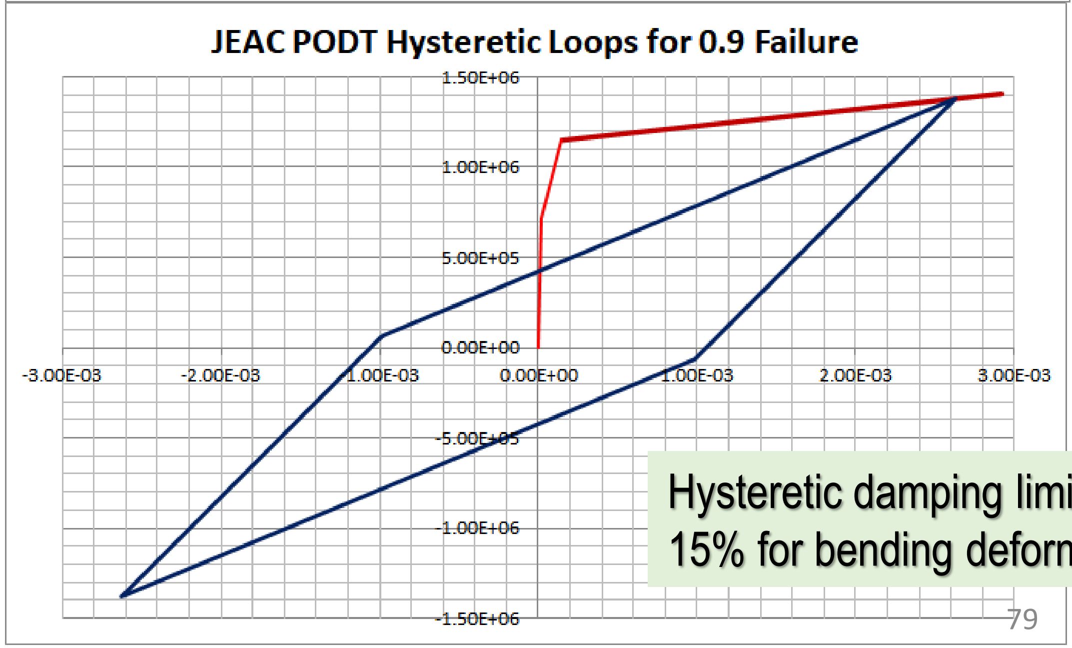
CM & JEAC 4601 PO Model Hysteretic Loops for Harmonic Inputs





No hysteretic damping
for shear deformation

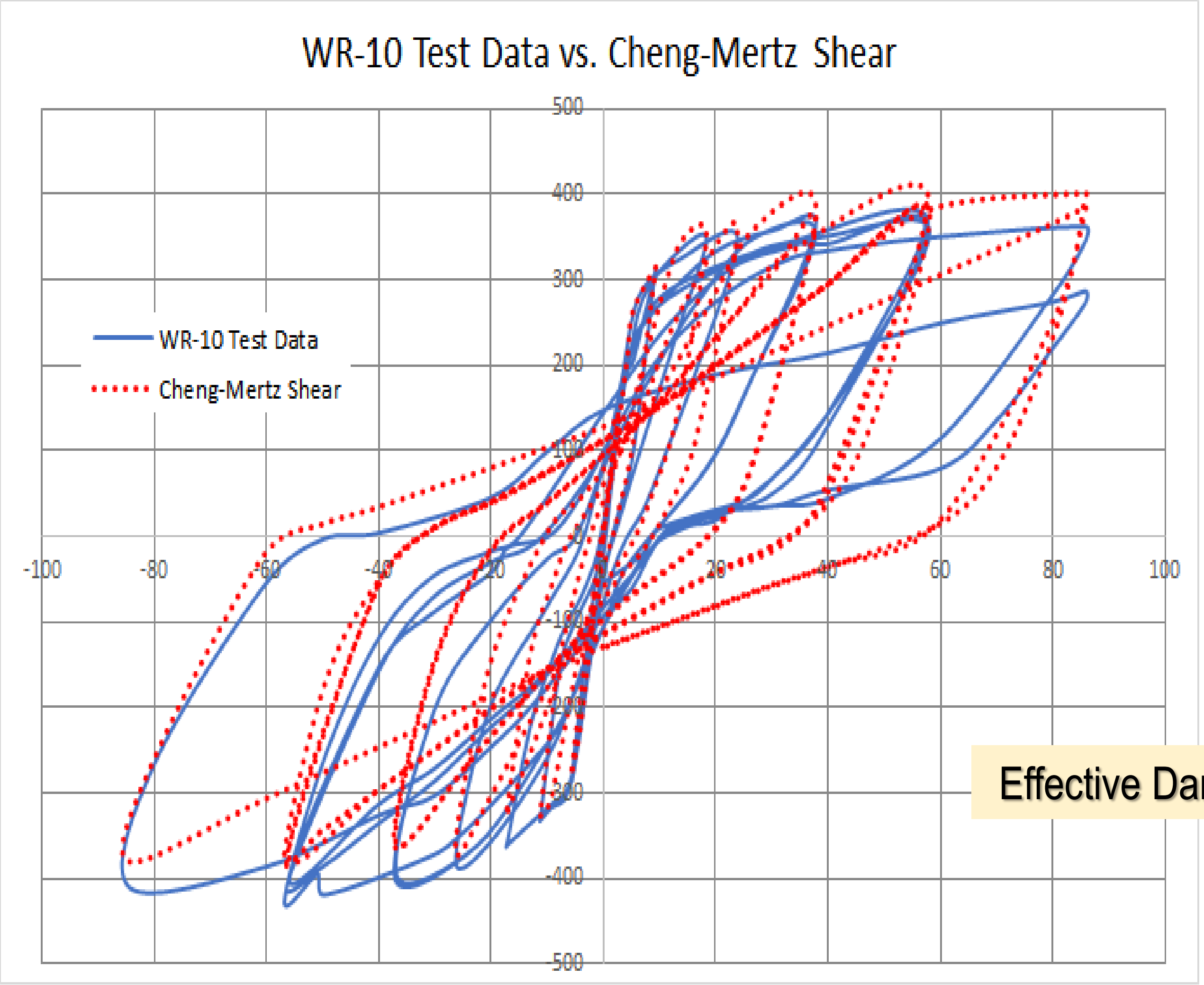


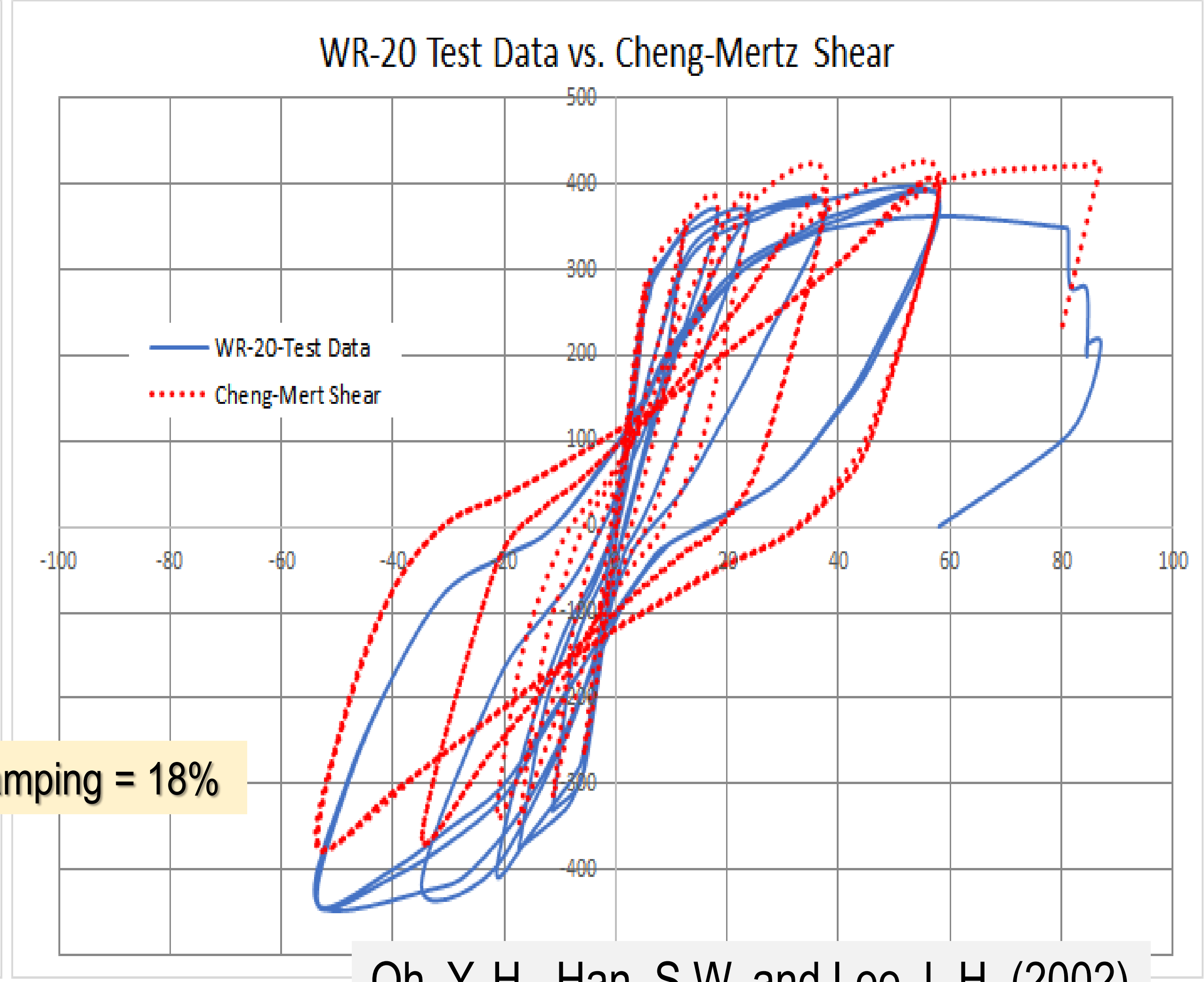


Hysteretic damping limited to
15% for bending deformation

Cheng-Mertz Shear Hysteretic Model Against Wall Test Data

Cheng-Mertz Shear Model (Model 1)



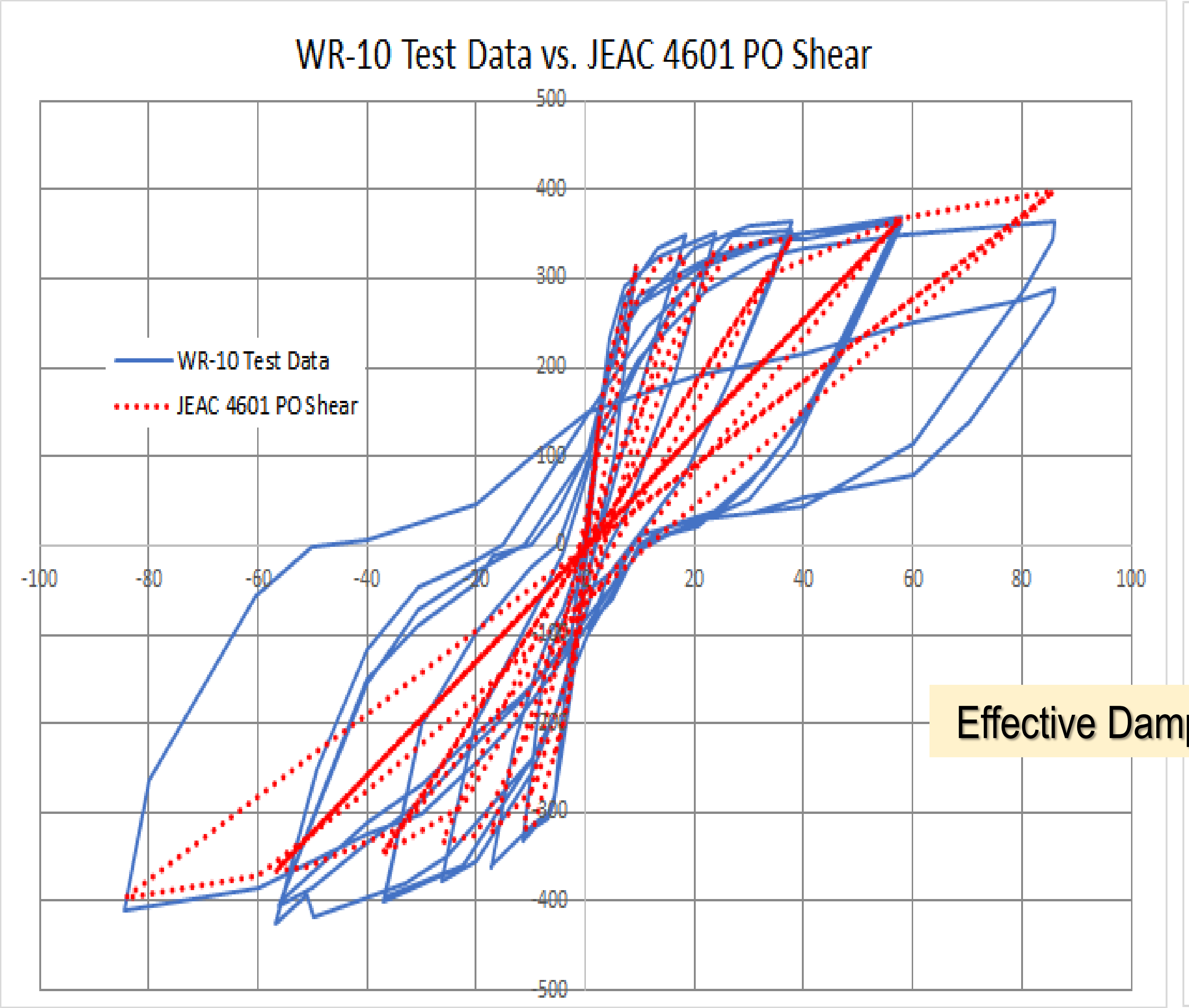


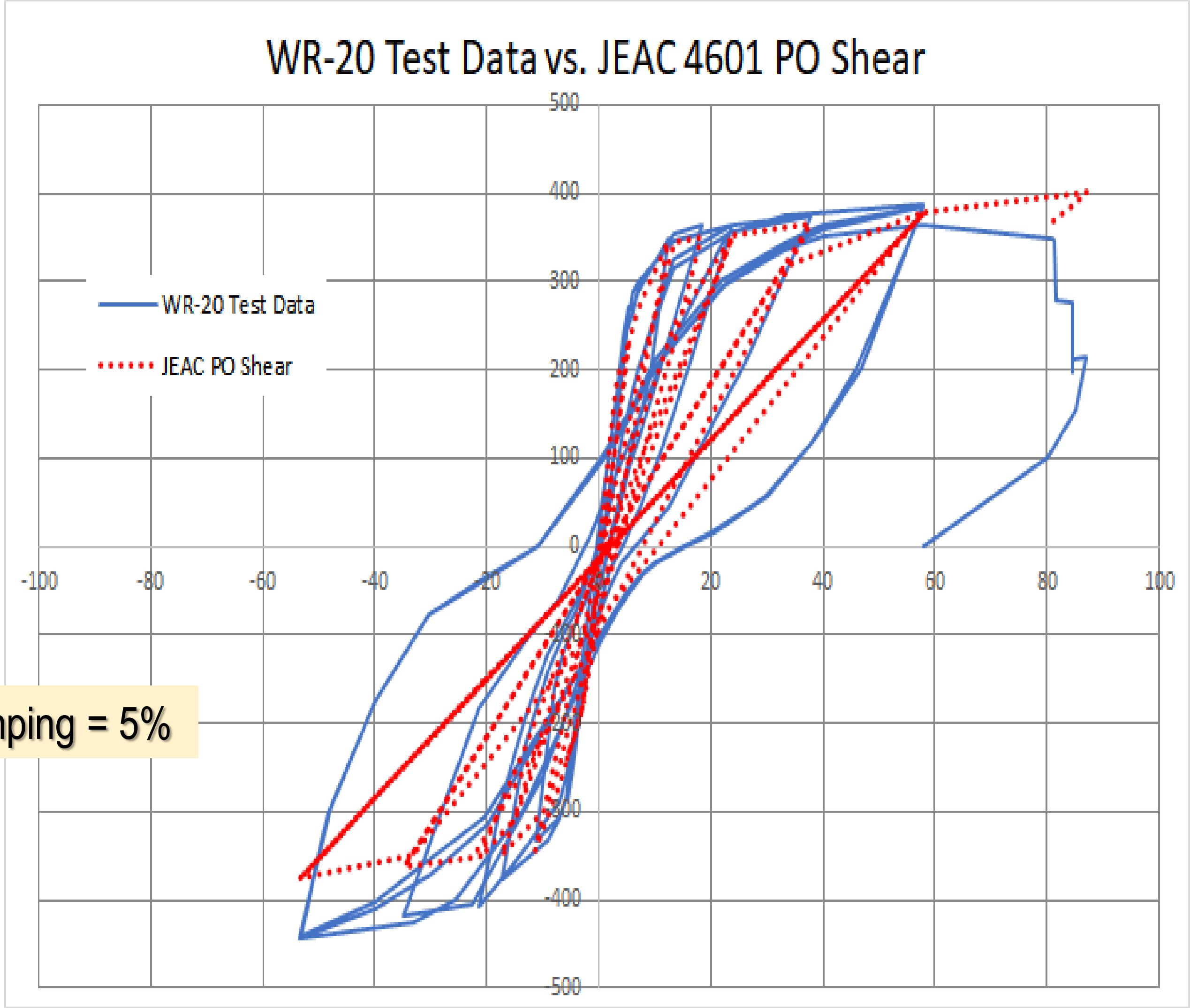
Effective Damping = 18%

Oh, Y. H., Han, S.W. and Lee, L.H. (2002)

JEAC PO Shear Hysteretic Model Against Wall Test Data

JEAC 4601 Point-Oriented (PO) Shear Model (Model 5)

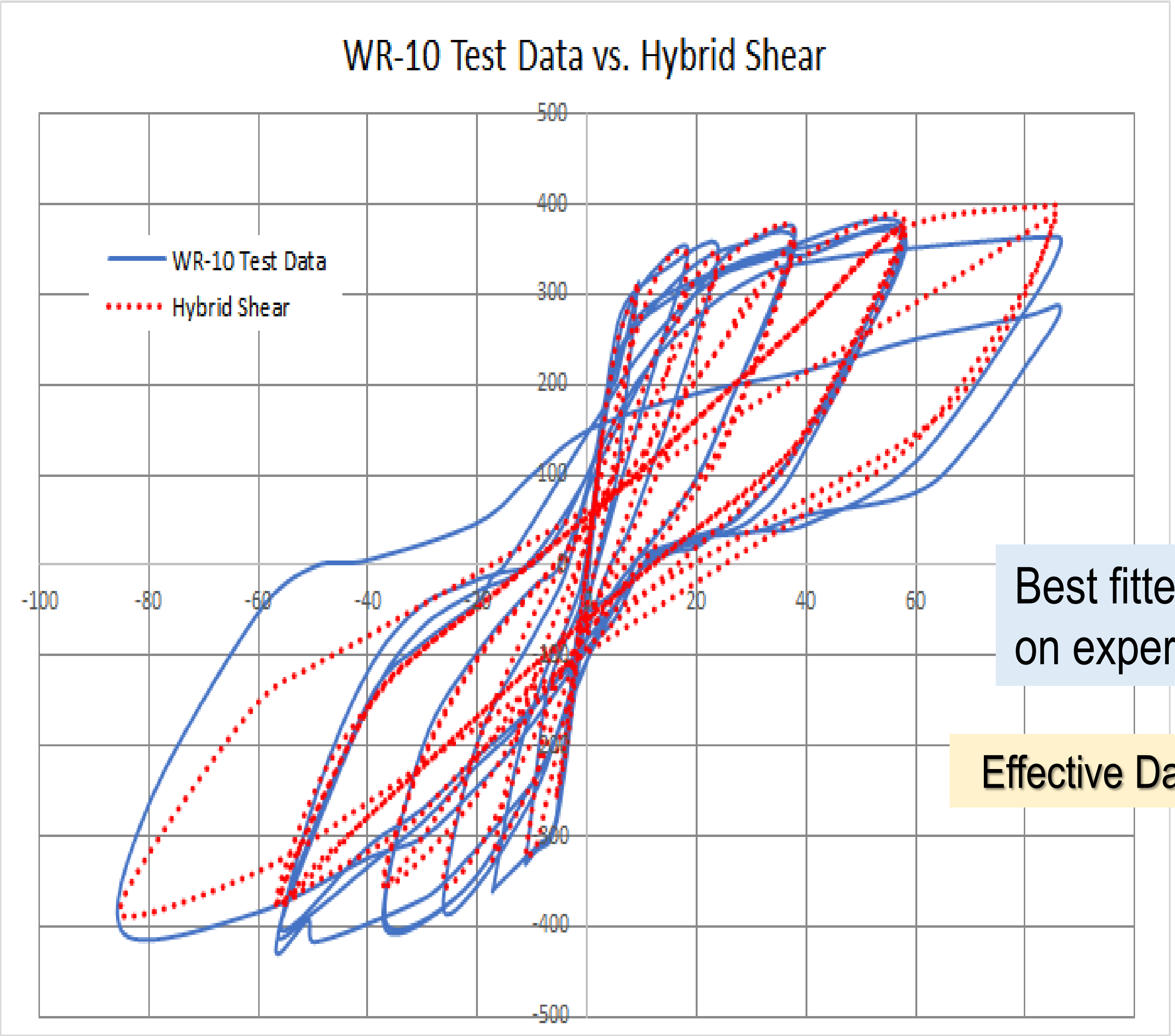


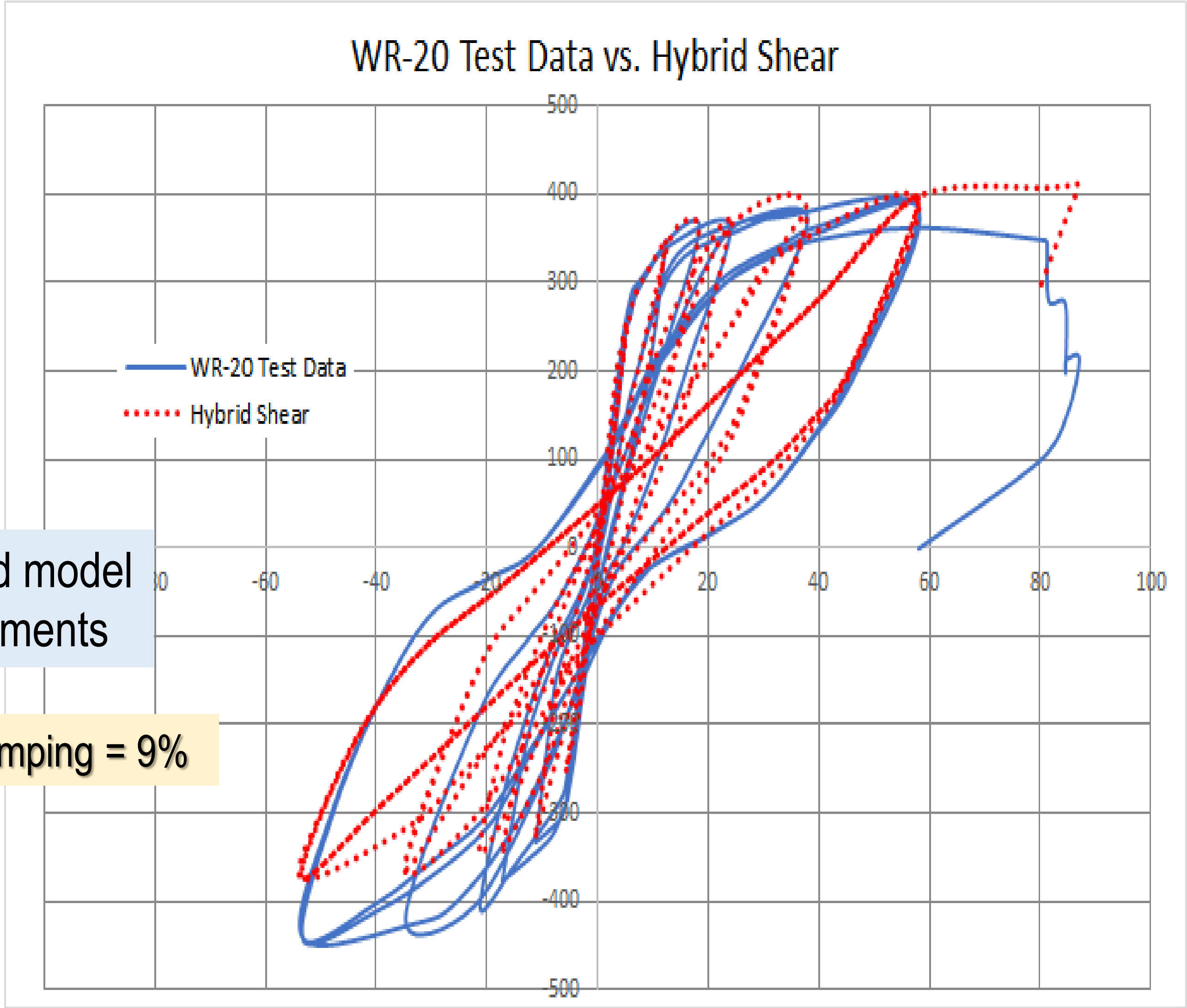


Effective Damping = 5%

Hybrid Shear Hysteretic Model Against Wall Test Data

Hybrid Shear Model (Model 7)



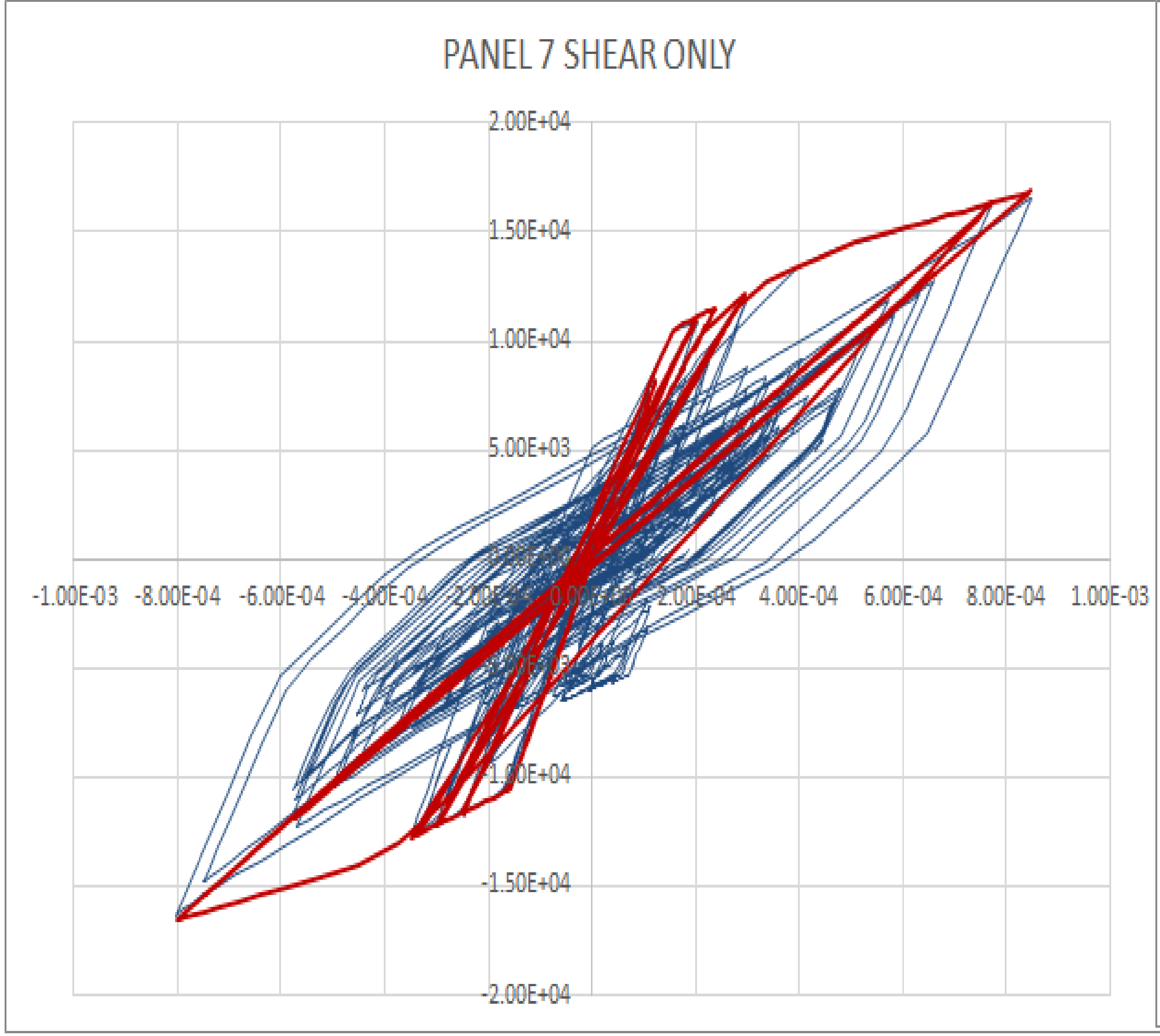


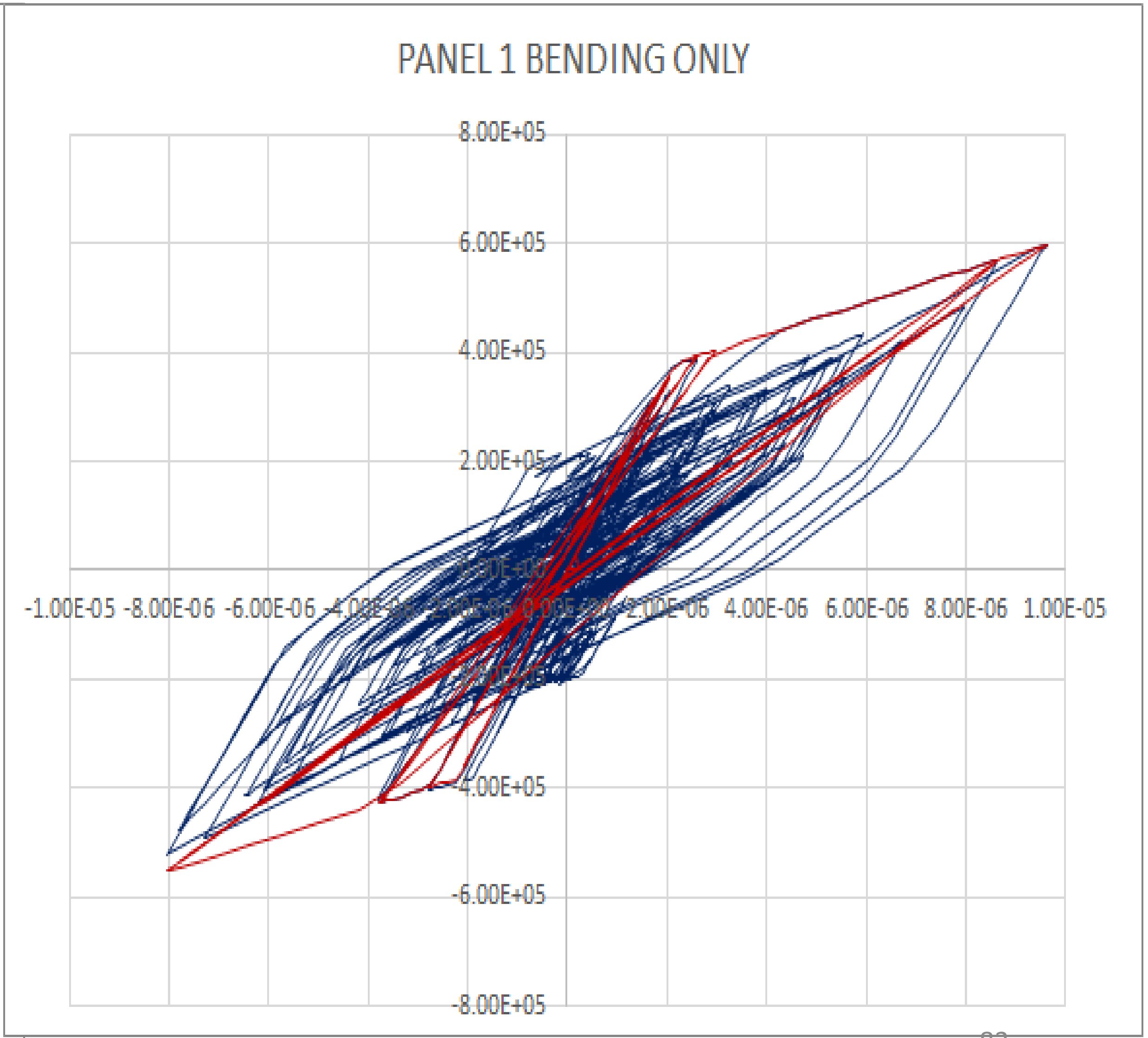
Best fitted model on experiments

Effective Damping = 9%

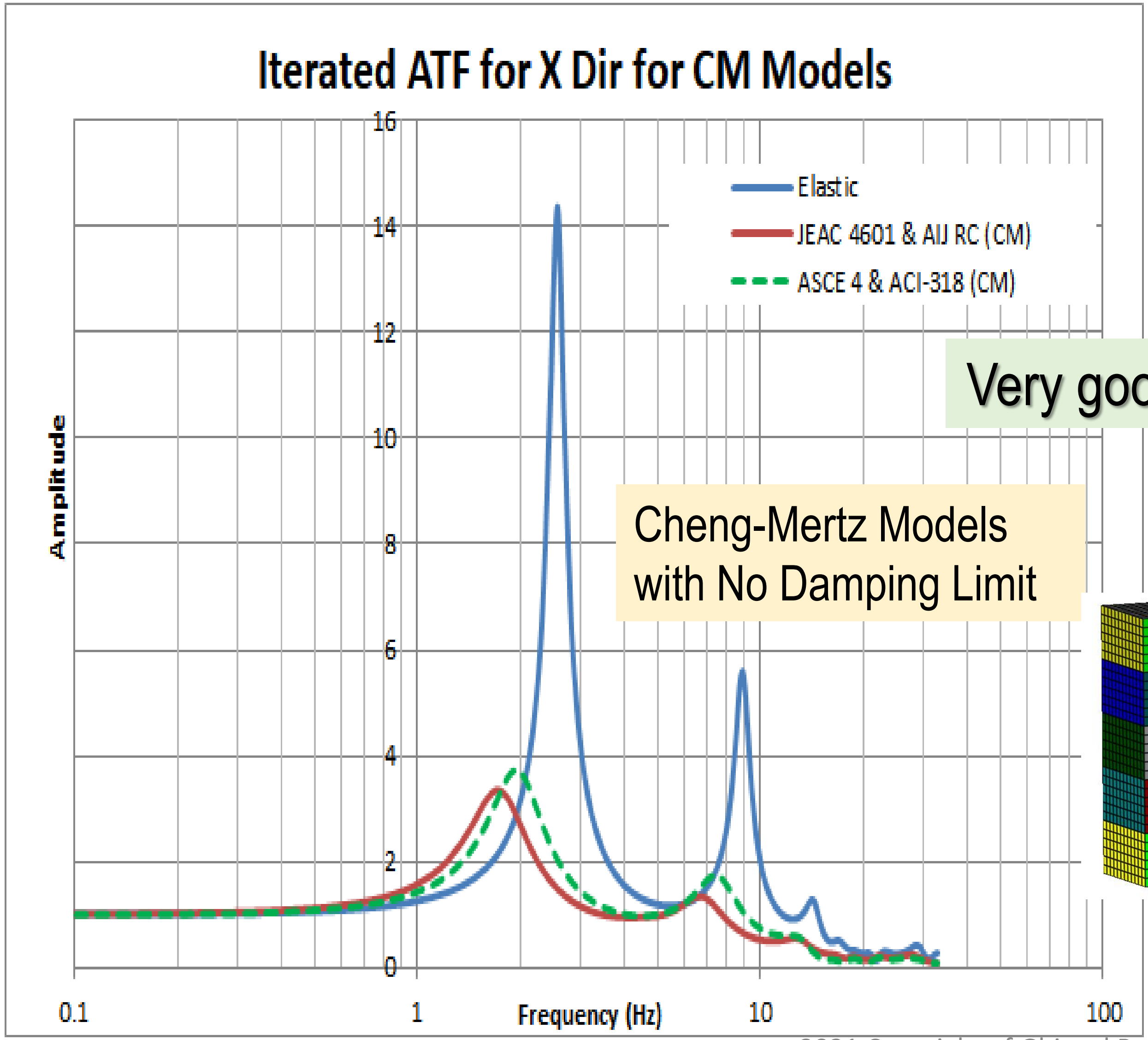
Comparisons of JEAC and Cheng-Mertz Model Hysteretic Loops

Same Input Displacement Histories for CMS and CMB vs. JEAC PO and PODT

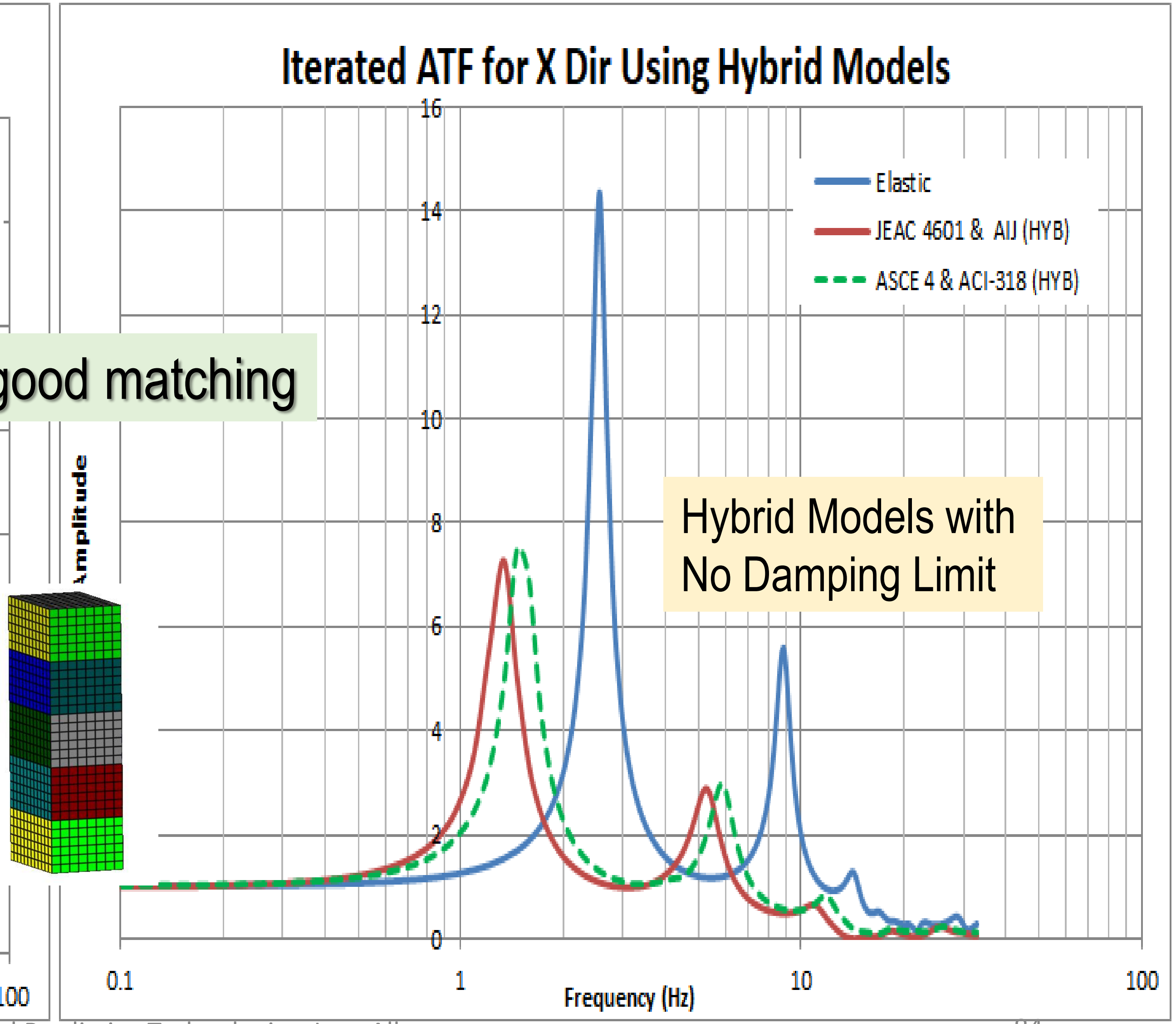




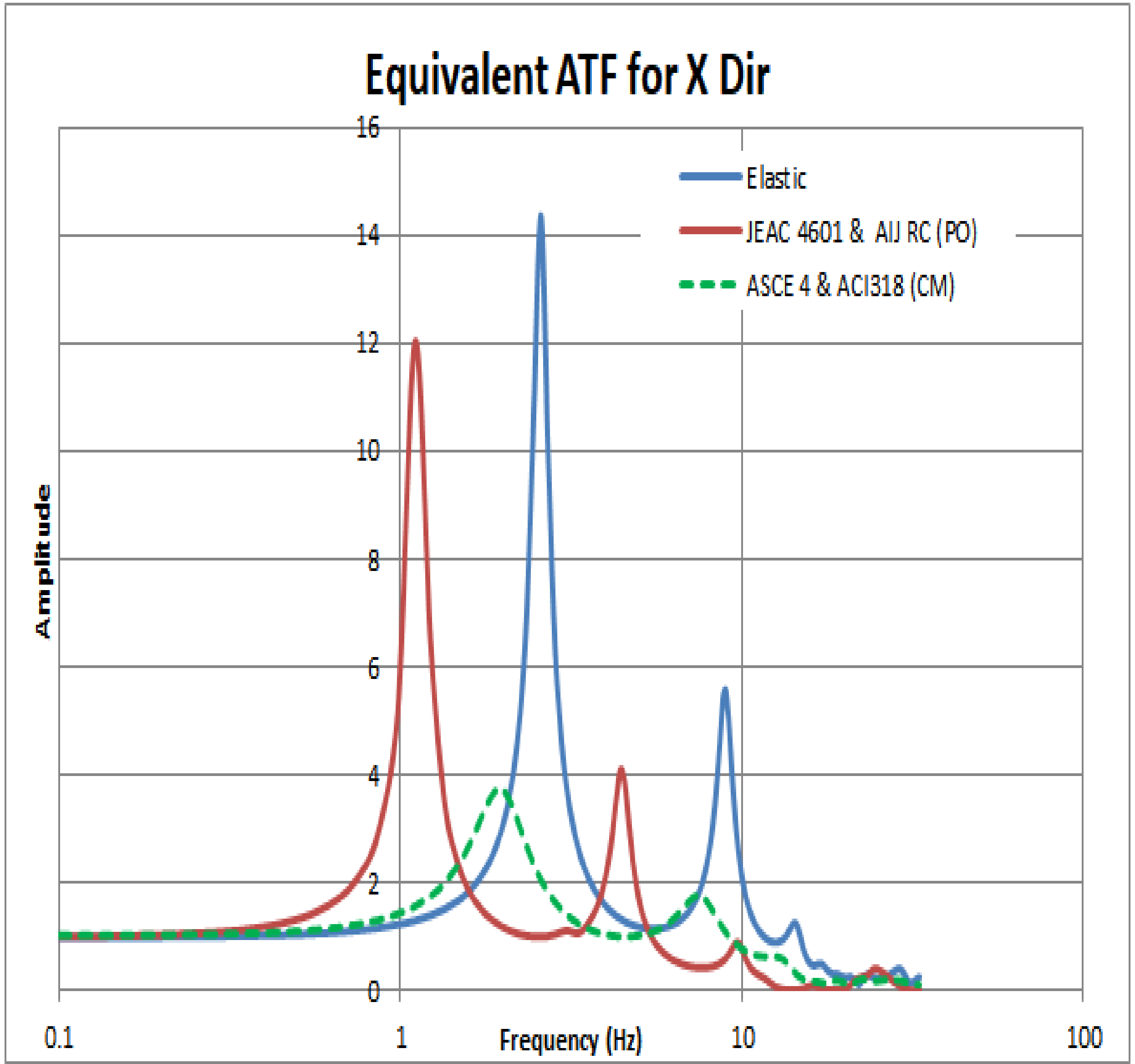
Iterated ATF Response Using Same Hysteretic Models for US and Japan Design Practices

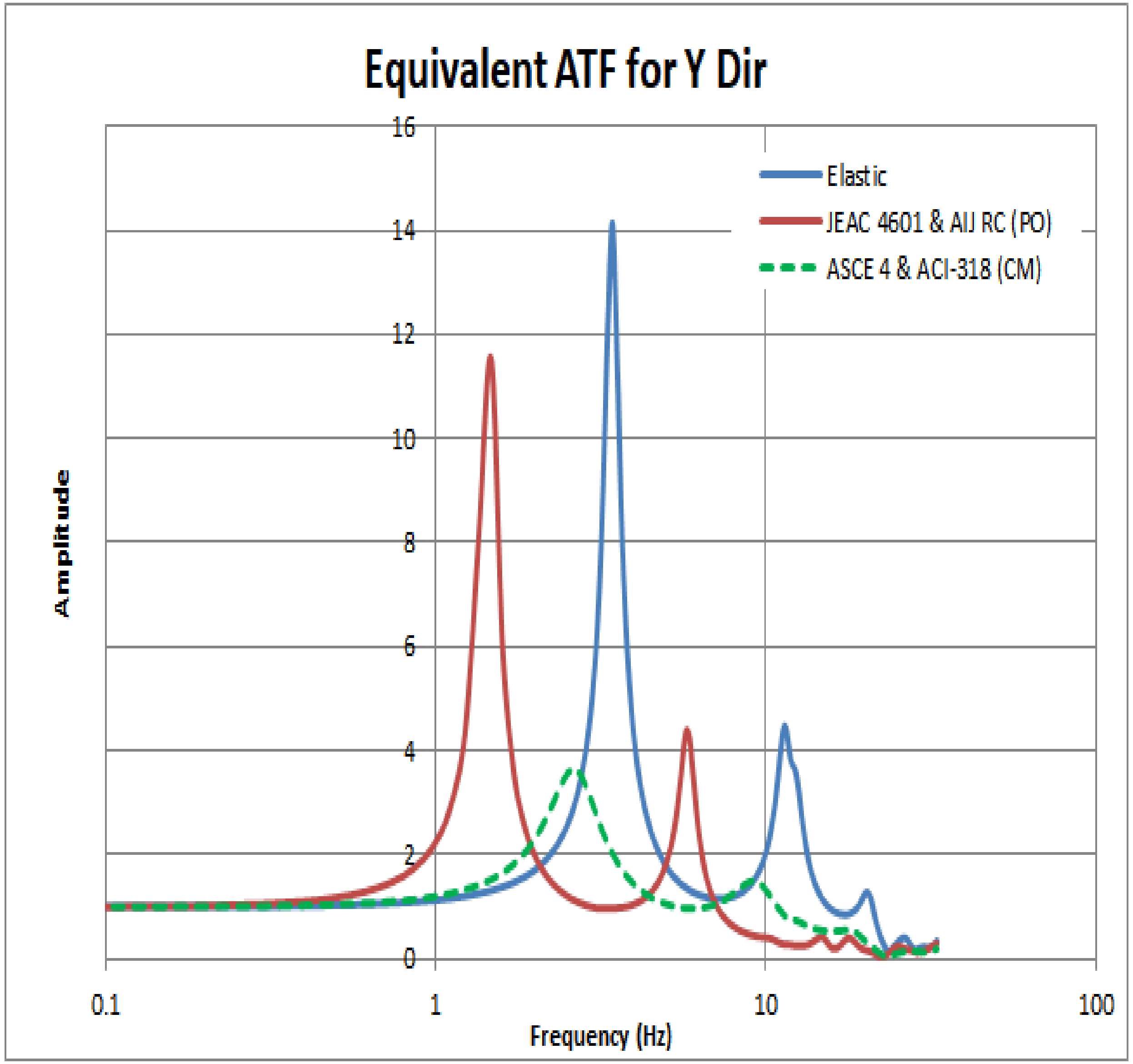


Very good matching

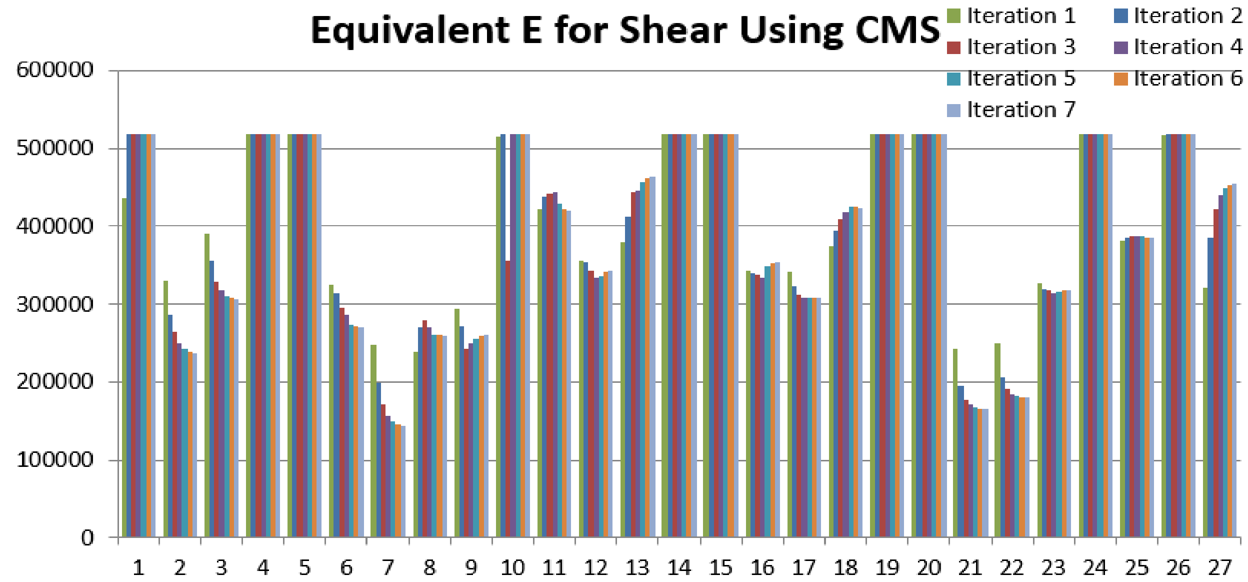


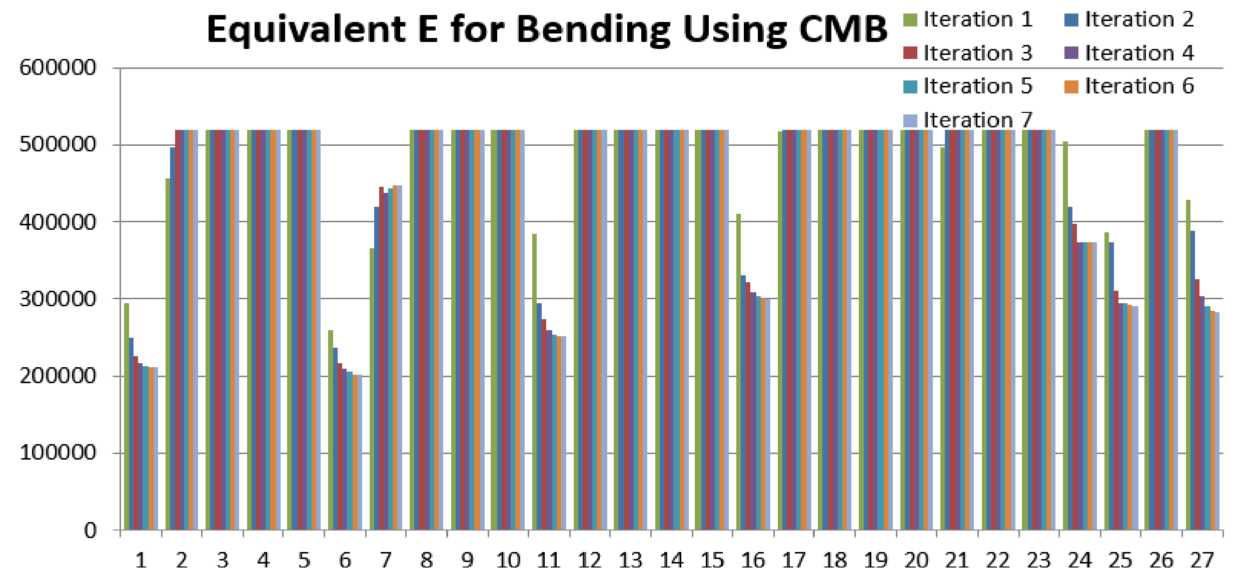
Iterated ATF for JEAC PO Models and CM Models w/ No Damping Limit

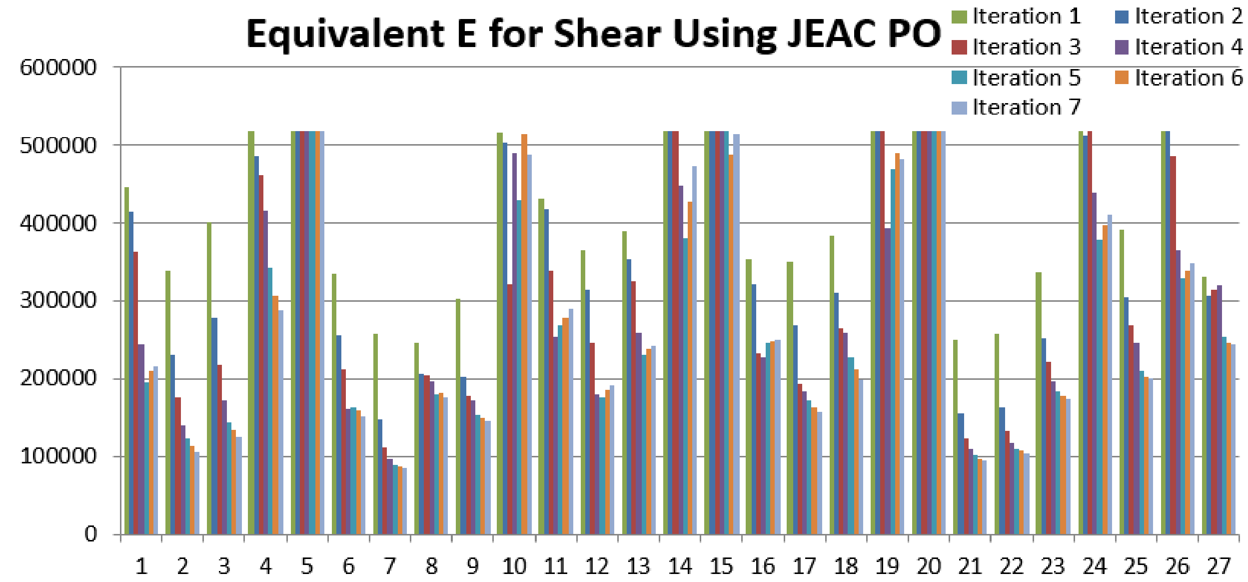


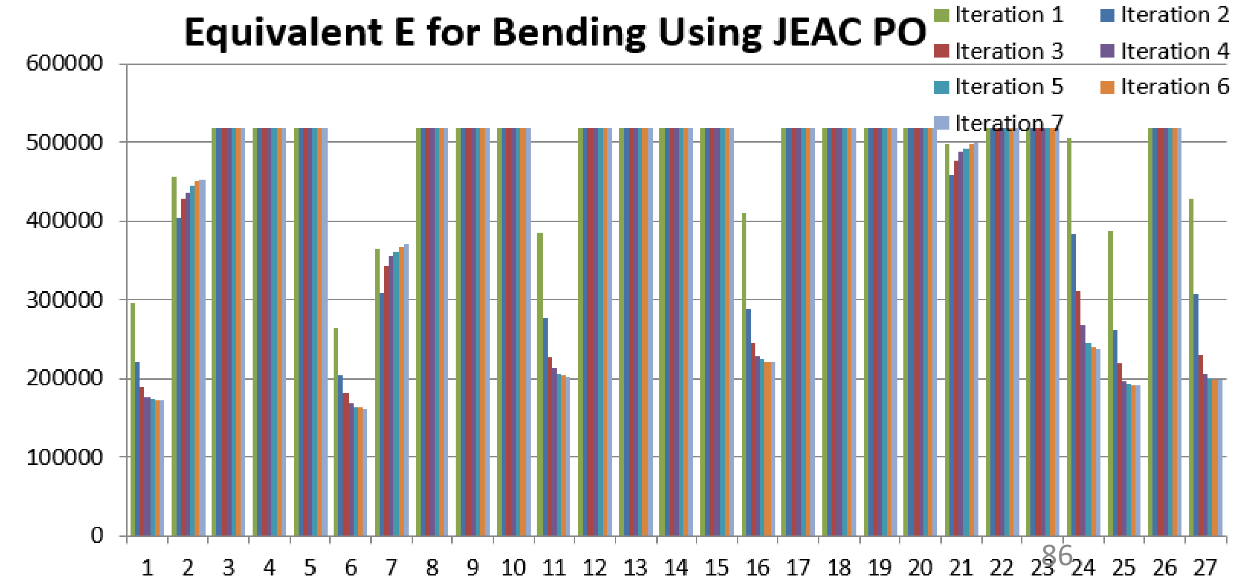


Comparisons of JEAC 4601 and ACI 318/ASCE 4 Model SSI Results from Separate Nonlinear SSI Analyses (CM & PO Models)



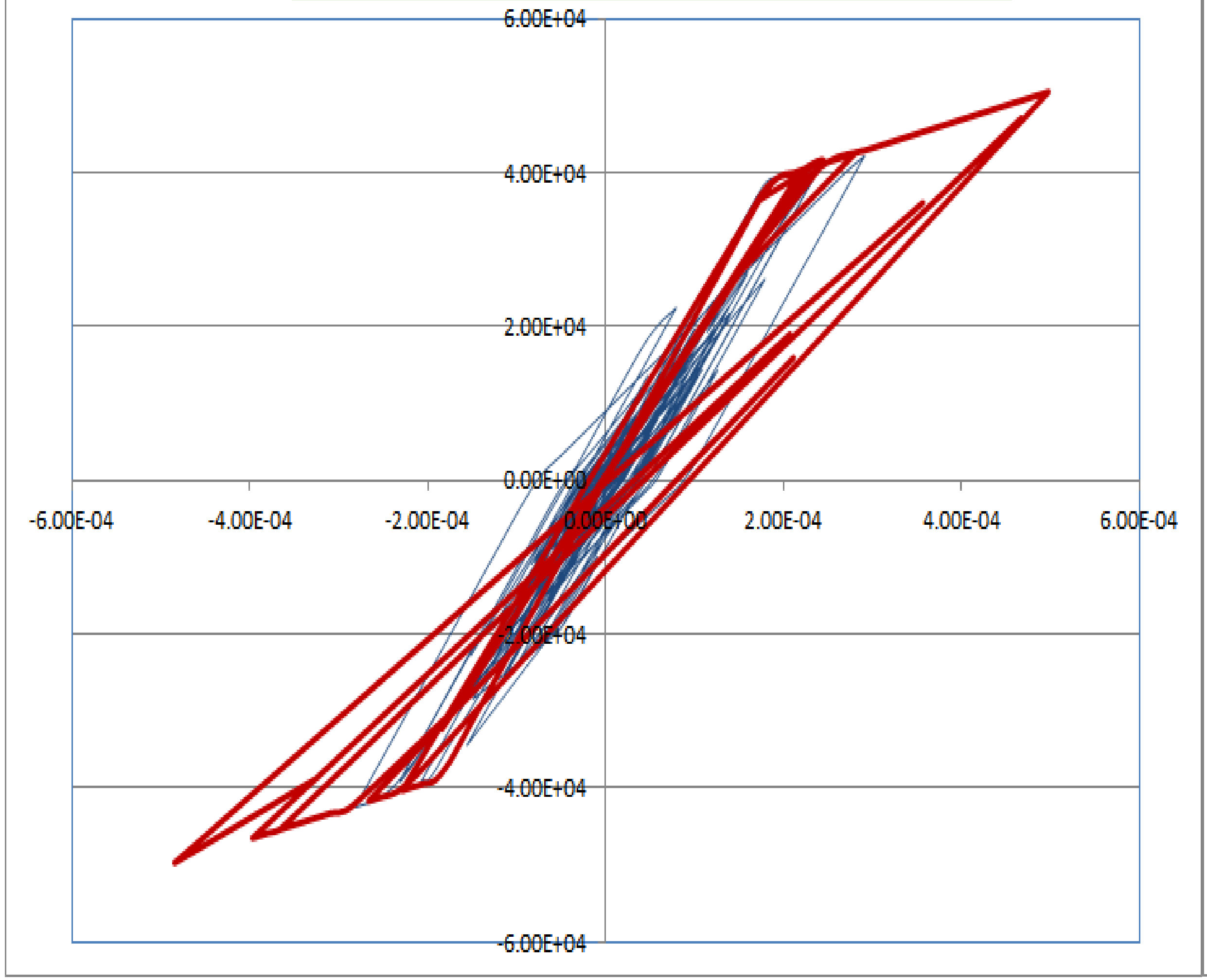




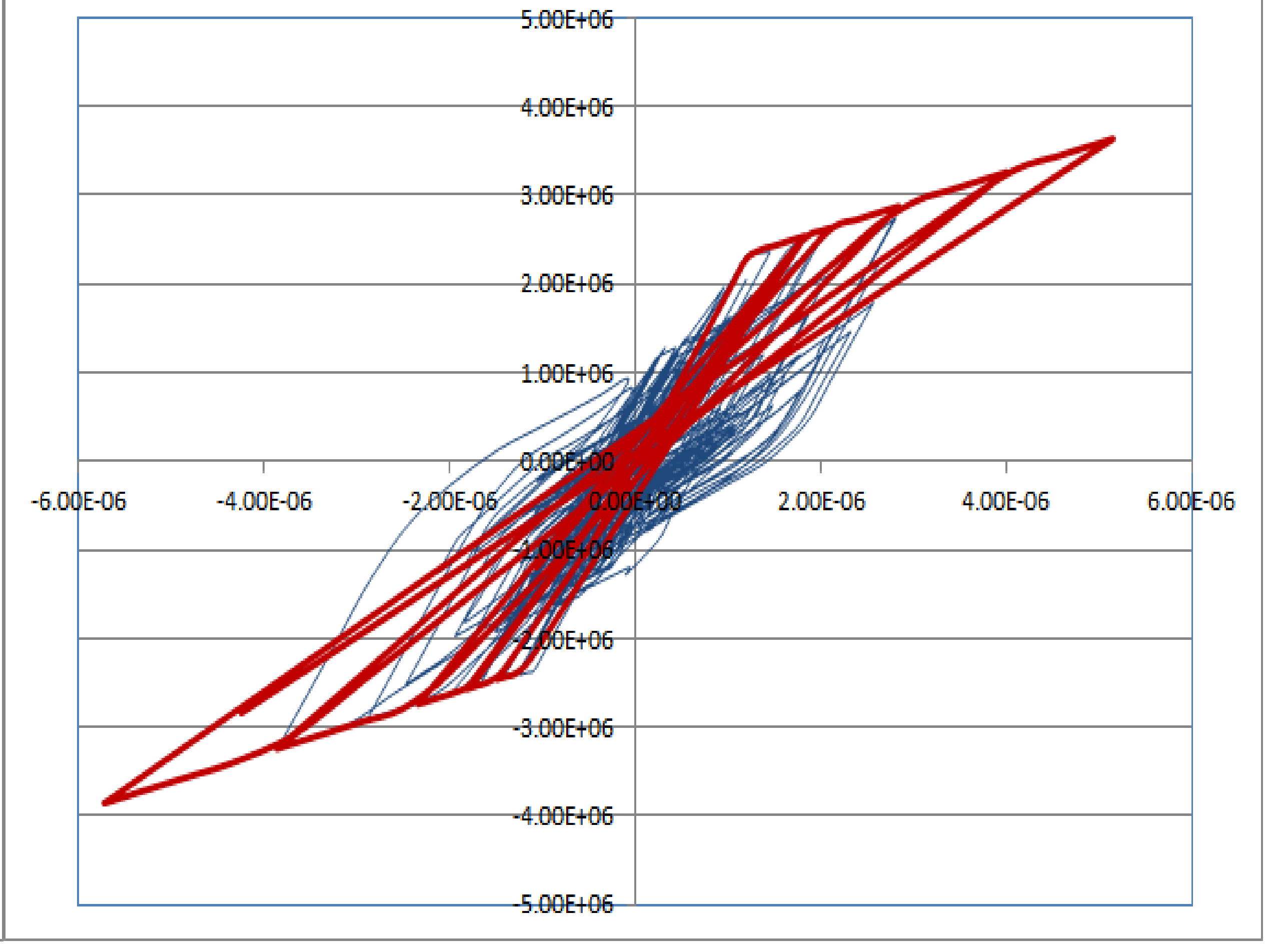


Comparisons of JEAC 4601 and ACI 318/ASCE 4 Hysteretic Loops Based on Separate Nonlinear SSI Analyses (CM & PO Models)

Panel 11 Shear for CMS vs. JEAC PO



Panel 11 Bending for CMB vs. JEAC PODT



3 Direction Nonlinear Responses Combined at Each SSI Iteration

For DBE level, ASCE 4-16 recommends reducing by 50% the shear and bending wall stiffnesses due to the concrete cracking, while the axial wall stiffness remains unchanged. The structure behaves nonlinearly under the horizontal input components and linearly elastic under the vertical seismic component. This is also JEAC 4601 practice.

To simulate the 3 directional seismic input motion, the horizontal and vertical SSI displacements computed at the corner nodes of each wall panel (or spring) shall be combined at each iteration. This is achieved by using the COMB_XYZ_THD module.

REMARK: JEAC 4601-2015 does not require the X and Y nonlinear responses to be combined during the nonlinear SSI analysis. Structural responses computed for the three seismic input directions are combined at the end of the nonlinear SSI analyses.

Modeling of Interaction Between Shear and Bending Effects

These interaction effects are included at each SSI iteration by the following Option NON options:

1) ***Shear Governing:*** *A*ssuming that the shear stiffness variations are governing the wall stiffness degradation at each SSI iteration *(RC wall material stiffness degradation based on the Shear hysteretic models only, i.e. material Esb=Es, fully coupled)*

2) ***Bending Governing:*** *A*ssuming that the bending stiffness variations are governing the wall stiffness at each SSI iteration *(RC wall material stiffness degradation based on the Bending hysteretic models only, i.e. material Esb=Eb, fully coupled)*

3) ***Shear and Bending:*** The equivalent bending and shear stiffnesses are computed independently at each SSI iteration *(RC wall material stiffness degradation based on both Shear and Bending hysteretic models, i.e. material Esb is different from Es and Eb). An elliptical interaction curve for combining the shear and bending stiffnesses is applied at each SSI iteration.*

Effects of M/Q Ratio on Shear and Bending Squat Wall Capacities

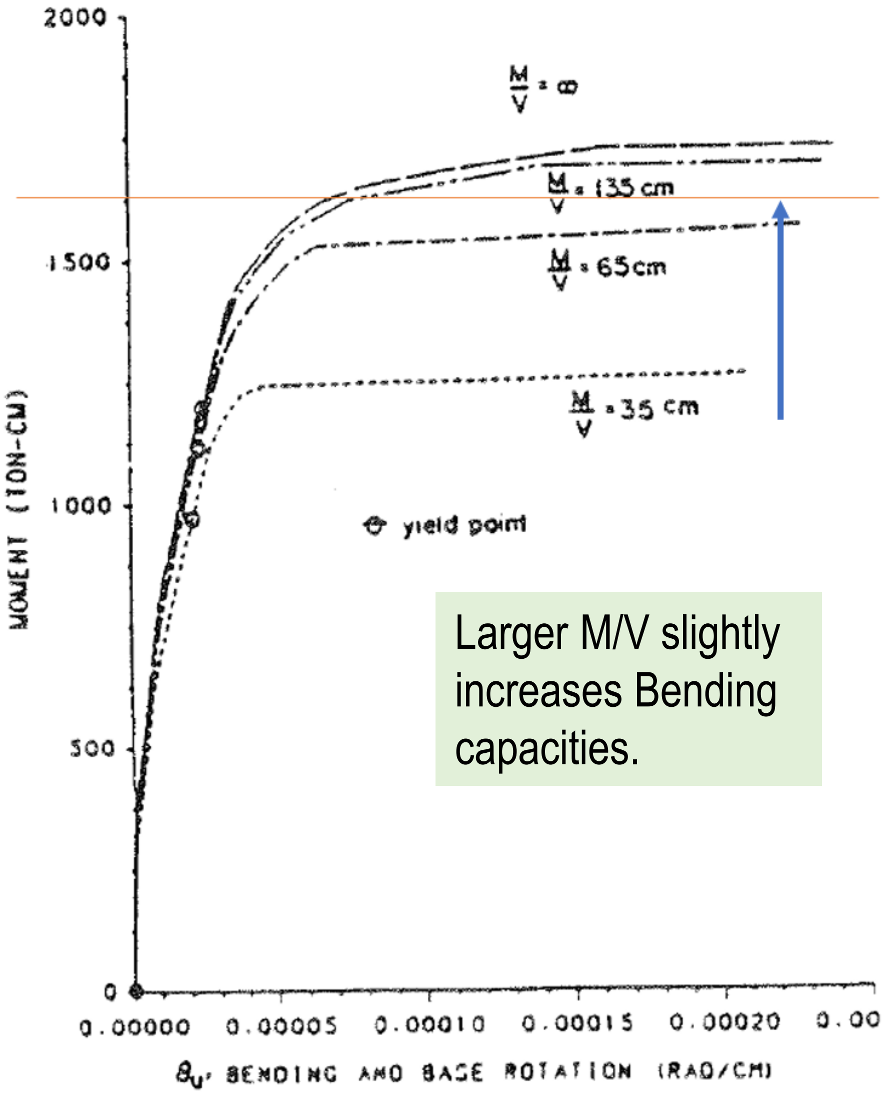


Figure 4a. Moment-curvature relationship at various

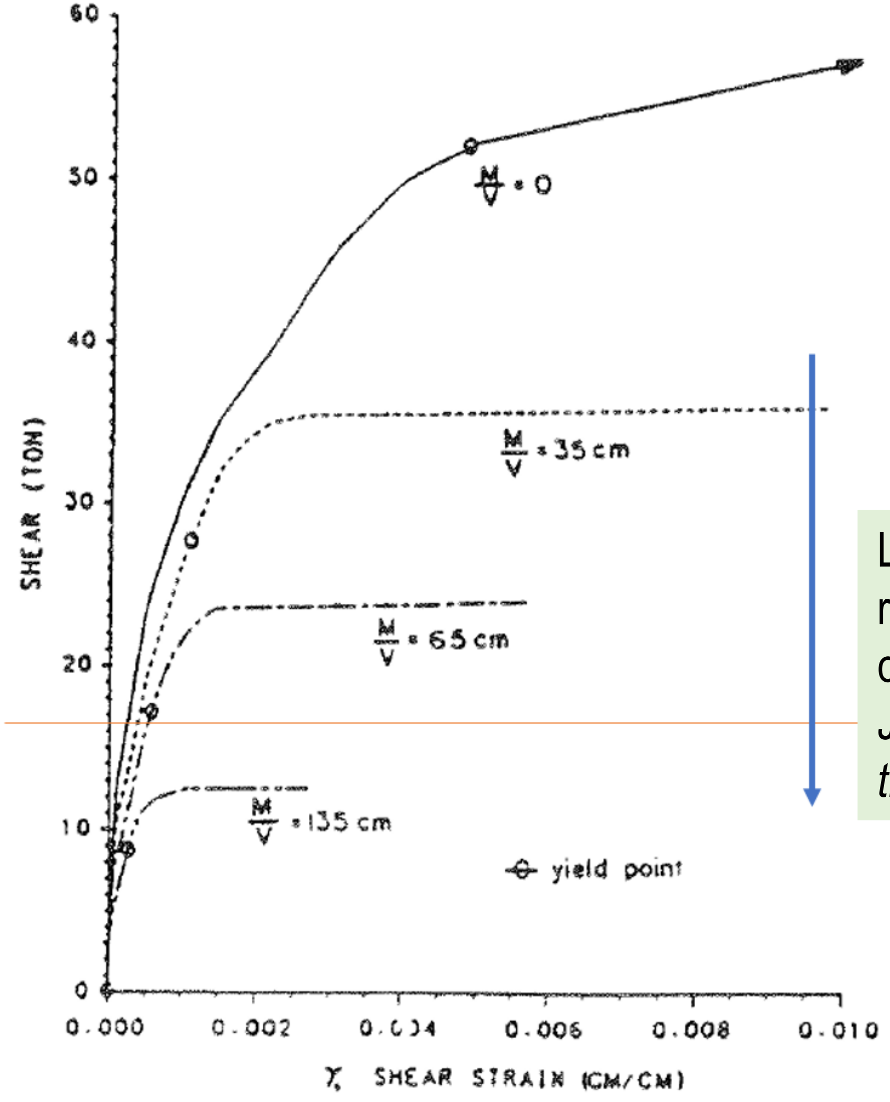
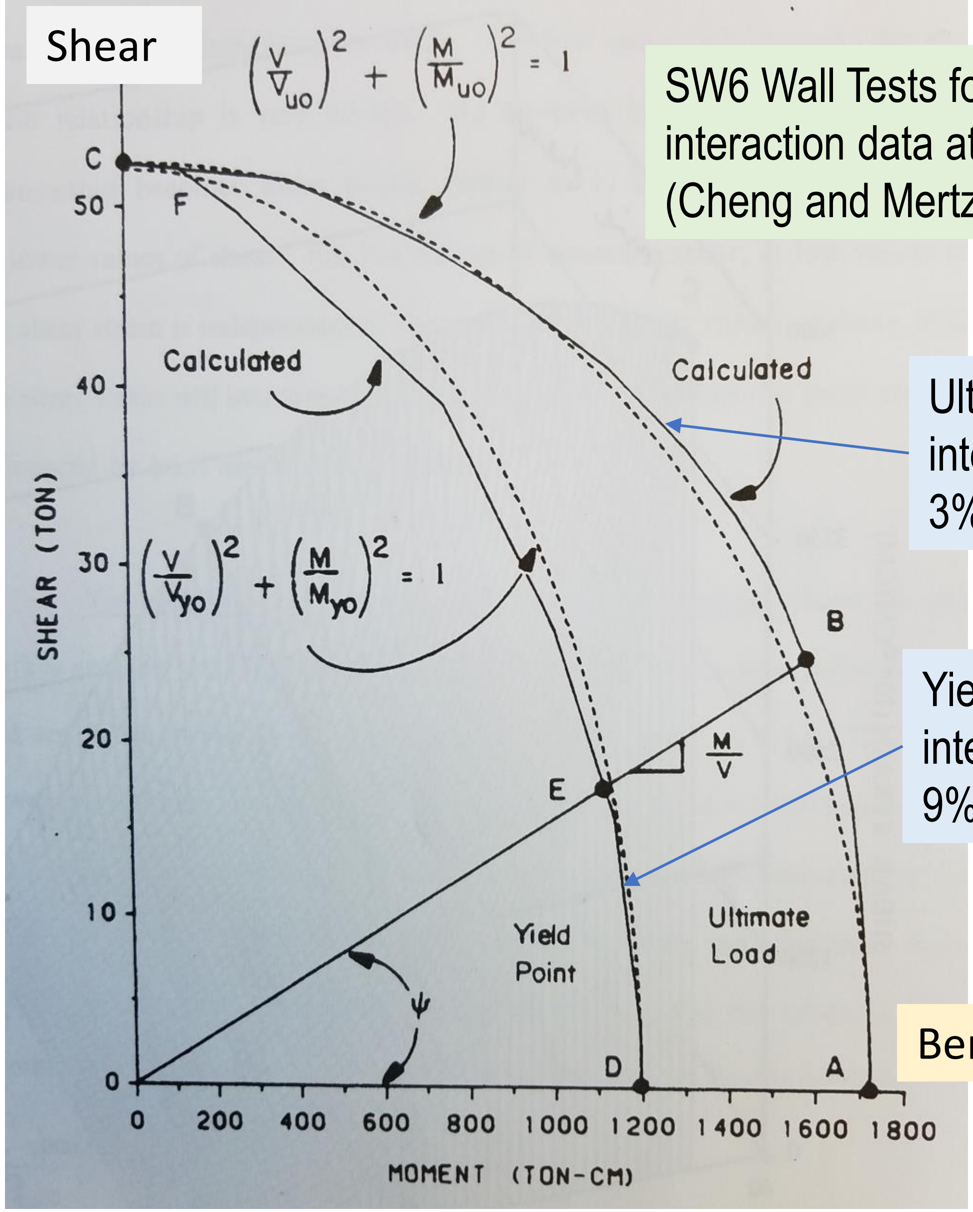


Figure 4b. Shear-shear strain relationship at various

Larger M/V largely reduces Shear capacities.
JEAC App. 3.7 includes this interaction.

Cheng, 1993

Nonlinear Shear-Bending Interaction Effects (Comb_Shear_Bend)

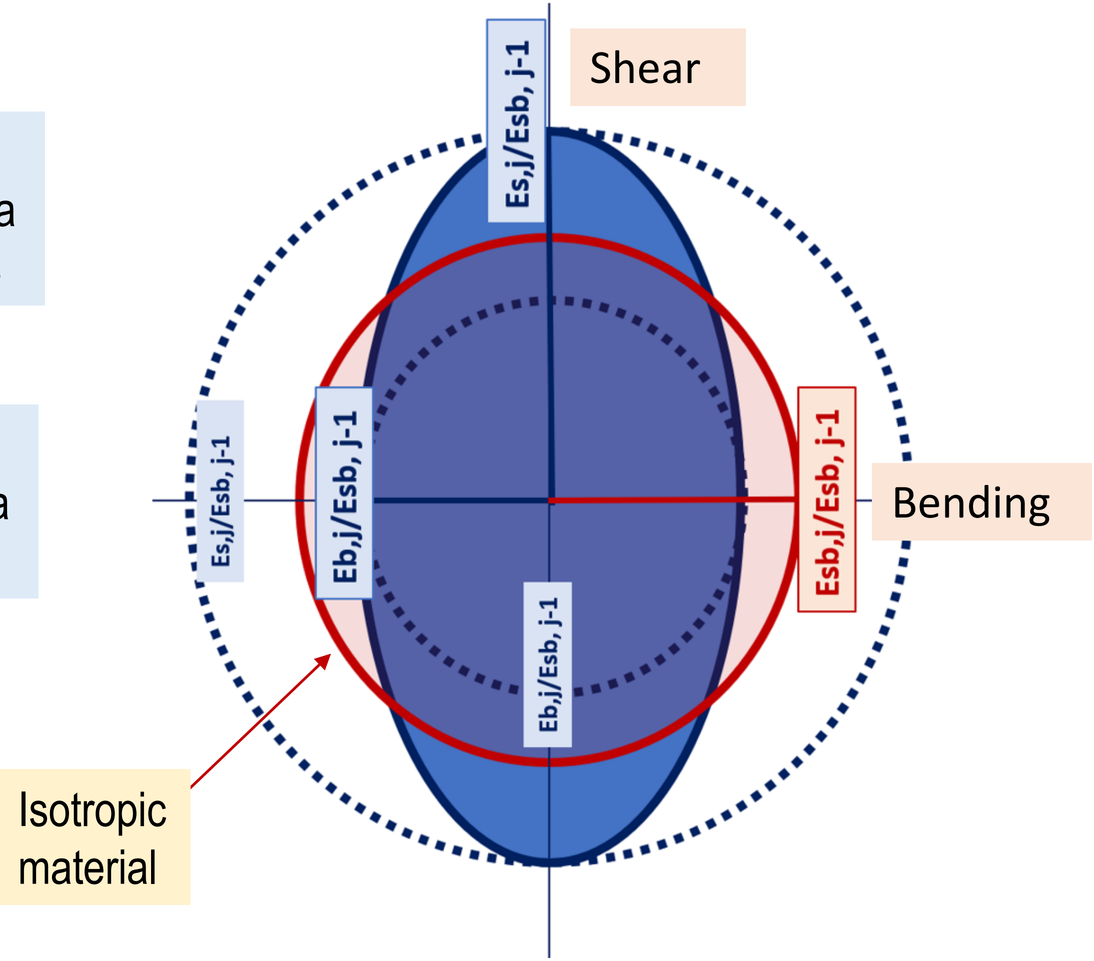


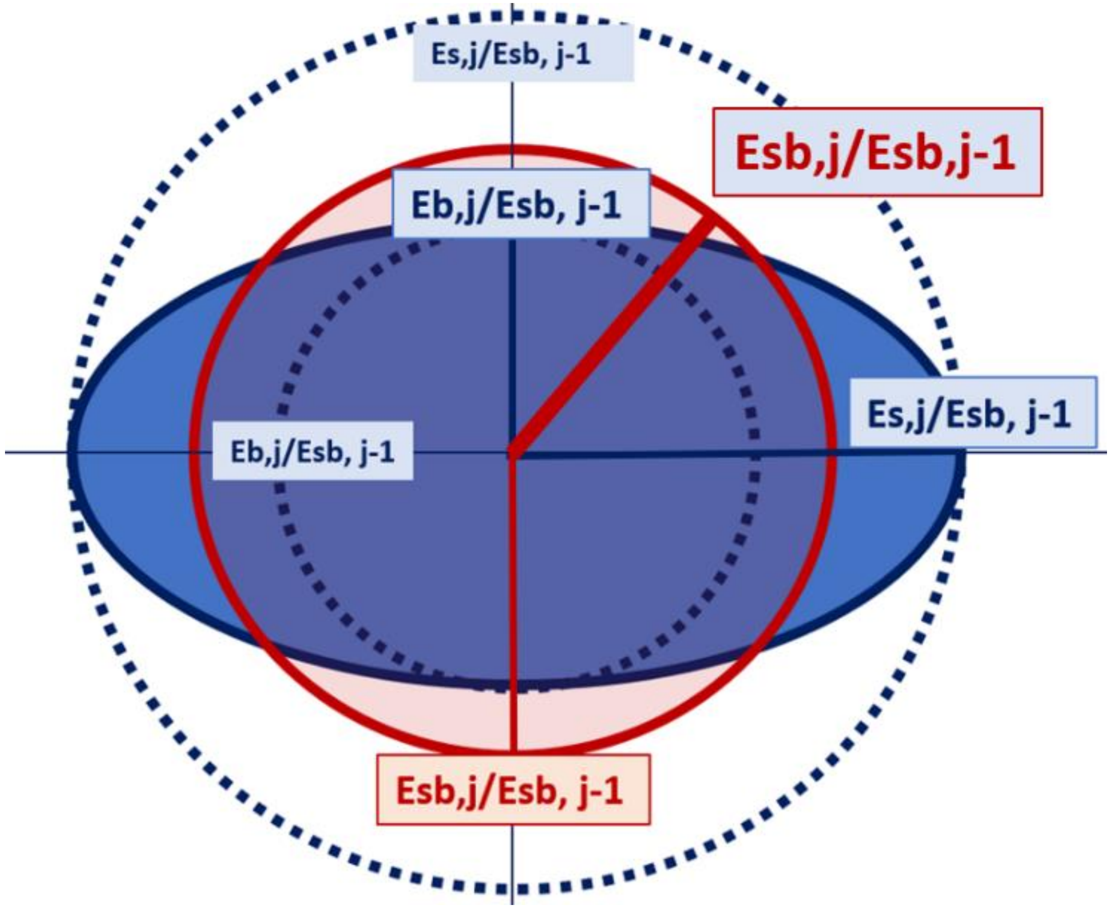
SW6 Wall Tests for the shear-bending interaction data at NCKU laboratories (Cheng and Mertz, 1989)

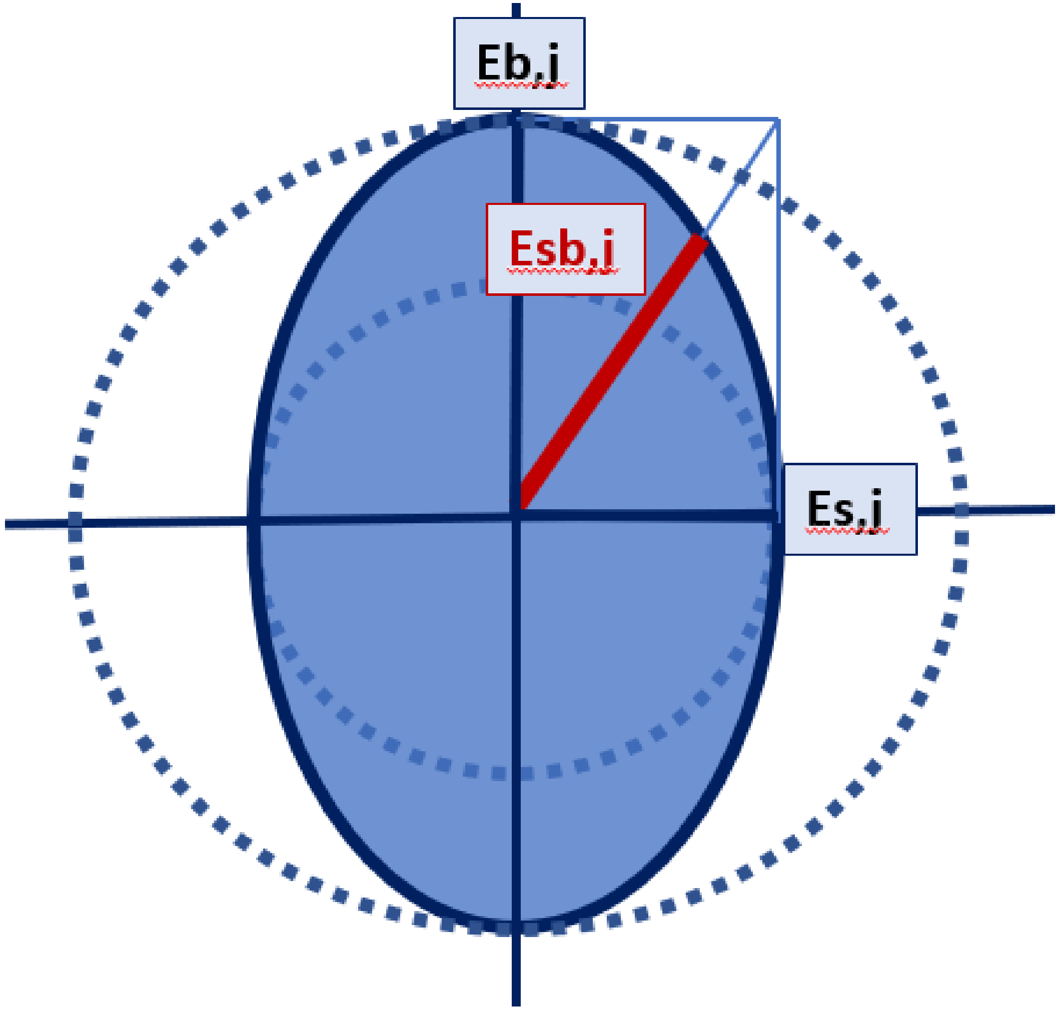
Ultimate state shear-bending interaction equation has only a 3% error comparing with tests

Yielding state shear-bending interaction equation has only a 9% error comparing with tests

In Option NON, shear-bending interaction effects are included *at each SSI iteration* based on an ellipsoidal interaction curve.



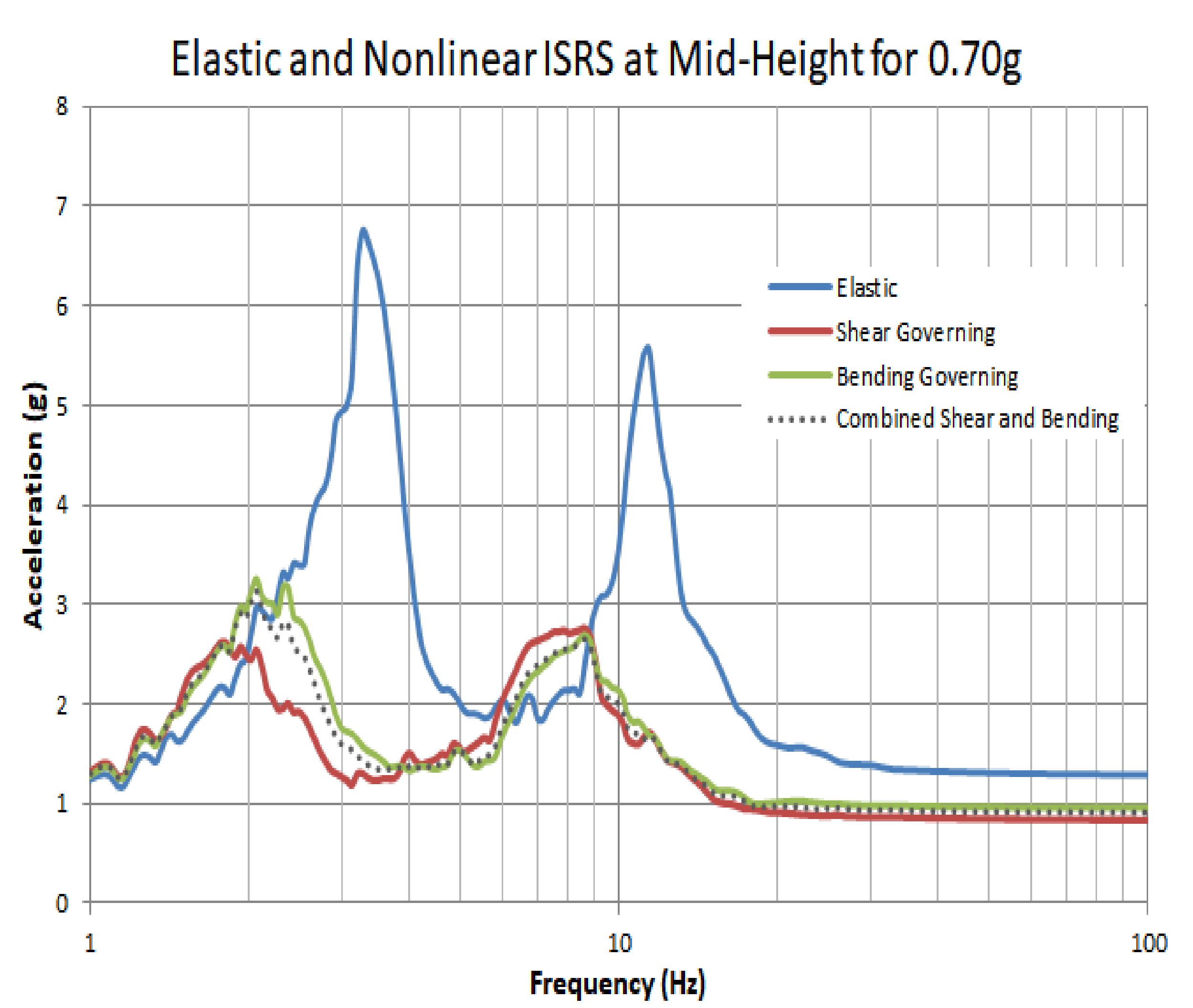


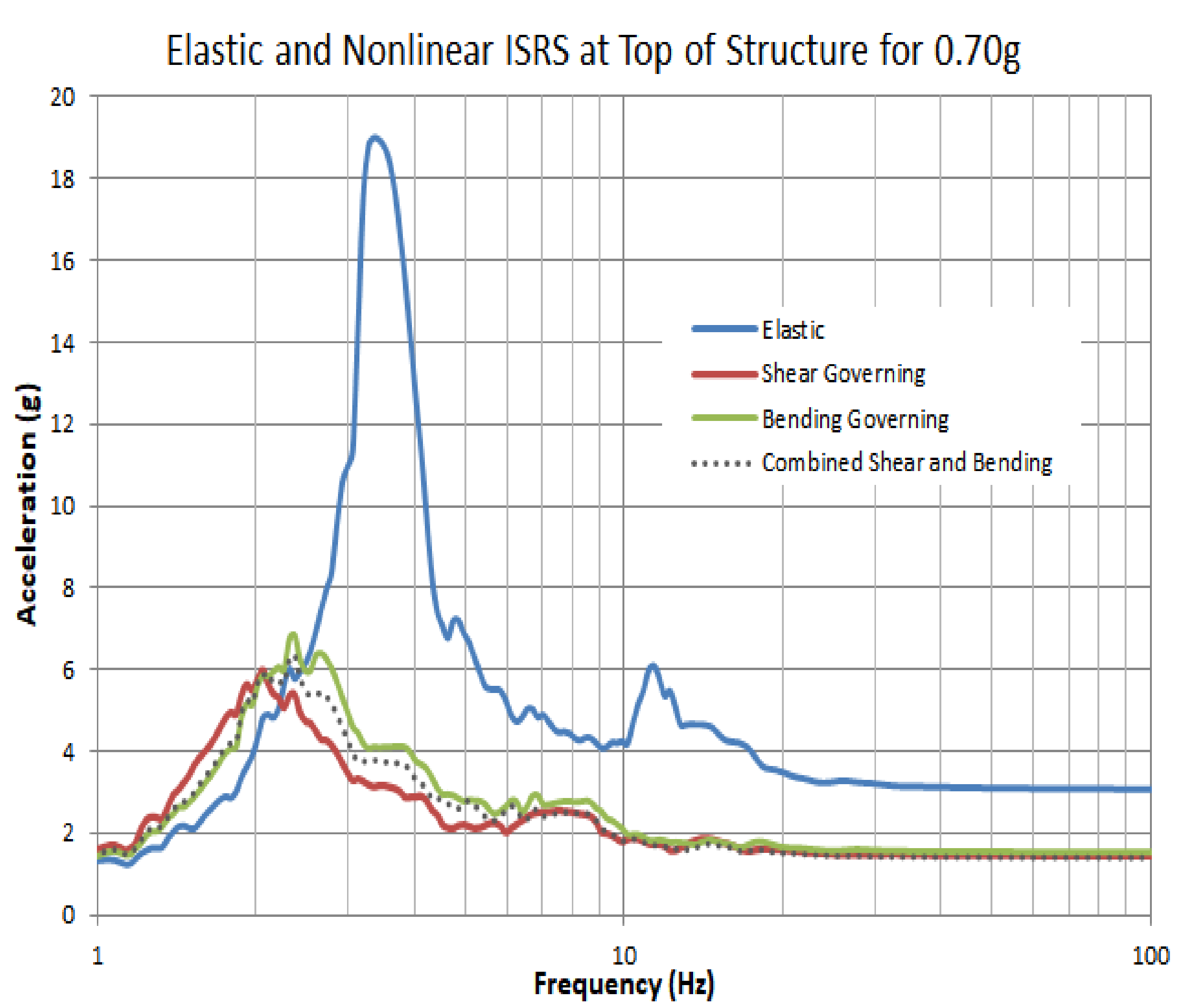


$$E\_comb_i = \frac{E\_shear_i * E\_bending_i}{E\_comb_{i-1}}$$

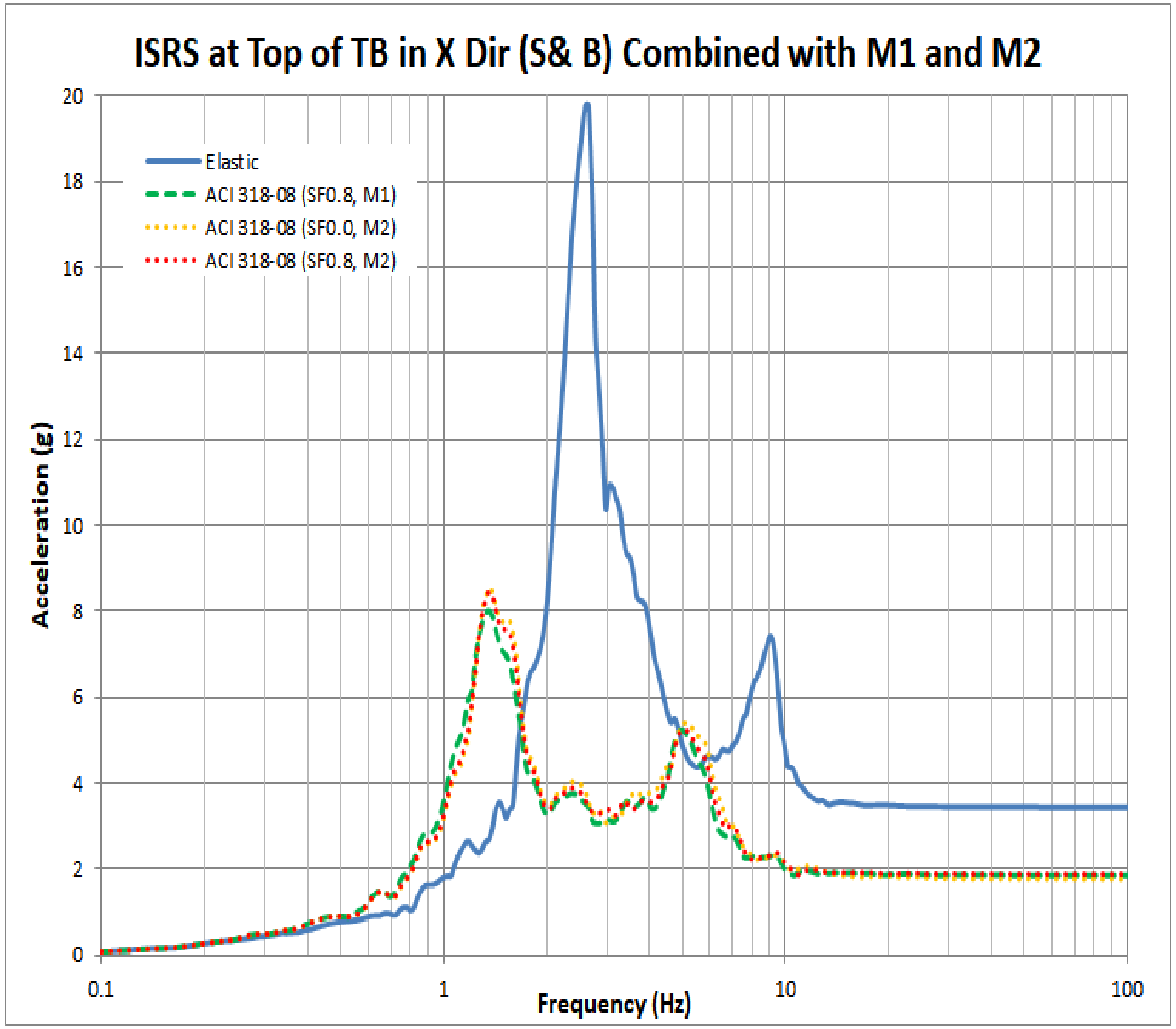
$$E\_comb_i = \frac{E\_shear_i * E\_bending_i}{\sqrt{0.5(E\_shear_i^2 + E\_bending_i^2)}}$$

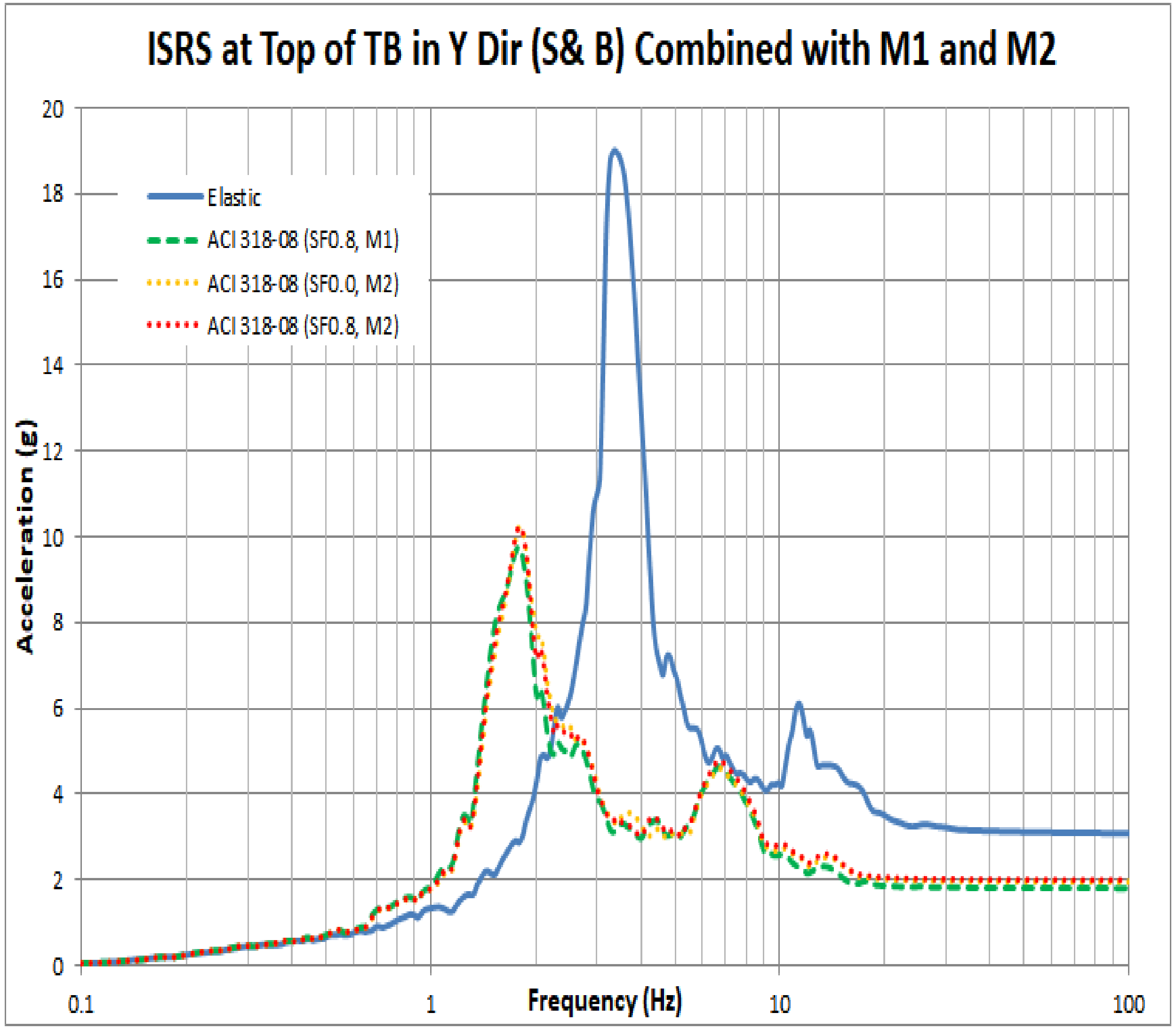
Computed ISRS for 0.70g: 1) Shear Governing, 2) Bending Governing and 3) Combined Shear and Bending with M1





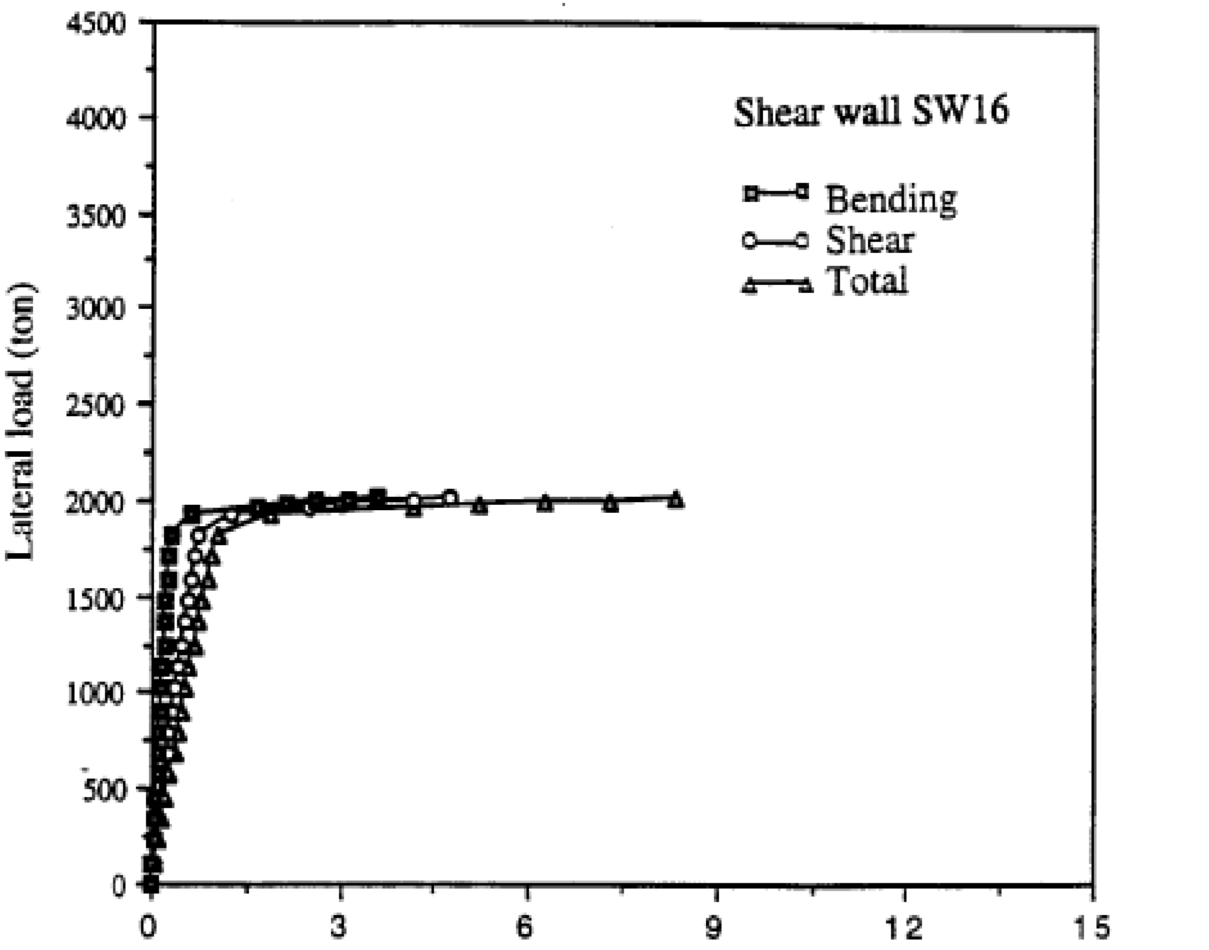
Combining Shear and Bending Interaction Effects Stiffness. Comparing ISRS Results for M1 and M2 Methods



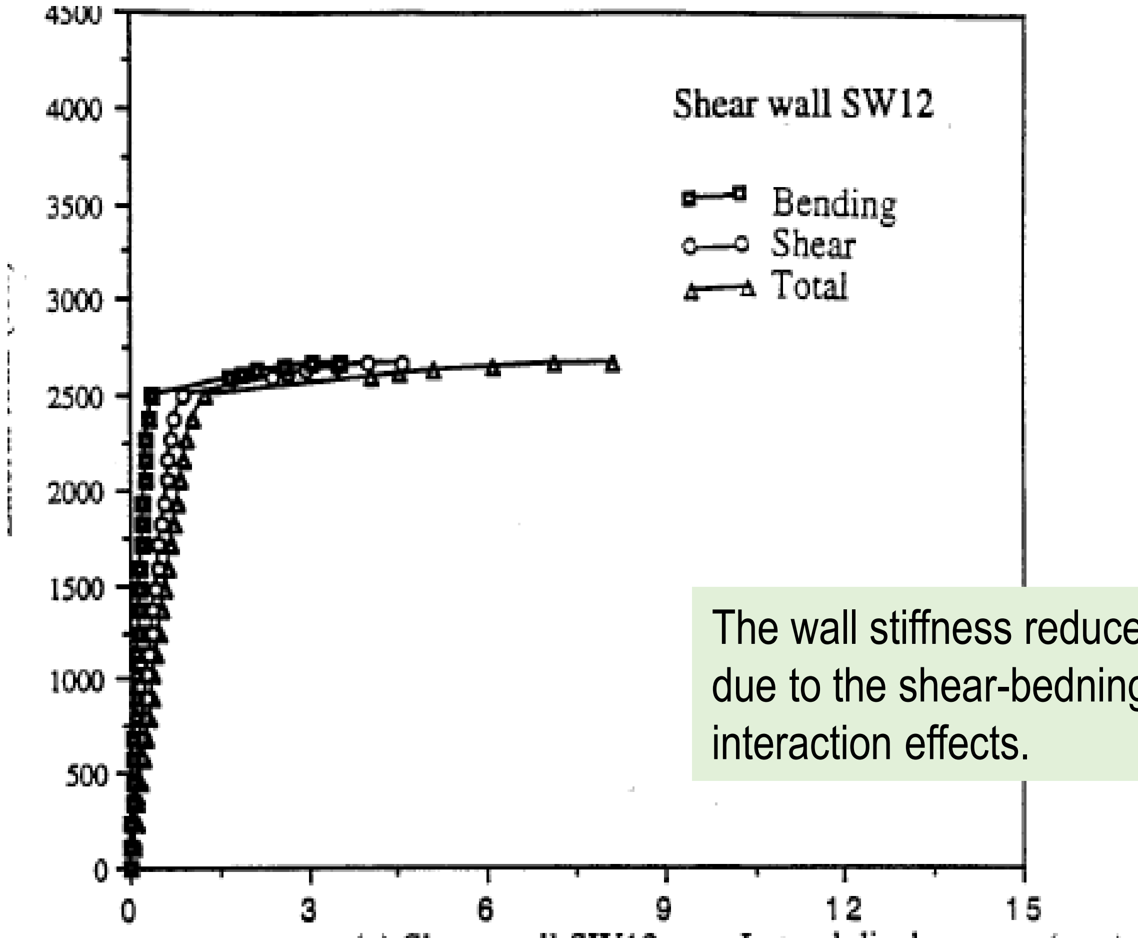


Experimental Tests for Shear and Bending Interaction Effects

Based on RC Squat Wall Tests Performed in 1990s at Los Alamos Lab



(b) Shear wall SW16



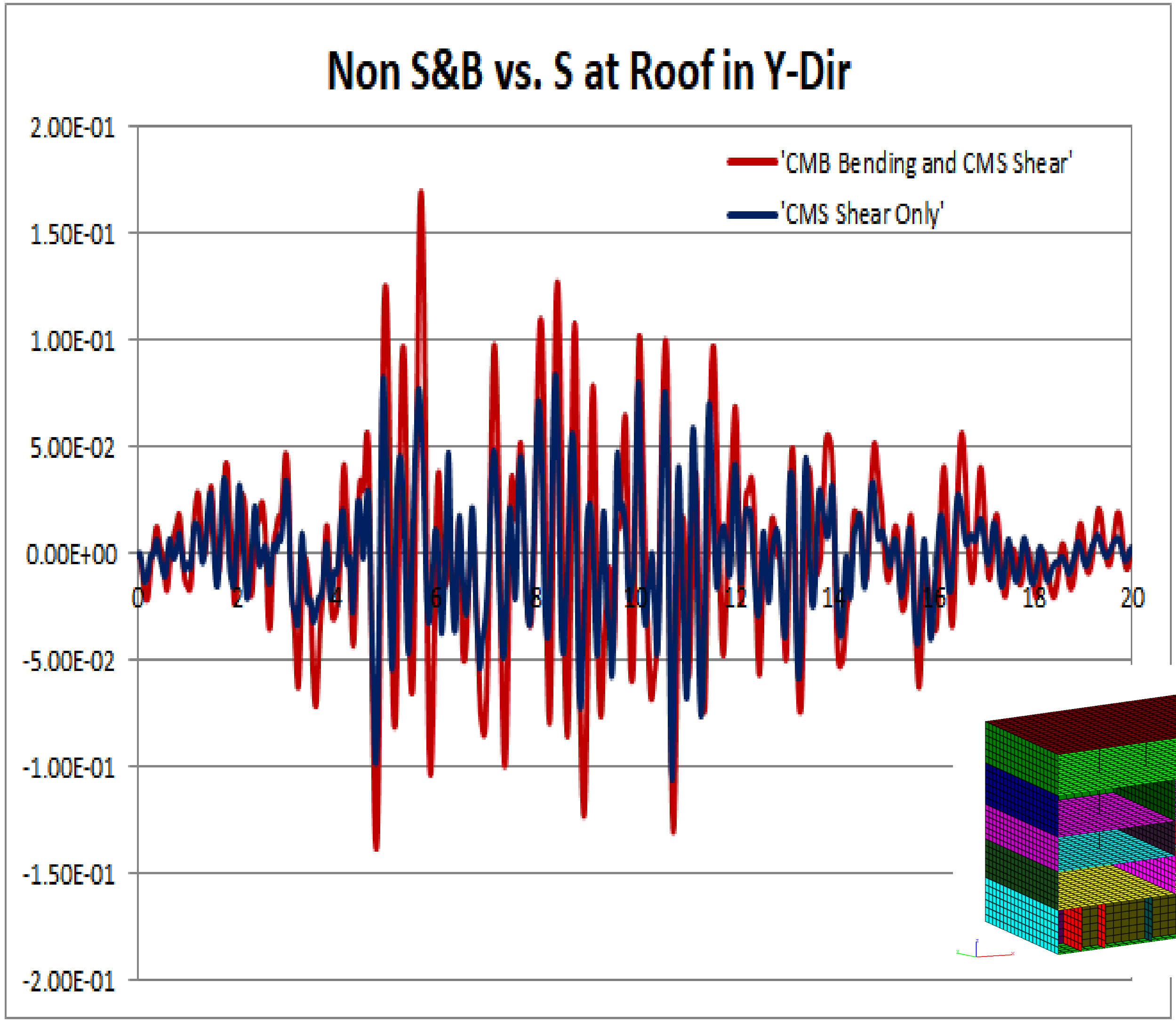
(a) Shear wall SW12

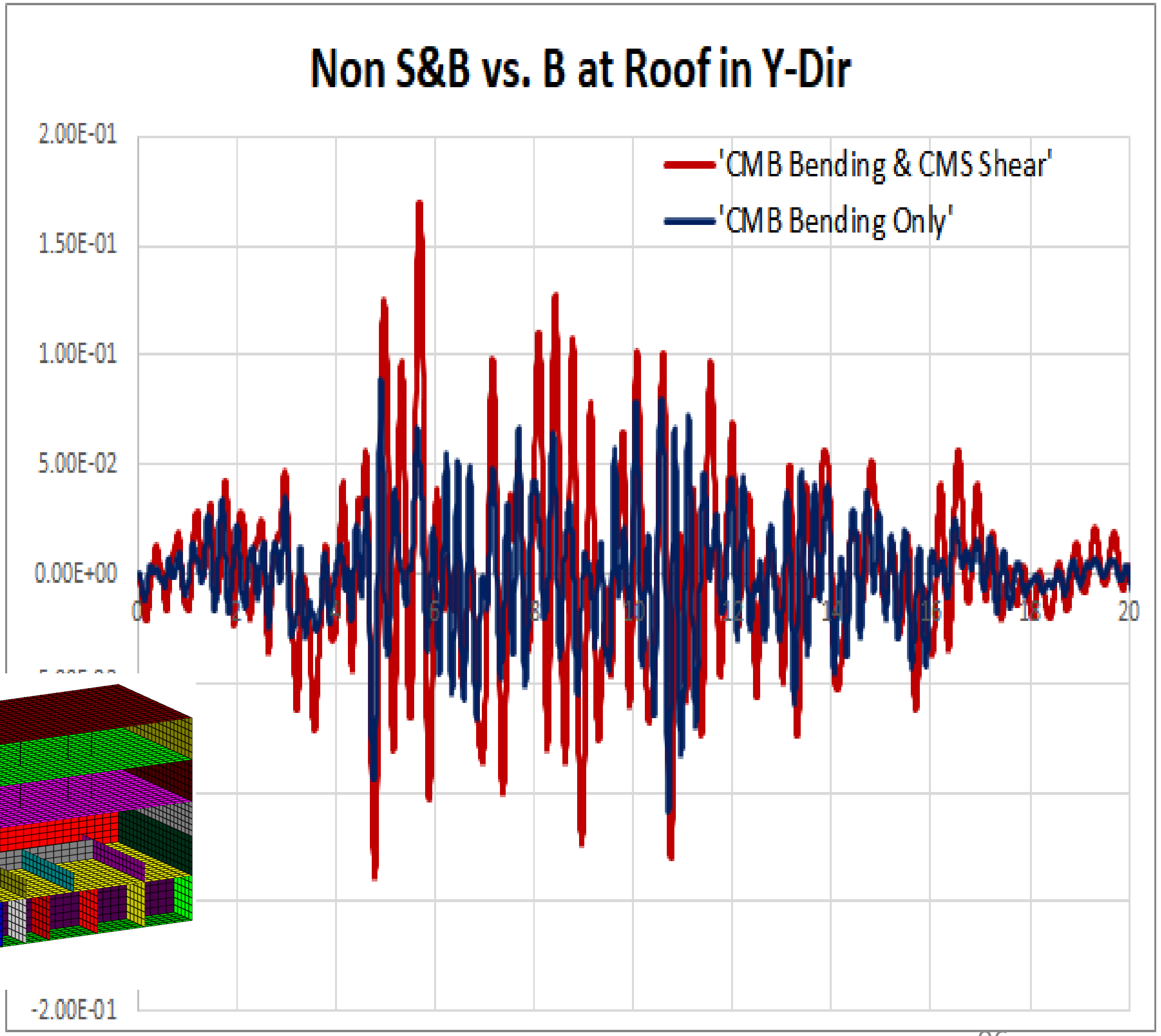
The wall stiffness reduces due to the shear-bedning interaction effects.

Figure 89 Comparison of bending, shear and total lateral displacements for backbone curve of shear walls

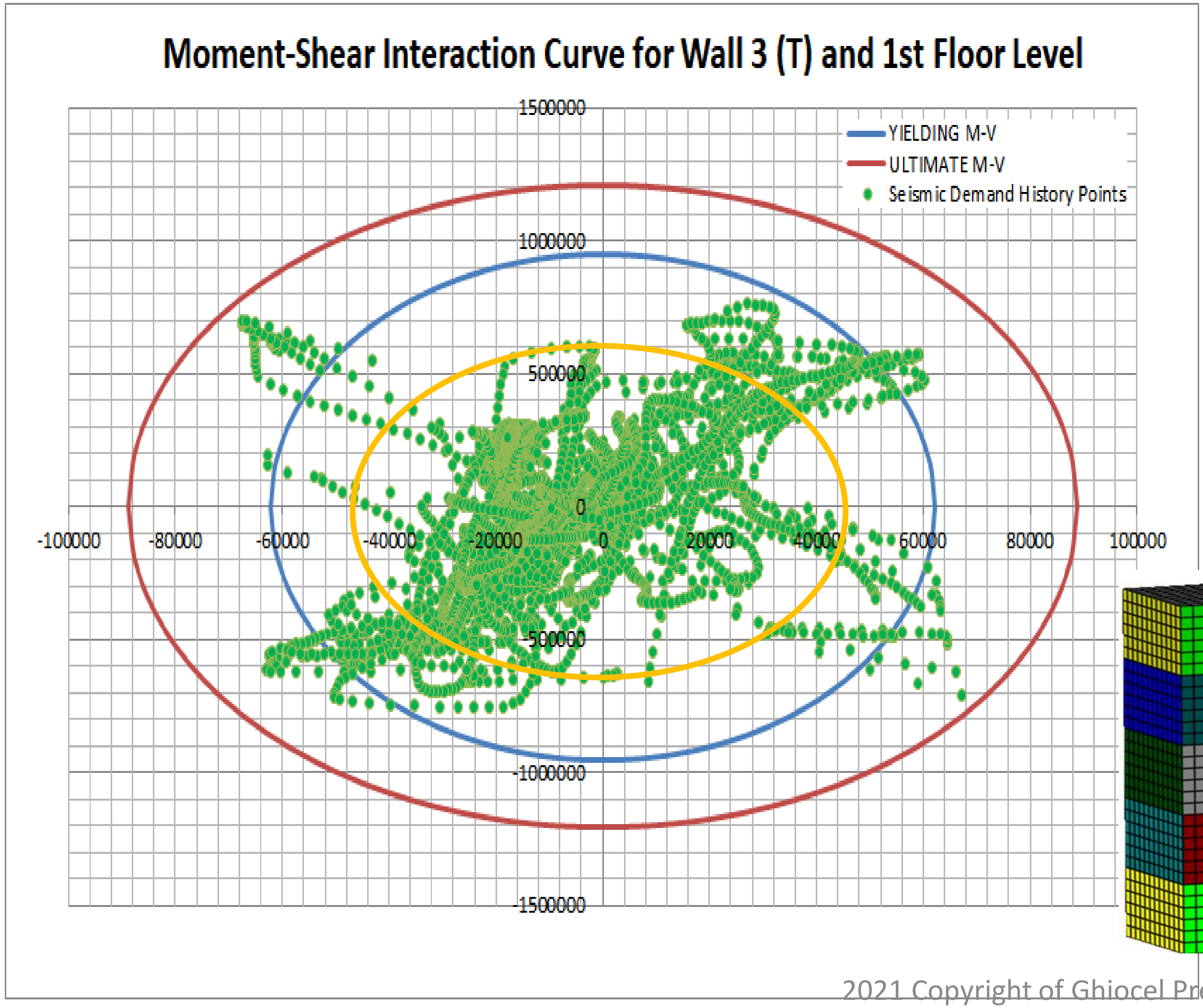
Cheng and Yang, 1996

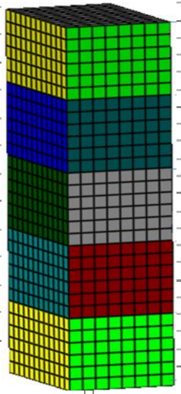
Nonlinear Structure Roof Displacements for 1) Shear Governing, 2) Bending Governing and 3) Combined Shear and Bending

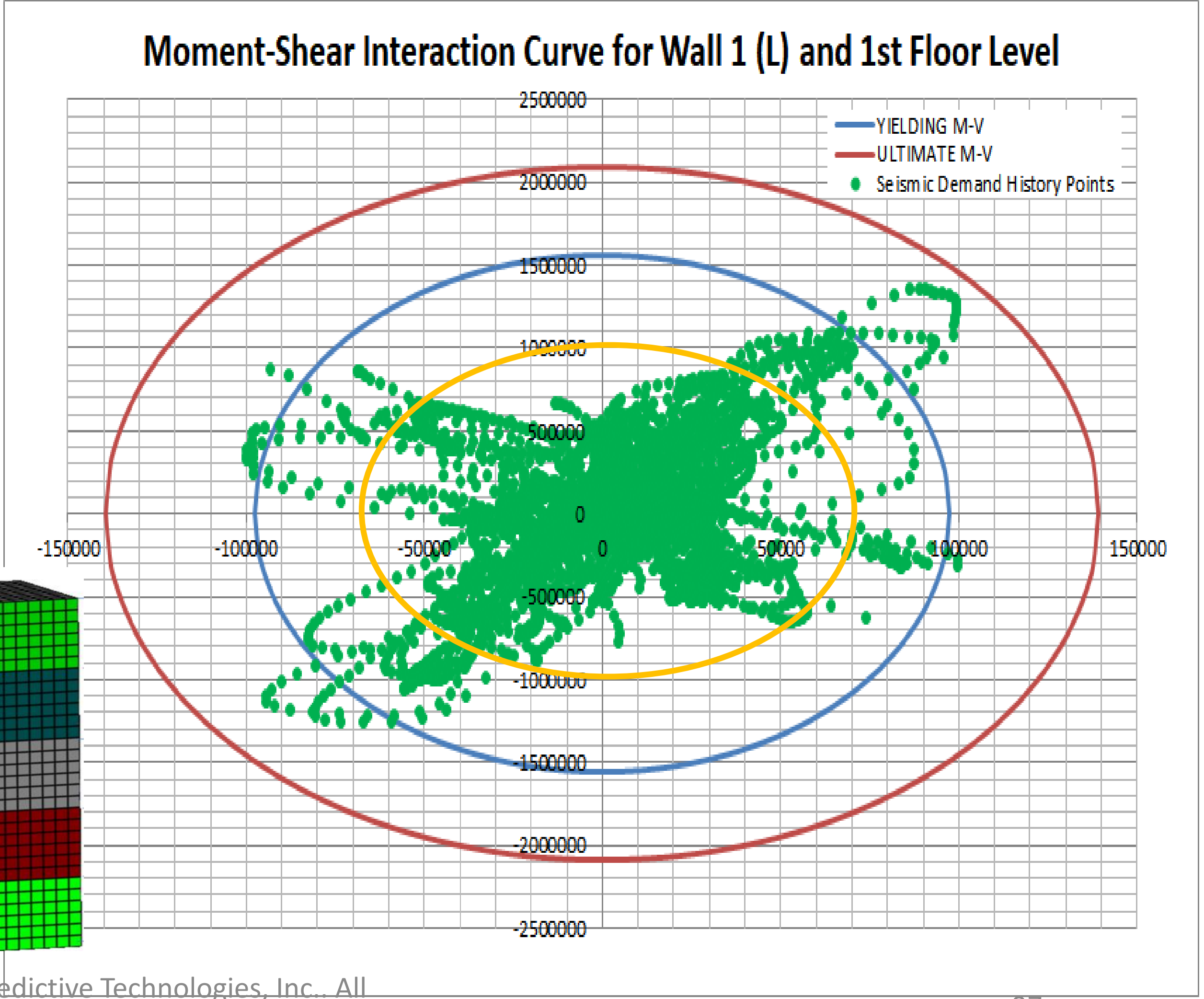




Bending-Shear Interaction Curves vs. 0.70g Seismic Demands for TB Structure, for Wall 3 (T) and Wall 1(L) at 1st Floor

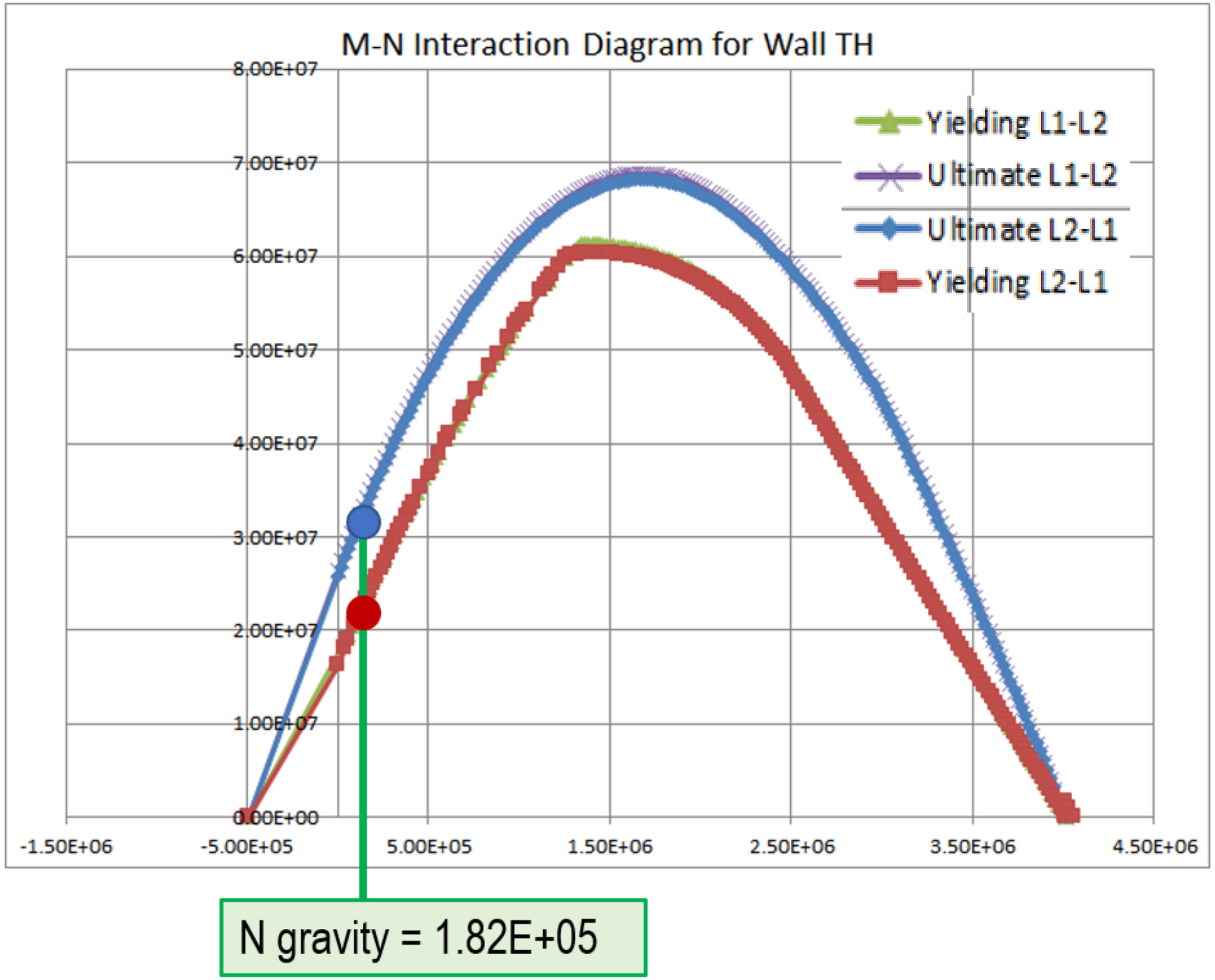






Moment-Axial Force (M-N) Interaction Curve Are Computed For Each Flange (L1 and L2) in Compression (see .dmn files)

N (kN)	M (kN-m)	Phi (1/km)	Xnu (cm)	eps c	eps s
-4.88E+05	0.00E+00	0.00E+00			
6.02E+04	1.96E+07	2.15E-08	2.15E+03	4.57E-04	1.85E-03
8.03E+04	2.04E+07	2.17E-08	2.23E+03	4.81E-04	1.85E-03
1.40E+05	2.29E+07	2.23E-08	2.48E+03	5.51E-04	1.85E-03
1.81E+05	2.46E+07	2.28E-08	2.64E+03	5.97E-04	1.85E-03
2.01E+05	2.54E+07	2.30E-08	2.72E+03	6.19E-04	1.85E-03
2.21E+05	2.62E+07	2.32E-08	2.79E+03	6.42E-04	1.85E-03
2.41E+05	2.70E+07	2.34E-08	2.86E+03	6.64E-04	1.85E-03
2.61E+05	2.78E+07	2.36E-08	2.93E+03	6.86E-04	1.85E-03
3.01E+05	2.94E+07	2.40E-08	3.07E+03	7.31E-04	1.85E-03
3.21E+05	3.02E+07	2.42E-08	3.13E+03	7.53E-04	1.85E-03
3.41E+05	3.10E+07	2.44E-08	3.20E+03	7.75E-04	1.85E-03
3.61E+05	3.17E+07	2.46E-08	3.26E+03	7.96E-04	1.85E-03
3.81E+05	3.25E+07	2.48E-08	3.32E+03	8.18E-04	1.85E-03
4.01E+05	3.32E+07	2.50E-08	3.38E+03	8.40E-04	1.85E-03
4.21E+05	3.40E+07	2.52E-08	3.44E+03	8.62E-04	1.85E-03
4.41E+05	3.47E+07	2.54E-08	3.50E+03	8.84E-04	1.85E-03
4.82E+05	3.62E+07	2.58E-08	3.62E+03	9.28E-04	1.85E-03
5.02E+05	3.69E+07	2.60E-08	3.67E+03	9.50E-04	1.85E-03
5.22E+05	3.77E+07	2.62E-08	3.73E+03	9.71E-04	1.85E-03
5.42E+05	3.84E+07	2.64E-08	3.78E+03	9.93E-04	1.85E-03
5.62E+05	3.91E+07	2.66E-08	3.84E+03	1.02E-03	1.85E-03
6.02E+05	4.05E+07	2.71E-08	3.94E+03	1.06E-03	1.85E-03
6.42E+05	4.19E+07	2.75E-08	4.05E+03	1.10E-03	1.85E-03
6.62E+05	4.26E+07	2.77E-08	4.10E+03	1.13E-03	1.85E-03

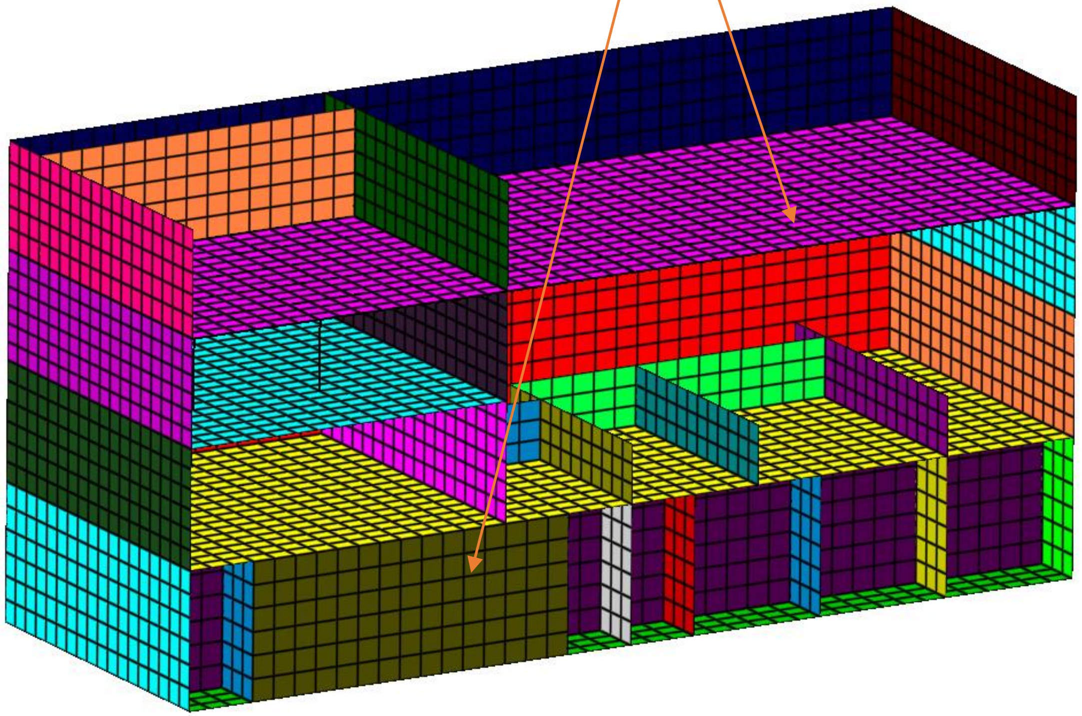


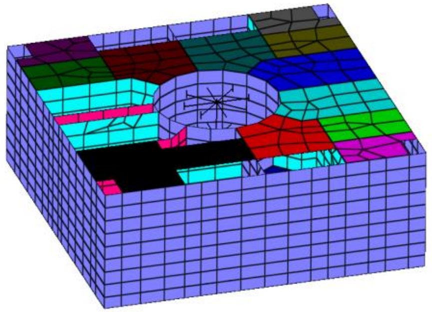
2.3 Nonlinear Modelling for Floor Cracking

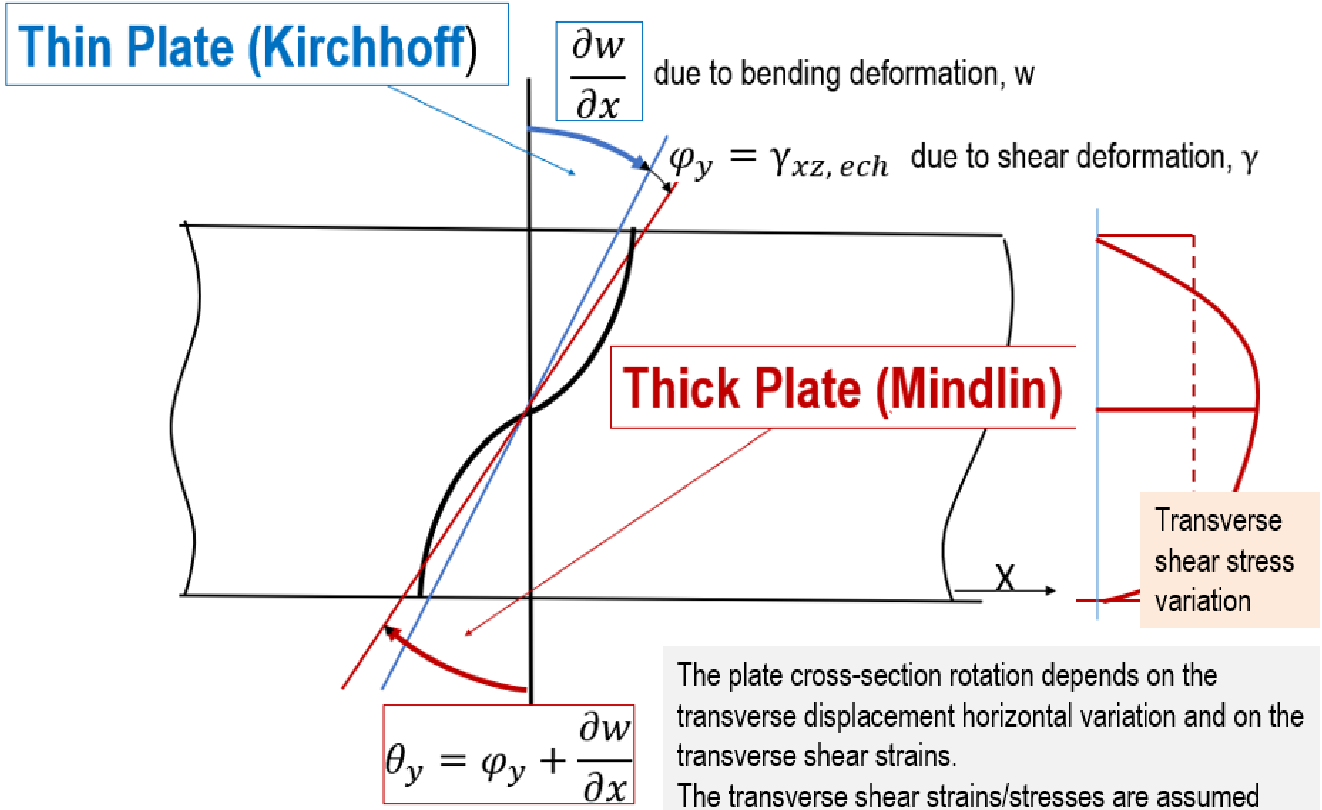
(Coming in V.4.3.3, planned by end of 2021)

Nonlinear Modeling for RC Floor Cracking (V4.3.3)

For floor cracking we consider the principal face stresses in each shell element (for S+G). If stress values are above the cracking strength, then, the shell element is considered cracked, and its damping is increased to 7% from 4% for US, or user sets cracking limits for stiffness and damping for Japan and oversee.







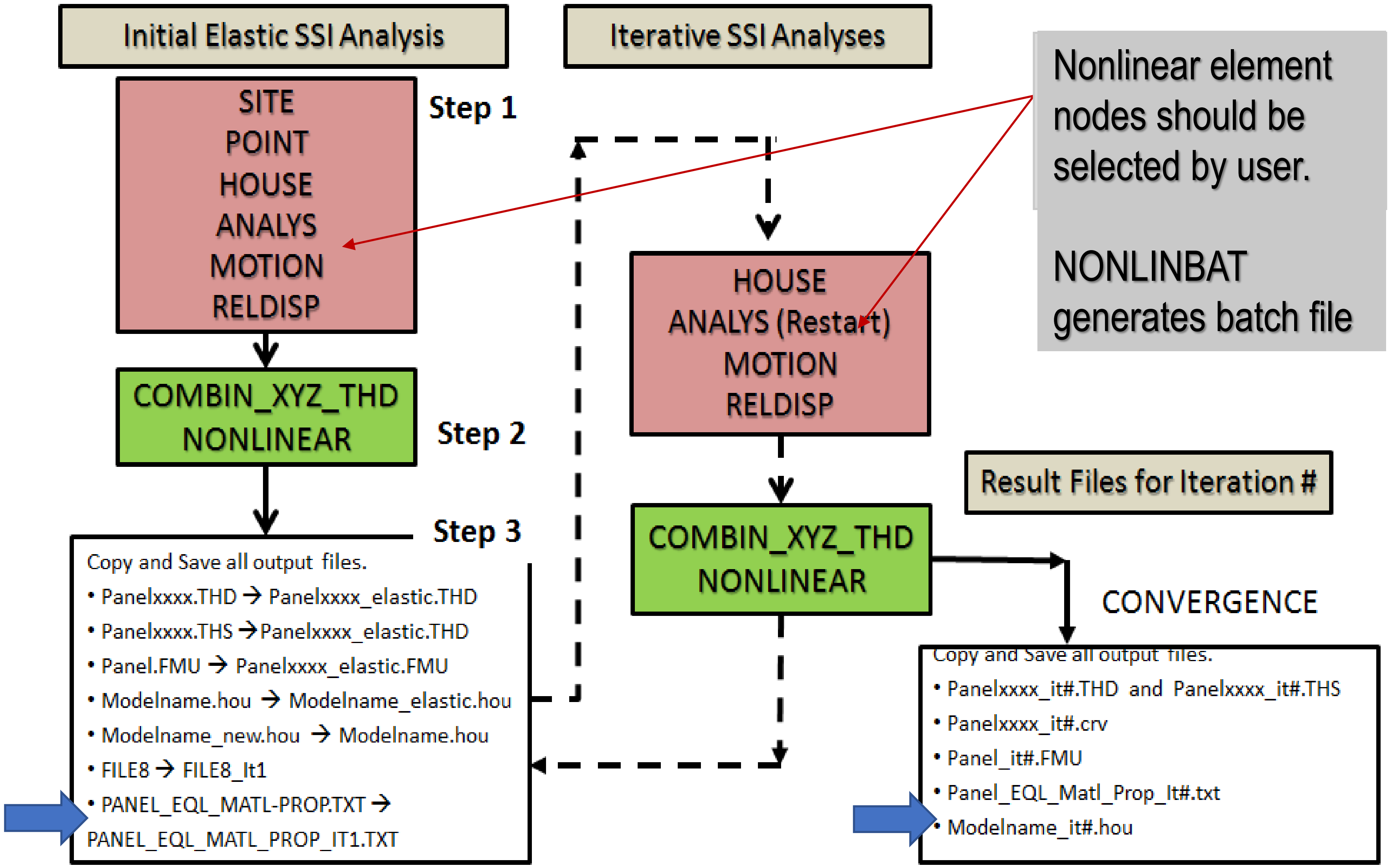
The plate cross-section rotation depends on the transverse displacement horizontal variation and on the transverse shear strains.
The transverse shear strains/stresses are assumed constant. Element strain energy adjusted for the parabolic shear stress variation by the shear factor for rectangular cross-section.

2.4 Option NON Simple:

Applicable to Low-Rise Shearwall Structures Dominated by Shear Deformation in RC Walls

(Include Only NONLINEAR Module)

Option NON Simple Application (NONLINEAR Module)



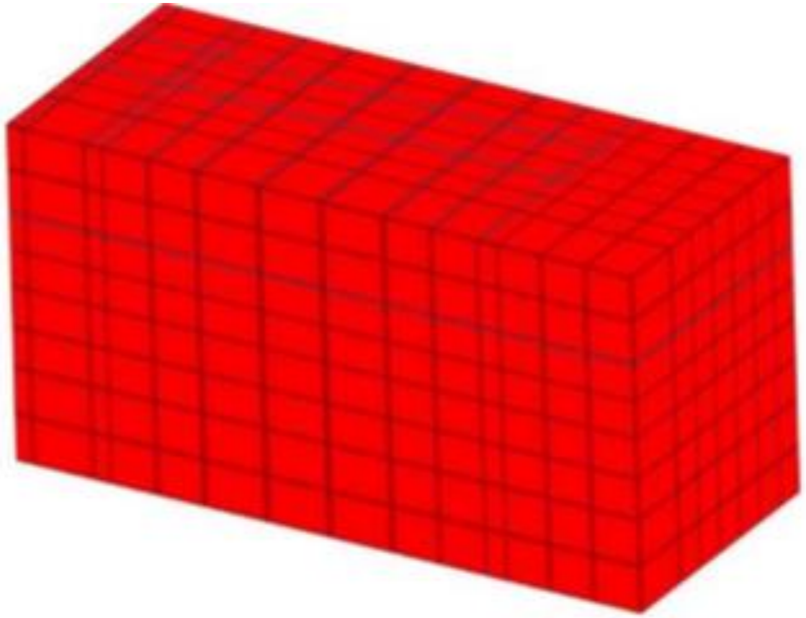
Option NON Simple Applicable to Low-Rise Shearwall Structures

Based on the hysteretic behavior of each wall panel, the local equivalent-linear properties are computed after each SSI iteration. The stiffness reduction is applied directly to the elastic modulus for each panel. This implies, under the isotropy material assumption, that the shear, axial and bending stiffness suffer same level of degradation. Poisson ratio remain constant.

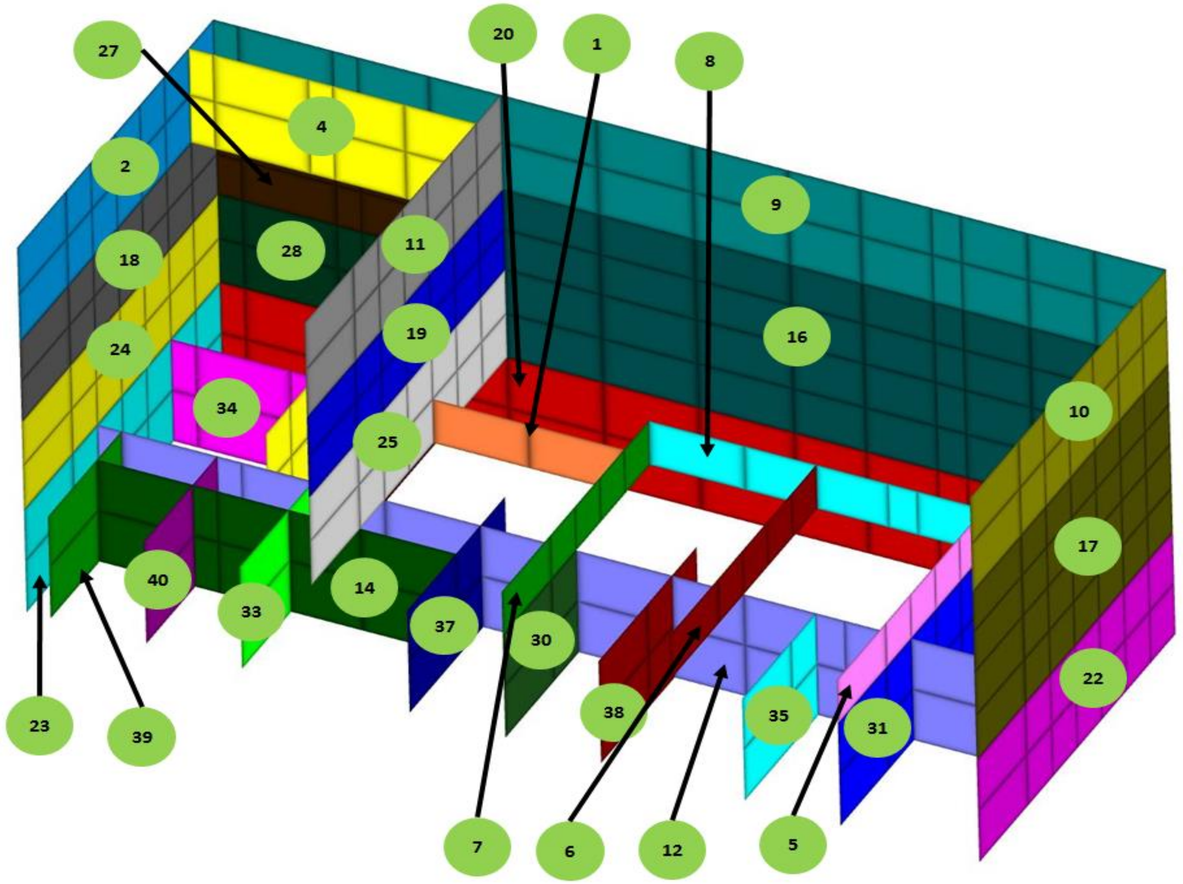
The wall panel shear stiffness modification as a result on nonlinear behaviour is fully coupled with the bending stiffness. This is a reasonable assumption *only f*or the low-rise shearwalls for which the nonlinear behaviour is governed by the shear deformation, while bending effects play an insignificant role.

Based on various experimental tests done at Cornell University, Gergely points out in NUREG/CR 4123, 1984 that in the low-rise walls such as those that occur in the modern nuclear power plants, the flexural distortions and associated vertical yielding play a negligible role. This was also recognized later by many other research studies, including the EPRI report on "*Methodology for Developing Seismic Fragilities*" (Reed and Kennedy, 1994).

Nonlinear Building Model Split in Simple Wall (Shear) Panels



Nuclear building model split in nonlinear ***panels*** with different nonlinear material properties.
Many ACS SASSI UI commands are available: WALLFLR, SPLITWALL, SEGWALLS, PNLGEN, etc.



Each panel should be described by its elastic properties, BBC and hysteretic model for in-plane shear such as, Cheng Mertz, PO Shear and Hybrid models

WALLFLR Command (No Parameter)

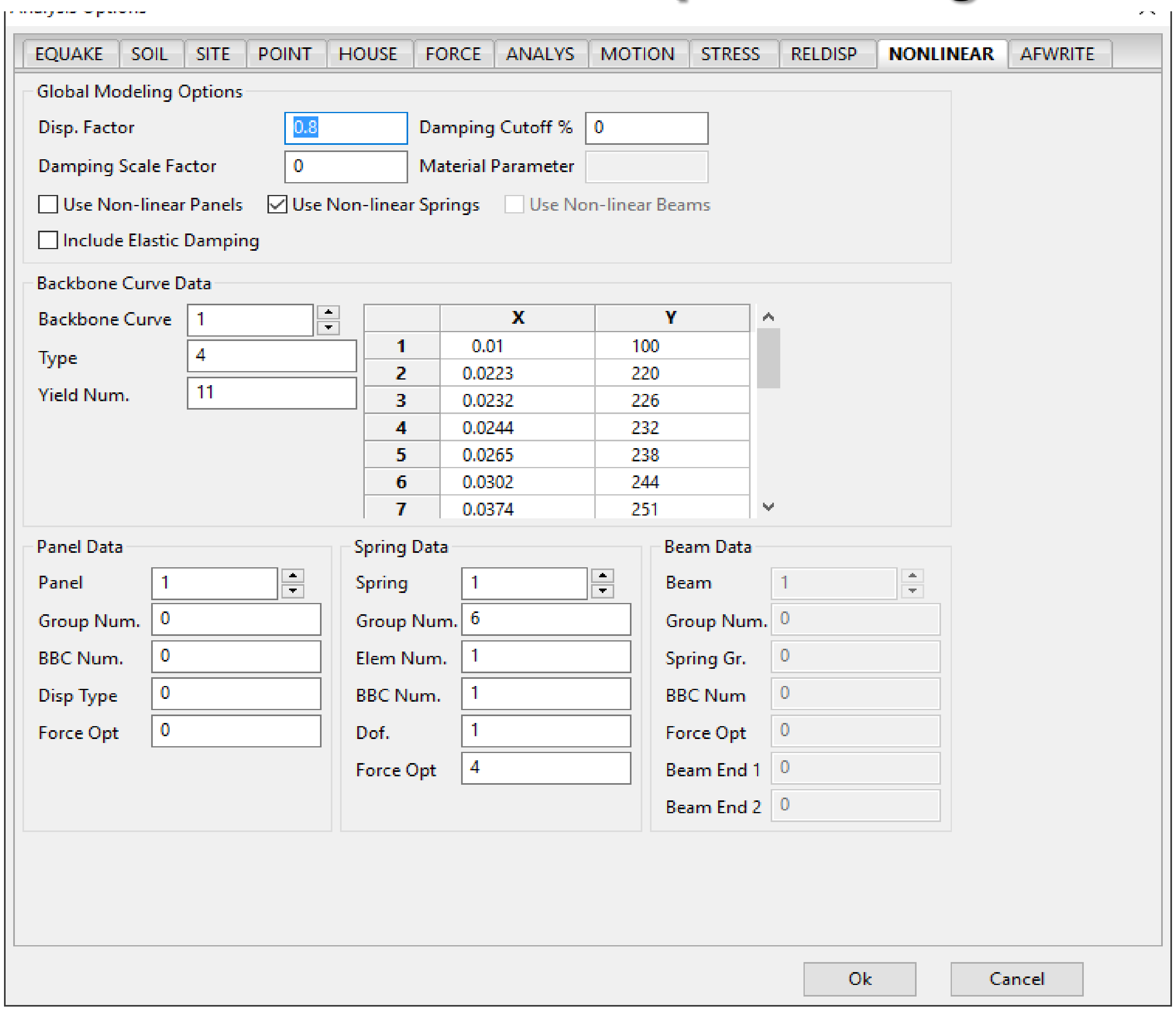
The WALLFLR command will take the current active model and delete all of the non shell elements in the model. Then the command will attempt to separate all of the shells into different wall and floors groups based on a coplanarity test of the shell elements. If 5 or more elements are found to be coplanar, then these elements will be put into a new group. All of the elements that were not put into wall or floor groups because there were not enough coplanar shells to form a new wall or floor in a separate group.

SPLITWALLS Command (No Parameter)

This command splits walls (shell groups that are not perpendicular to the global Z axis) by using intersections with other floors (shell groups that are perpendicular to the global Z axis).

This command does not change floors groups. This command should be used before SEGWALLS in most cases.

NONLINEAR Module UI Input Dialog Window



EQL Command

EQL,<disp>,<NonLinOpts>,<dampCutoff>,<dampScale>,<ElasicD>

Set the options for the nonlinear structure simulation. This command sets header information for the nonlinear module input (*.eql) file.

This information can also be set interactively using the NONLINEAR analysis options tab, found in the Options→Analysis menu selection.

- Disp – displacement reduction factor (DRF, typically 0.80, or PSD-based)
- NonLinOpts - nonlinear modeling options
- DampCutoff - damping cutoff value
- DampScale - damping scaling factor
- ElasicD - Include elastic damping flag
  - 0 - Don't include
  - 1 - Include

Nonlinear Structure SSI Input .Pre File (EQL, P)

AB_SHEAR_NL.pre

```
L,11,5,0.15,200000,100000,0.01,0.01
L,12,5,0.15,200000,100000,0.01,0.01
L,13,5,0.15,200000,100000,0.01,0.01
L,14,5,0.15,200000,100000,0.01,0.01
L,15,5,0.15,200000,100000,0.01,0.01
L,16,5,0.15,200000,100000,0.01,0.01
* Real Property Table
R,1,11.111,0,0,17.387,10.288,10.288
R,2,13,0,0,22.316,9.75,20.343
R,3,2.849,0,0,28.958,0.333,28.292
* NonLinear
EQL,0.8,1,0,1,1
P,1,3,1,1,1
P,2,8,2,1,1
P,3,9,3,1,1
P,4,10,4,1,1
P,5,11,5,1,1
P,6,12,6,1,1
P,7,13,7,1,1
P,8,14,8,1,1
P,9,15,9,1,1
P,10,16,10,1,1
P,11,17,11,1,1
P,12,18,12,1,1
P,13,19,13,1,1
P,14,20,14,1,1
P,15,21,15,1,1
P,16,22,16,1,1
P,17,23,17,1,1
P,18,25,18,1,1
P,19,26,19,1,1
P,20,27,20,1,1
P,21,28,21,1,1
```

EQL command

EQL,<disp>,<NonLinOpts>,<dampCutoff>,<dampScale>,<ElasicD>

PANELGEN and P commands

P,<num>,<group>,<bbc>,<disp>,<force>

Nonlinear Structure SSI Input .Pre File (BBCP)

```
P,106,113,106,1,1
P,107,114,107,1,1
P,108,115,
P,109,116,
P,110,117,
P,111,118,
P,112,119,
P,113,120,
BBCI,1,21,1
BBCP,1,1,0.00013825,2415.18
BBCP,1,2,0.000152075,2650.66
BBCP,1,3,0.0001659,2874.06
BBCP,1,4,0.000179724,3085.39
BBCP,1,5,0.000193549,3284.65
BBCP,1,6,0.000207374,3471.82
BBCP,1,7,0.000221199,3646.92
BBCP,1,8,0.000235024,3809.95
BBCP,1,9,0.000248849,3960.9
BBCP,1,10,0.000262674,4099.77
BBCP,1,11,0.000276499,4226.57
BBCP,1,12,0.000290324,4341.29
BBCP,1,13,0.000304149,4443.93
BBCP,1,14,0.000317974,4534.5
BBCP,1,15,0.000331799,4612.99
BBCP,1,16,0.000345624,4679.41
BBCP,1,17,0.000359449,4733.75
BBCP,1,18,0.000373274,4776.02
BBCP,1,19,0.000387099,4806.21
BBCP,1,20,0.000400924,4824.32
BBCP,1,21,0.000414749,4830.36
BBCP,1,22,0.02,4926.97
BBCI,2,21,1
BBCP,2,1,0.00013825,805.06
BBCP,2,2,0.000152075,883.554
BBCP,2,3,0.0001659,958.022
BBCP,2,4,0.000179724,1028.46
```

BBCGEN

BBCGEN,<Panel>,<ShearModel>,[fc],[fy],[Pn],[Nu],[bre],[bys],[CrackingForceLevel]

BBCI and BBCP Commands

UI Commands for Option NON Simple Runs (NONLINEAR module)

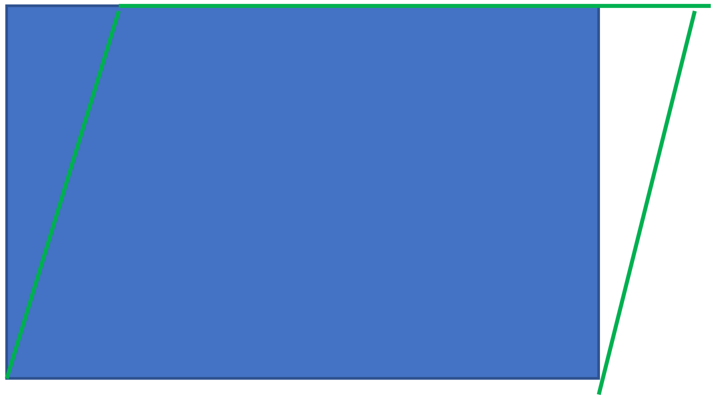
- Batch file for a typical nonlinear analysis can be created with the **NONLINBAT** command
  - Option 0 = Create batch file for single input direction, X
  - Option 1 = Create batch file for three-direction input, X, Y, Z
- This will only create the .bat file. The remaining input files need to be created using the AFWRITE function in the UI.
- Nonlinear spring nodes need to be requested as outputs for MOTION and RELDISP runs

NONLINMOTDISP Command

This UI command finds the corner nodes of all panels defined by the P command. The corner nodes are then added to the output request list of the MOTION and RELDISP modules.

SHEAR Command Per US Standard Recommendations

SHEAR, <panel>,[fc],[fy],[P],[Nu],[Fvw],[Fbe]



Walls have no openings!

This command calculates the peak shear strength of a single panel or all wall panels. The SHEAR command uses four different peak shear equations, such as those provided by *ACI 318-19, Wood, 1990, Barda et al.,1977 and Gulec-Whitakker, 2009* (see Gulec and Whittaker, 2009 for details).

The lower bound value for Wood, 1990, and the upper bound value for Wood, 1990 and ACI 318-19 equations are also included.

A total of six columns with computed peak shear strength are written for each panel. The columns of the result table are in order, the panel number, upper bound of ACI 318-08 and Wood, 1990, lower bound of Wood, 1990, Barda,1977 and Gulec-Whittaker, 2009.

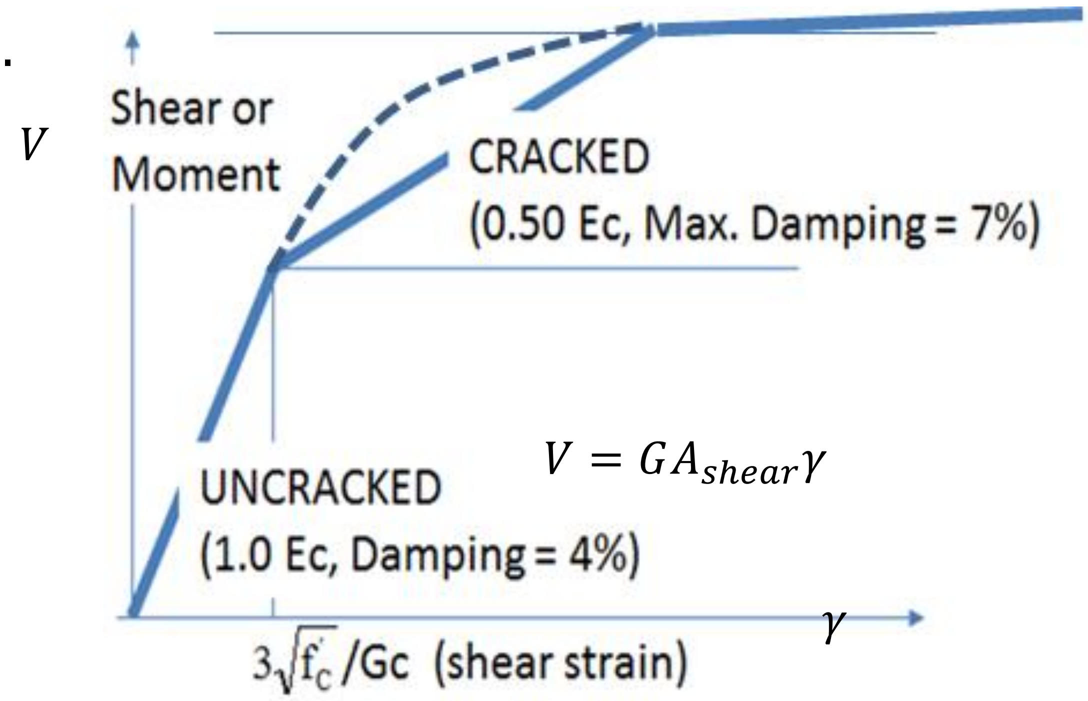
SHEAR Command Example for 20 Wall Panels

SHEAR,#,2,4.771,83.25,0.01

Panel #	Upper Bound ACI 318-08	ACI 318-08	Wood (1990)	Lower Bound (Wood, 1990)	Barda (1977)	Gulec-Whittaker (2009)
1	5968.3261	8983.4501	1798.2381	3580.9957	6904.5338	4850.7109
2	12533.4754	18865.2311	3776.2971	7520.0853	14484.2127	10054.6795
3	29692.4449	44692.6981	8946.2412	17815.4669	35128.3838	36663.1603
4	8952.4780	13475.1583	2697.3537	5371.4868	10175.8698	6069.8205
5	10966.7910	16507.0772	3304.2600	6580.0746	12918.2495	12082.1974
6	9400.1066	14148.9233	2832.2228	5640.0639	11033.3518	9587.9496
7	9400.1066	14148.9233	2832.2228	5640.0639	11033.3518	9587.9496
8	10444.6076	15721.0933	3146.9277	6266.7646	12290.0041	11229.6125
9	29692.4449	44692.6981	8946.2412	17815.4669	35128.3838	36663.1603
10	12533.4754	18865.2311	3776.2971	7520.0853	14484.2127	10054.6795
11	12533.4754	18865.2311	3776.2971	7520.0853	14484.2127	10054.6795
12	29692.4449	44692.6981	8946.2412	17815.4669	35083.6236	35357.2905
13	6266.7377	9432.6155	1888.1486	3760.0426	6899.8619	3428.2487
14	11190.6031	16843.9563	3371.6939	6714.3618	12823.8260	8180.6964
15	20739.9669	31217.5398	6248.8874	12443.9802	23898.7329	16082.1780
16	20739.9669	31217.5398	6248.8874	12443.9802	23898.7329	16082.1780
17	12533.4754	18865.2311	3776.2971	7520.0853	14025.4002	7555.0970
18	12533.4754	18865.2311	3776.2971	7520.0853	14577.4707	10949.3572
19	12533.4754	18865.2311	3776.2971	7520.0853	14577.4707	10949.3572
20	29692.4449	44692.6981	8946.2412	17815.4669	35083.6236	35357.2905

BBCGEN Command (continuation)

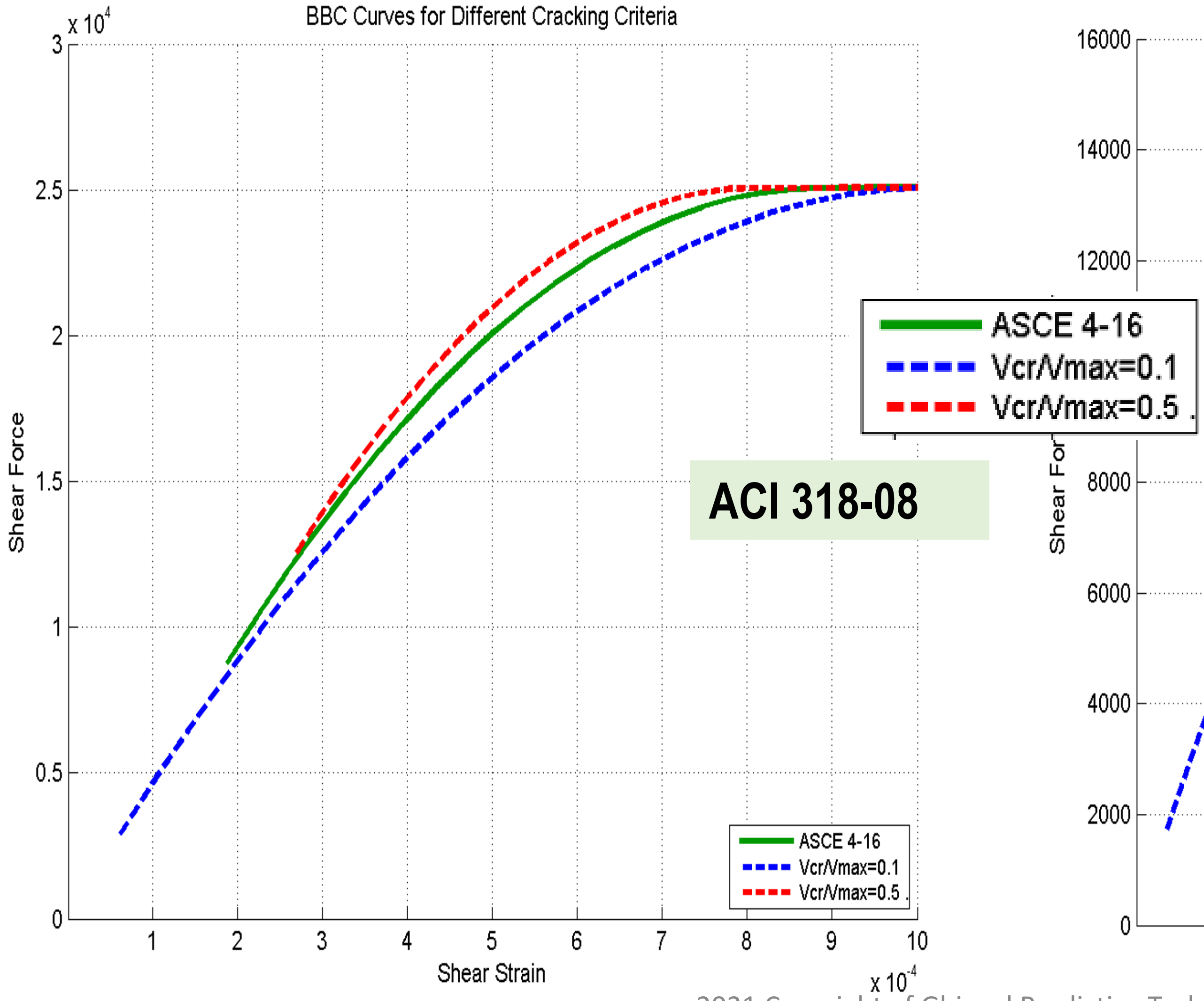
<Panel>
= 0, the BBC curves will be generated for all panels defined by the user assuming the same command parameters. The Panel = 0 option, it can be used in conjunction of submodels, to define properties of panel subsets.
= K, the BBC will be generated only for Panel K.

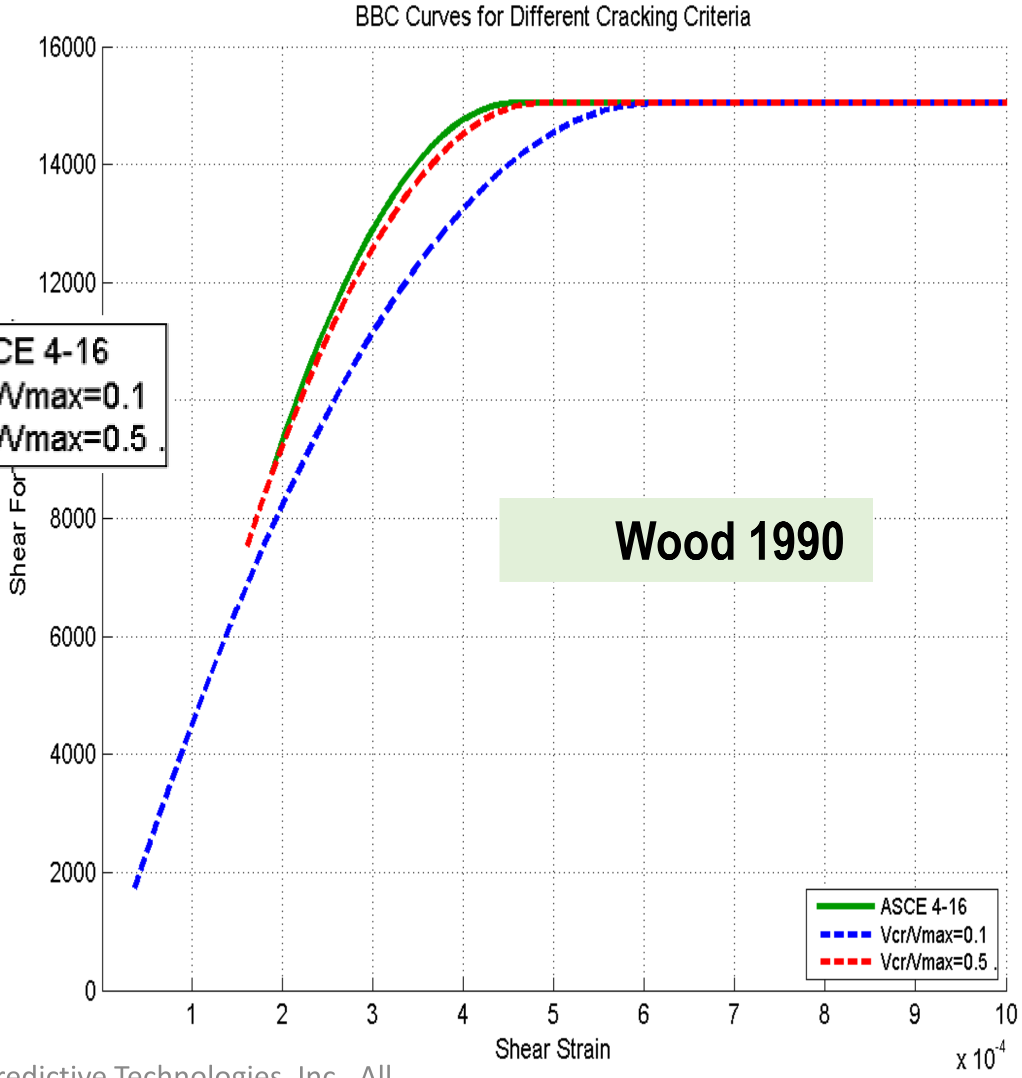


[CrackForceLevel]
= 0. Default option for building BBC curves uses new ASCE 4 standard recommendation in Section C.3.3.2 for defining the concrete cracking stress level by the value of

= Vcr/Vu alue in the [0.1 0.5] interval. Uses the cracking shear/ultimate shear force ratio to build the BBC curves.

BBCGEN for Different Concrete Shear Wall Concrete Cracking Criterion Parameter Options



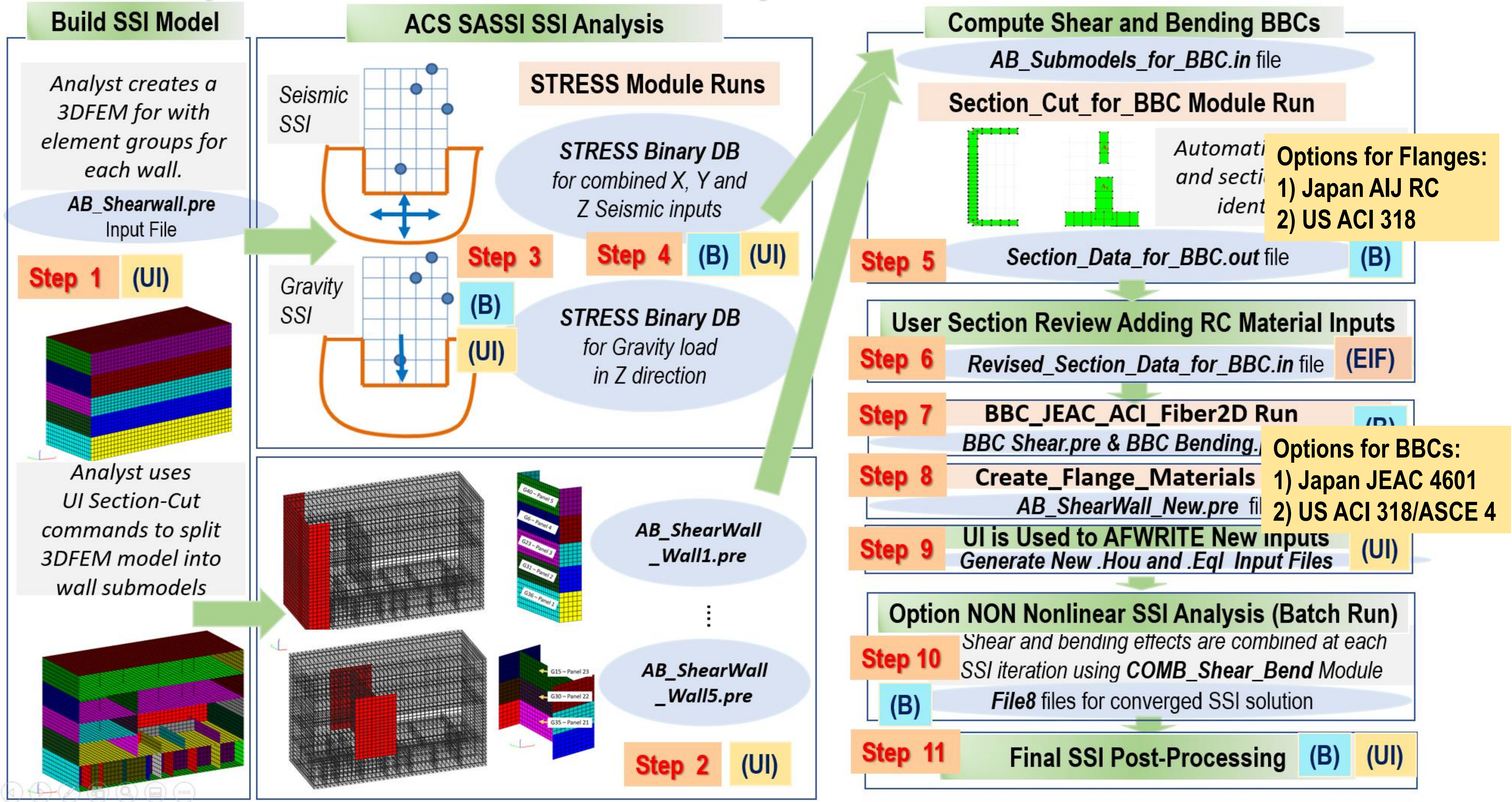


2.5 Option NON Advanced:

Applicable to General RC Shearwall Structures Including Both Shear & Bending Effects in Walls

(Multistep Analysis which optimally combines using the UI commands and Batch Runs, including a Pause-Step for User Nonlinear Input Reviews)

Option NON Advanced Implementation Flowchart



Nonlinear SSI Analysis Steps Per Best Practices in US and Japan

Here are the main steps of the nonlinear SSI analysis procedure:

1. Prepare *structure FE model. (ACS SASSI UI)*
2. Create the *nonlinear RC wall FE submodels* from structure FE model *(ACS SASSI UI)*
3. Perform *initial SSI analysis* for the gravity and seismic loads (*ACS SASSI SSI* modules *Batch/UI*)
4. Perform *automatic wall cross-section geometry identification and automatic section cuts* for each wall at each floor level for the gravity and seismic loads. (*Section_Cuts_for_BBC* module)
5. Compute *shear and bending BBCs* for each wall *per US or Japan standard recommendations (BBC_JEAC_ACI_Fiber2D* module*)*
6. Select *hysteretic wall models per US or Japan standard recommendations (NONLINEAR* module*)*
7. *Perform iterative nonlinear SSI analysis* using shear and bending hysteretic wall models and *combine shear and bending responses* at each iteration (*Change_Flange_Materials* and *COMB_Shear_Bend* modules).
8. *Post-process the final SSI results* for the converged nonlinear response (*ACS SASSI UI/Batch*)

Option NON Advanced Modules (Plus NONLINEAR Module)

- ***The Section_Cuts_for_BBC module*** – Performs automatic wall section geometry identification and computes the wall section-cut forces for user-defined panels
- ***The BBC_JEAC_ACI_Fiber2D module*** – Computes shear and bending back-bone curves (BBC) for all the user-defined panels based on either the US standards or Japan standard recommendations, or 2D Fiber Model
- ***The Create_Flange_Materials module*** – Creates wall flange nonlinear materials for each wall panel which are used to create a new structure model .pre input file named *ModelName_NEW.pre* file.
- ***COMB_Shear_Bend module*** – This combines the nonlinear shear and bending interactive effects in wall panels after each SSI iteration.

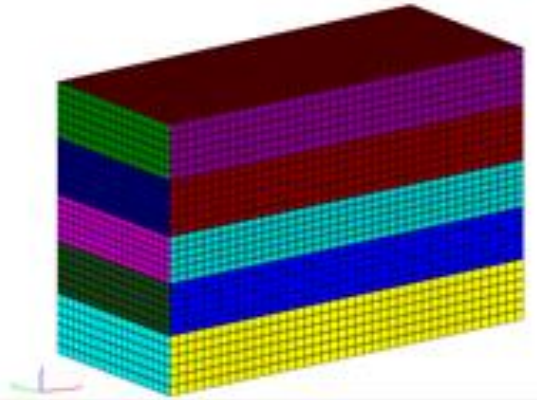
Steps 1-2: Prepare the 3DFEM with Separate Shell Groups for Walls

Build SSI Model

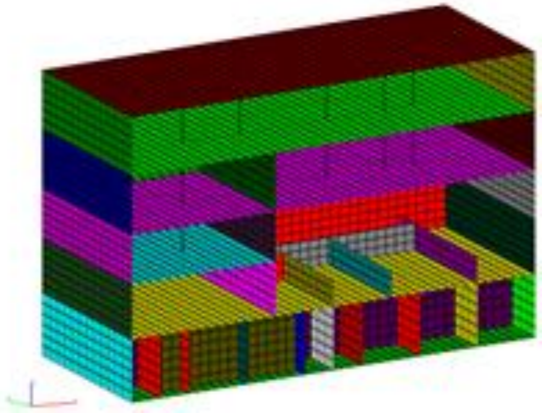
Analyst creates a 3DFEM for with element groups for each wall.

AB_Model.pre
Input File

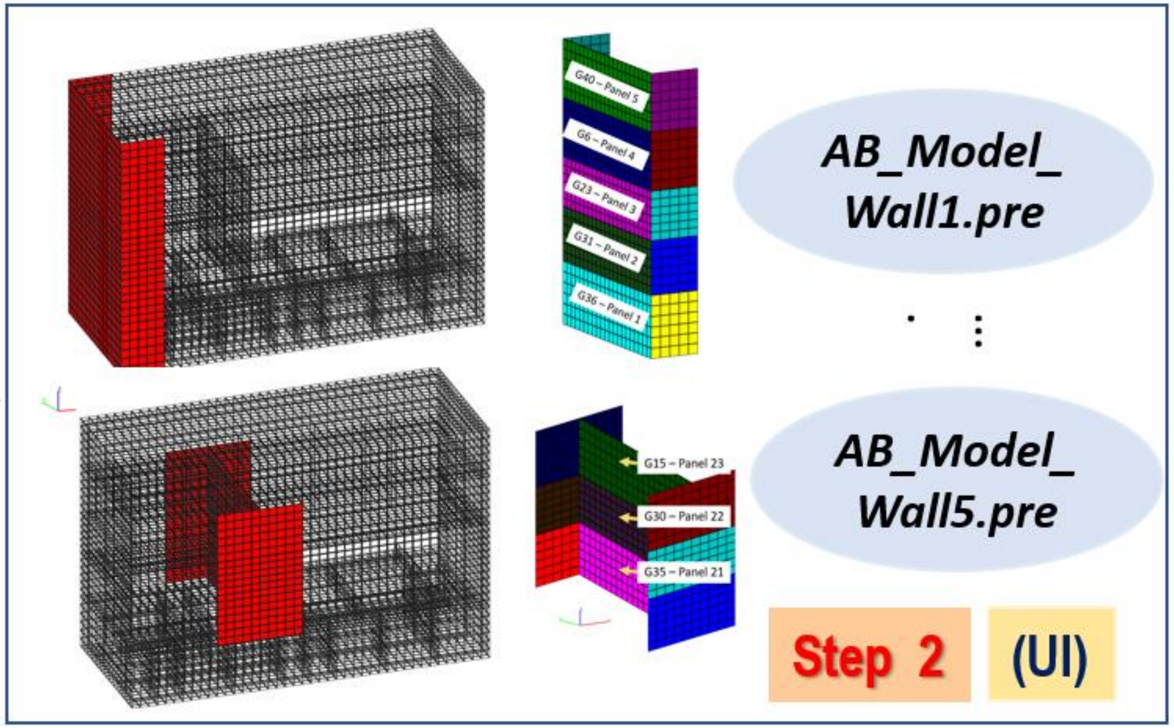
Step 1 (UI)



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

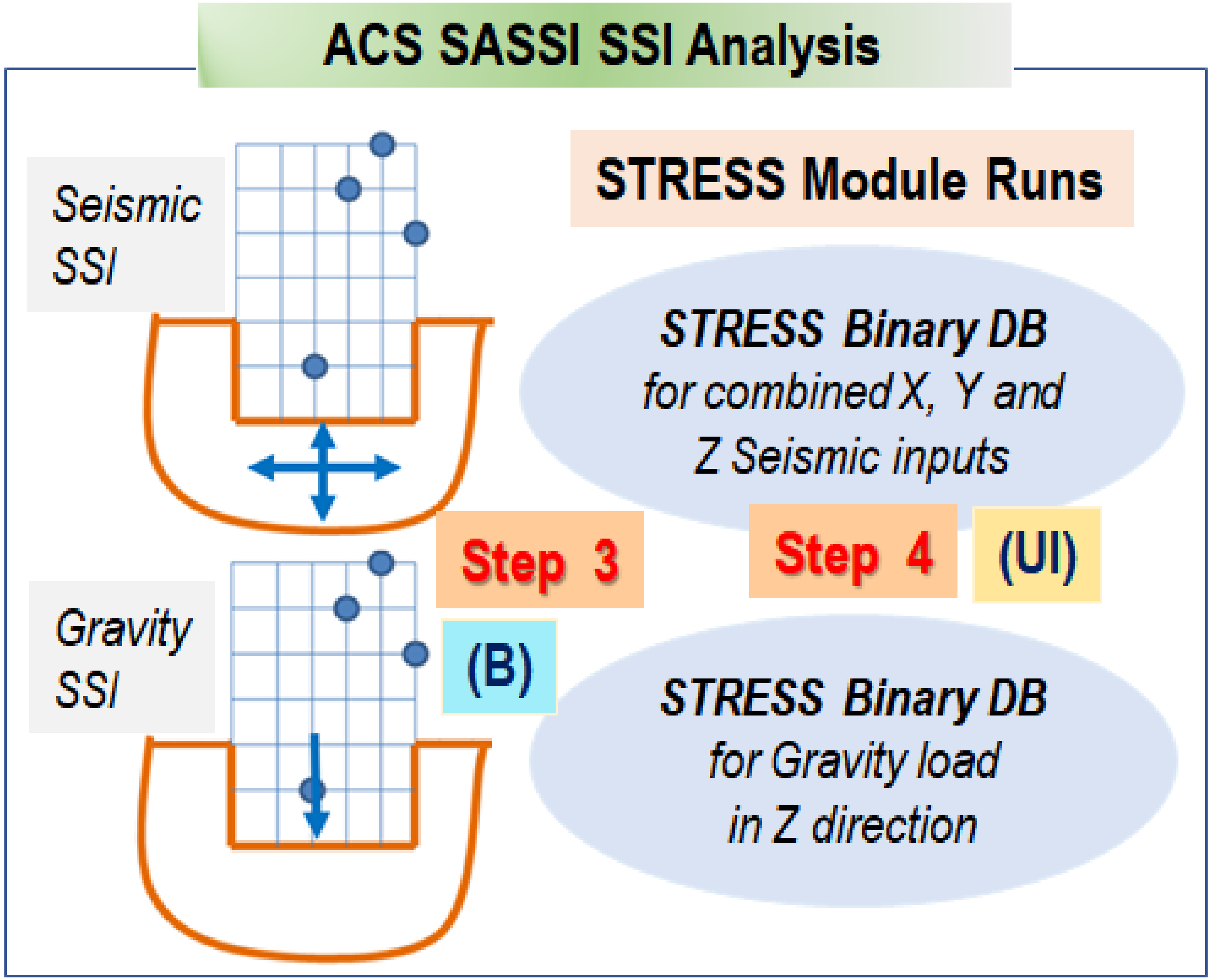


Use UI Section-cut commands to split the 3DFEM model in Wall submodels (Shell Groups). See Demos 18 and 19



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

Steps 3-4: 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 X,Y,Z STRESS binary BD (B or UI):

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

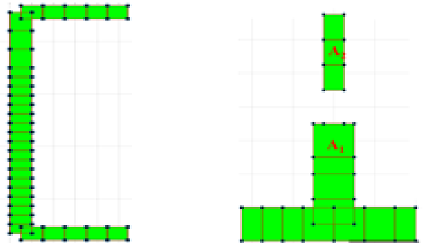
The Gravity and Seismic binary DBs are used in Step 5 for automatic section-cut calculations.

Step 5: Automatic Section Geometry Identification and Section-Cuts at Each Floor Level

Compute Shear and Bending BBCs

AB_Submodels_for_BBC.in file

Section_Cut_for_BBC Module Run



Automatic section-cut and section geometry identification

Step 5 *Section_Data_for_BBC.out* file **(B)**

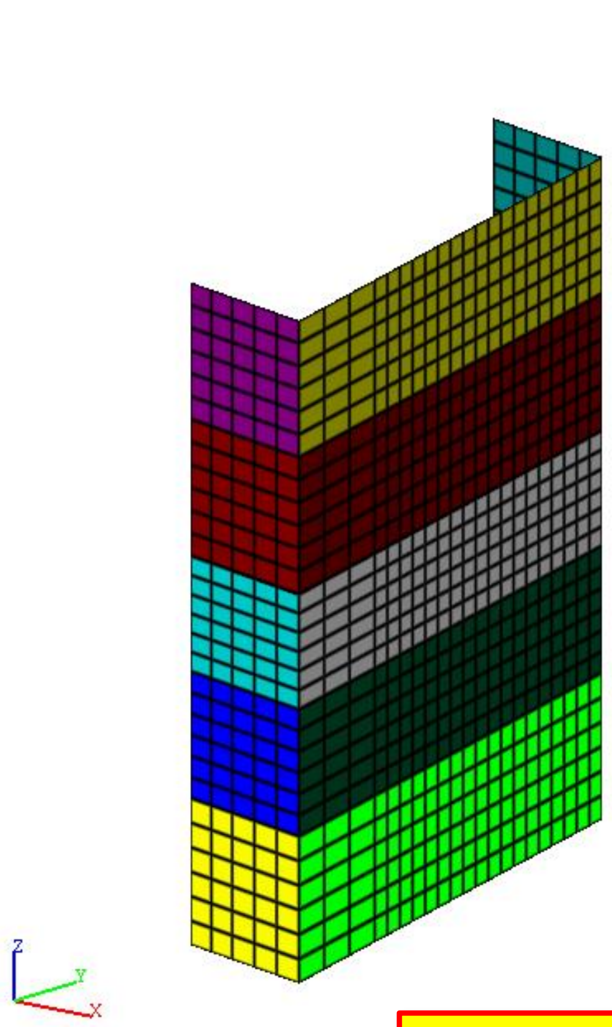
Step 5:

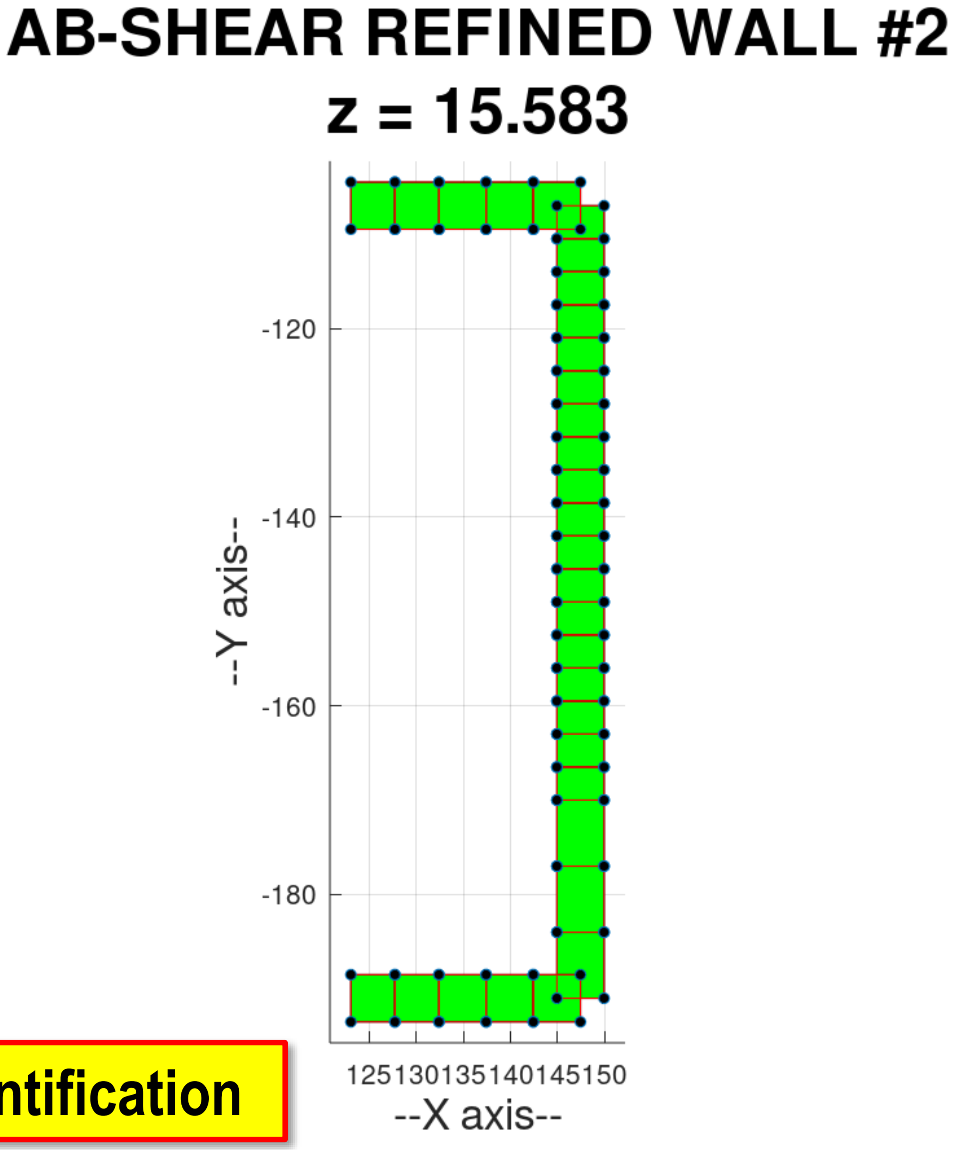
Section_Cut_for_BBC **Module_runs (Batch):**
This module performs automatic section-cuts and identify the section geometries for all floor levels.

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 input data for next step

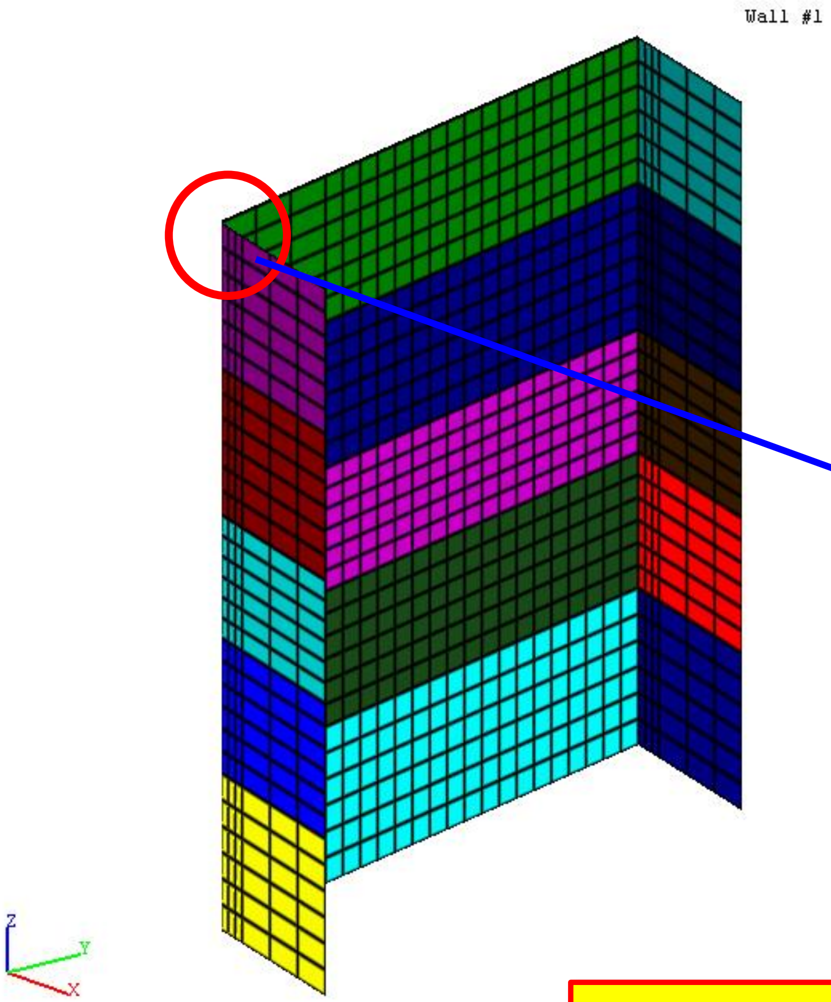
Example of Section Geometry Identification



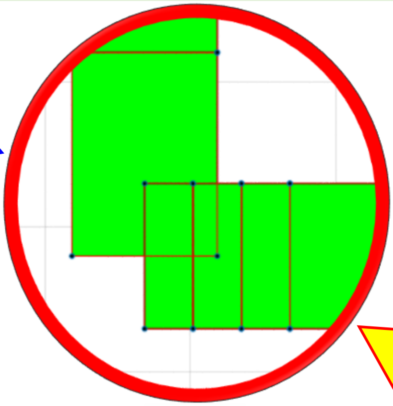


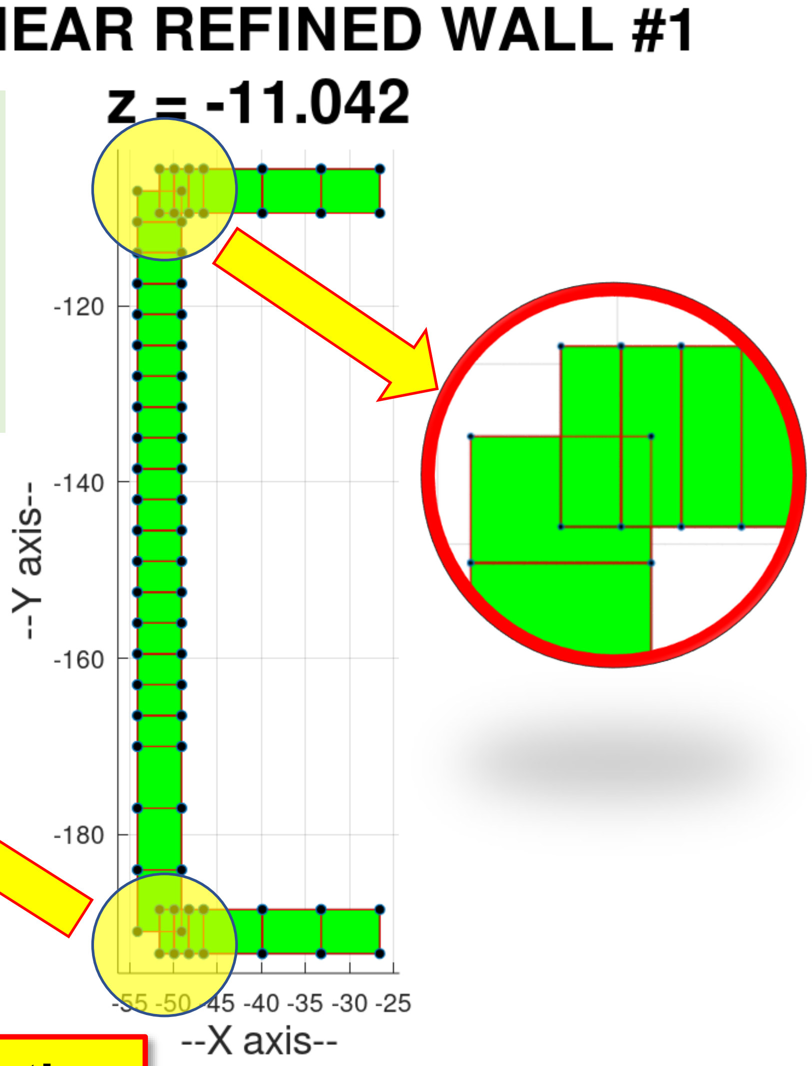
Correct Section Geometry Identification

Example of Section Geometry Identification



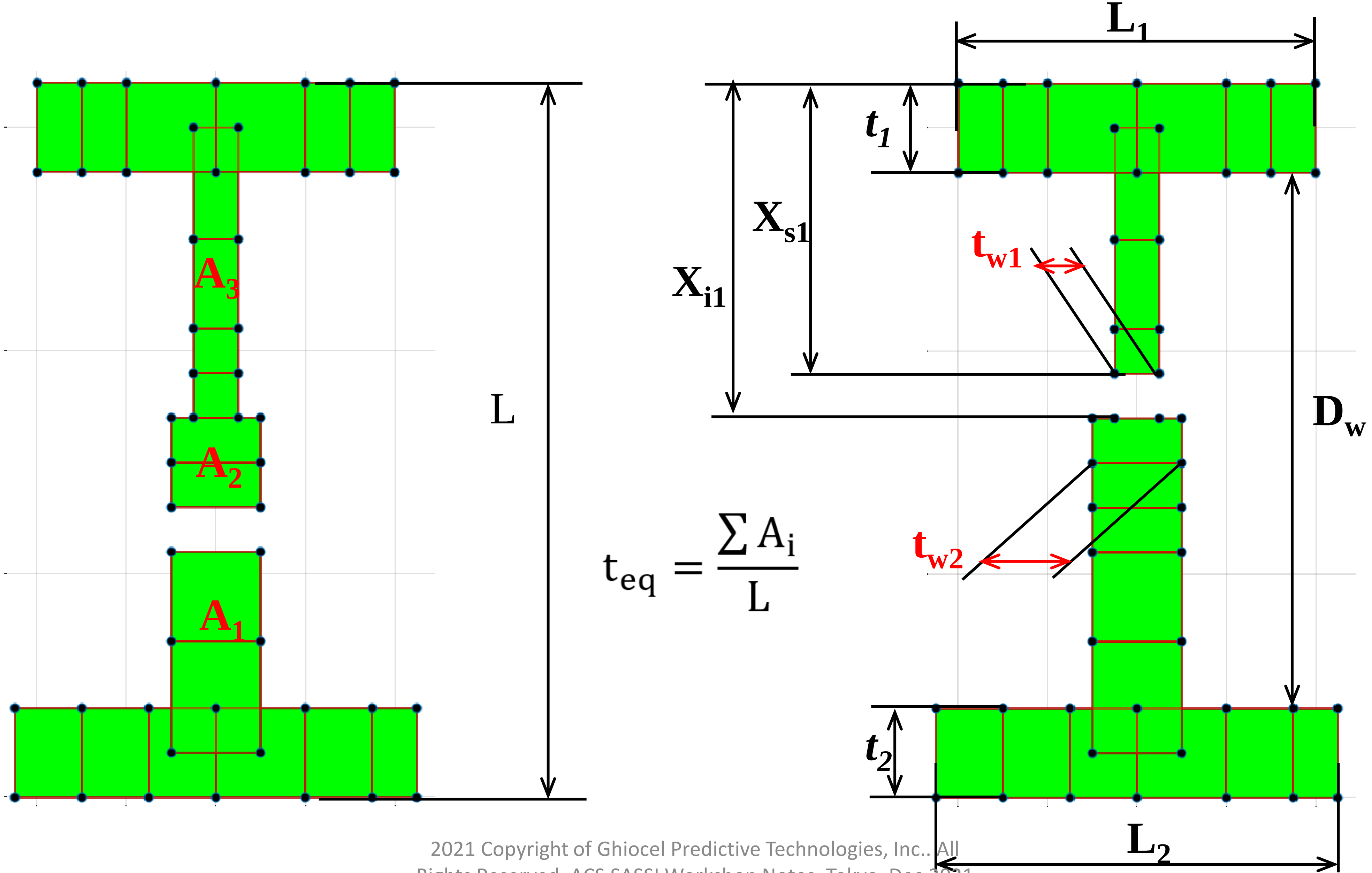
These larger web elements covers two flange elements. It is not a correct mesh modeling. User has to merge the two small size elements into one element.





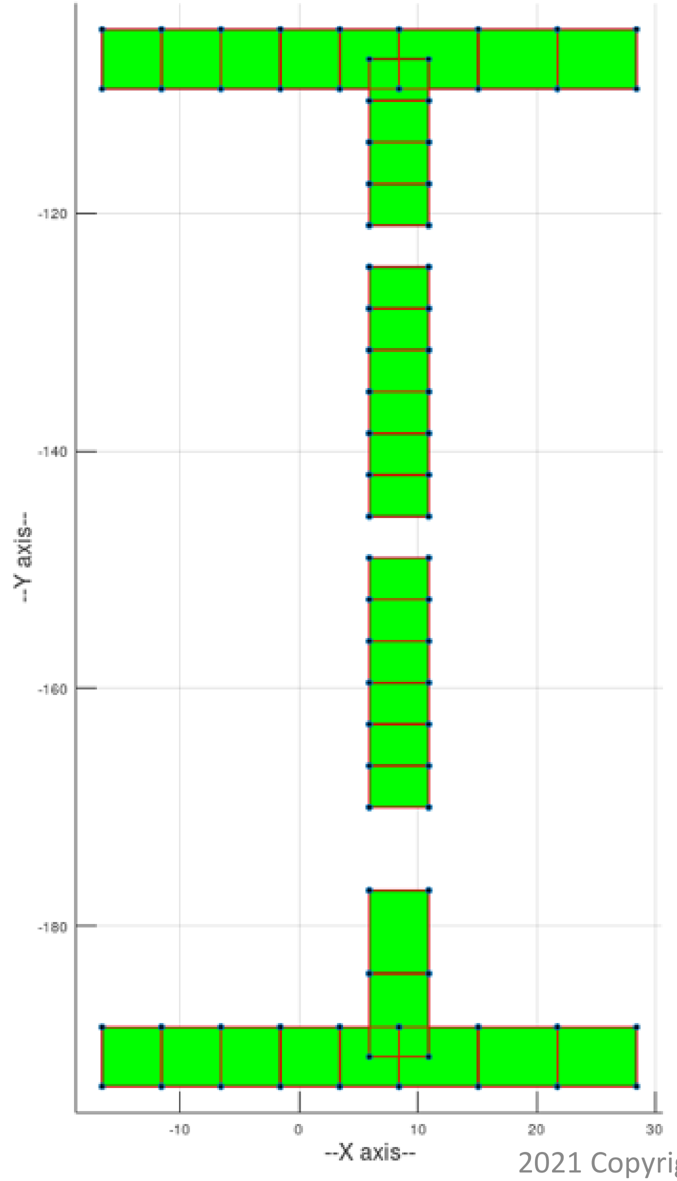
Incorrect Mesh for Geometry Identification

Examples of Section Geometry Identification



$$t_{eq} = \frac{\sum A_i}{L}$$

Example of Section Geometry Identification Data



Section Shape ID = 5
Web Direction = y+
Section has opening = 3

Number of web segments = 4

Seg #	Location	Length	Thickness
1	5.000000	11.500000	5.000000
2	23.500000	21.000000	5.000000
3	48.000000	21.000000	5.000000
4	72.500000	11.500000	5.000000

The web equivalent thickness = 3.651685

Flange #1 Length = 45.000000
Flange #1 Thickness = 5.000000

Flange #2 Length = 45.000000
Flange #2 Thickness = 5.000000

Open #	Location	Length
1	16.500000	7.000000
2	44.500000	3.500000
3	69.000000	3.500000

Step 6: Analyst Review of *Section_Data* Files To Prepare Nonlinear Input

User Section Review Adding RC Material Inputs

Step 6 *Revised_Section_Data_for_BBC.in* file

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)

Section_Data_for_BBC.out (Step 5)

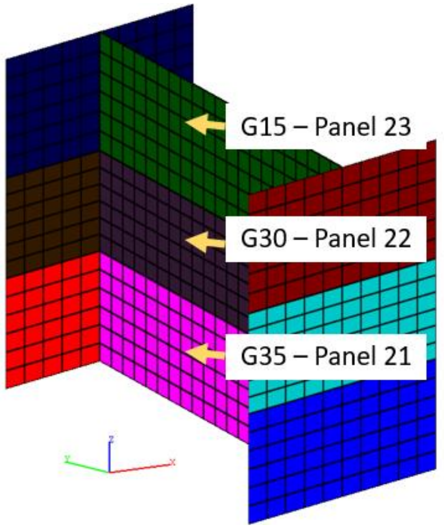
```
 5
-8.0264     0.0000     16.764
 1
   0.949395E+05   0.336417E+07   0.153516E+06
-3.3650     7.9827     1.5240     7.9827     1.5240     24.079     1.5240     5.0674     5.0674
 0
 0.0000     0.0000     0.0000     0.0000
   0.248546E+08   0.106216E+08  0.0000E+00  0.0000E+00   0.000000E+00   0.000000E+00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

Section_Data_for_BBC.out File from *Section_Cuts_for_BBC Module* (Step5)

Example for Wall 5 Submodel 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
  0.0000     0.0000     0.0000     0.0000
  0.248546E+08   0.106216E+08   0.00E+00   0.00E+00   0.000E+00   0.000E+00   0.00E+00  0.00E+00
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
  0.0000     0.0000     0.0000     0.0000
  0.248546E+08   0.106216E+08   0.00E+00   0.00E+00   0.000E+00   0.000E+00   0.00E+00  0.00E+00
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
  0.0000     0.0000     0.0000     0.0000
  0.248546E+08   0.106216E+08   0.00E+00   0.00E+00   0.000E+00   0.000E+00   0.00E+00  0.00E+00
```

Automatic Section Cut results for N, M and V

Automatic Section Data

Concrete and steel material parameters, reinforcement ratios. To be completed by analyst after reviewing section geometries.

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)

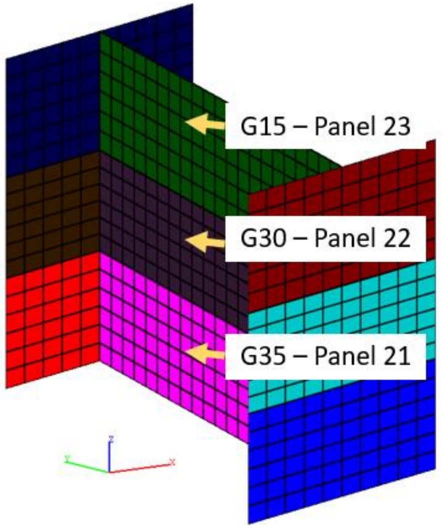
Line 8: Ec, Fc, Epsc_y, Epsc_u, Es, Fs, Epss_y, Epss_u
Ec = Concrete E modulus
Fc = Concrete Fc strength
Epsc_y = Concrete Yielding strain
Epsc_u = Concrete Ultimate strain
Es – Steel E modulus
Fs – Steel Fy yielding
Epss_y – Steel Yielding strain
Epss_u – Steel Ultimate strain

These are parameters shall be input by analyst for each wall Submodel and each floor level

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)

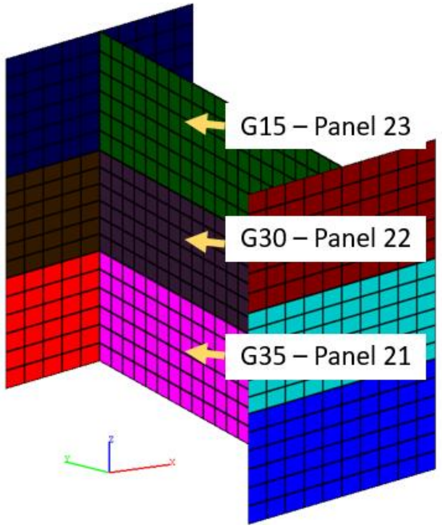
Revised_Section_Data_for_BBC.in File for Curved Walls - For Option 1

Example for Wall Submodel 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    2
 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    0.00    1.
 0
1.1950    1.5980    1.2460    0.95300
0.248546E+08  0.3300E+05  0.200E-02  0.400E-(
 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
```

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

--- For plane walls

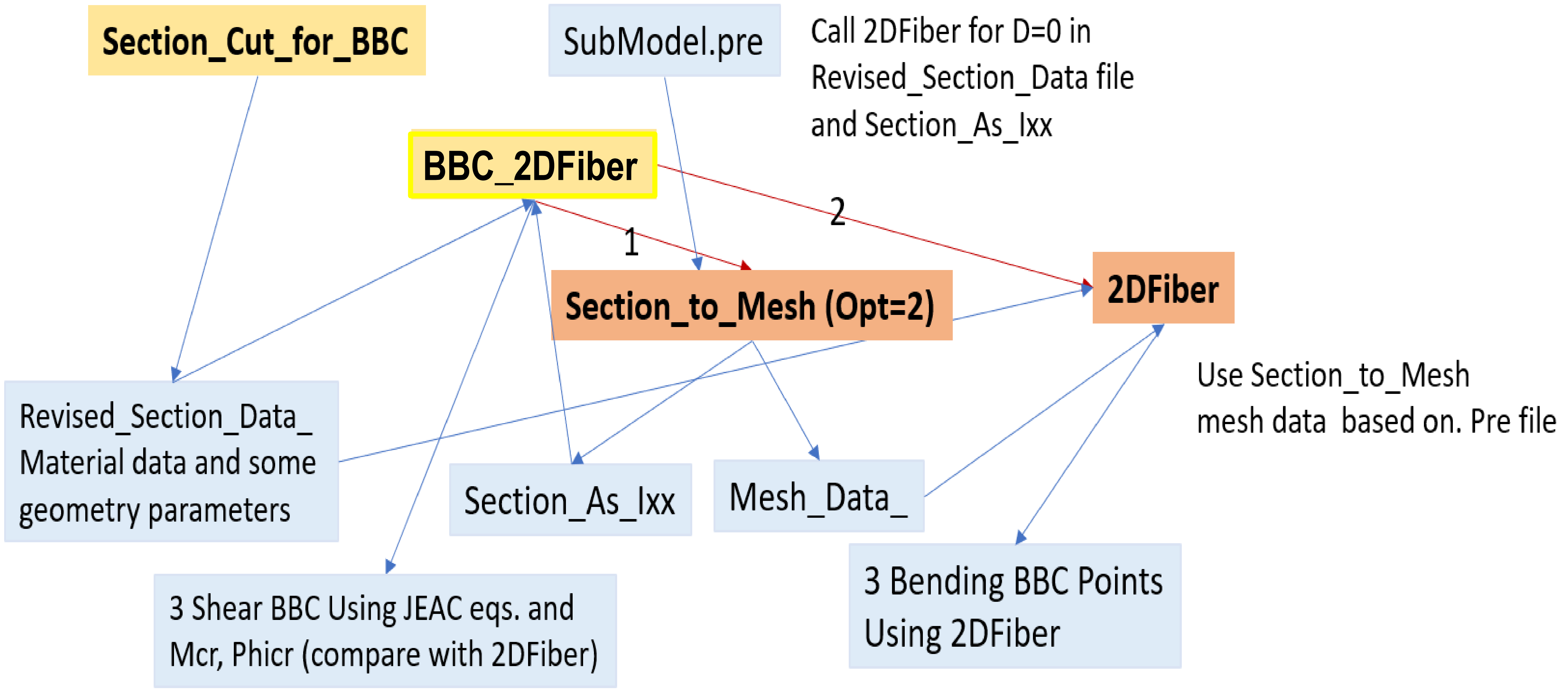


D=0.00 indicates no plan wall section geometry was identified

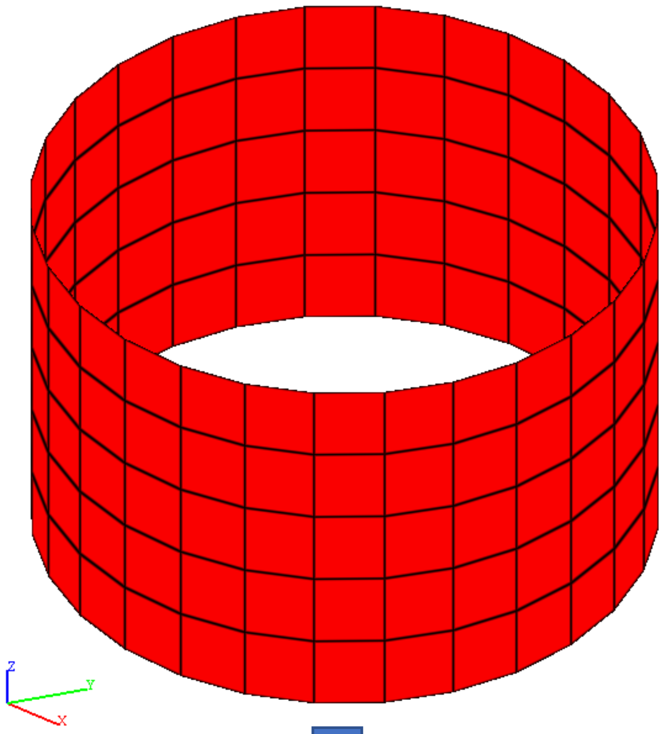
--- For closed section walls, BBC_2DFiber module computes the section geometry parameters using wall submodel .pre

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

Computing BBCs for Closed Section Wall Geometries Using *BBC_2DFiber* Module

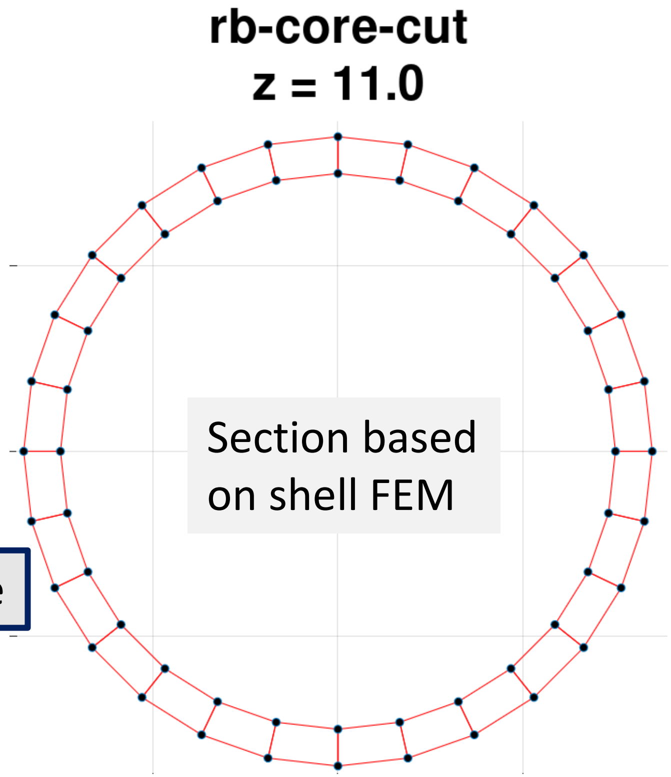


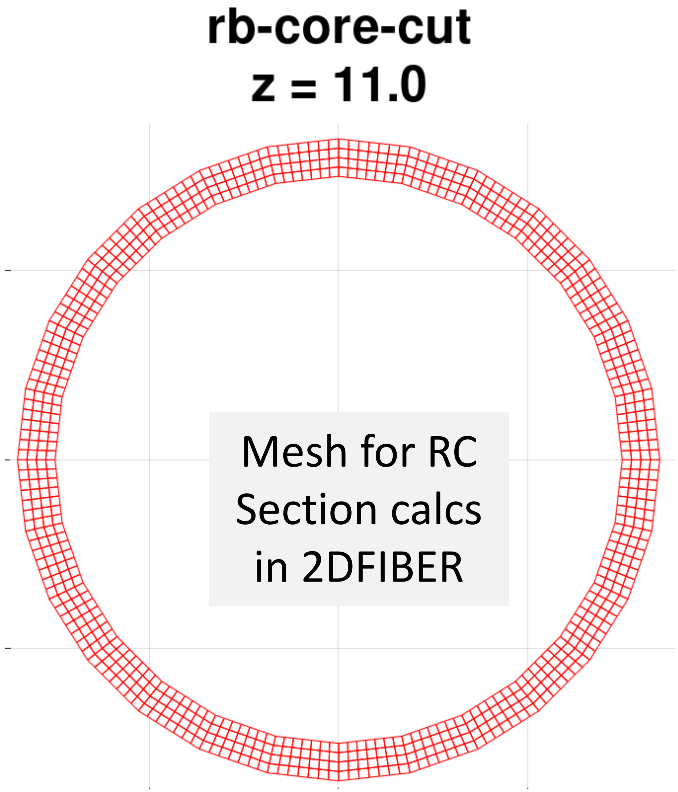
Computing RC Section BBC for Circular Walls Using *BBC_2DFiber*



Generate input for 2DFIBER Module for Bending BBC

Mesh_Data file



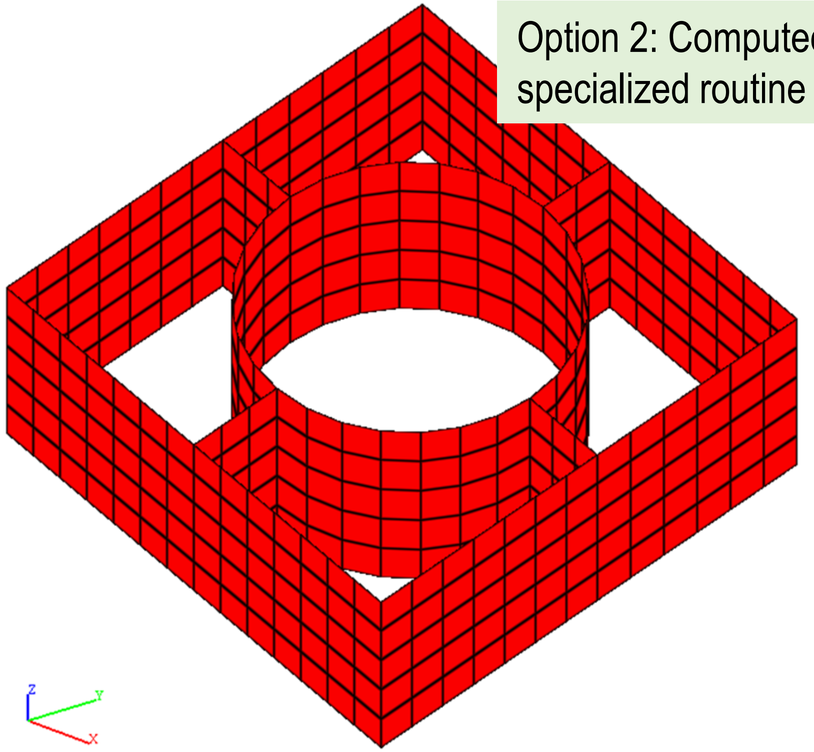


Compute BBC using JEAC 4601 App.3.7 equations for Shear BBC

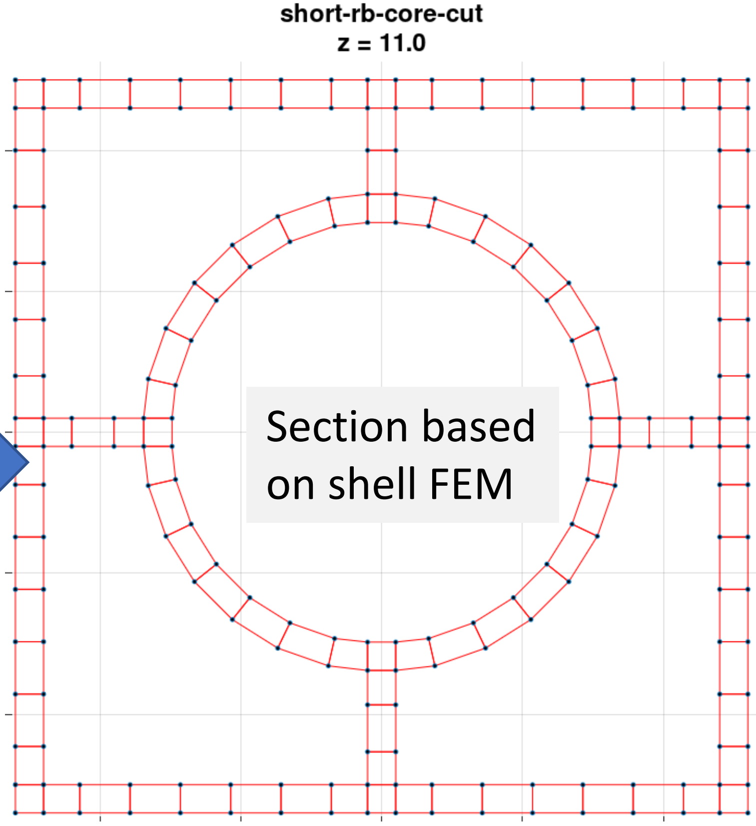
Center of gravity:
xc = -0.566621E-15 yc= -0.301017E-15
Area:
A= 200.640 Ash_x =106.667 Ash_y = 106.667
Moment of Inertia:
Ixx = 25500.7 Iyy = 25500.7 Ixy = -0.966338E-12

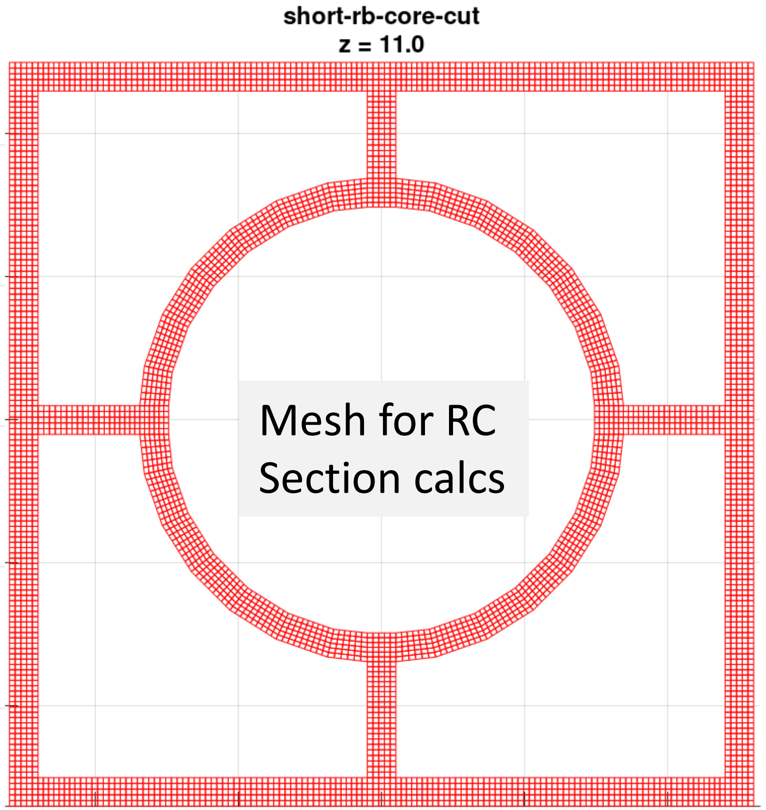
Section_As_Ixx file

Computing BBCs for Arbitrary Shape Walls



Option 2: Computed BBC specialized routine





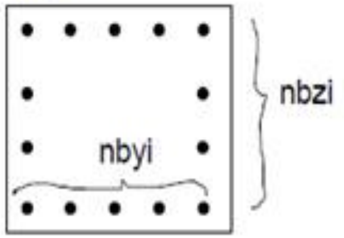
Option 1: Compute BBC using JEAC 4601 App.3.7 or ACI 318 equations

Center of gravity:
xc =-0.422540E-15 yc =-0.743339
Area:
A = 672.640 Ash_x = 303.333 Ash_y = 303.333
Moment of Inertia:
Ixx = 208118. Iyy = 207618.

Defining Reinforcement for BBC Calcs Using *BBC_2DFiber* Module

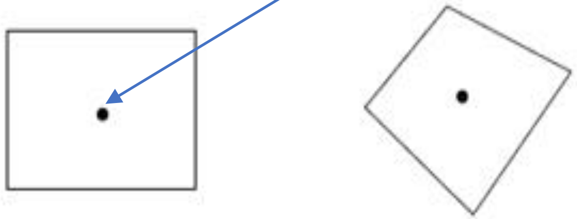
On each type of subsection different types of automatic reinforcement can be used.
For intersections there are 3 types of functions that can be used:

* arm_loc_re/arm_loc - for rectangular subsections that are rotated (arm_loc_re.m) or not (arm_loc.m) - Rectangular

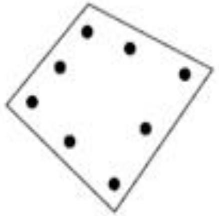


Default

* arm_loc_conc - a single rebar in the center of the gravity of the intersection patch - Concentrated

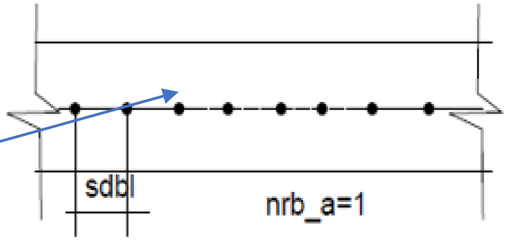


* arm_plo - for poligonal surfaces - Quad

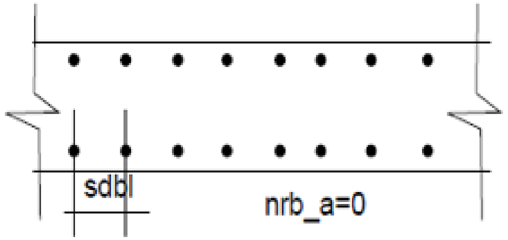


For spans one single type of function is used:

* arm_distrib_re/arm_distrib - for rectangular spans that are rotated (arm_distrib_re.m) or not (arm_distrib.m)



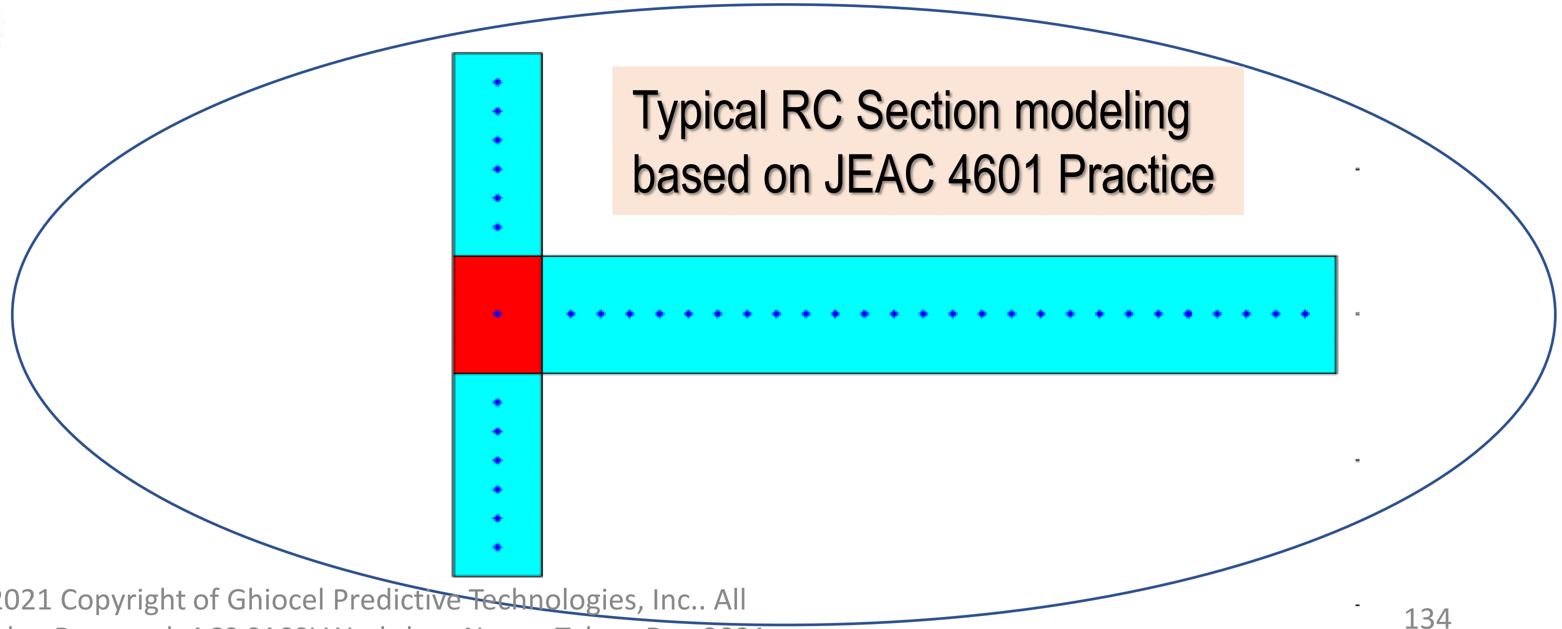
use only a middle row



use real number of rows

For arcs one single type of function is used:

* arm_distrib_arc - distrubtes reinforcement automatically on arc spans - it can use one middle row or maximum 2 rows.



If D=0, New Lines Shall be Added for Non-Planar Wall Section Shapes

```
SMR_surf_interior1.pre
  0.5
  3 1
  2 1
```

Line 9: FPRE – The submodel.pre file name

Line 10: MESH – The 2D section mesh parameter used for the 2D Fiber Model calculations

Line 11: SECTYPE NDIRECT

SECTYPE = 1 to 5

= 1 for L shape section

= 2 for T shape section

= 3 for I shape section

= 4 for Circular section (see Figure 1.24) – nonplanar wall

= 5 for Rombic/Rotated Square section (see Figure 1.24) – nonplanar wall

NDIRECT = 1 or 2

= 1 Along input direction. User should always select this option.

= 2 Perpendicular to input. User should not select this option.

Line 12: CONCMODEL CONCTENSION

CONCMODEL = 1 or 2

= 1 Mander concrete model (unconfined concrete)

= 2 EC2 concrete model (EC = Euro Code)

CONCTENSION = 1 or 2

= 1 Concrete tension strength is not zero. It is taken equal with 0.38 (f'c)^0.5 in N/mm2.

= 2 Concrete tension strength is zero (most used in practice)

BBC_JEAC_ACI_Fiber2D Module Run and Files (Step 7)

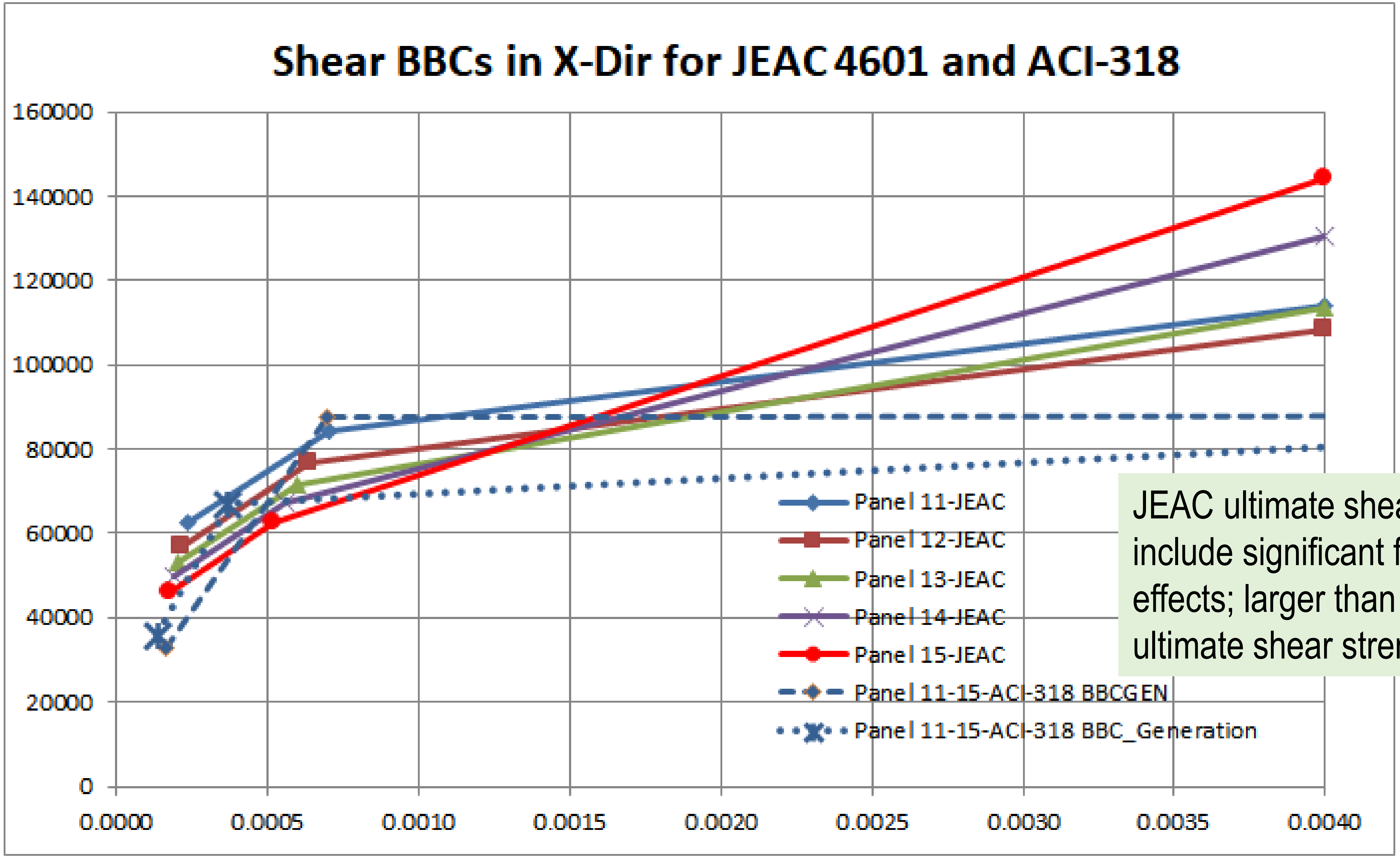
Step 7:

Batch *BBC_JEAC_4601_2015* Module V4.3.1 or *BBC_JEAC_ACI_Fiber2D* Module V4.3.2 run – for Directional Walls:
This module computes the shear and bending BBC for each Wall submodel based on JEAC 4601-2015 App.3.7 approaches. 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 namely the module *.out file and BBC_ShearForce.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 *.out* file *and two BBC_Moment.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.

***BBC_JEAC_ACI_Fiber2D* Module V4.3.2 run – for Non-directional Walls (closed sections, circular, square, composite):**
Computes the shear and bending BBC for each Wall submodel based on 2D Fiber model and shear area numerical integration for non-planar walls (without flanges). The 2D Fiber Model is launched when Dw=0, i.e. the flange and web identification fails.

Computed Shear BBCs for TB Transverse Walls in X-Dir



JEAC ultimate shear forces include significant flange effects; larger than ACI-318 ultimate shear strengths.

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 equations

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

Automatic Writing of BBC_Shear.pre and BBC_Bending.pre Files (Step 7)

BBC-SHEARFORCE.PRE - Notepad

File Edit Format View Help

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BBCP,1,1,0.2445468127E-03, 20891.9
BBCP,1,2,0.7336404382E-03, 28204.0
BBCP,1,3,0.4000000000E-02, 49435.8          EXTERIOR
BBCP,1,3,0.4000000000E-02, 39837.4          INTERIOR
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BBCP,2,3,0.4000000000E-02, 45751.5          INTERIOR
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BBCP,3,1,0.2218756743E-03, 18955.1
BBCP,3,2,0.6656270229E-03, 25589.3
BBCP,3,3,0.4000000000E-02, 53978.9          EXTERIOR
BBCP,3,3,0.4000000000E-02, 47307.5          INTERIOR
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BBCP,5,3,0.4000000000E-02, 47931.9          INTERIOR
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BBC-MOMENTS_AVERAGE.PRE - Notepad

File Edit Format View Help

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BBCP,4,2,0.3357192573E-04,0.212802E+07
BBCP,4,3,0.6714385147E-03,0.273360E+07
BBCI,5,2,1
BBCP,5,1,0.2689307422E-05, 681891.
BBCP,5,2,0.3250784534E-04,0.190724E+07
BBCP,5,3,0.6501569068E-03,0.248413E+07
```

BBC-MOMENTS_MIN.PRE - Notepad

File Edit Format View Help

```
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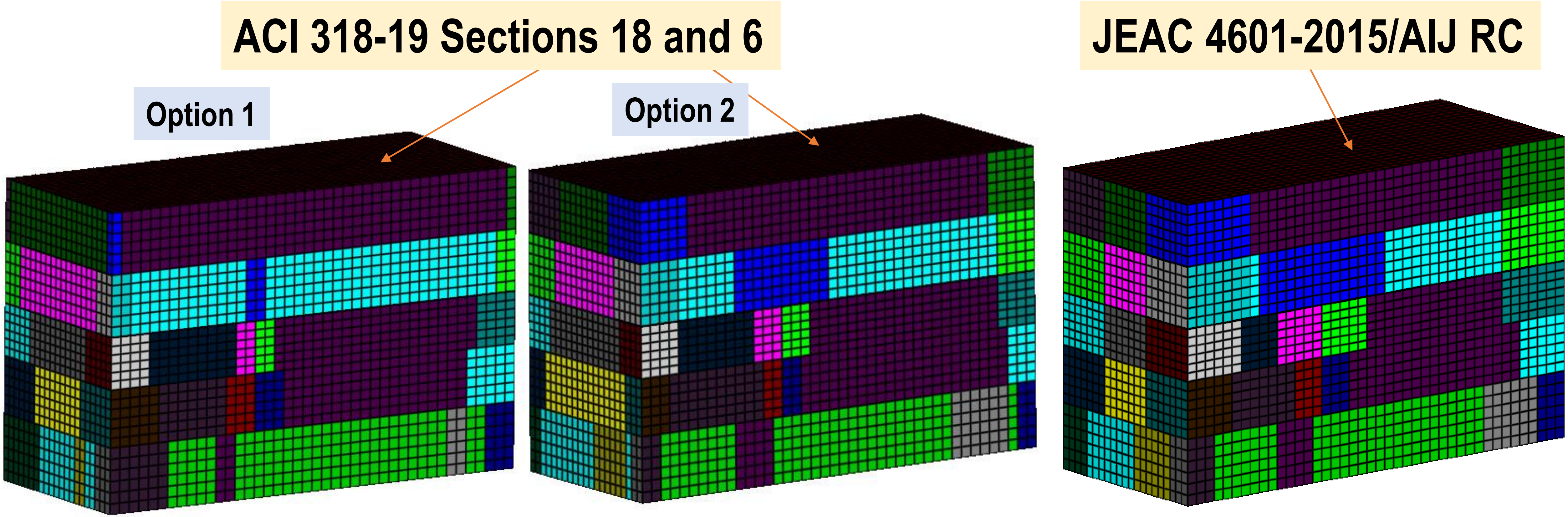
BBCP,1,3,0.6687100387E-03,0.260626E+07
BBCI,2,2,1
BBCP,2,1,0.4656650222E-05,0.102923E+07
BBCP,2,2,0.3545543831E-04,0.225709E+07
BBCP,2,3,0.7091087662E-03,0.290794E+07
BBCI,3,2,1
BBCP,3,1,0.4107017591E-05, 975215.
BBCP,3,2,0.3442170737E-04,0.218275E+07
BBCP,3,3,0.6884341474E-03,0.280903E+07
BBCI,4,2,1
BBCP,4,1,0.3363718149E-05, 832847.
BBCP,4,2,0.3323524759E-04,0.196979E+07
BBCP,4,3,0.6647049519E-03,0.256634E+07
BBCI,5,2,1
BBCP,5,1,0.2689307422E-05, 681891.
BBCP,5,2,0.3221712360E-04,0.174086E+07
BBCP,5,3,0.6443424719E-03,0.231233E+07
```

Create_Flange_Materials Module Run (Step 8) for Next Iteration

Step 8 Create_Flange_Materials Run (B)
AB_ShearWall_New.pre file

Step 8:
***Create_Flange_Material* Module** is run to create a new FE model including additional effective flange width materials.
Creates a new structure FEA model, *Modelname_New.pre*

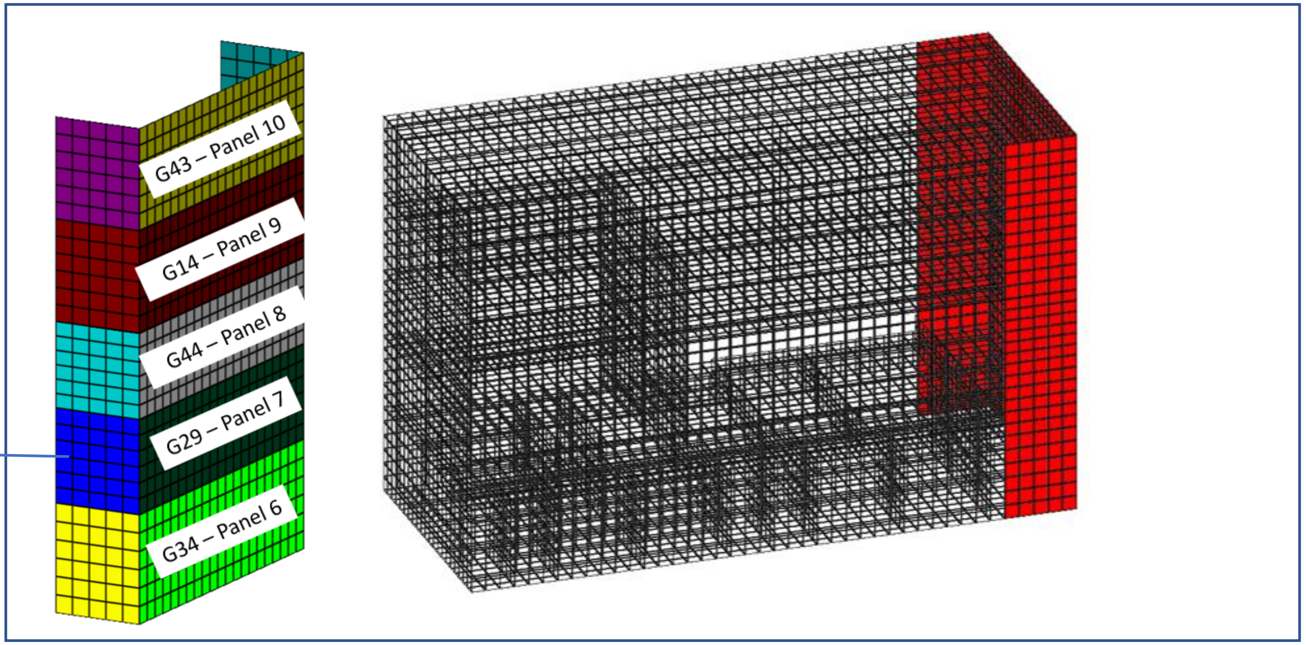


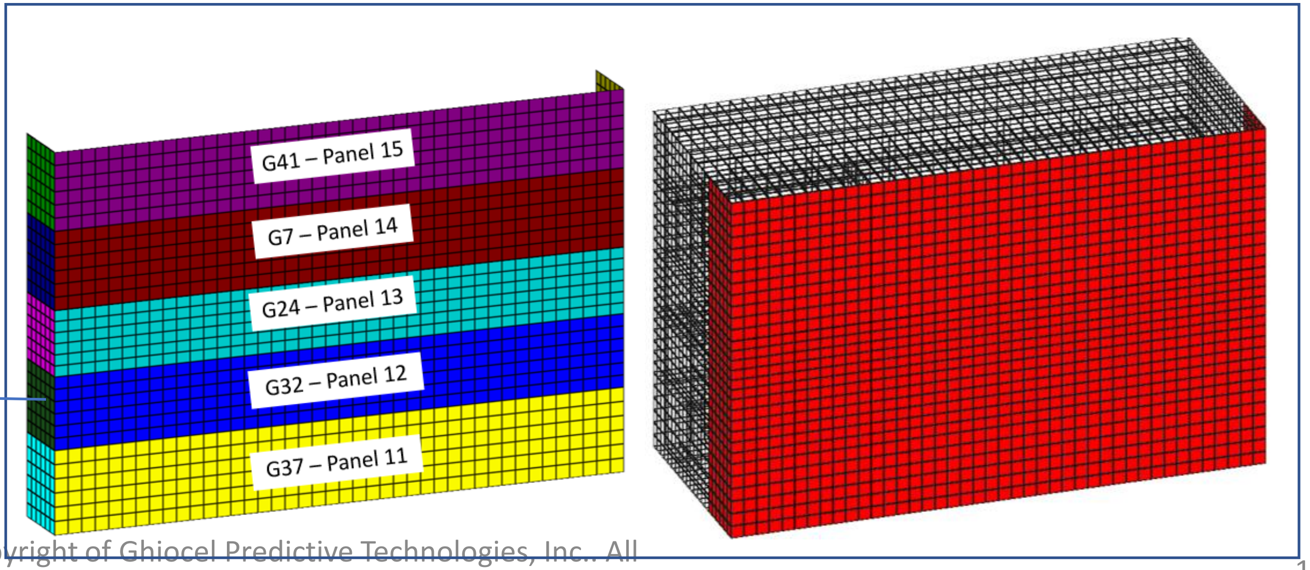
Flange Materials in Wall Panels Generated by Create_Flange-Materials Module

PANEL_EQL_MATL_PROP_SB - Notepad

File Edit Format View Help

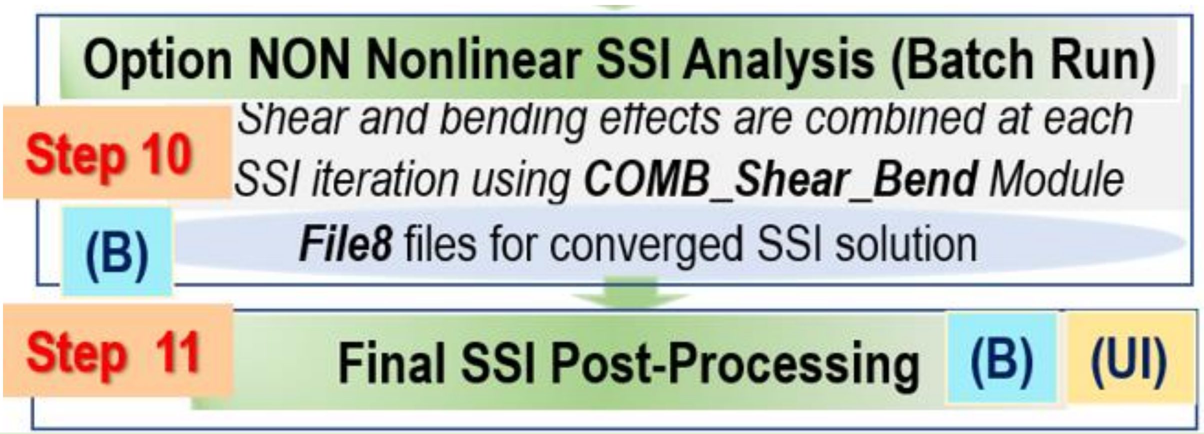
4	1	23240978.	0.058459
	2	22232838.	0.058459
	3	23240978.	0.058459
5	1	24400000.	0.050000
	2	24400000.	0.050000
	3	24400000.	0.050000
6	1	11430251.	0.093000
	2	16729636.	0.065000
	3	13712597.	0.093000
7	1	7161102.	0.084000
	2	8023446.	0.084000
	3	6027320.	0.084000
8	1	9851974.	0.098228
	2	20082859.	0.064000
	3	12380402.	0.098228
9	1	24400000.	0.050000
	2	24400000.	0.050000
	3	24400000.	0.050000
10	1	24400000.	0.050000
	2	24400000.	0.050000
	3	24400000.	0.050000
11	1	11588397.	0.091000
	2	17794868.	0.065000
	3	14502395.	0.091000
12	1	9140197.	0.082205
	2	8837852.	0.075514
	3	11062073.	0.082205
13	1	12778189.	0.050000





Integrate Final Model and Perform Nonlinear Analysis (Steps 9,10)

Step 9:
User integrates the Modelname_New.pre file with BBC .pre files to create a complete input for NONLINEAR module.
This can be done automatically by using a UI script as shown in Demos 18 and 19.



Step 10:
Option NON Nonlinear SSI Analysis Batch Run
The shear and bending deformation can be combined using the *COMB_Shear_Bend* module as described in Demos 18 and 19.

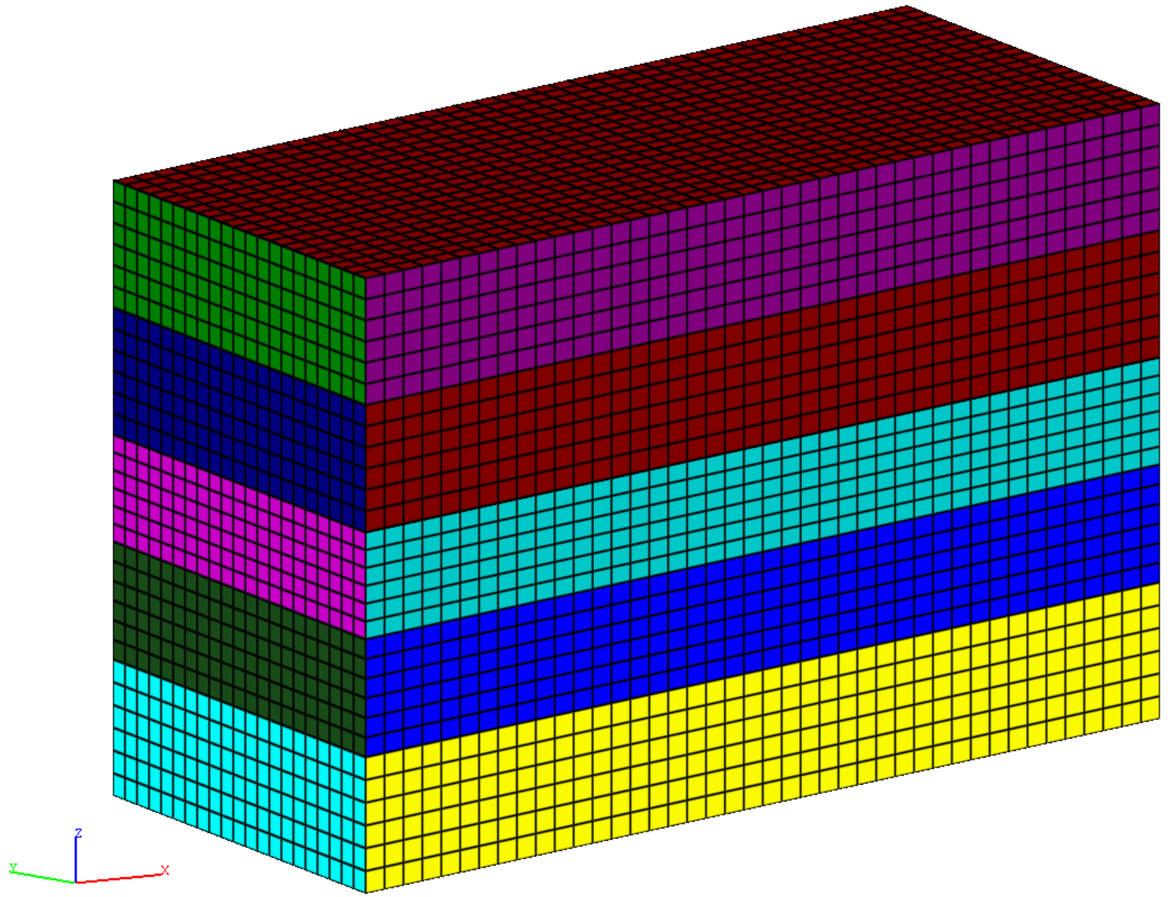
Step 11:
Post-Processing:
The main results of the nonlinear SSI analysis are the FILE8 and FILE4 (.n4) files for the converged solution that can be post-processed exactly like for a linear analysis to compute structural node displacements and accelerations, and element stresses.

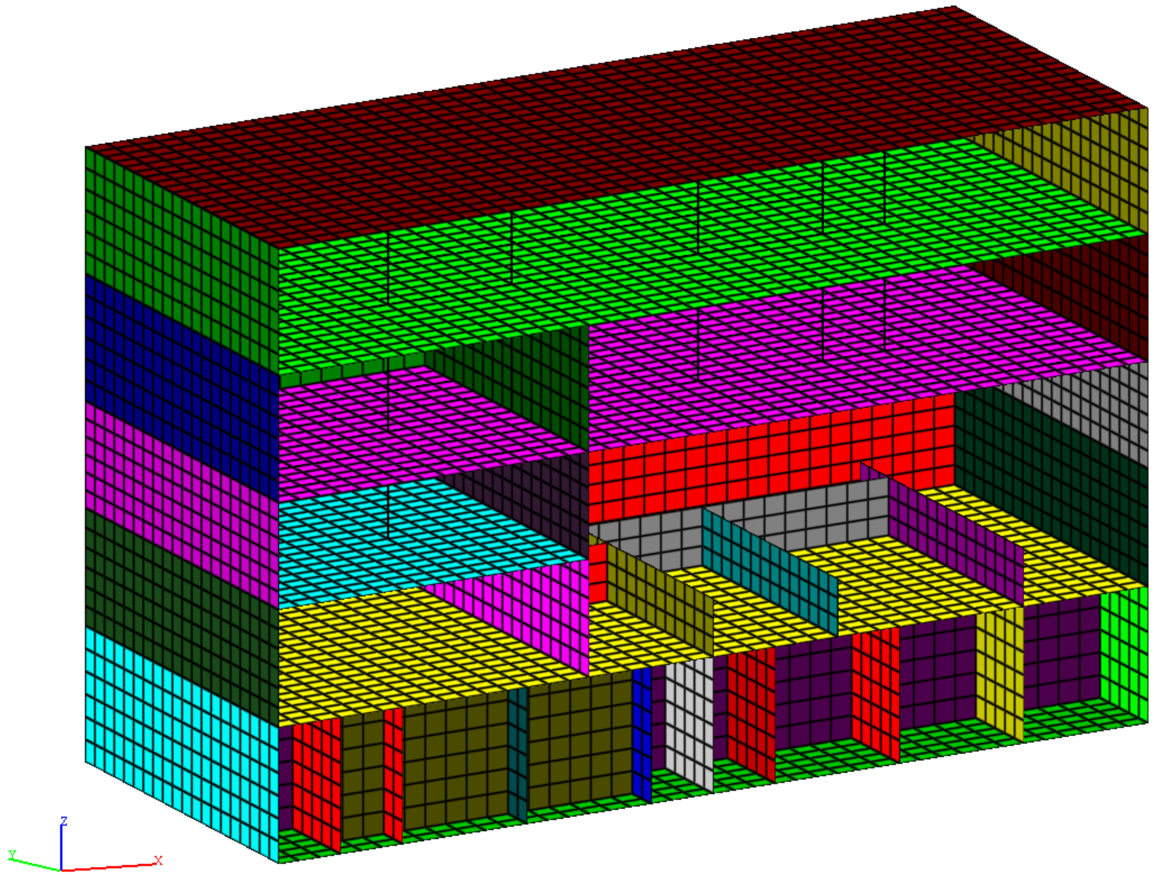
2.6 Nonlinear SSI Analysis Case Studies:

A. AB Shearwall Structure Model (AB)
B. Tower Building Structure Model (TB)

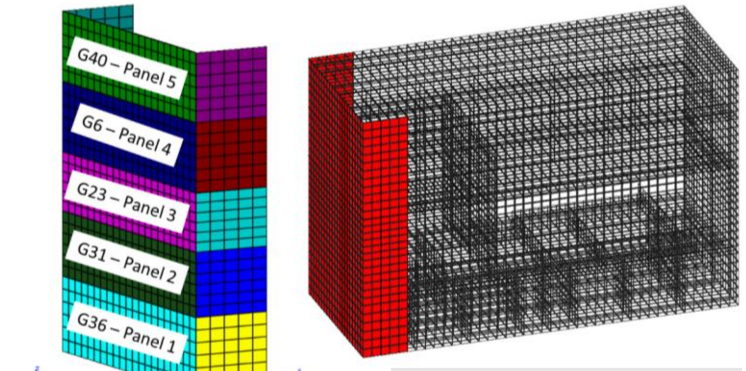
Seismic inputs based on RG1.60 spectra with 0.70g and 0.50g ZPGA

A. AB Shearwall Structure 3DFEM Nonlinear SSI Analysis

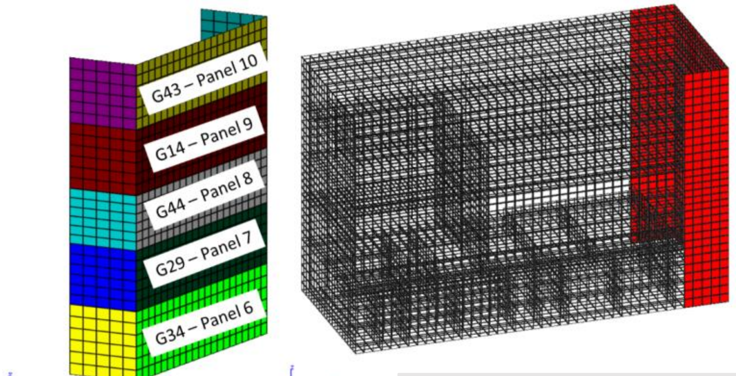




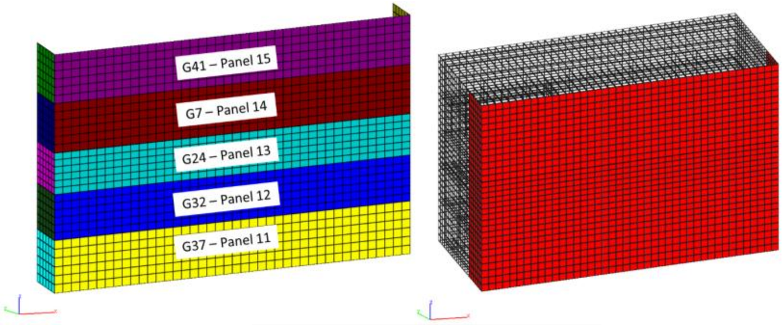
AB Shearwall 9 Wall Submodels for Nonlinear SSI Analysis



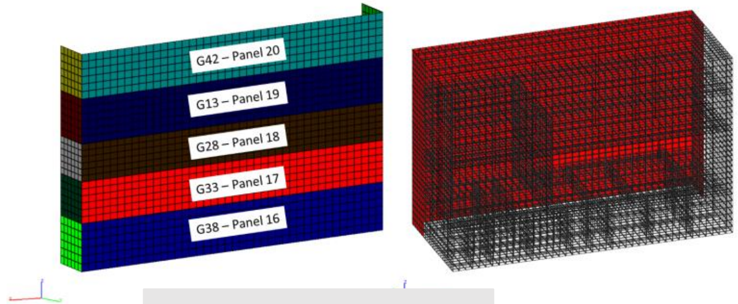
Wall Submodel 1



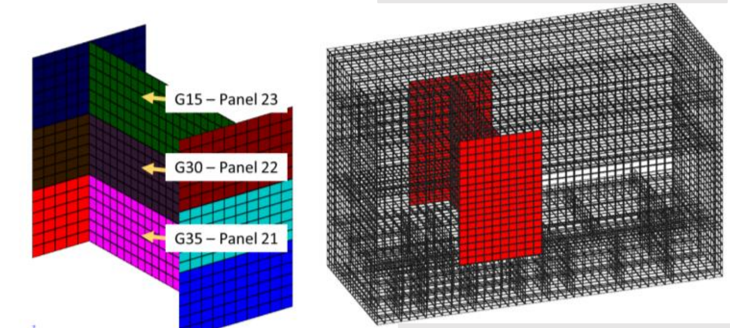
Wall Submodel 2



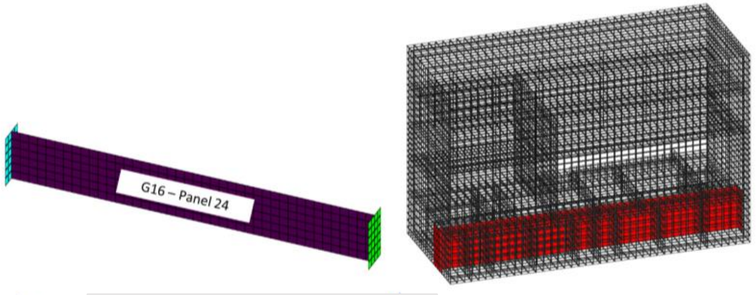
Wall Submodel 3



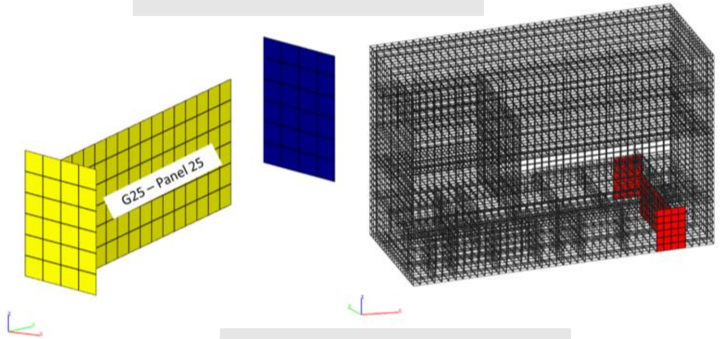
Wall Submodel 4



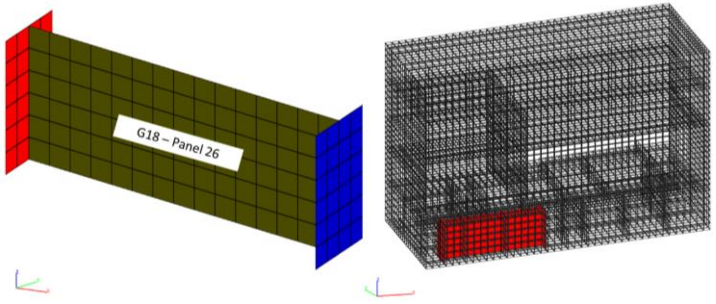
Wall Submodel 5



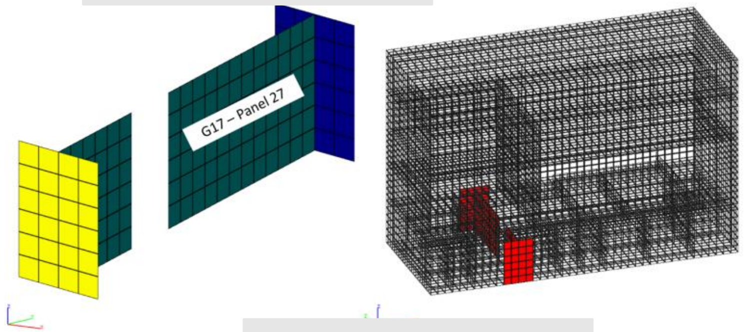
Wall Submodel 6



Wall Submodel 7

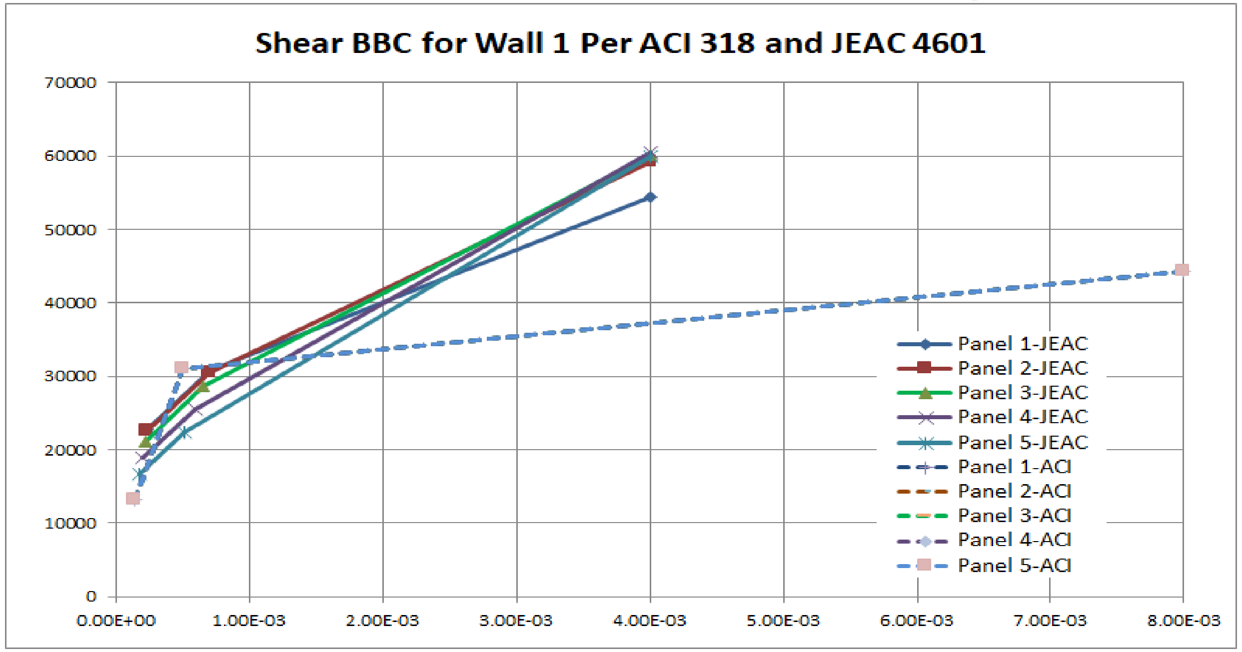


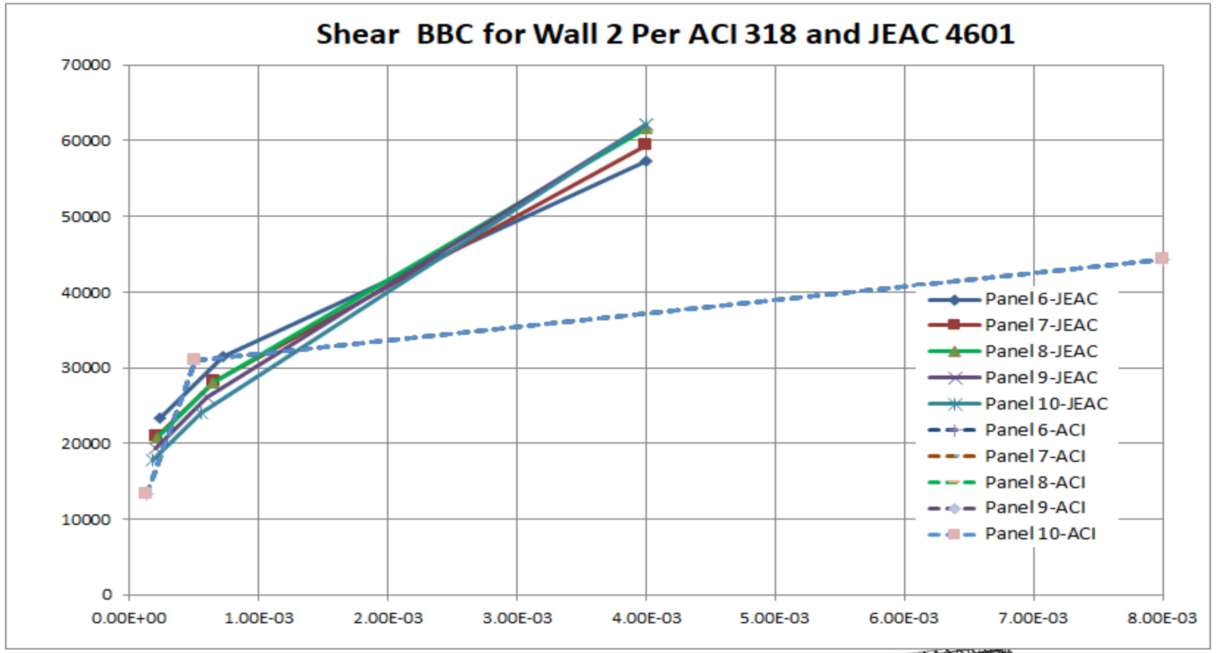
Wall Submodel 8

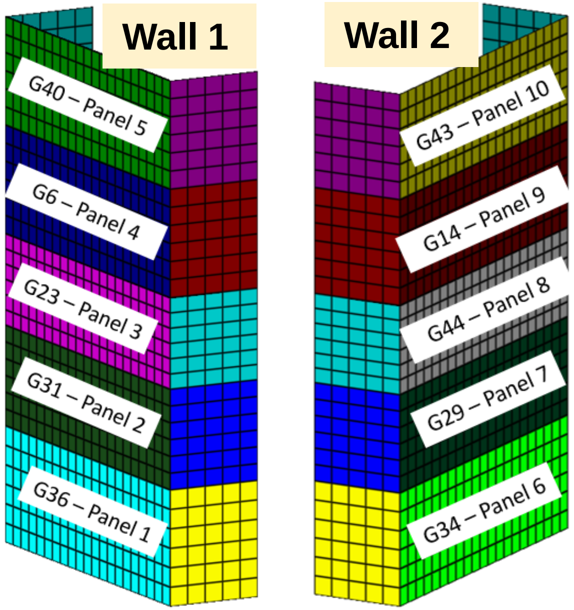


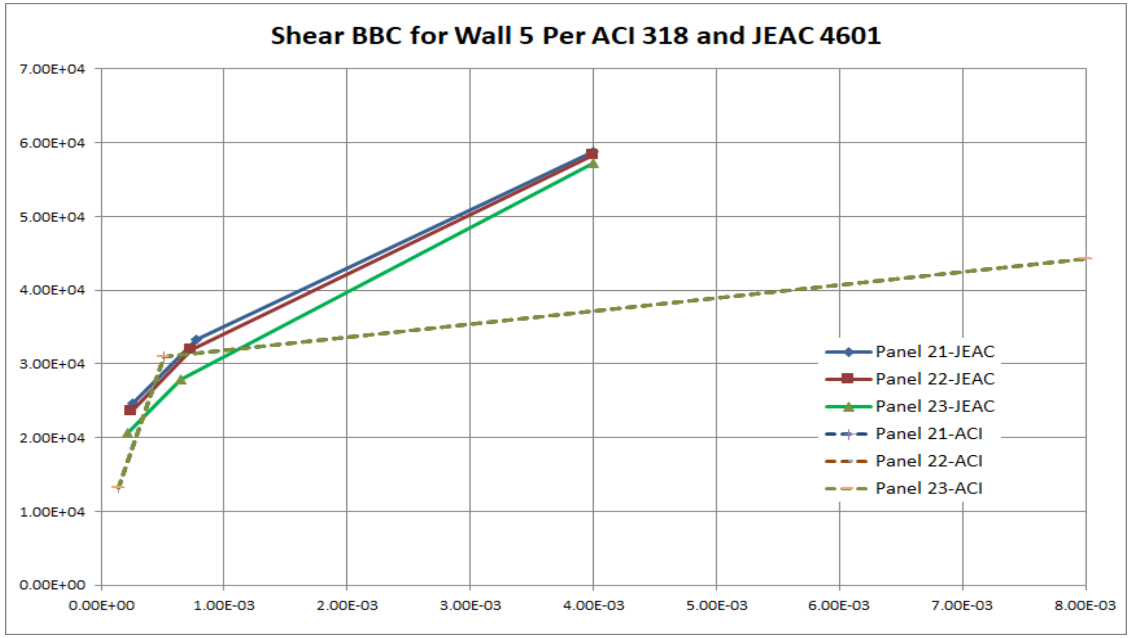
Wall Submodel 9

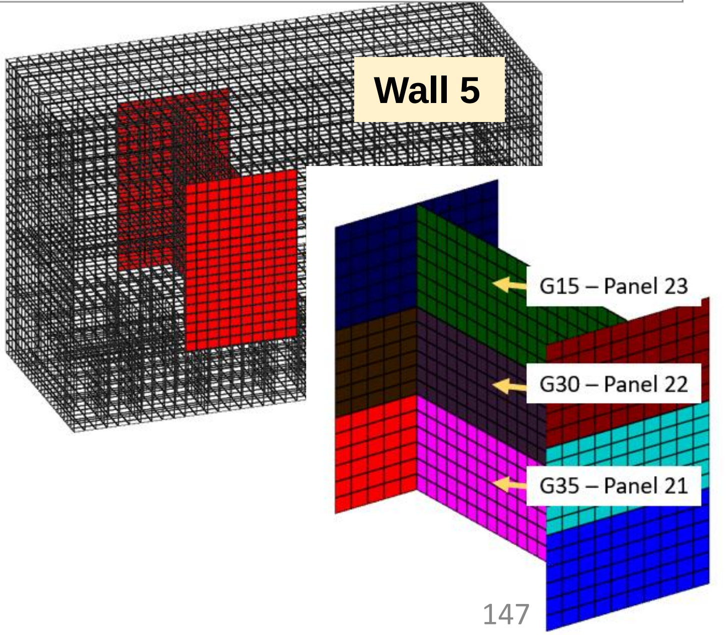
Shear BBCs for Wall 1, 2 and 5 Based on JEAC 4601-2015



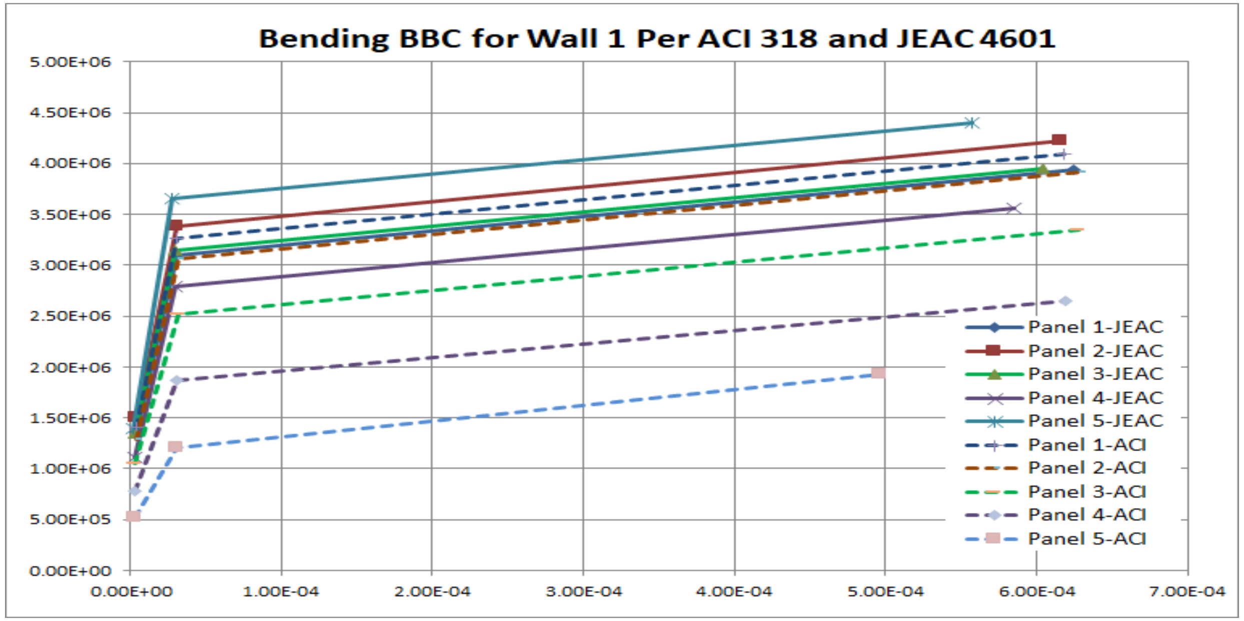


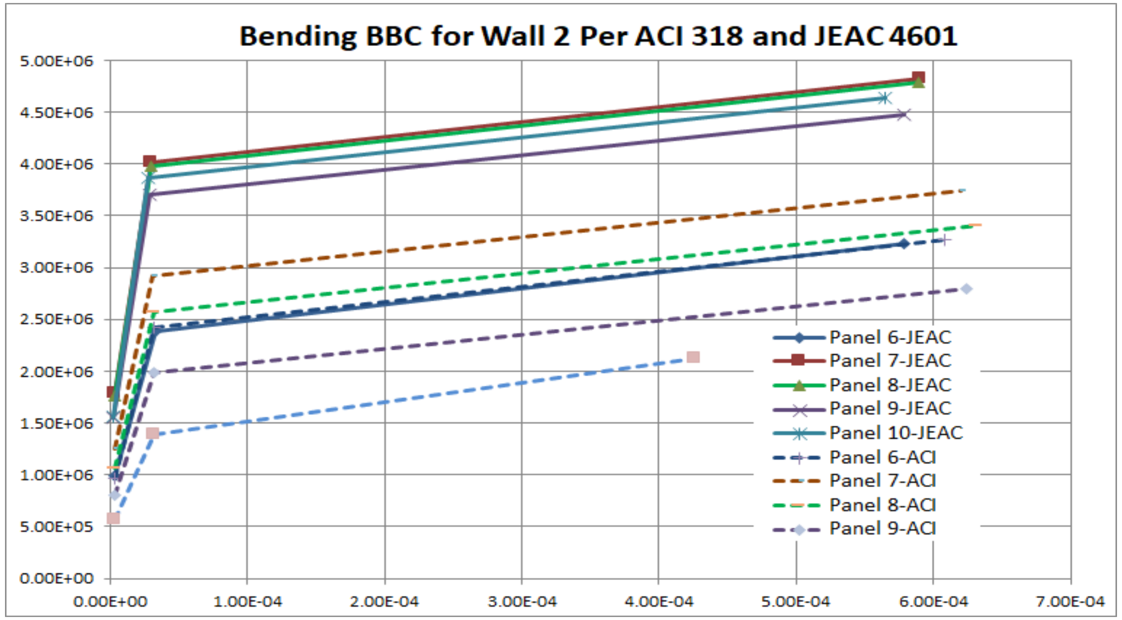


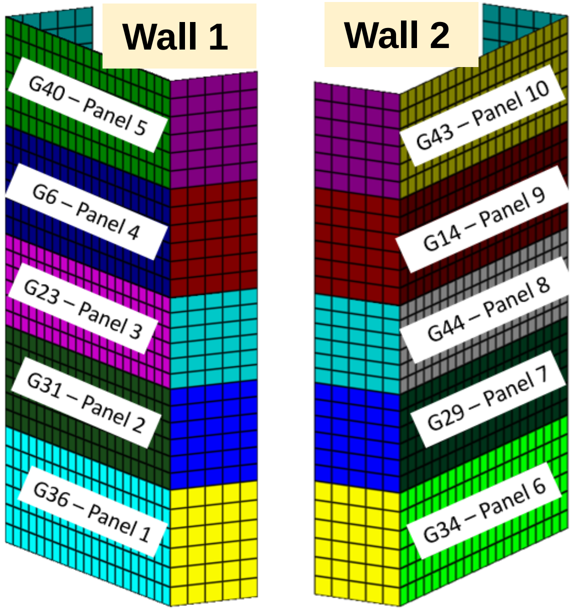


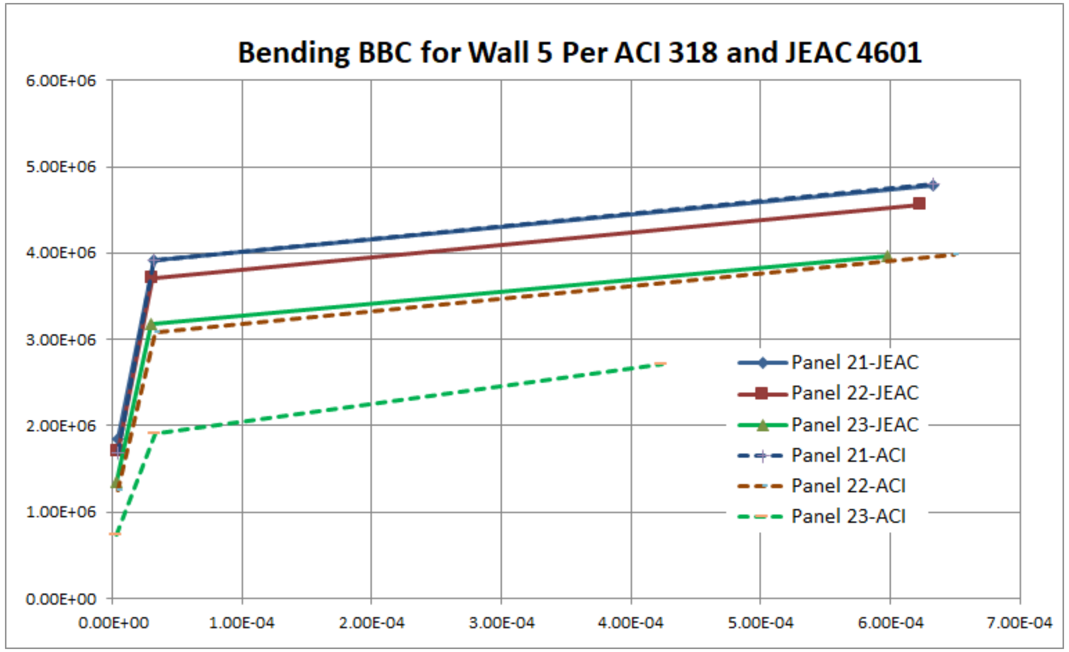


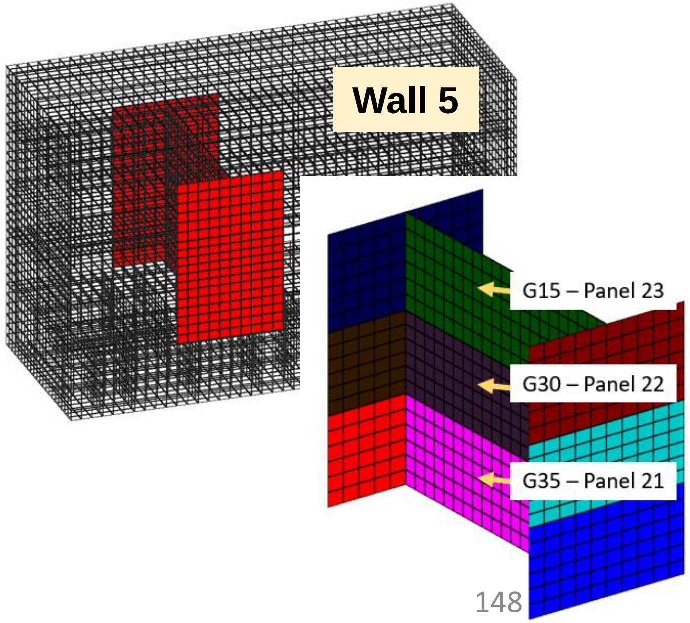
Bending BBCs for Wall 1, 2 and 5 JEAC 4601-2015



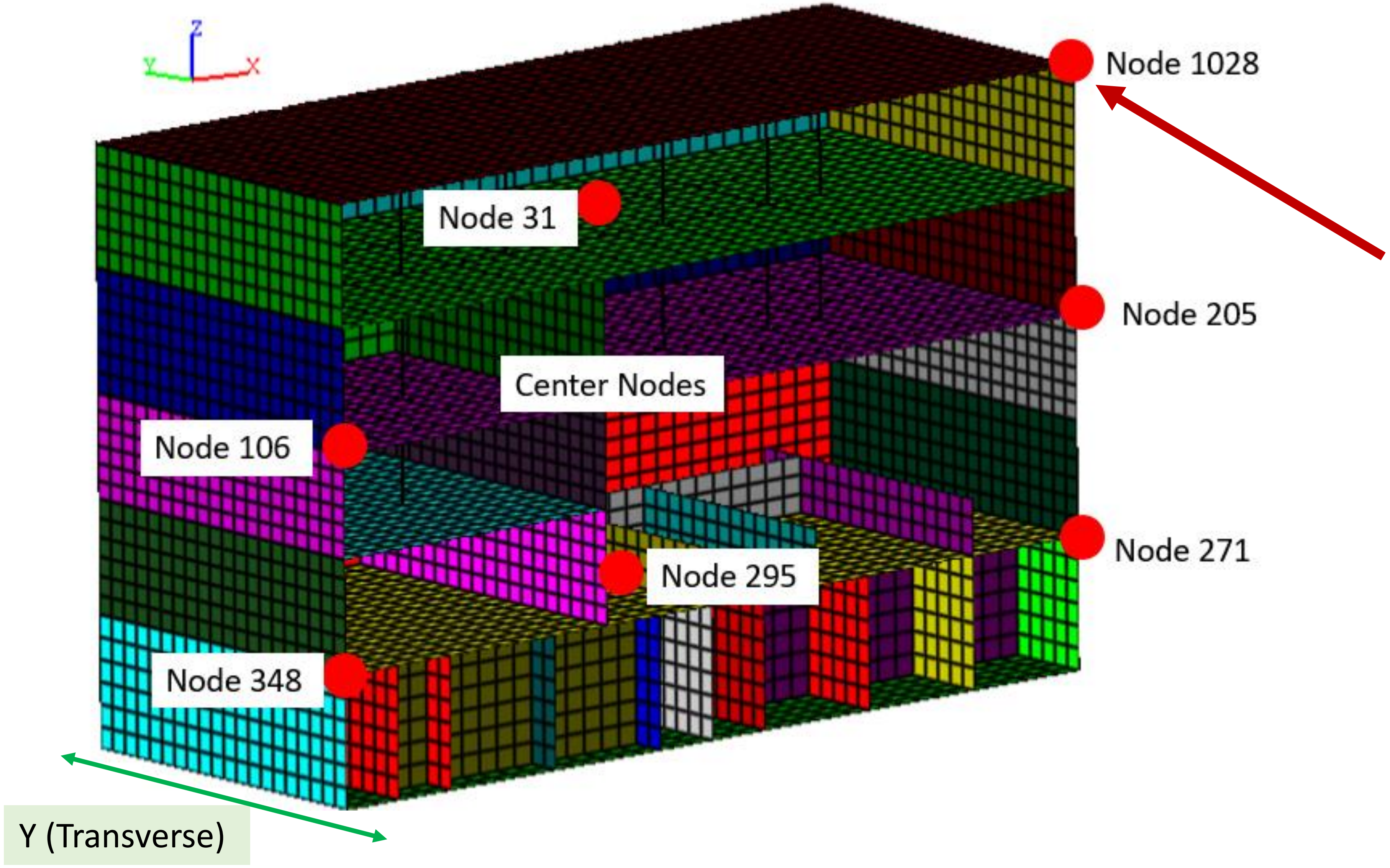




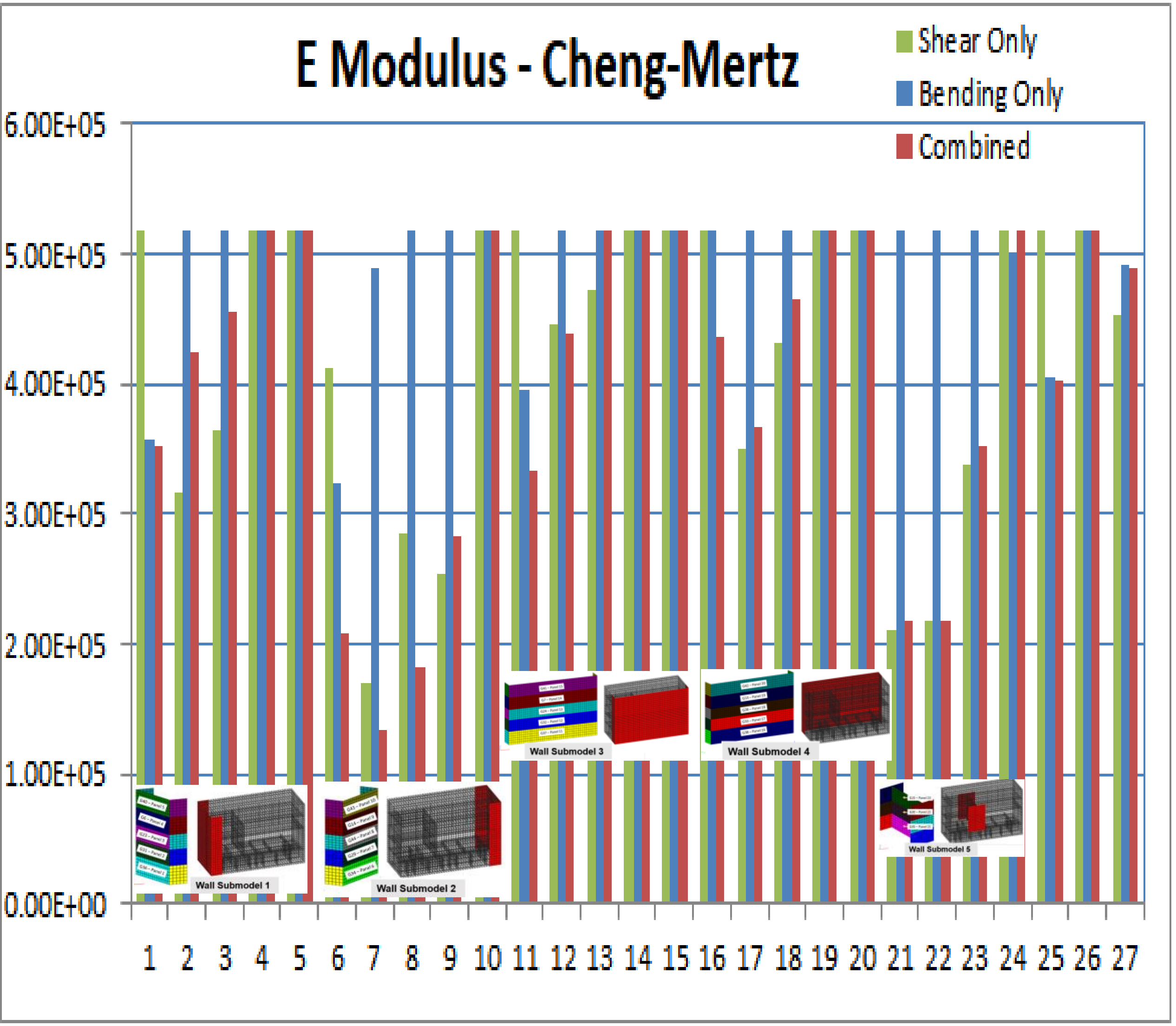


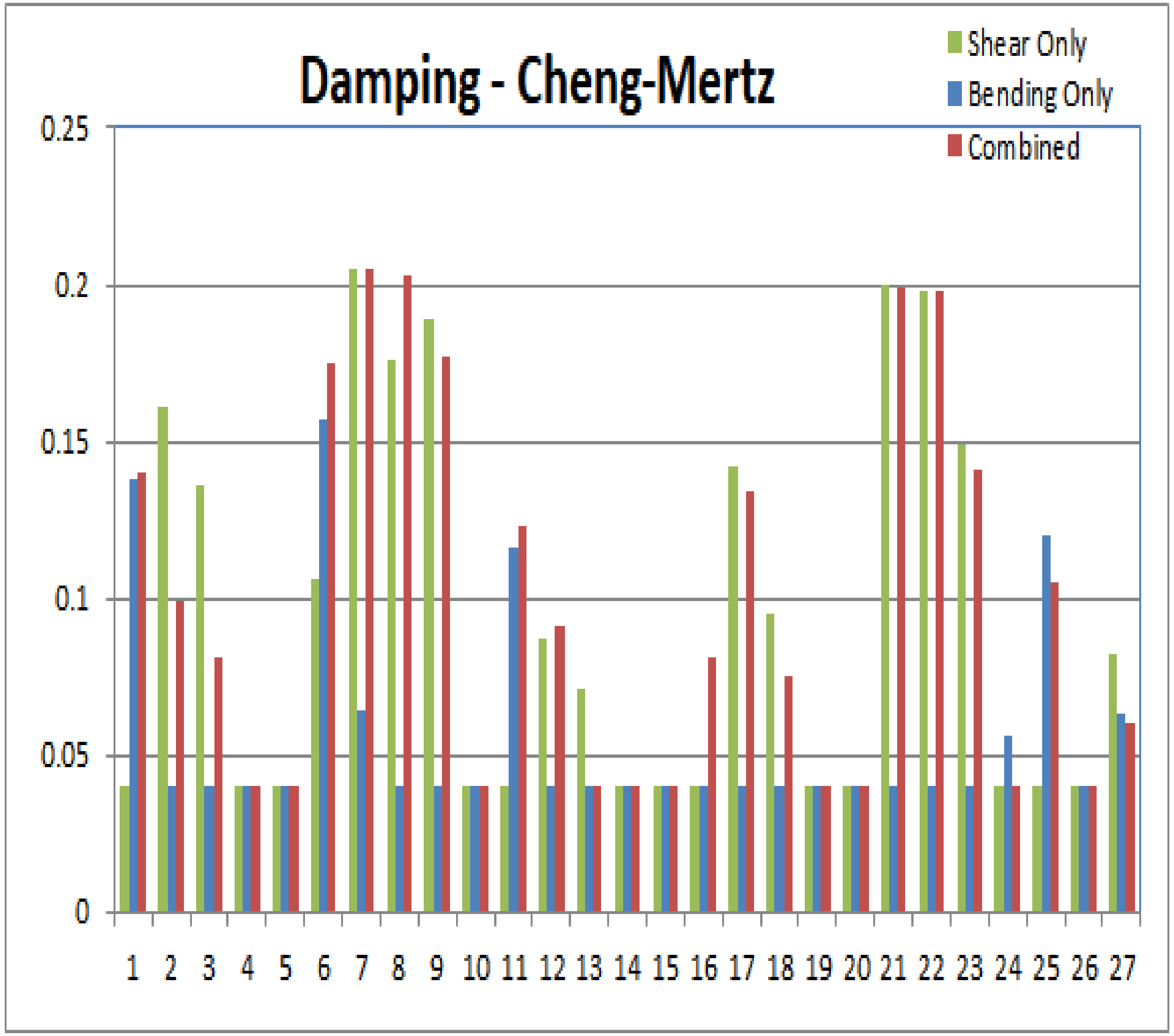


Selected Structural Nodes for SSI Response Outputs



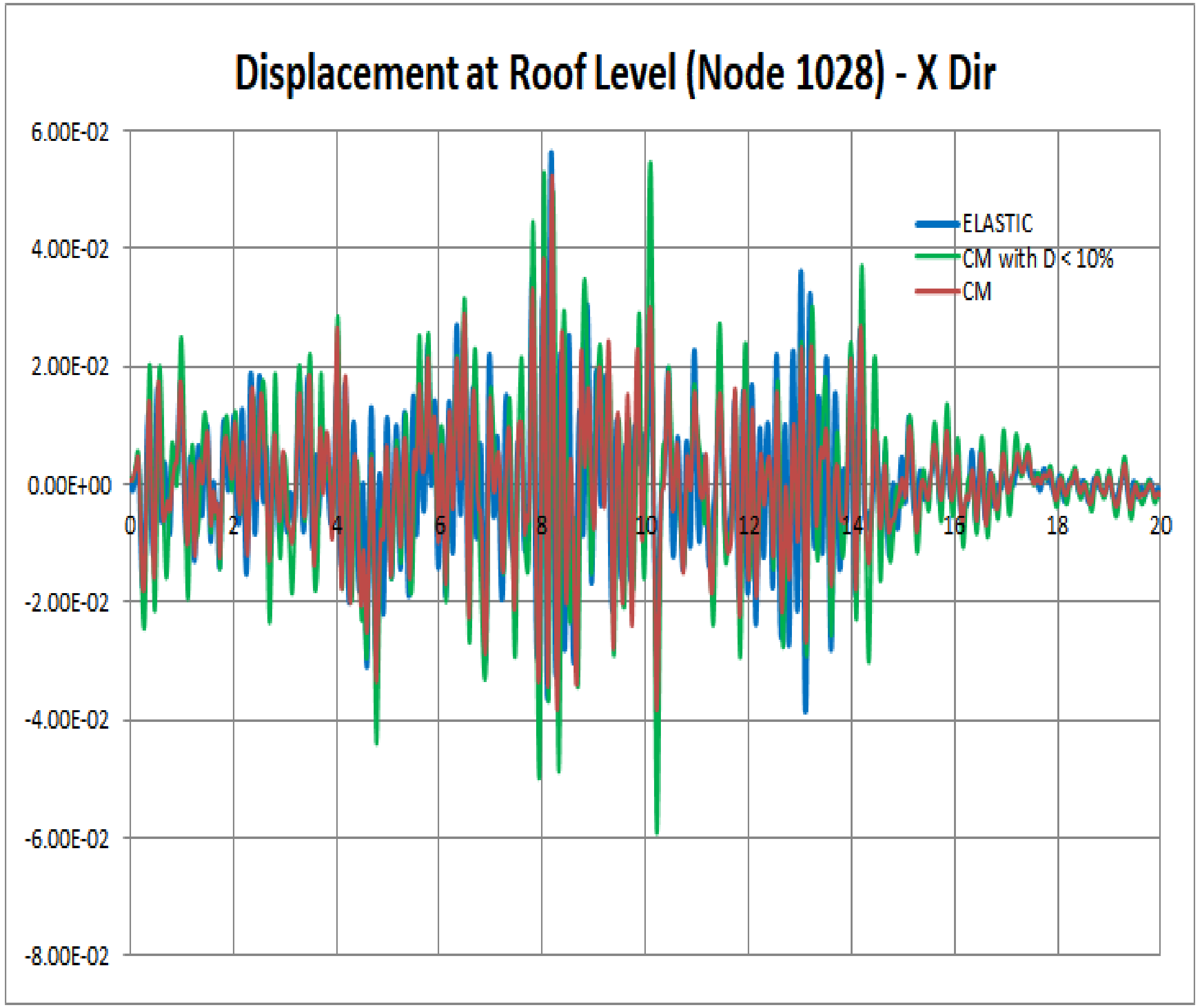
Iterated Stiffness and Damping for ACI 318 CM Models for 0.70g



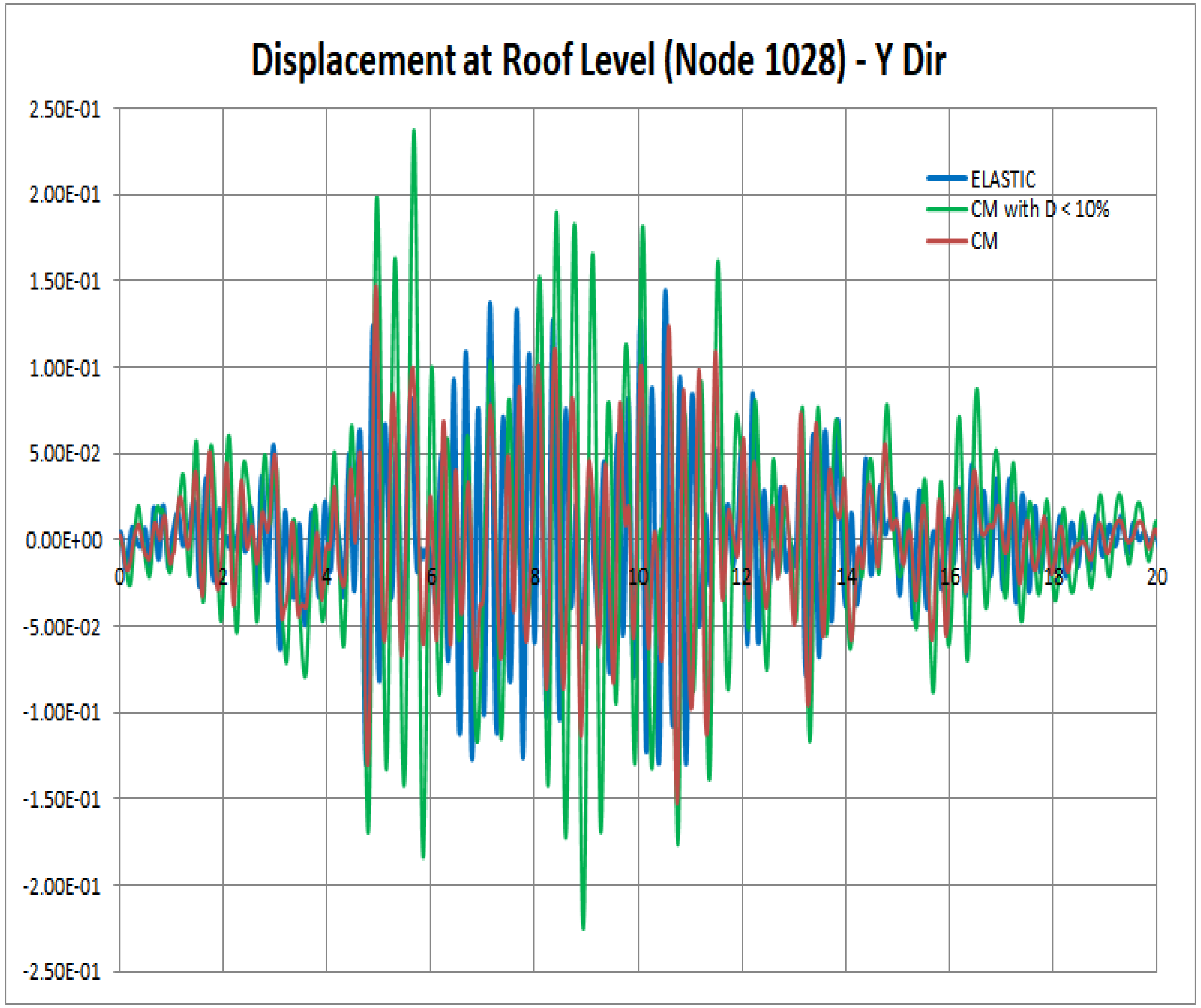


Roof Structure Displacements for Cheng-Mertz w/ and w/o D<10%

X-Dir

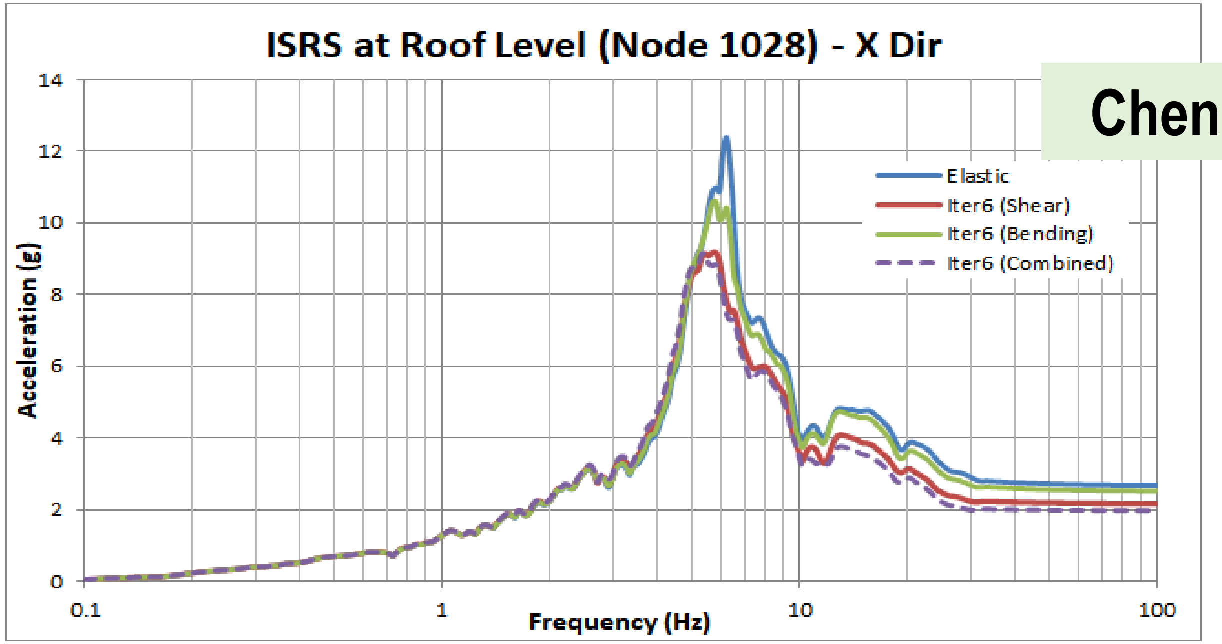


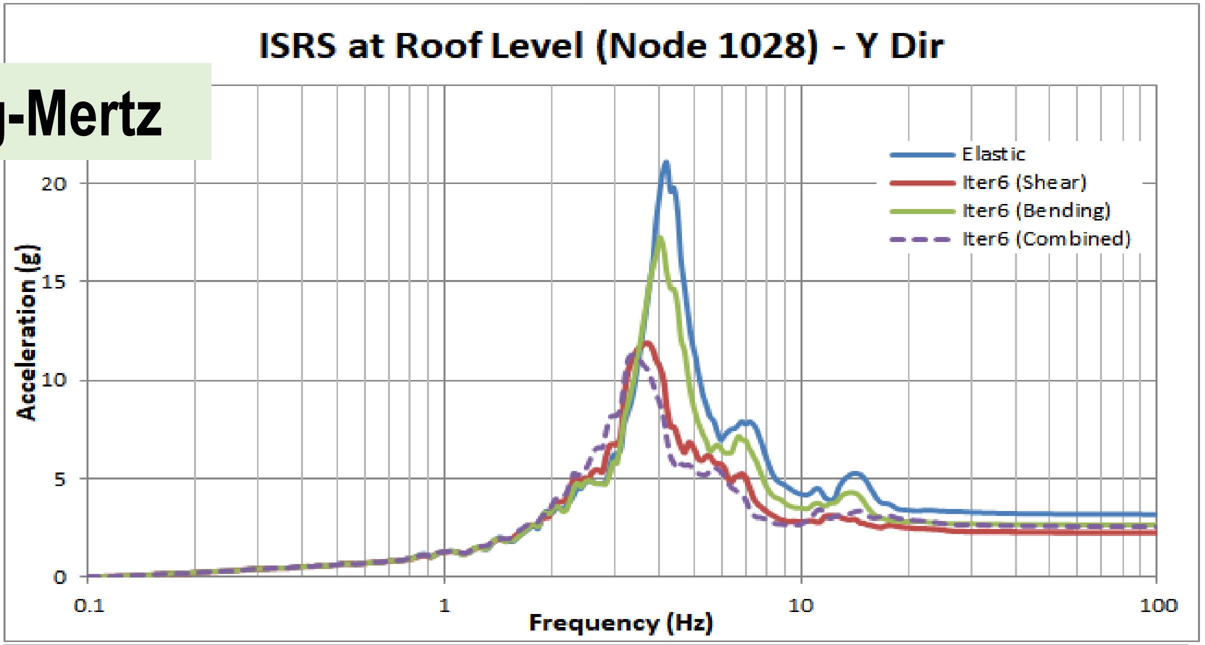
Y-Dir



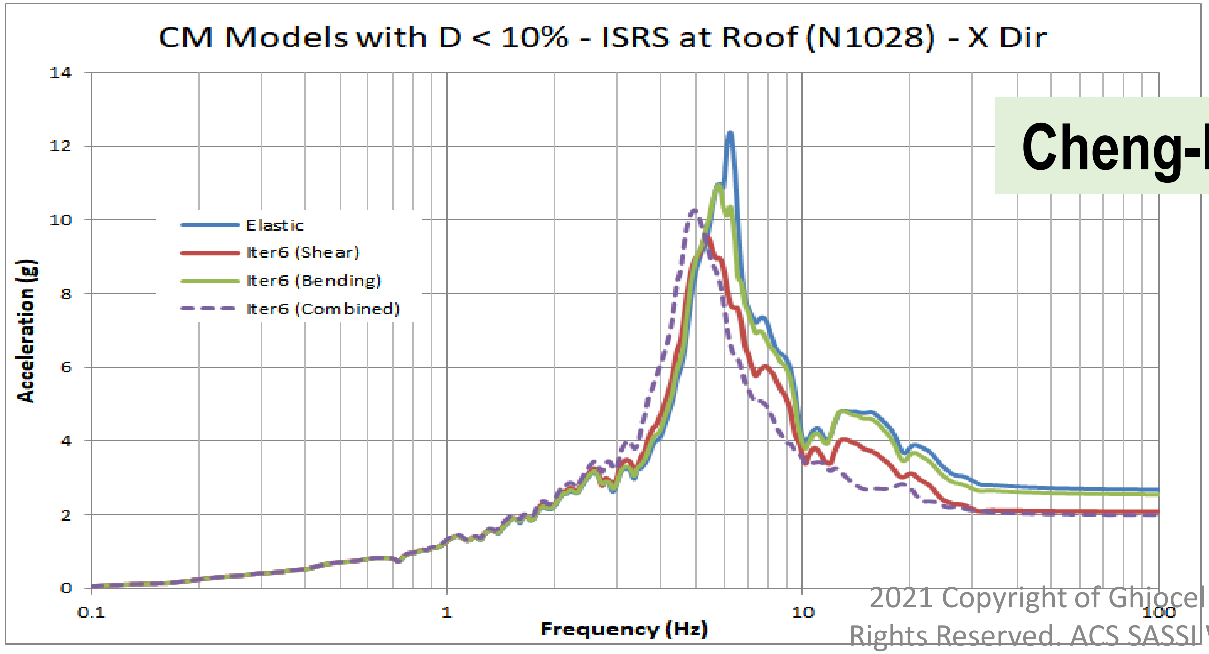
ISRS for Cheng-Mertz With and Without Damping Cut-Off D < 10%

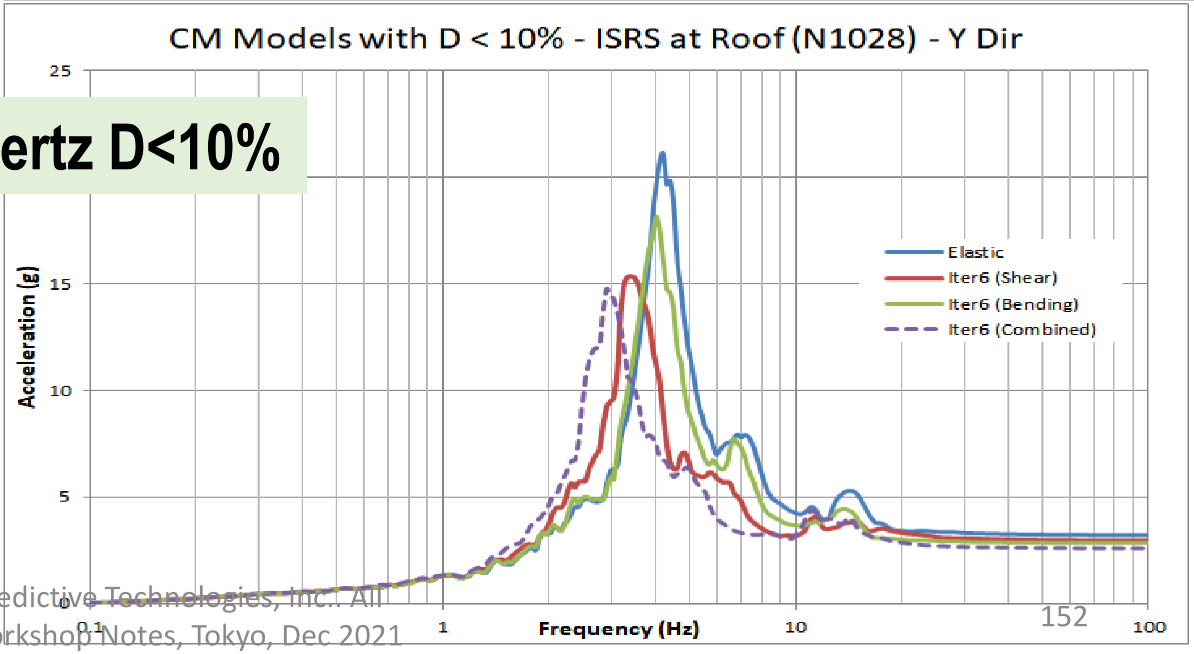
Cheng-Mertz



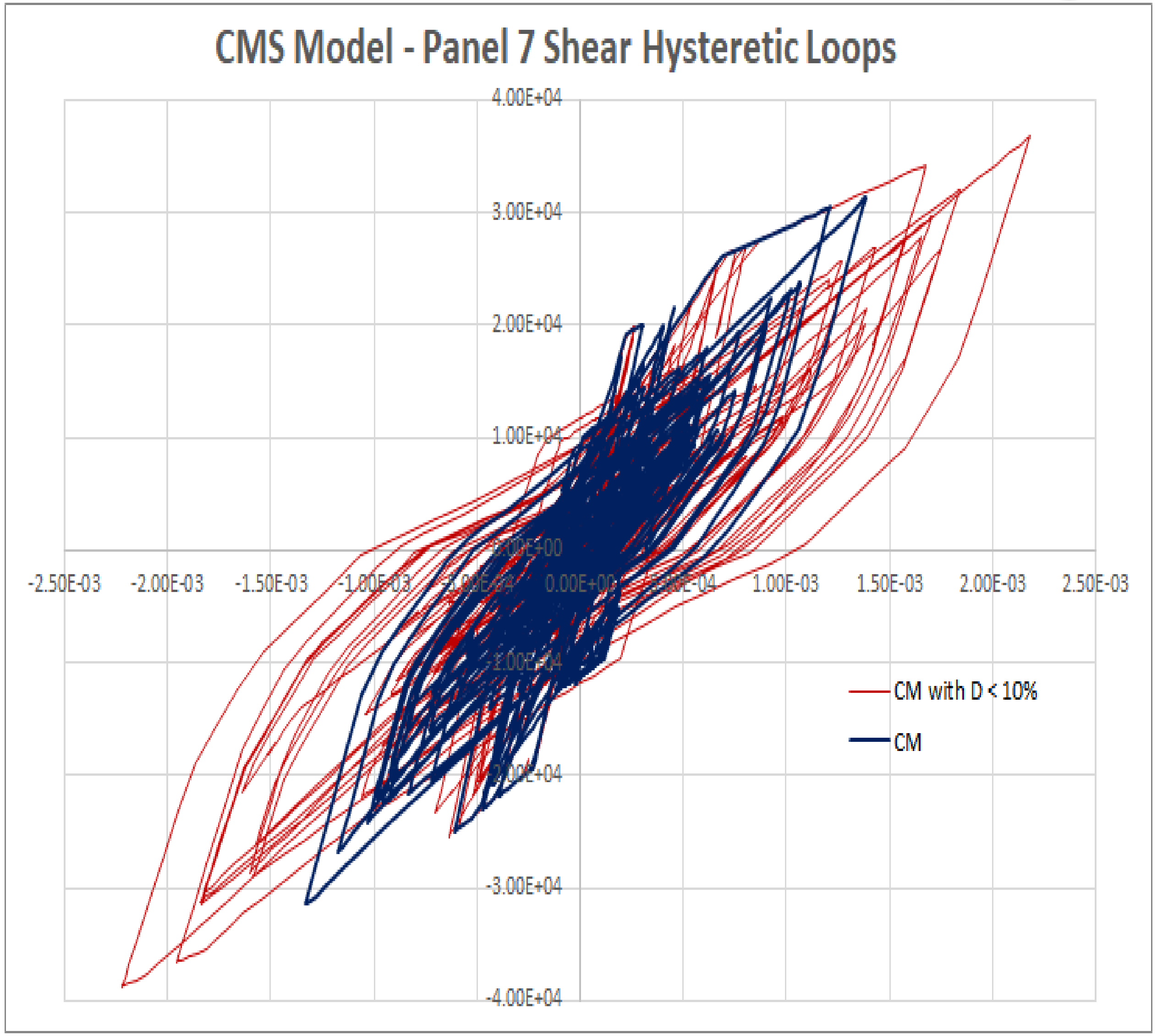


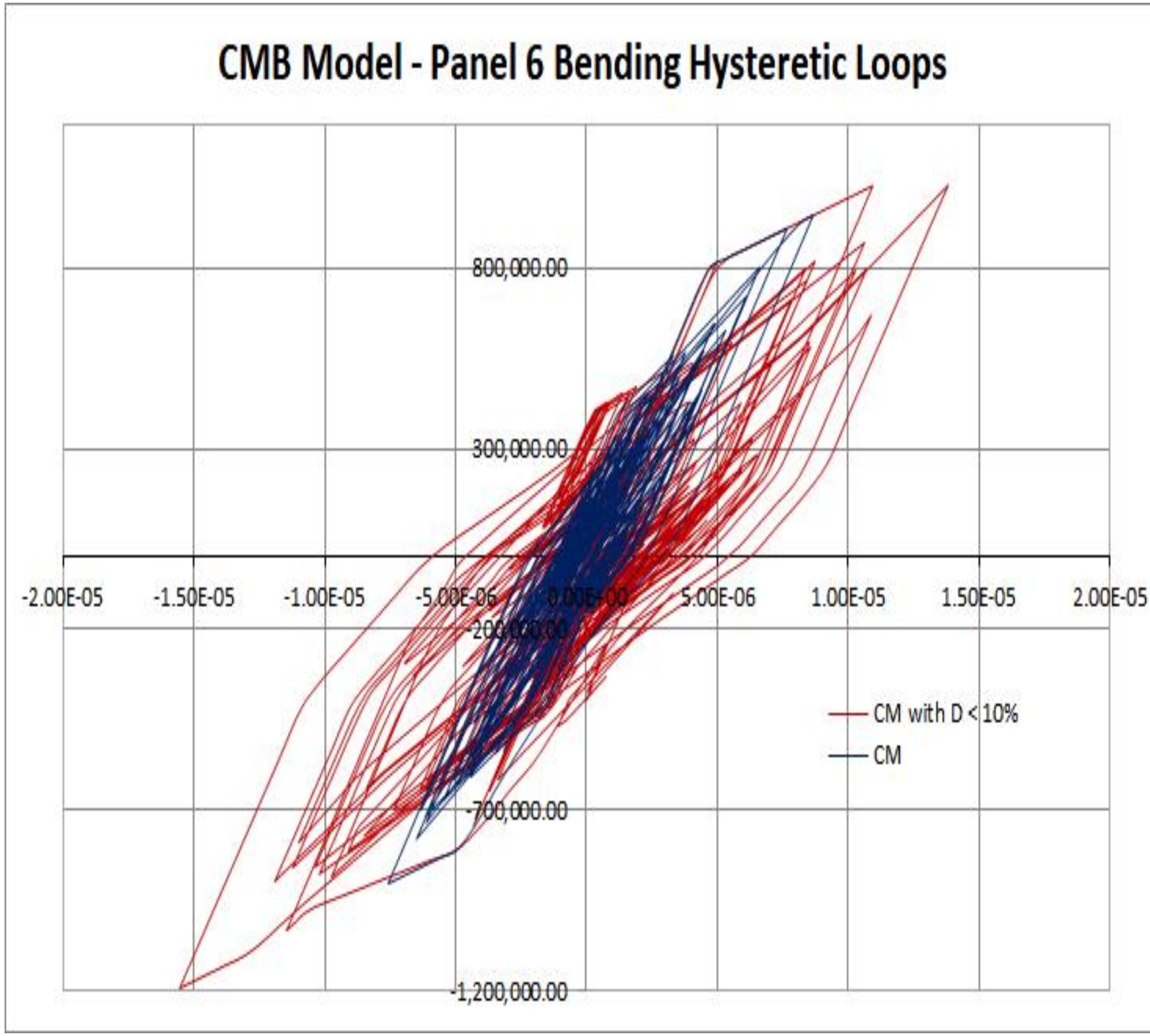
Cheng-Mertz D<10%



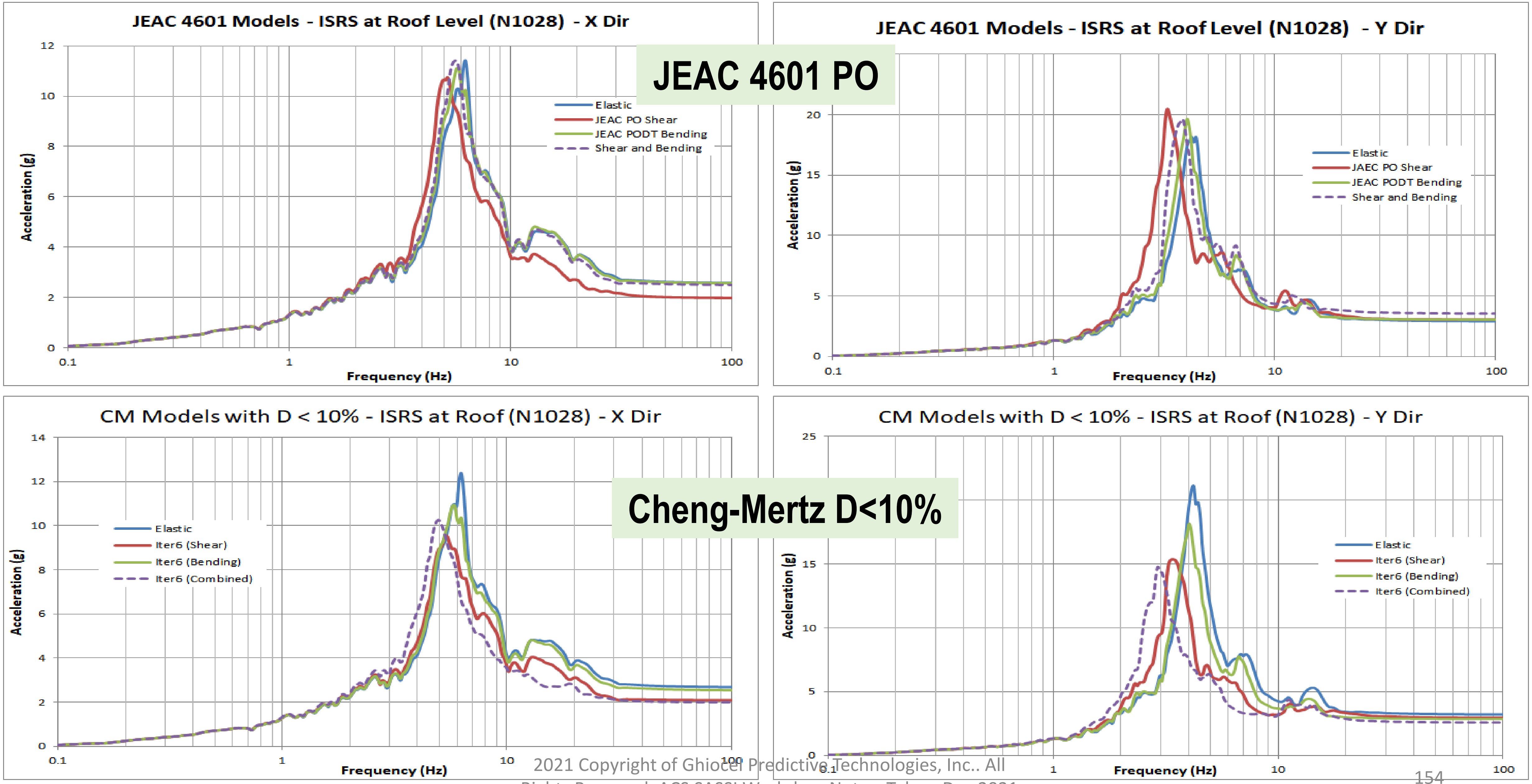


Base Wall Panels 6 and 7 Bending and Shear Hysteretic Loops for CM w/ No Damping-Cut and CM w/ D<10%

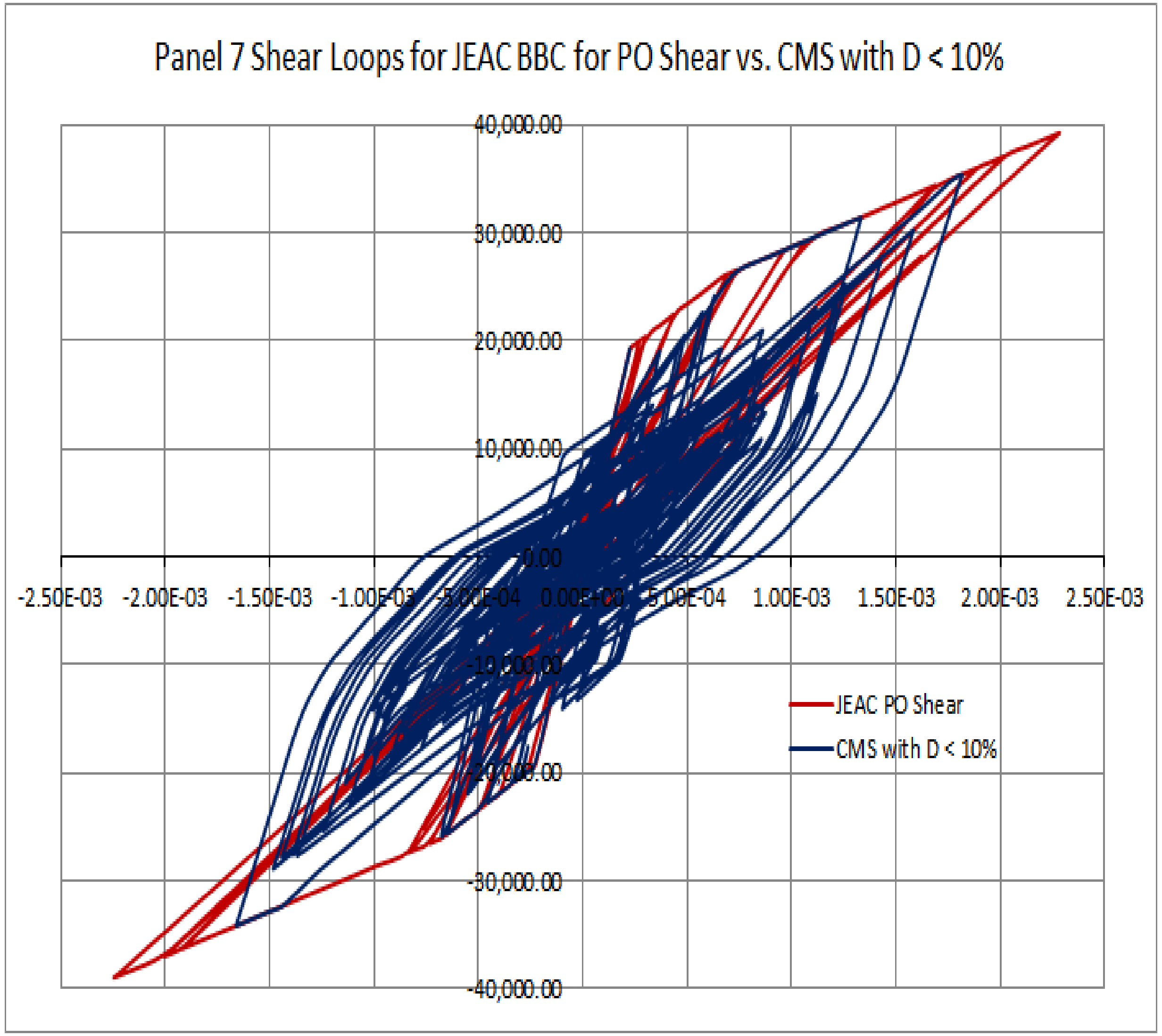


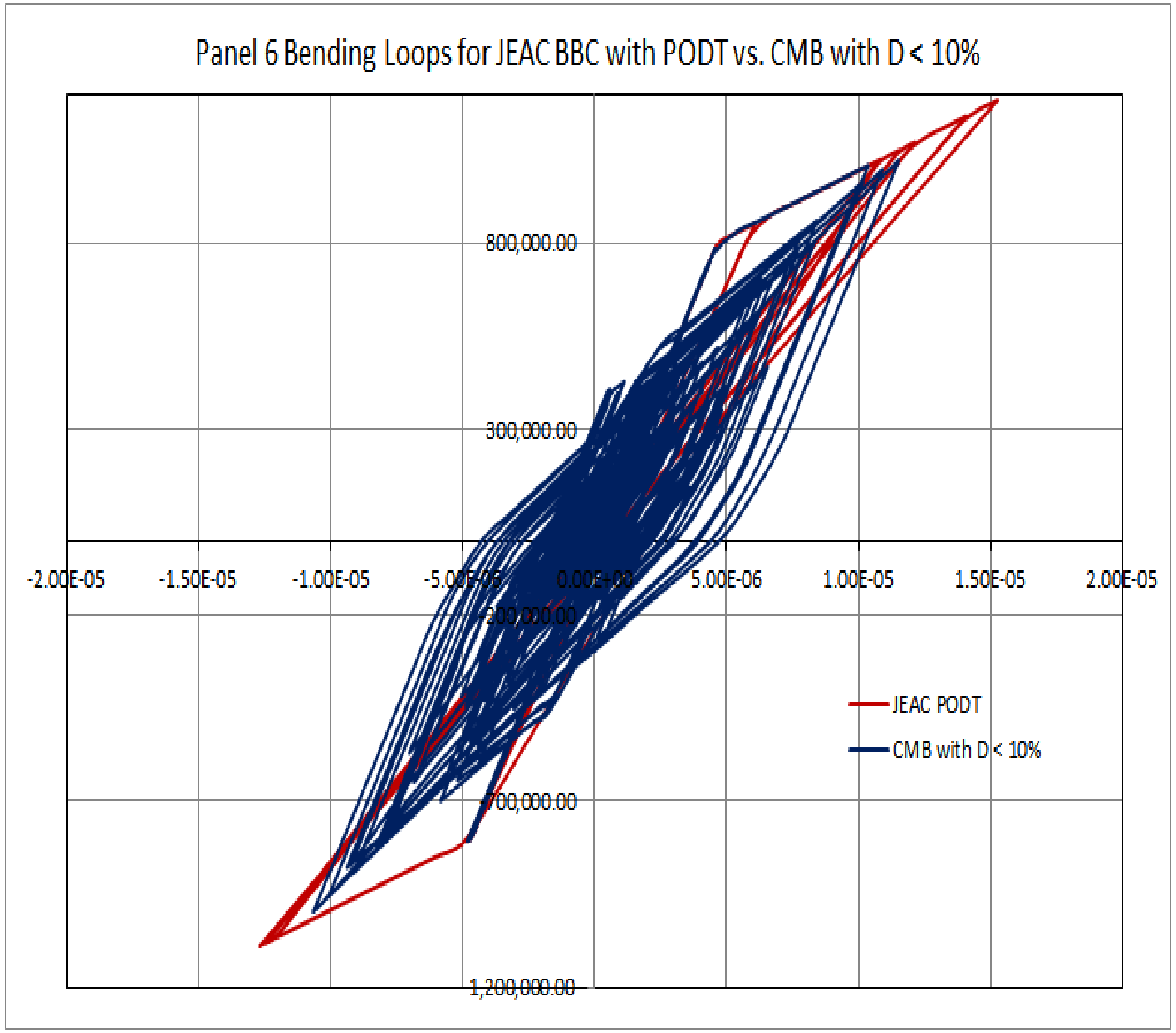


ISRS for Cheng-Mertz D < 10% and JEAC 4601 PO Models for 0.70g

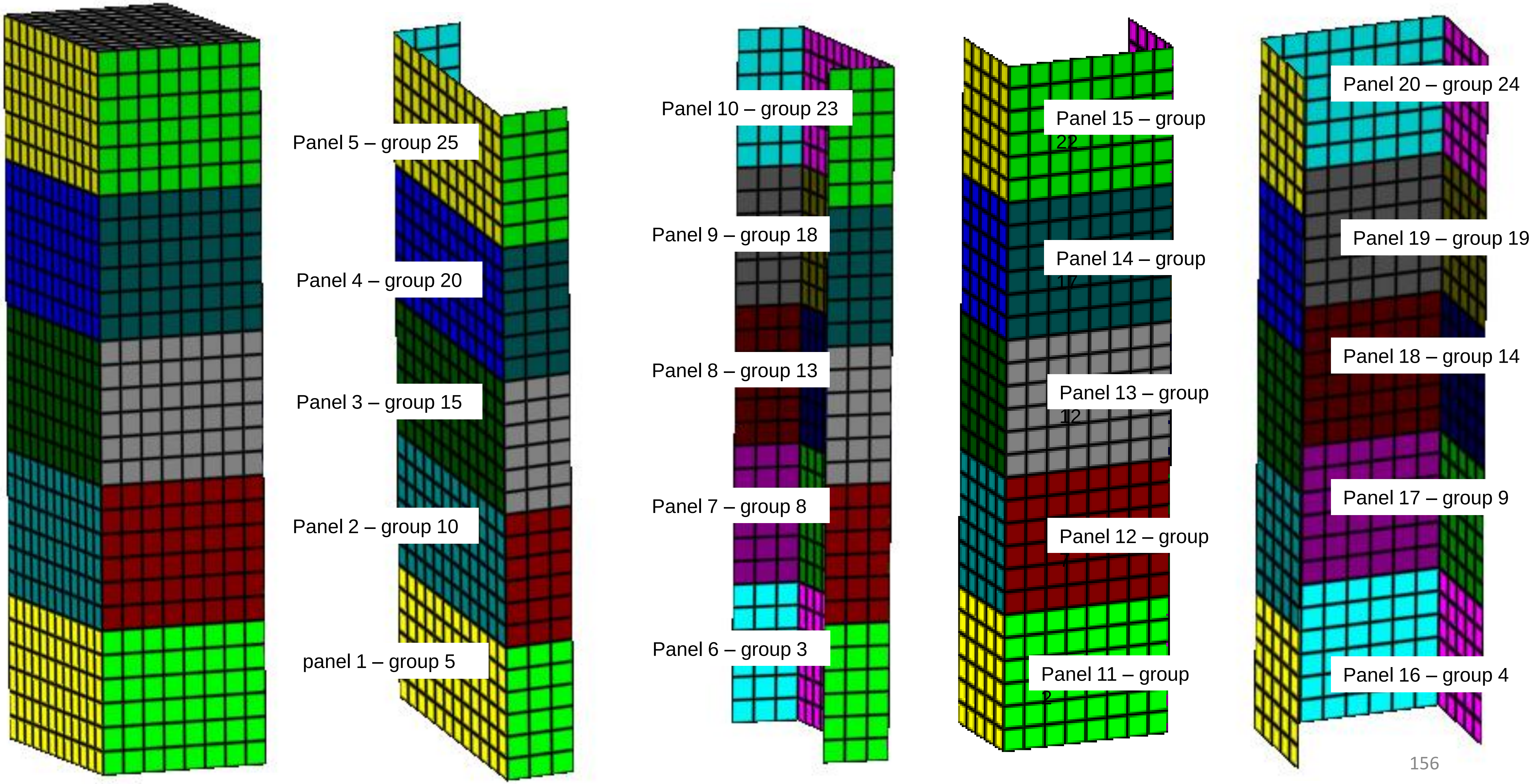


Base Wall Panels 6 and 7 Bending and Shear Hysteretic Loops for JEAC PO and Cheng-Mertz w/ D<10%



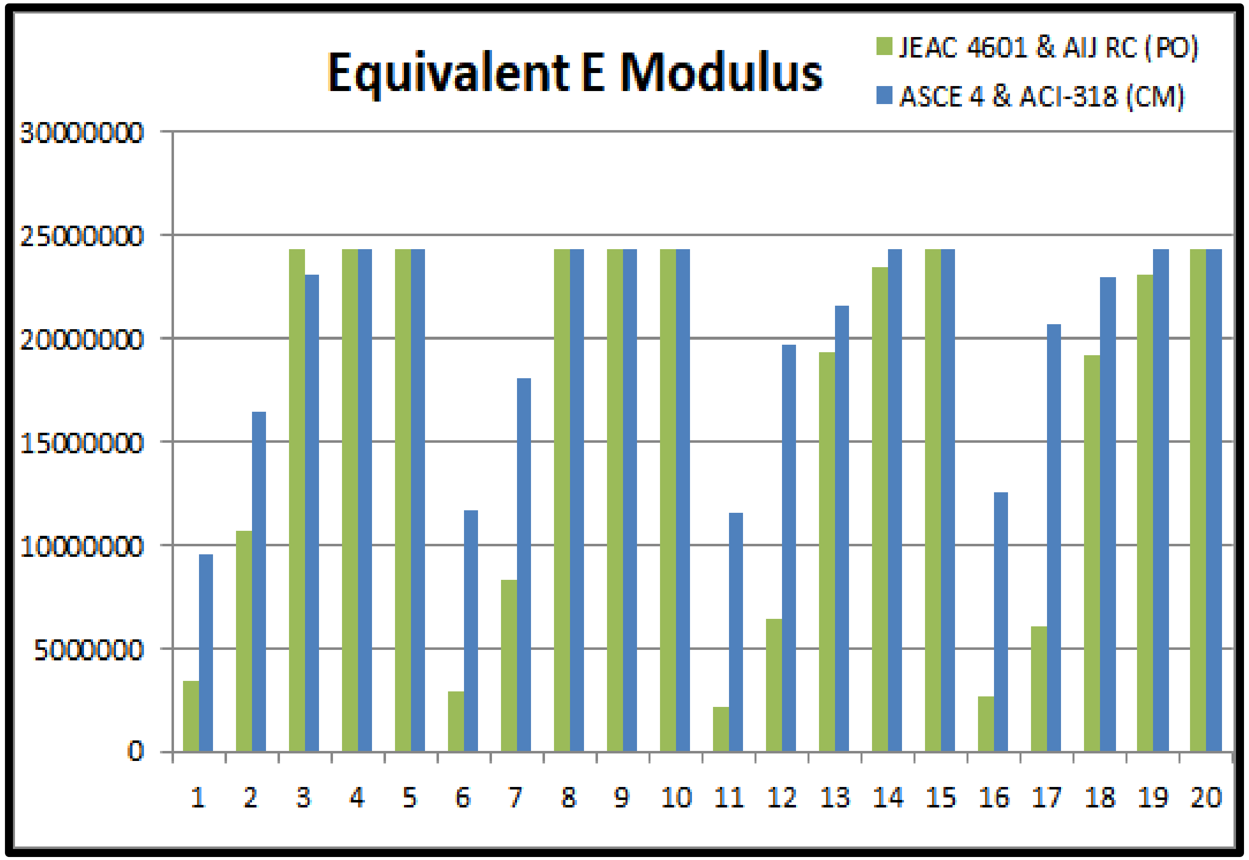


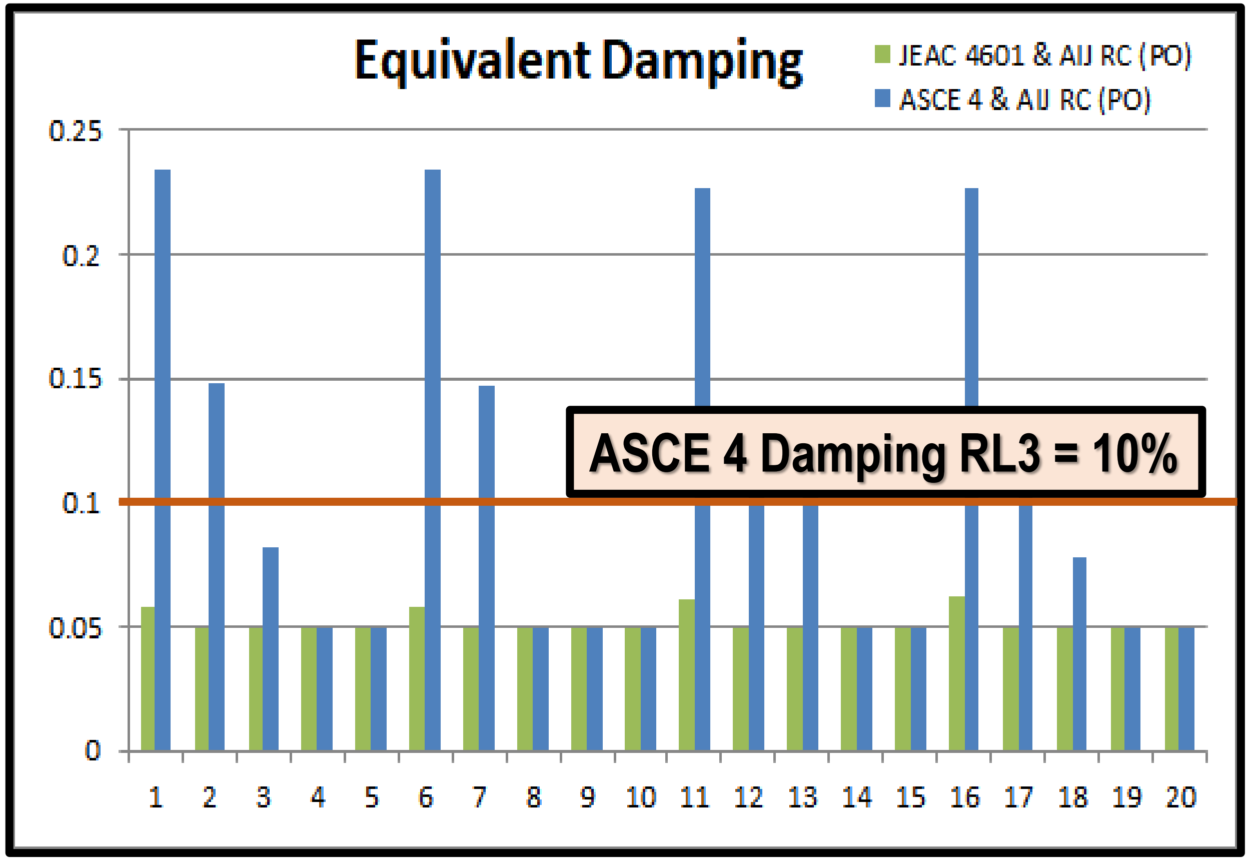
TB Model Study for RG1.60 with 0.50g and 0.70g Inputs



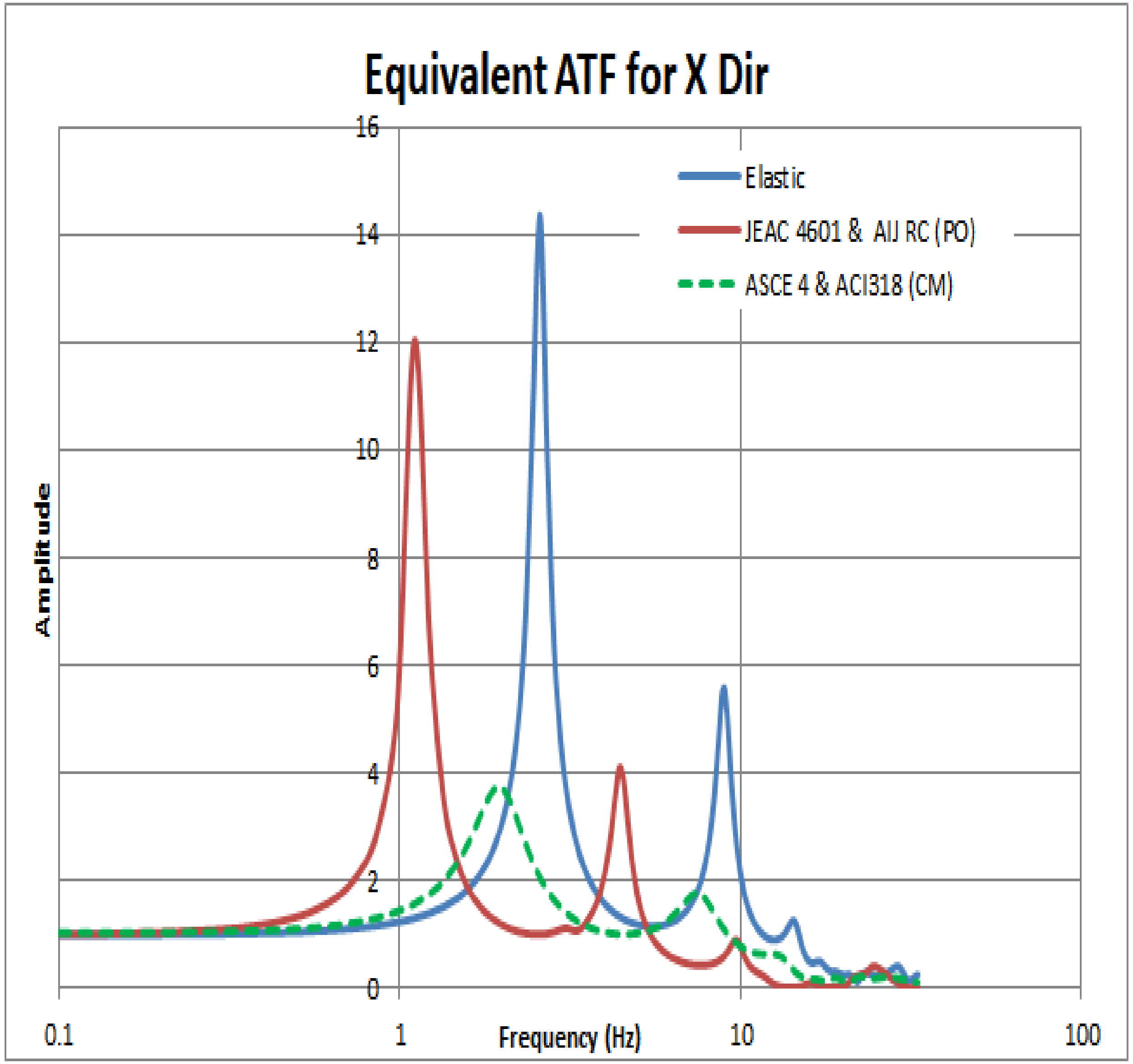
Iterated ATF for JEAC PO Models and CM Models w/ No Damping Limit for 0.70g RG1.60 Input

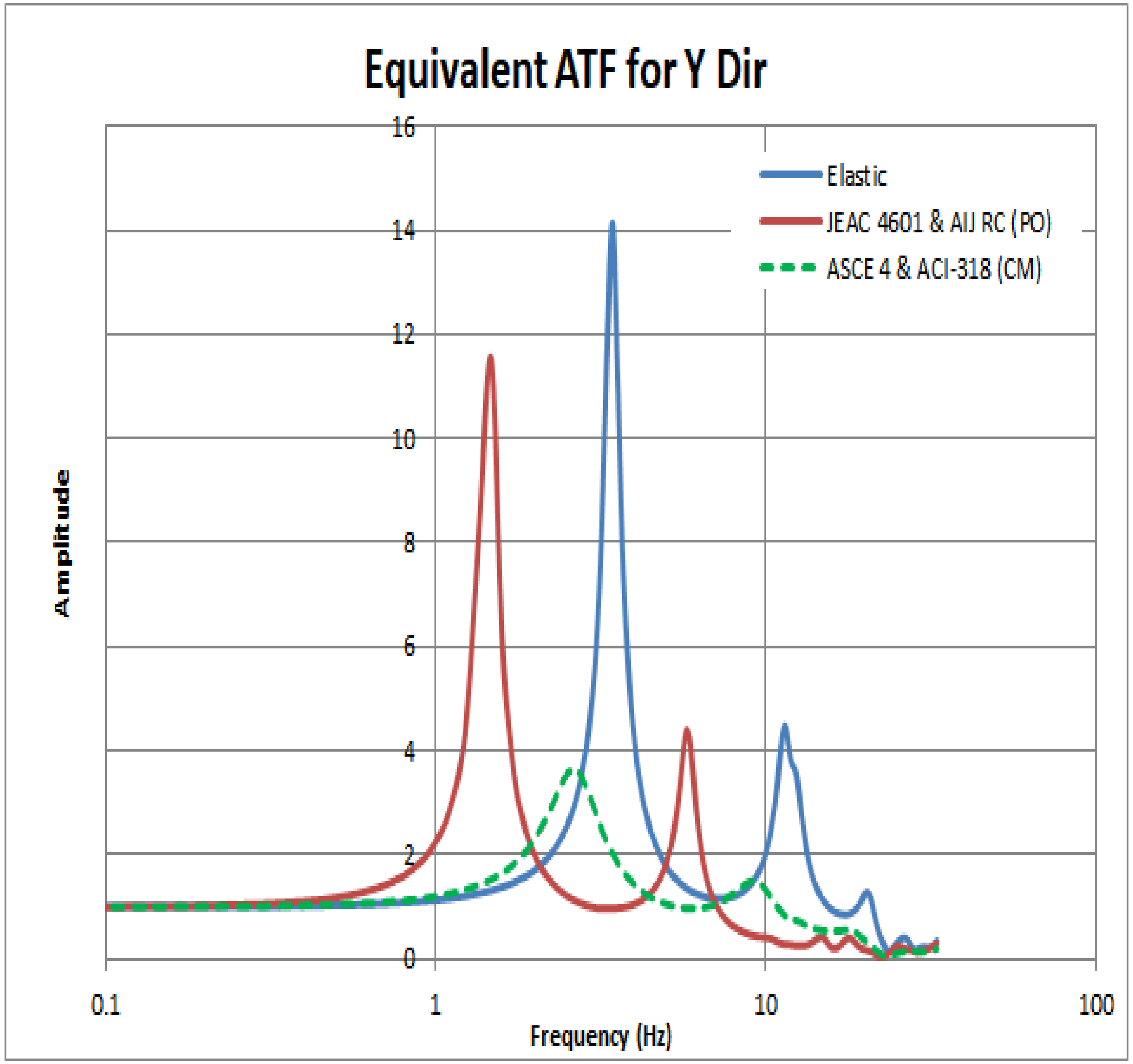
Using JEAC PO Models and CM Models with **No Damping Limit** (directly FEA nonlinear results)



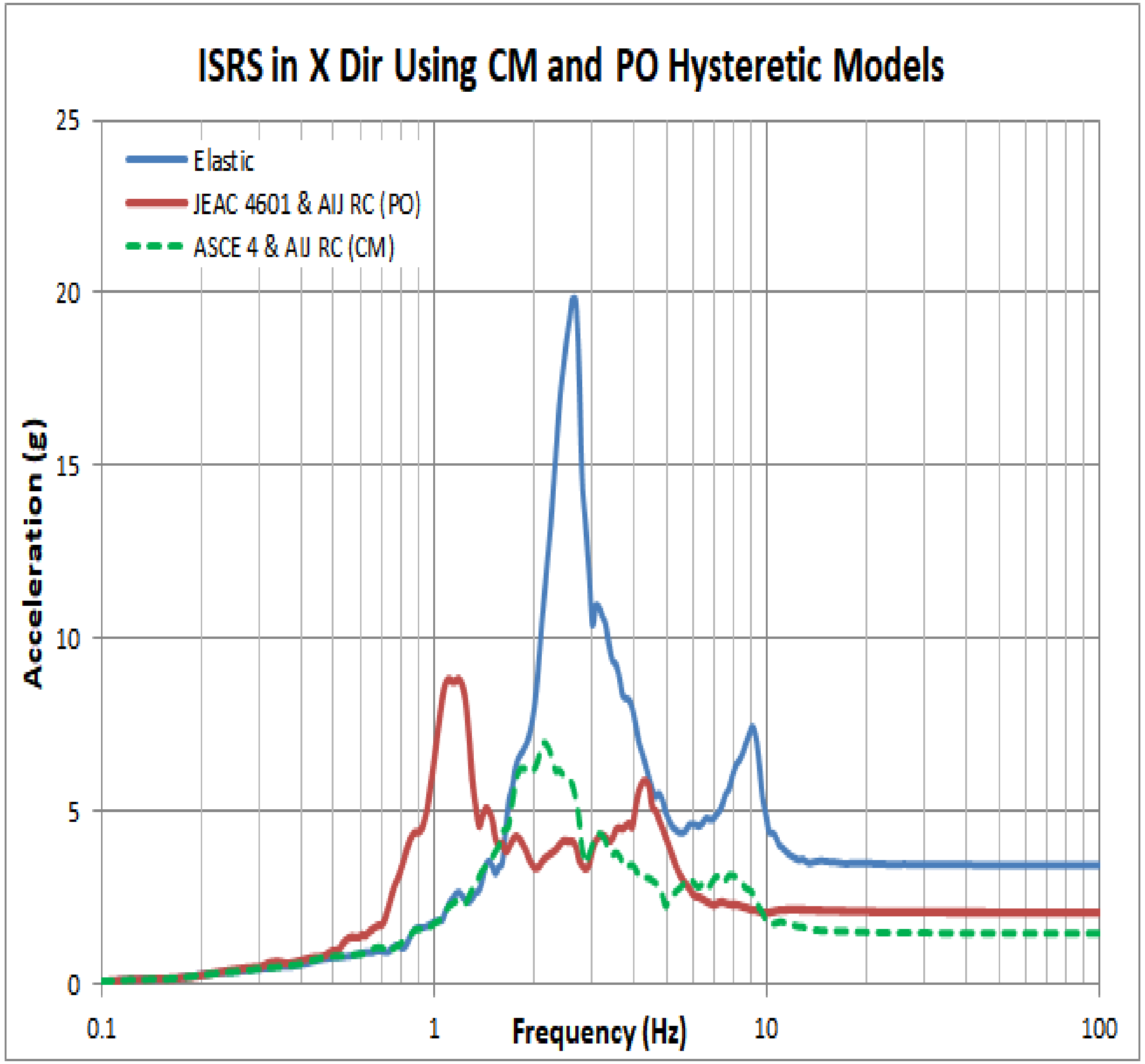


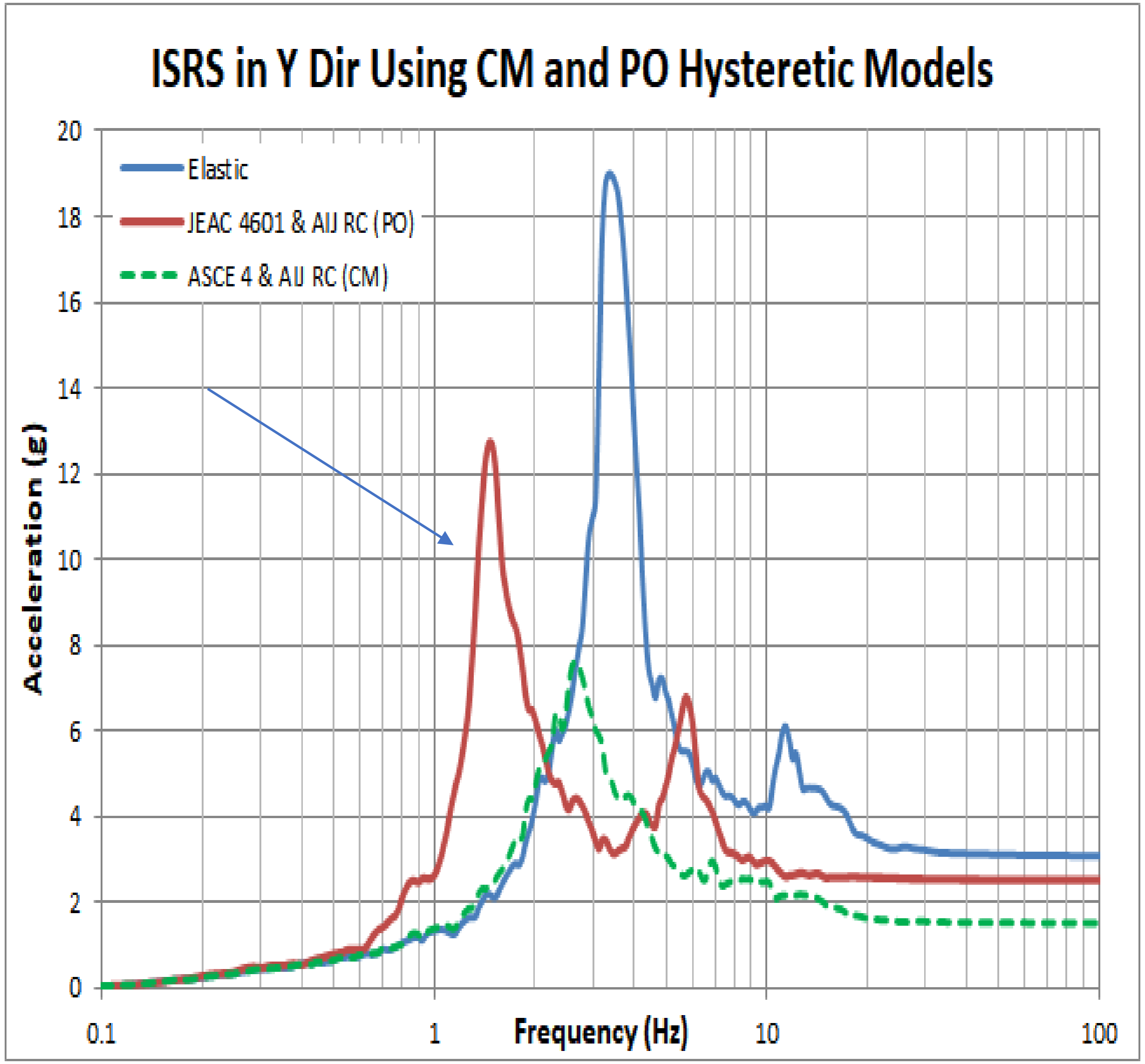
Iterated ATF for JEAC PO Models and CM Models w/ No Damping Limit





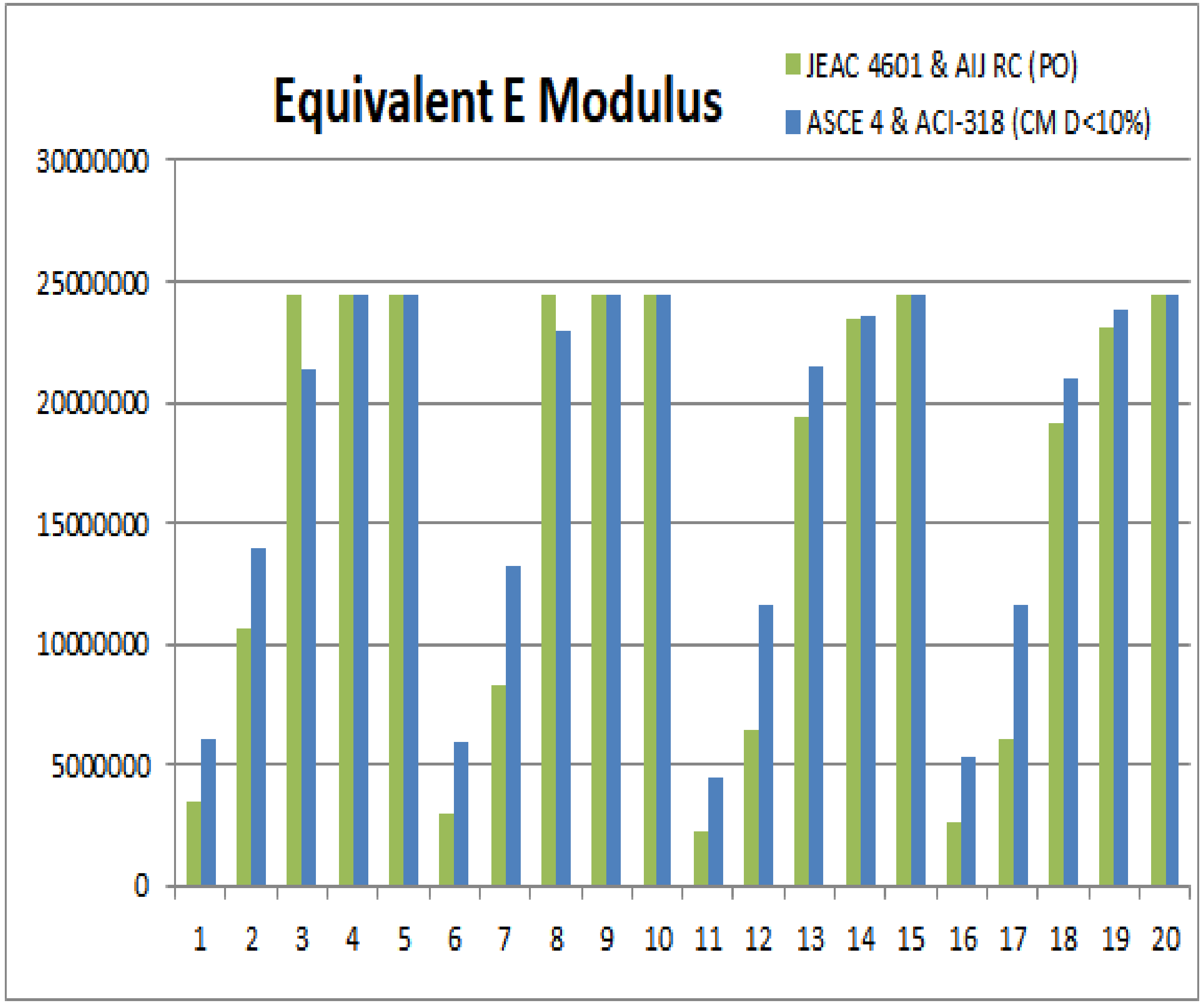
Iterated ISRS for JEAC PO Models and CM Models w/ No Damping Limit)

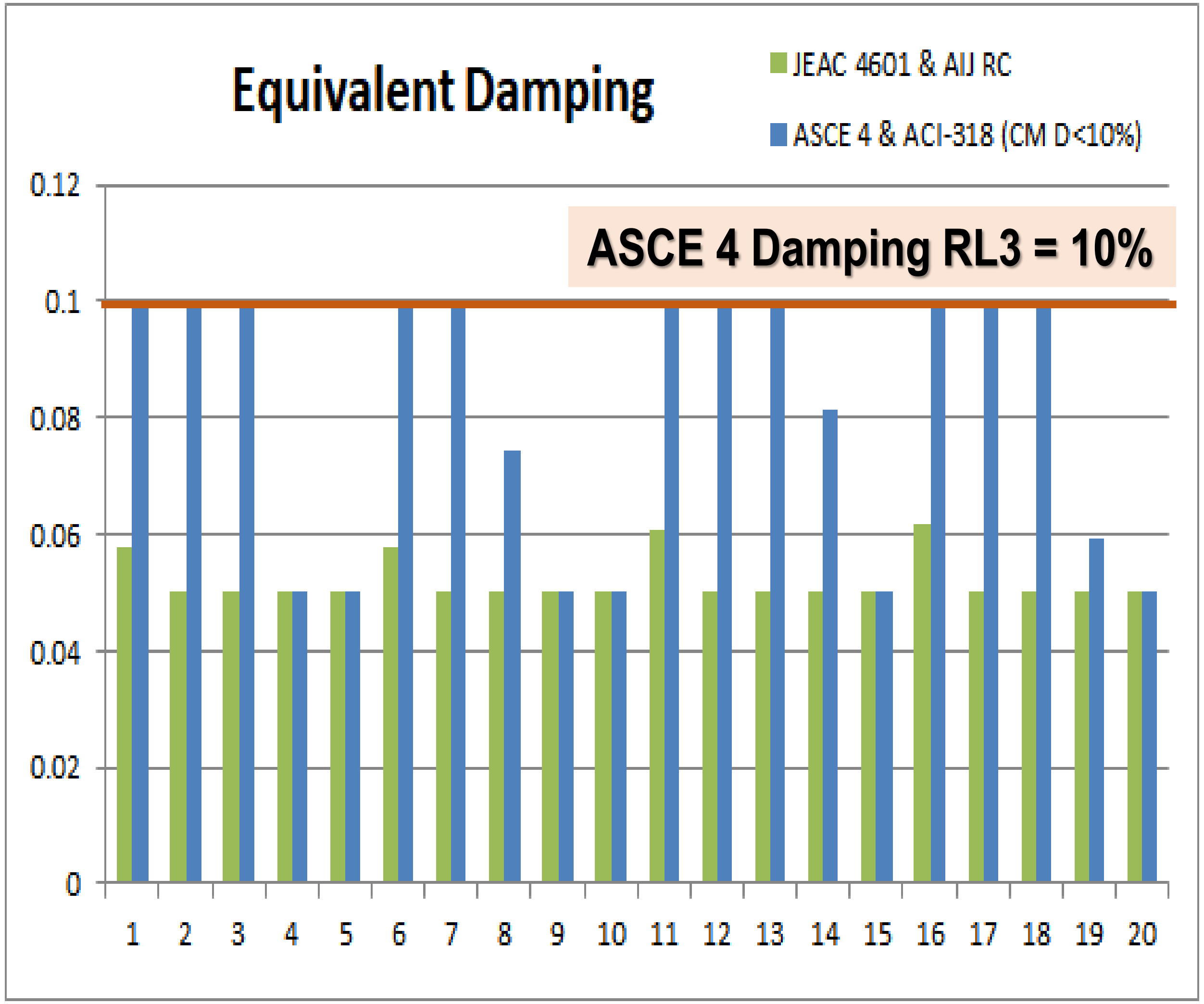




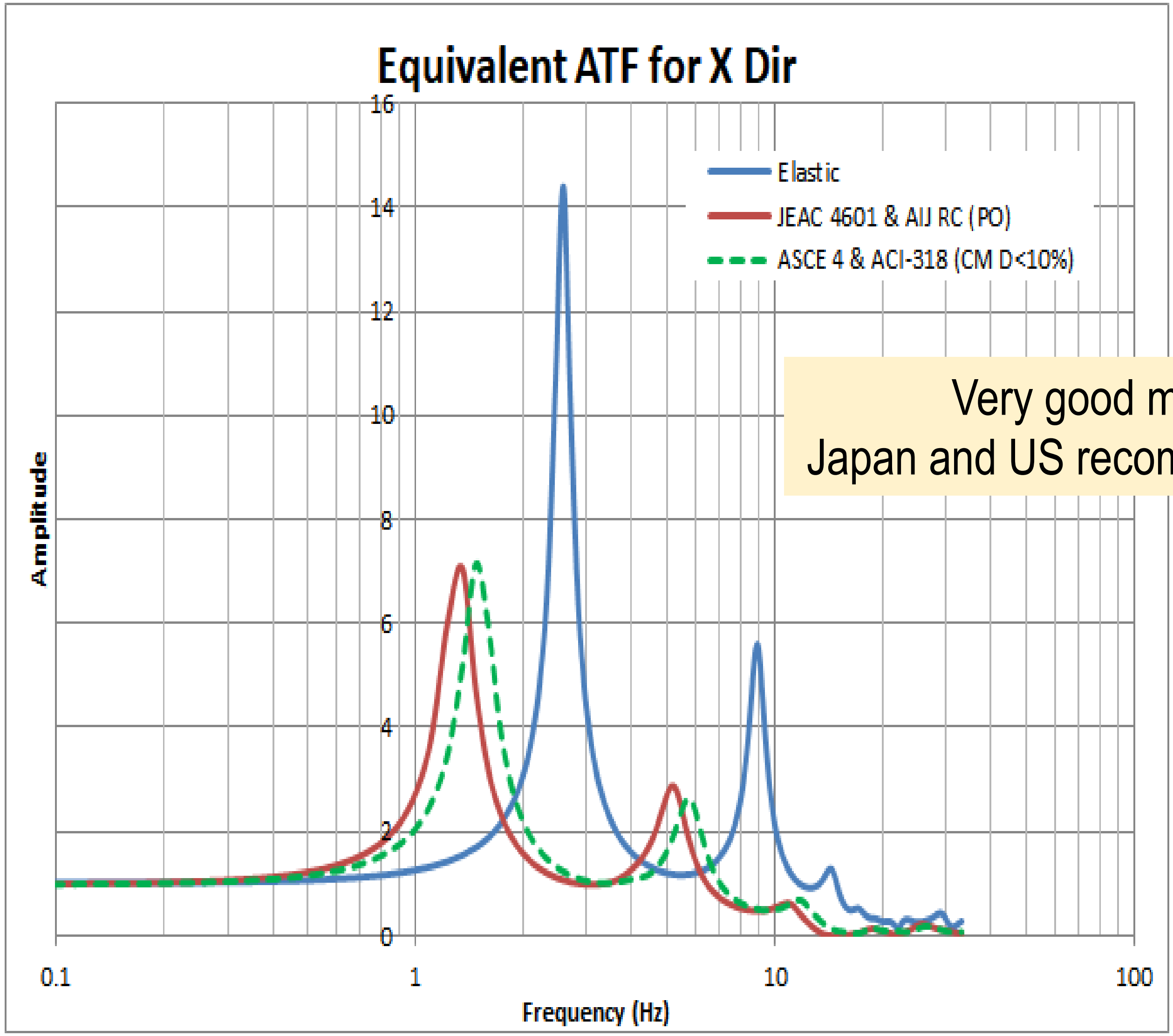
Iterated ATF for JEAC PO Models and CM Models w/ 10% Damping Limit for 0.70g RG1.60 Input

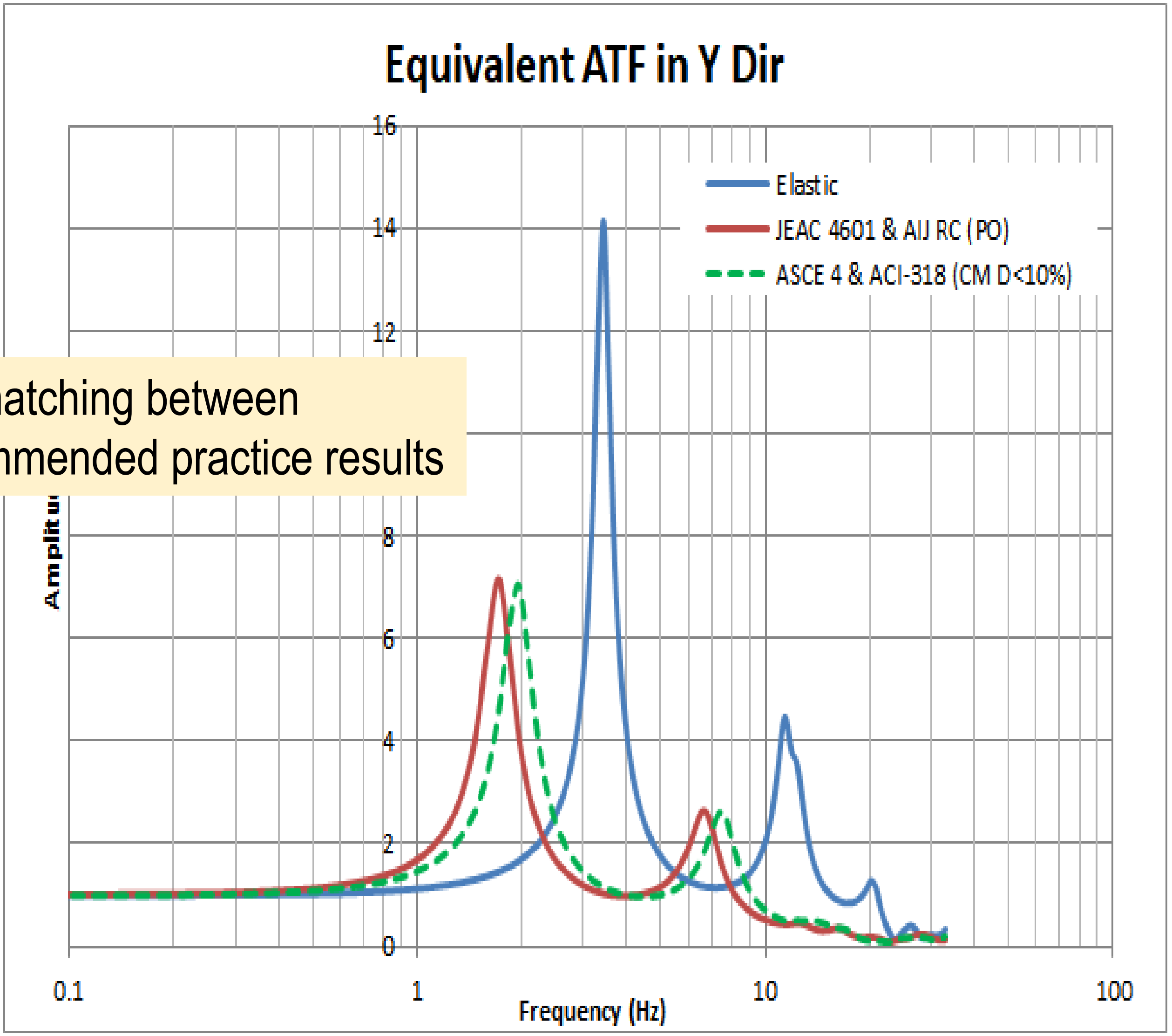
Using JEAC PO and CM Models with **Damping < 10%** per ASCE 4 Section 3 Recommendation





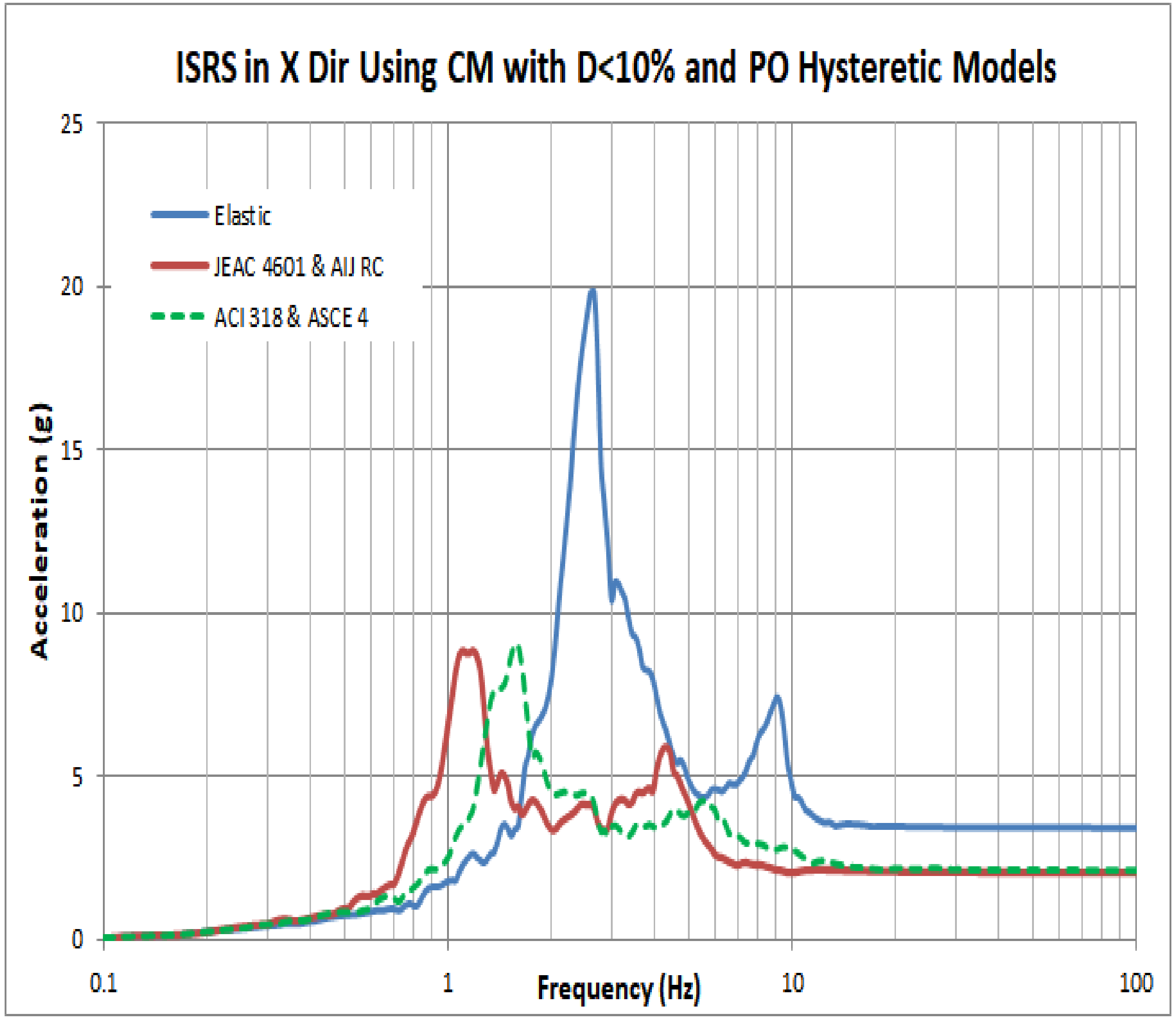
Iterated ATF for JEAC PO Models and CM Models with D<10%

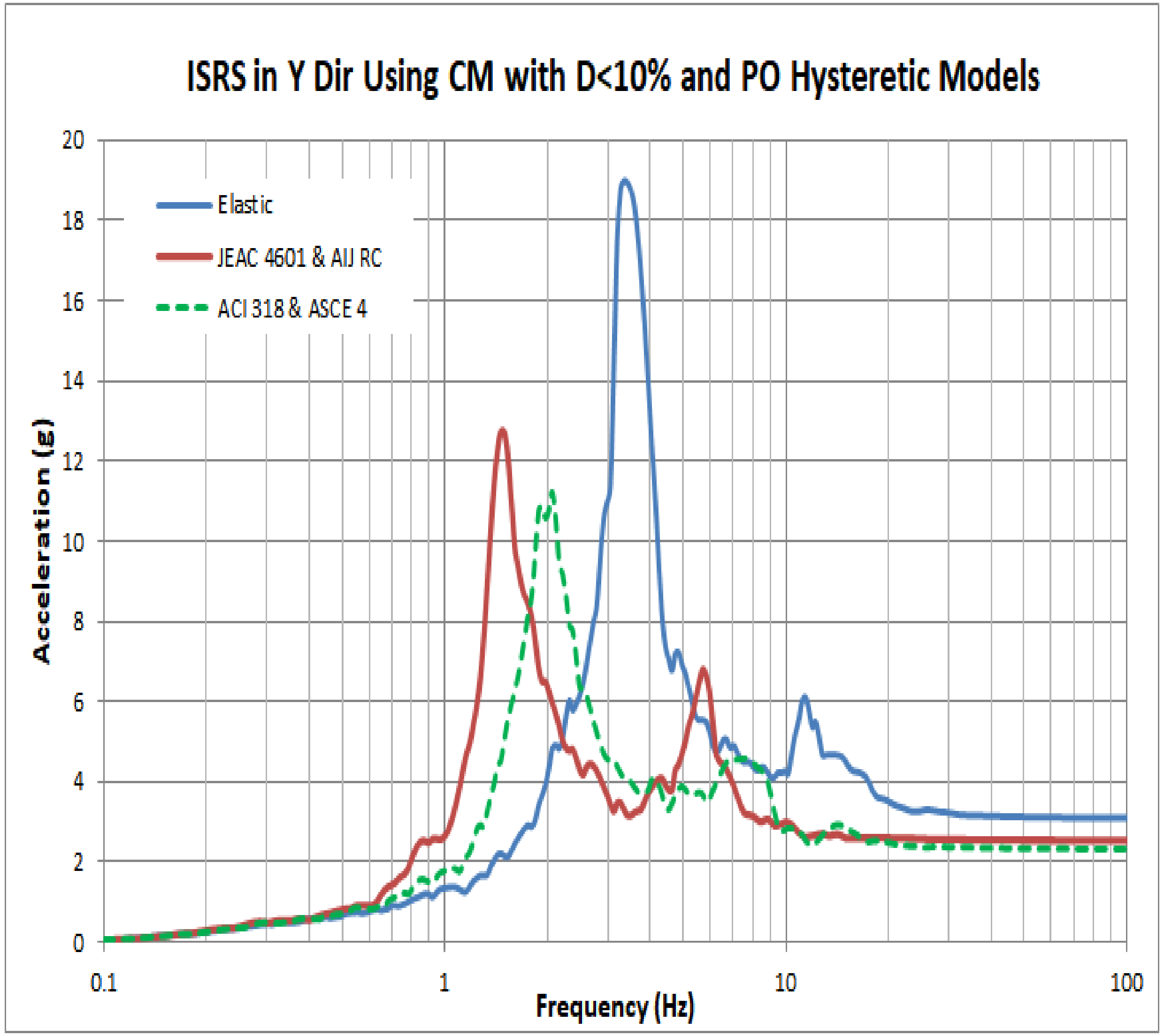




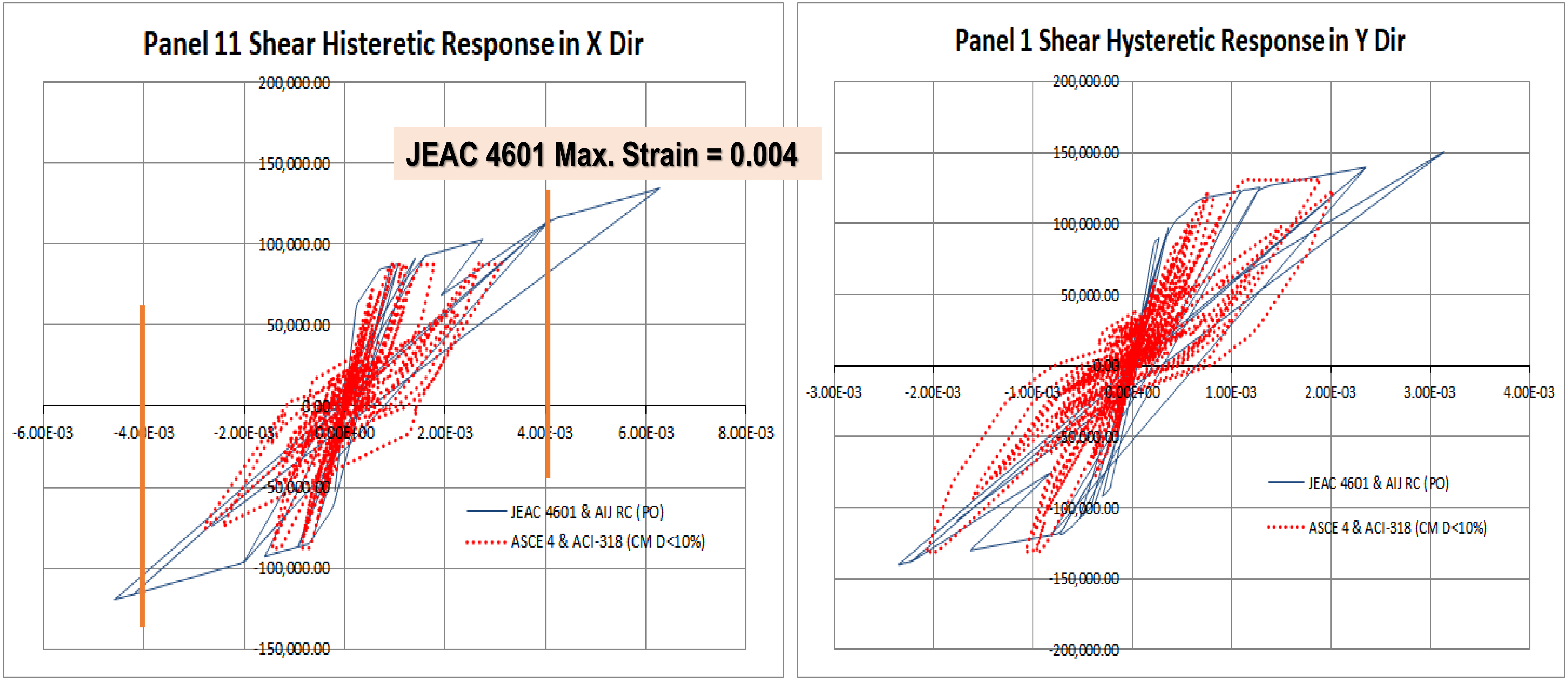
Very good matching between
Japan and US recommended practice results

Iterated ISRS for JEAC PO Models and CM Models with D<10%

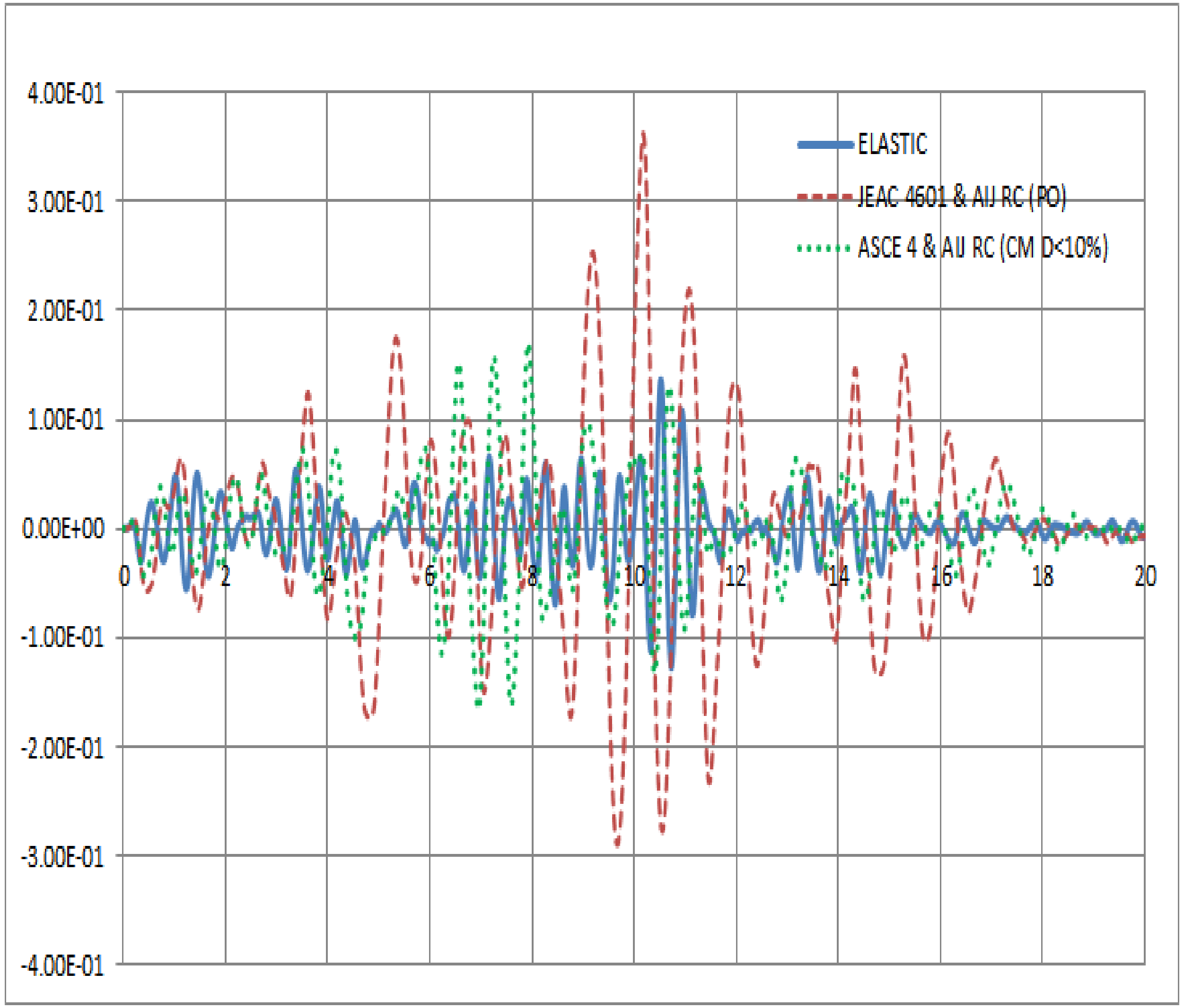


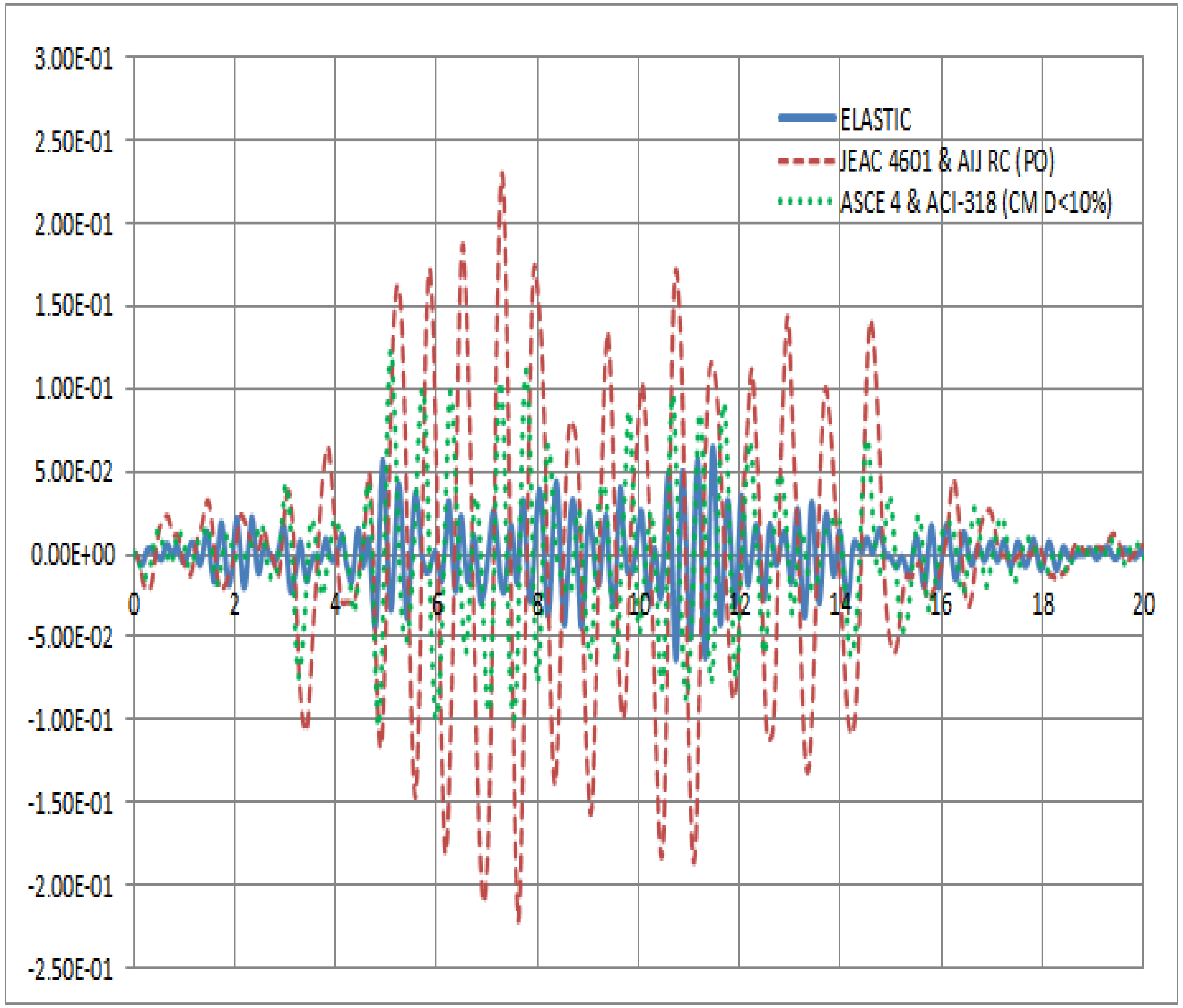


Shear Hysteretic Response for JEAC PO and CM with D<10%



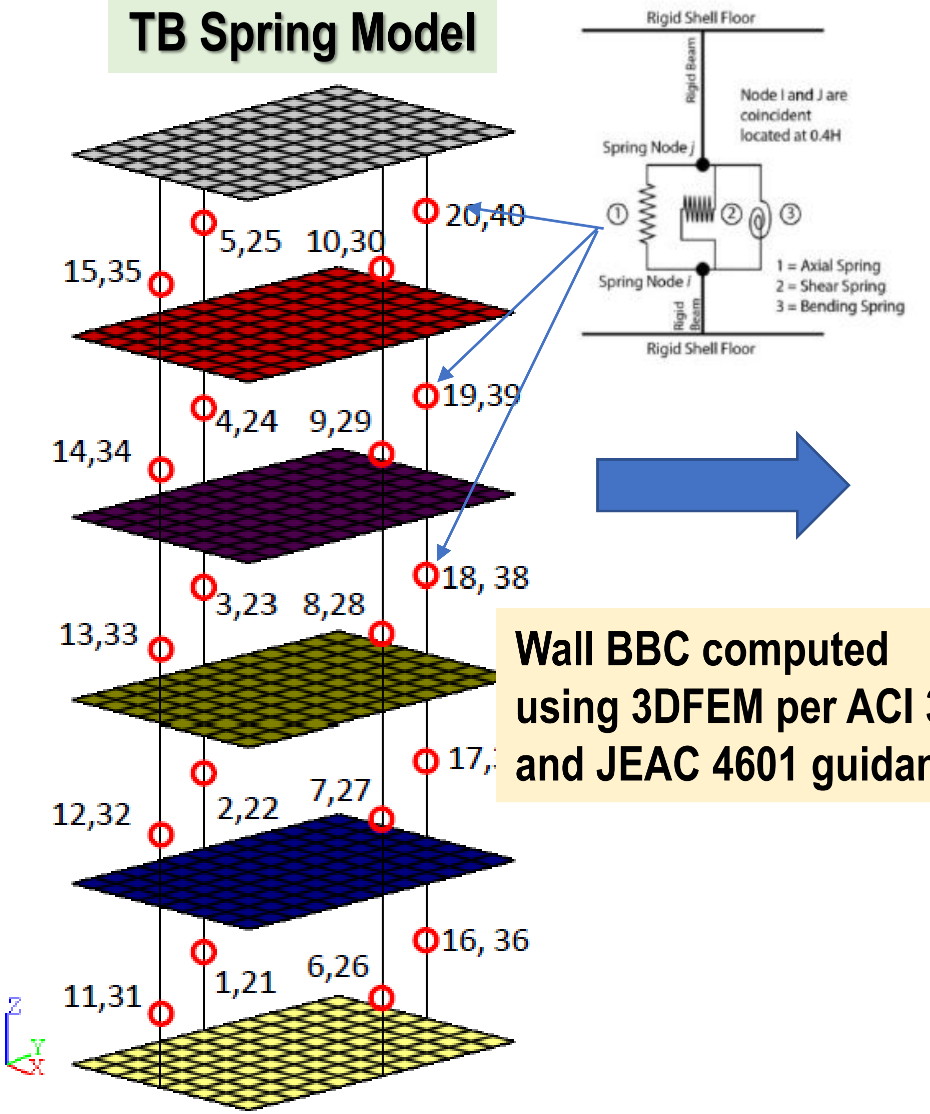
Nonlinear TB Roof Displacements for X and Y Dir for JEAC 4601 PO Models and ASCE 4 CM with D<10%



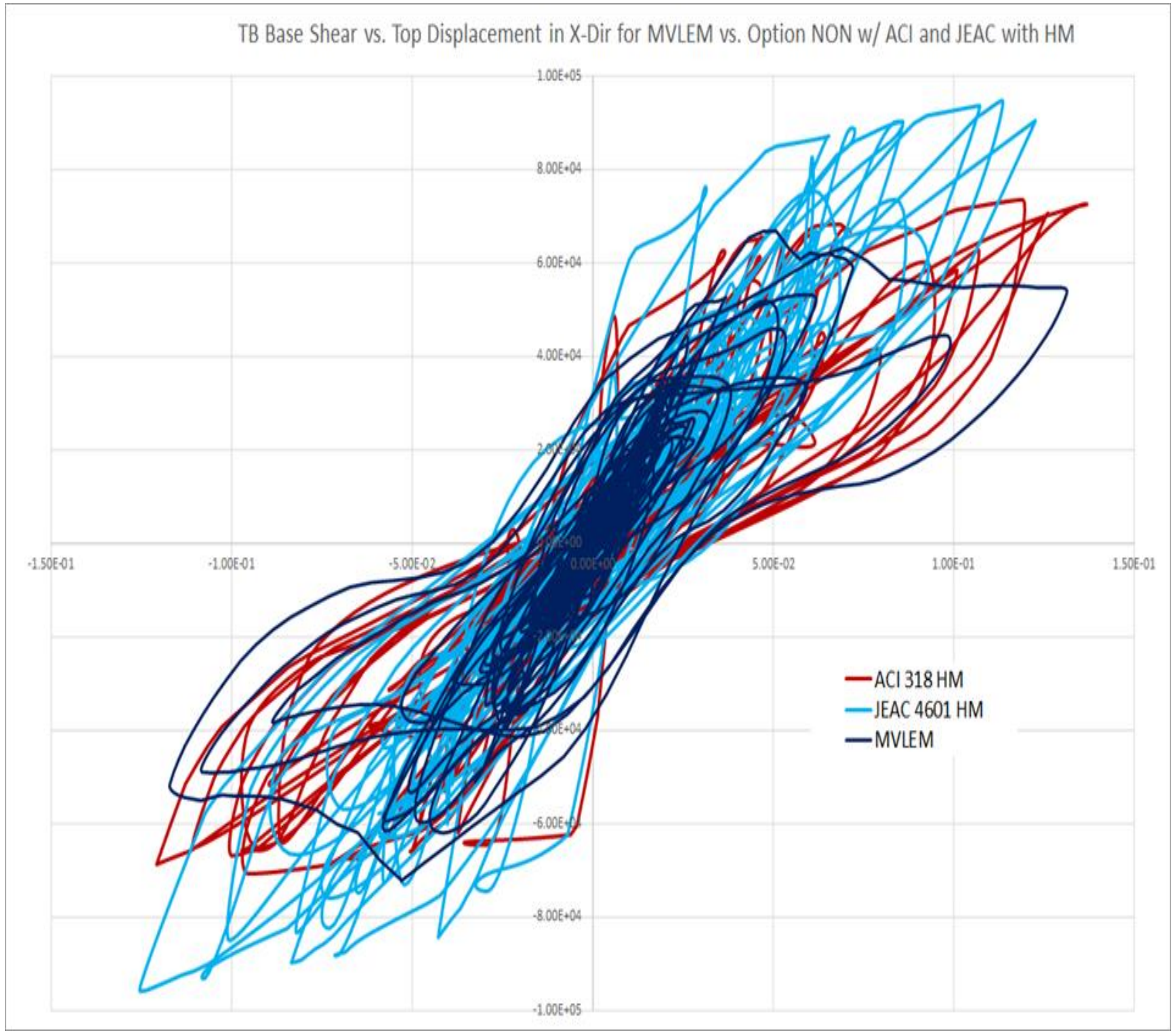


TB Stick Result Comparisons with OpenSees 2D SFI-MVLEM and 3D FIBER Specialized RC Software (Rigid Floors) for RG1.60 w/ 0.70g

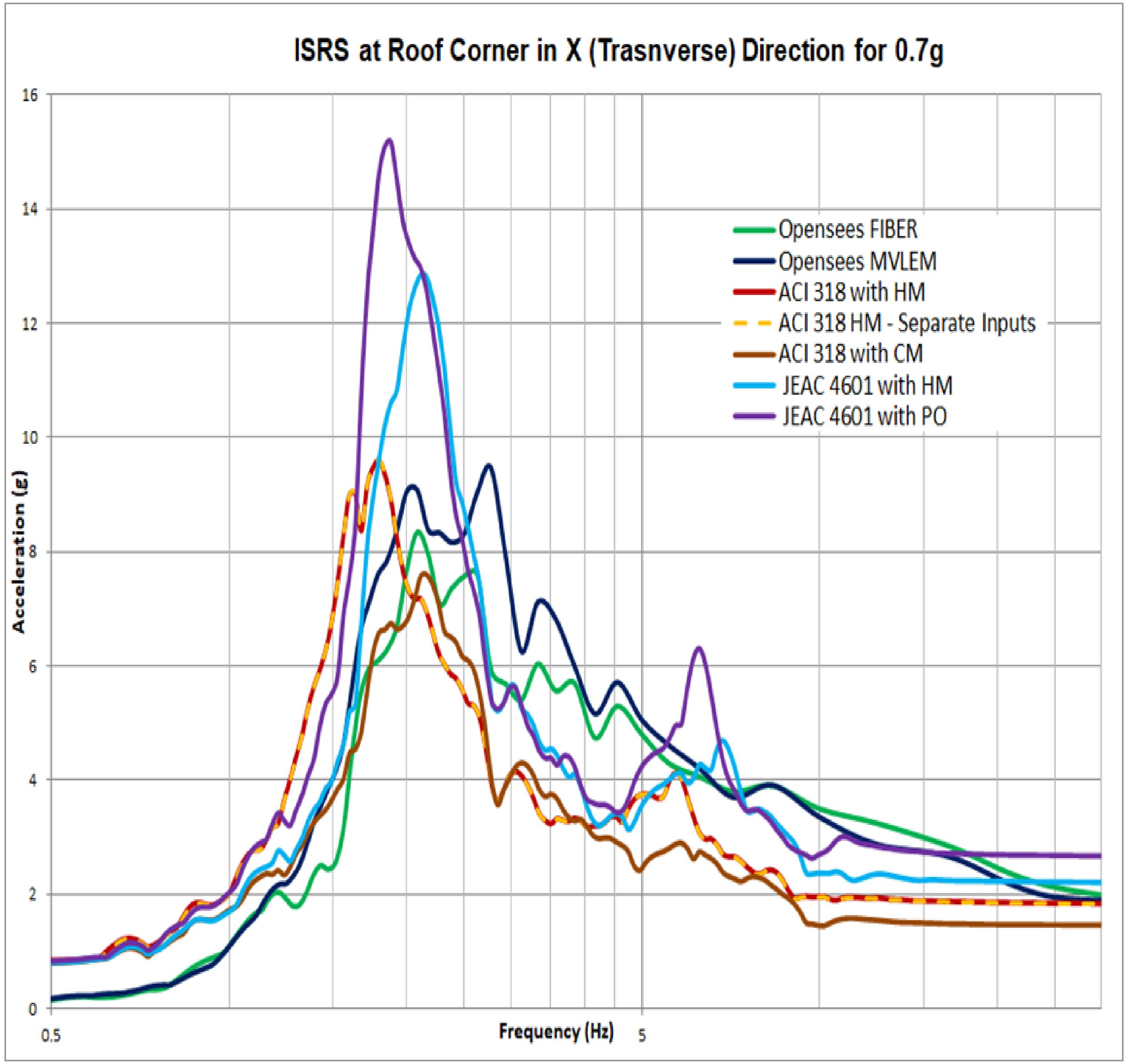
TB Spring Model

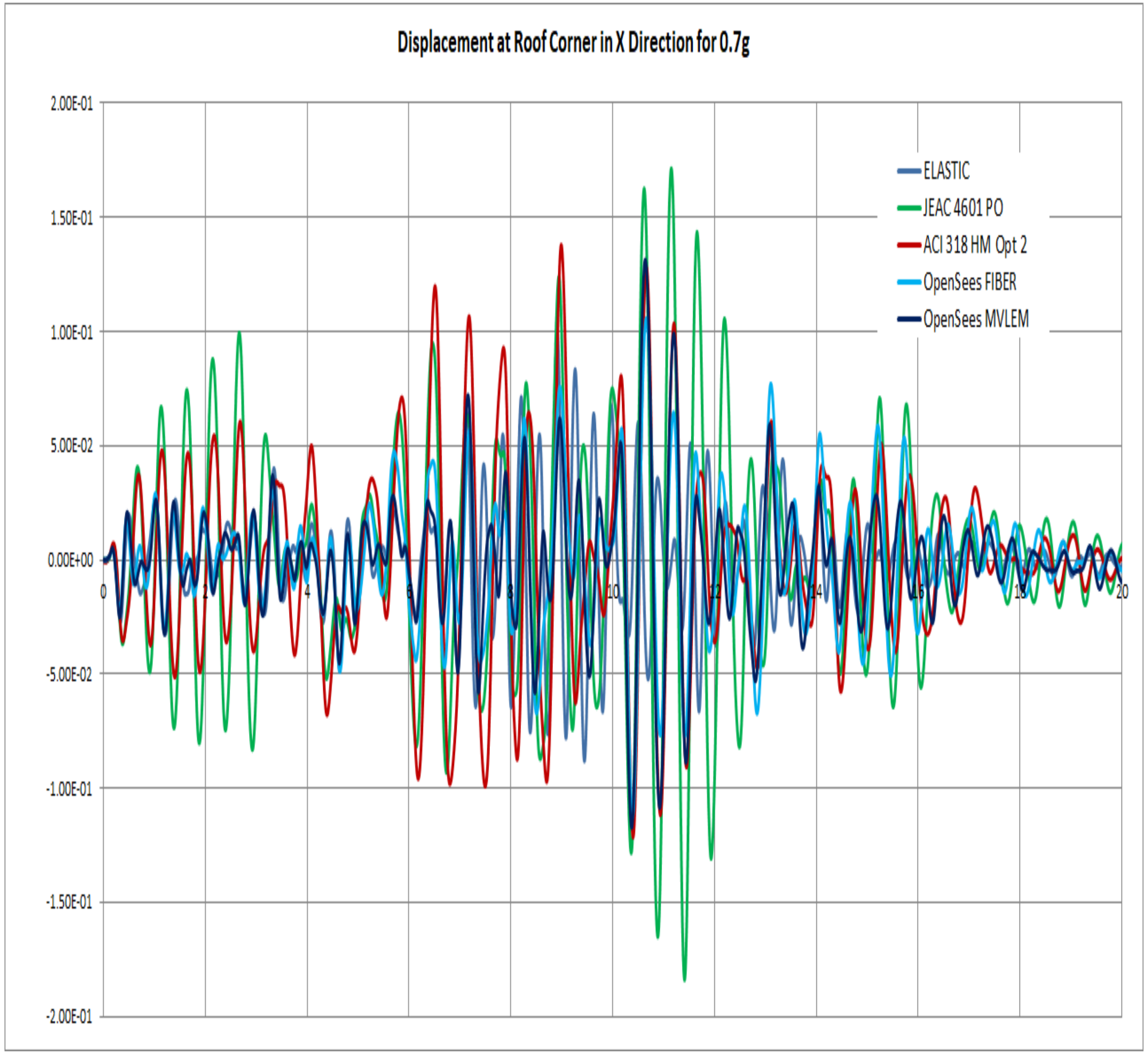


Wall BBC computed using 3DFEM per ACI 318 and JEAC 4601 guidance



Nonlinear ISRS and Displacements at Top Structure for 0.70g





2.7 Concluding Remarks

Concluding Remarks

A. Remarks on Nonlinear SSI Analysis Procedure Based on Best Practices

Very importantly, the developed nonlinear SSI analysis tool (ACS SASSI Option NON) *maintains the safety margins as accepted by the current standards and regulations*, at the same time providing a large reduction of the nonlinear SSI analysis costs in comparison with the existing, more sophisticated nonlinear FEA codes in the time domain.

We believe that such a *practical engineering analysis tool* is highly needed for nuclear industry.

B. Remarks on Nonlinear Results Based on US and Japan Design Practices

1. The comparative study results show that if the Japanese and US standard recommendations for hysteretic damping limitation are respected, then, the computed nonlinear ISRS amplitudes are close.
2. The JEAC PO hysteretic models have much lower hysteretic damping (PO shear model has no damping and PODT bending has between 0 and 15%) which amplifies seismic responses and produces a shift of the structural dominant frequencies to lower frequencies. As a result of the lower damping, the structural displacements are significantly larger for the JEAC PO models.
3. Using directly the nonlinear FEA code results (similar with using the CM models with no damping limit) could produce much lower nonlinear SSI responses than those computed by respecting the Japanese or US standard recommendations, especially due to the lack of hysteretic damping limitation.

WARNING: *Using directly the nonlinear FEA code results without checking the compliance with regulatory requirements could significantly lower the nonlinear responses. By this may produce much lower seismic safety margins that those corresponding to the existing design regulation requirements. Nuclear industry analysts should understand and pay attention to these serious methodology risks*.

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

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.

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

7) Taitokui (1987). Report in Japanese. Communication from SHIMIZU.

Thank You!