NONLINEAR SEISMIC SSI FOR REINFORCED CONCRETE BUILDINGS IN ACCORDANCE WITH ENGINEERING BEST PRACTICES IN US AND JAPAN

PART 2: Implementation & Application Based on US and Japan Practices

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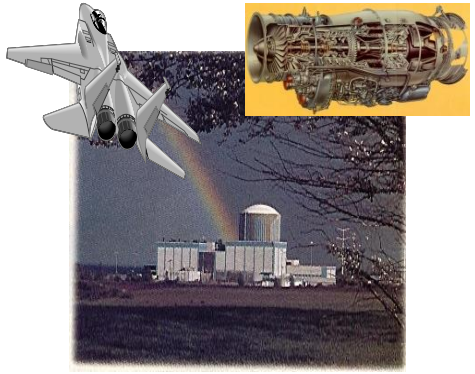


DOE/NRC Natural Phenomena Hazards Meeting

October 20-22, 2020

Part 2 Presentation Content

6. ACS SASSI Option NON Implementation for Nonlinear SSI Analysis
7. Comparative TB Nonlinear Results for US and Japan Practices
8. Concluding Remarks

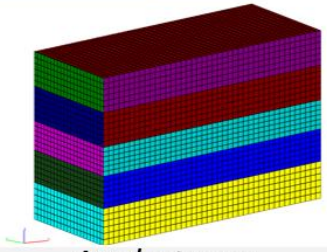
6. ACS SASSI Opt NON Implementation for Nonlinear SSI Analysis

Build SSI Model

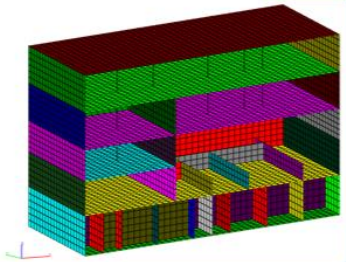
Analyst creates a 3DFEM for with element groups for each wall.

AB_Model.pre Input File

Step 1 (UI)

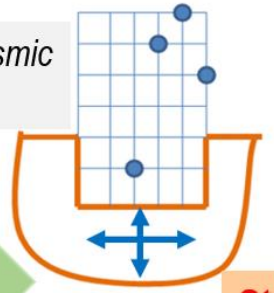


Analyst uses UI Section-Cut commands to split 3DFEM model into wall submodels

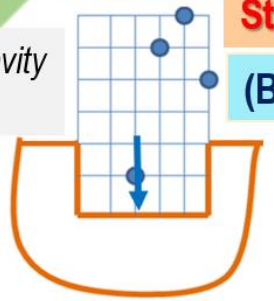


ACS SASSI SSI Analysis

Seismic SSI



Gravity SSI



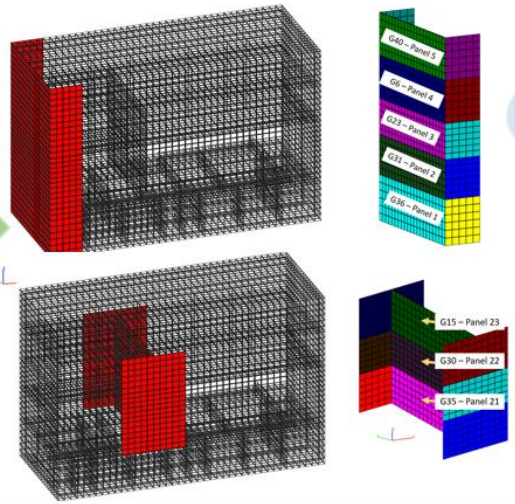
Step 3 (B)

STRESS Module Runs

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

STRESS Binary DB *for Gravity load in Z direction*

Step 4 (UI)



AB_Model_ Wall1.pre

⋮

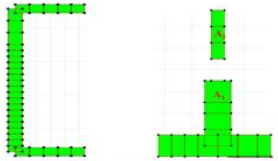
AB_Model_ Wall5.pre

Step 2 (UI)

Compute Shear and Bending BBCs

AB_Submodels_for_BBC.in file

Section_Cut_for_BBC Module Run



Automatic s and section identifi

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

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

User Section Review Adding RC Material Inputs

Step 6 ***Revised_Section_Data_for_BBC.in*** file

BBC_JEAC_4601_2015 Module

Step 7 ***Section_BBC_Data.out*** file

Step 8 ***BBC Shear.pre & BBC Bending.pre*** (UI)

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

Option NON Nonlinear SSI Analysis (Batch Run)

Step 9 *Shear and bending effects are combined at each SSI iteration using* ***COMB_Shear_Bend*** *Module*

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

Step 10 **Final SSI Post-Processing** (B) (UI)

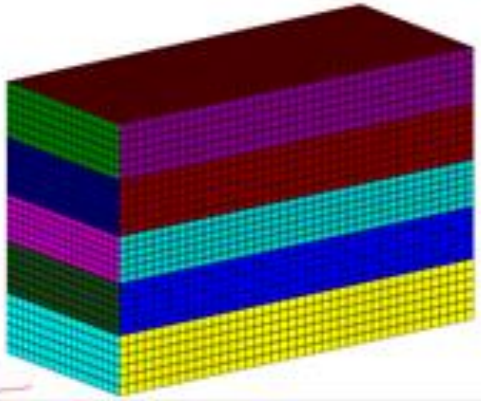
Steps 1-2: Prepare the 3DFEM with Separate Shell Groups for Walls

Build SSI Model

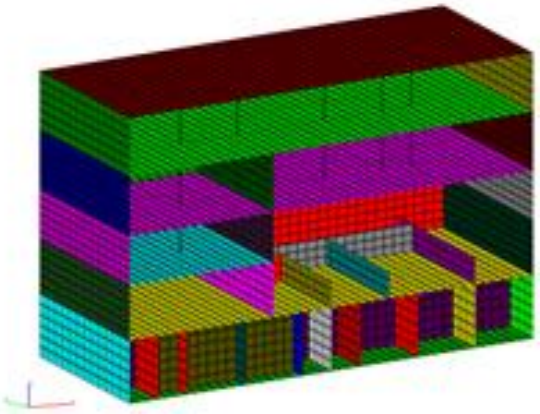
Analyst creates a 3DFEM for with element groups for each wall.

AB_Model.pre
Input File

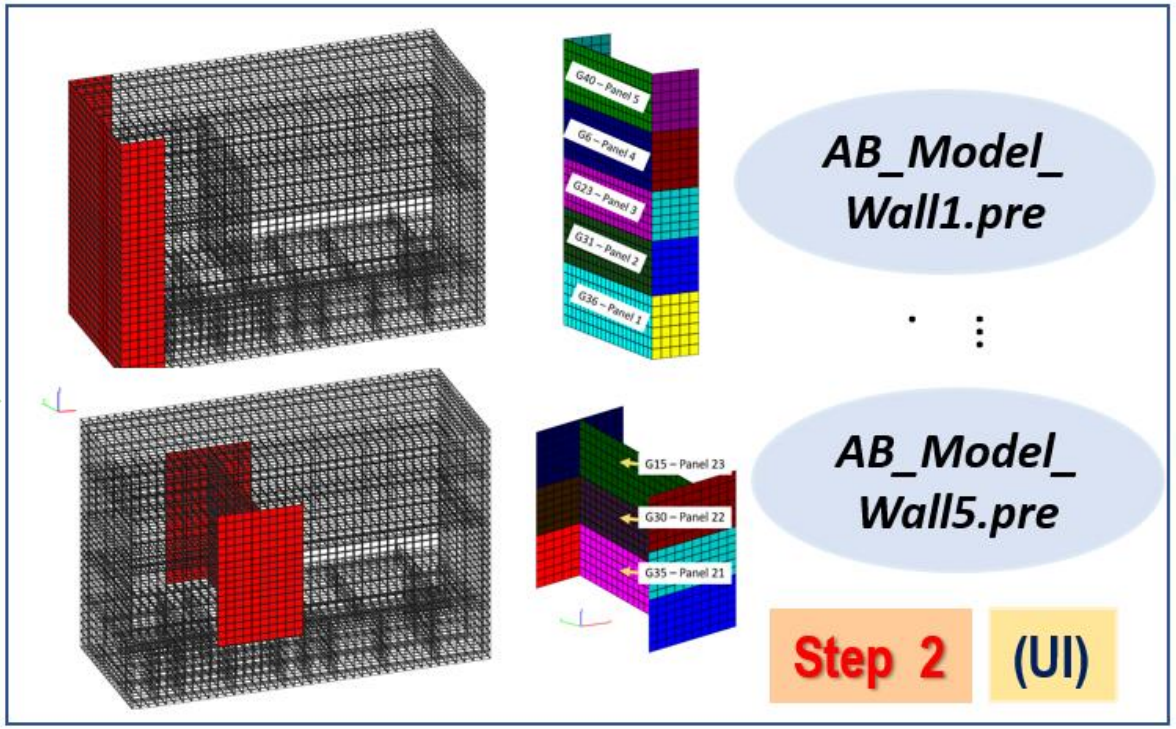
Step 1 (UI)



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

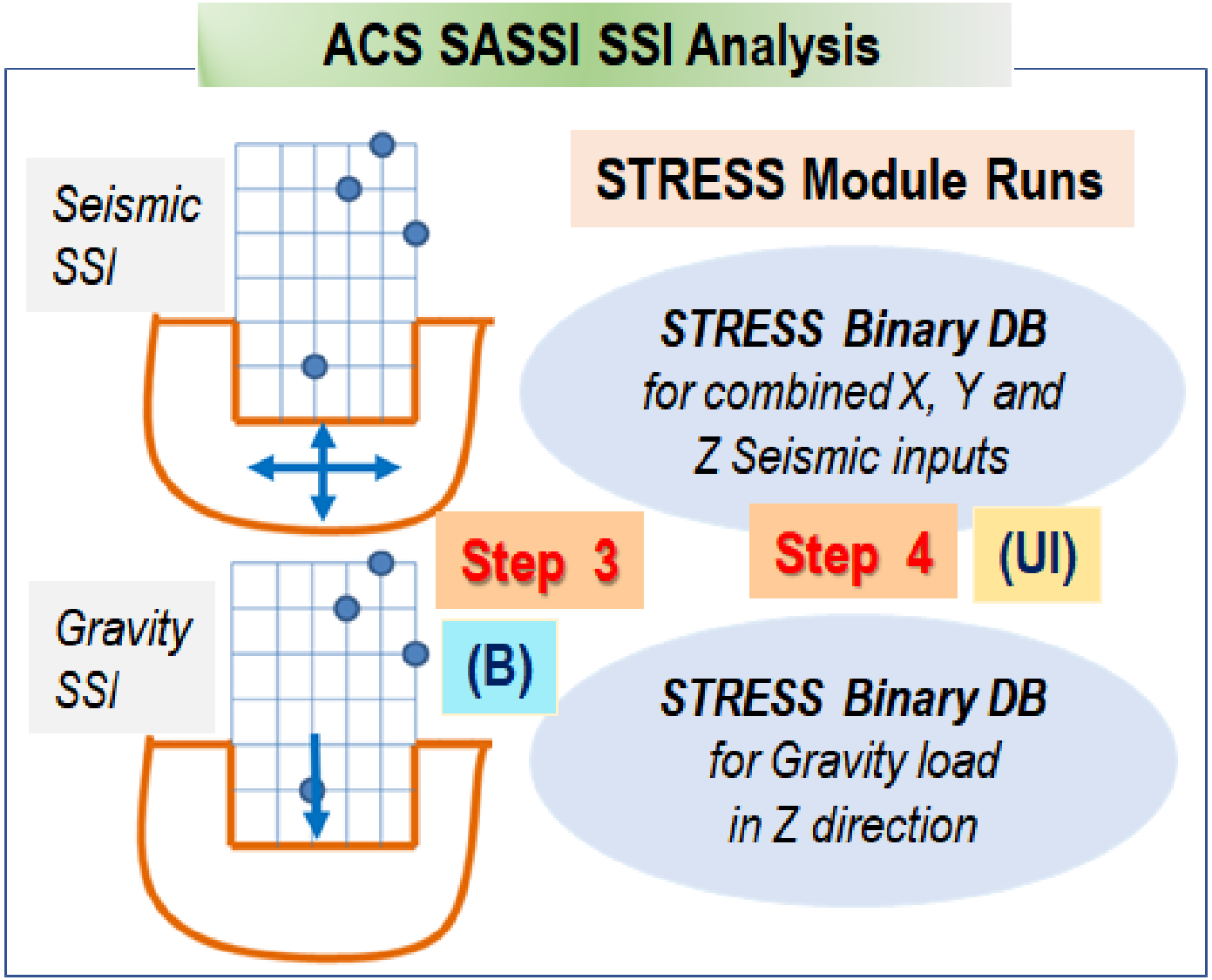


Use ACS SASSI UI Section-cut commands to split the 3DFEM model in Wall submodels (Shell Groups).



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

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 Three Seismic STRESS binary BD (UI):

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

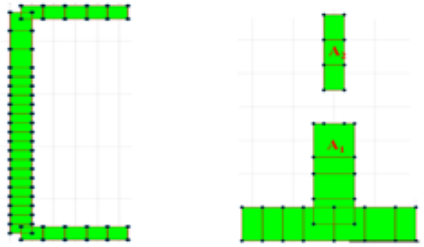
The Gravity and Seismic binary DBs are used in Step 5 for automatic section-cut calculations.

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)

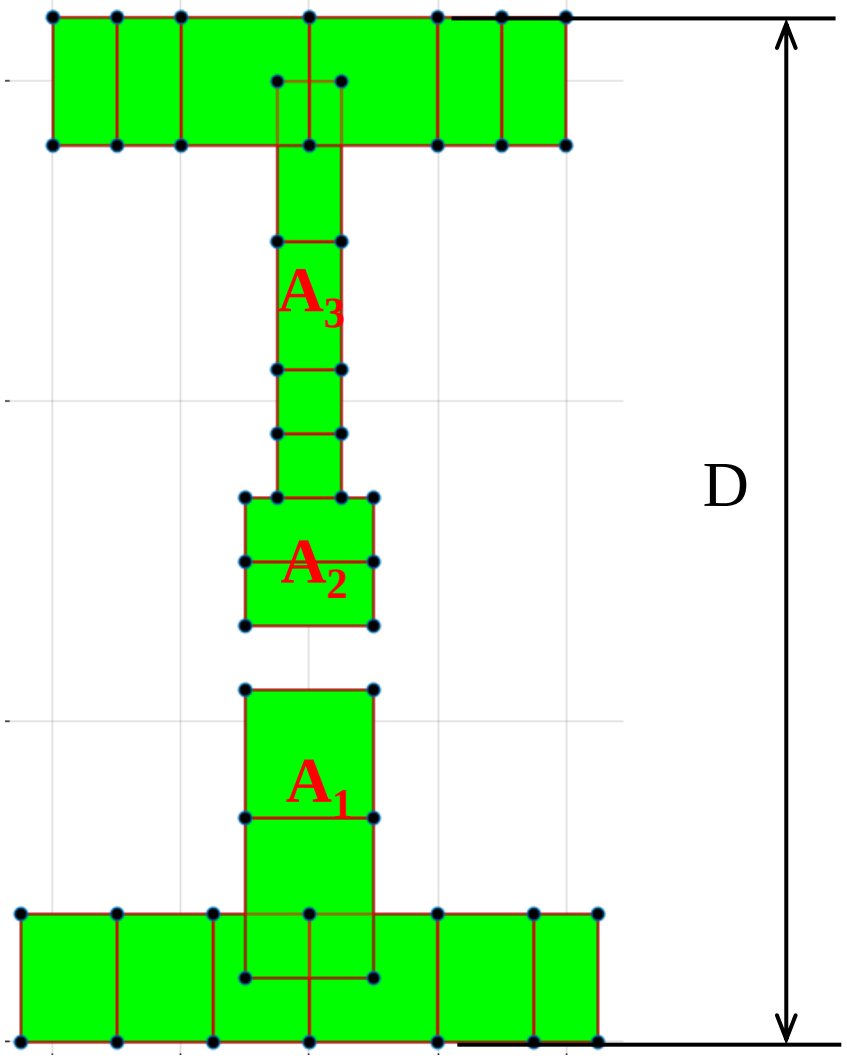
Step 5:

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

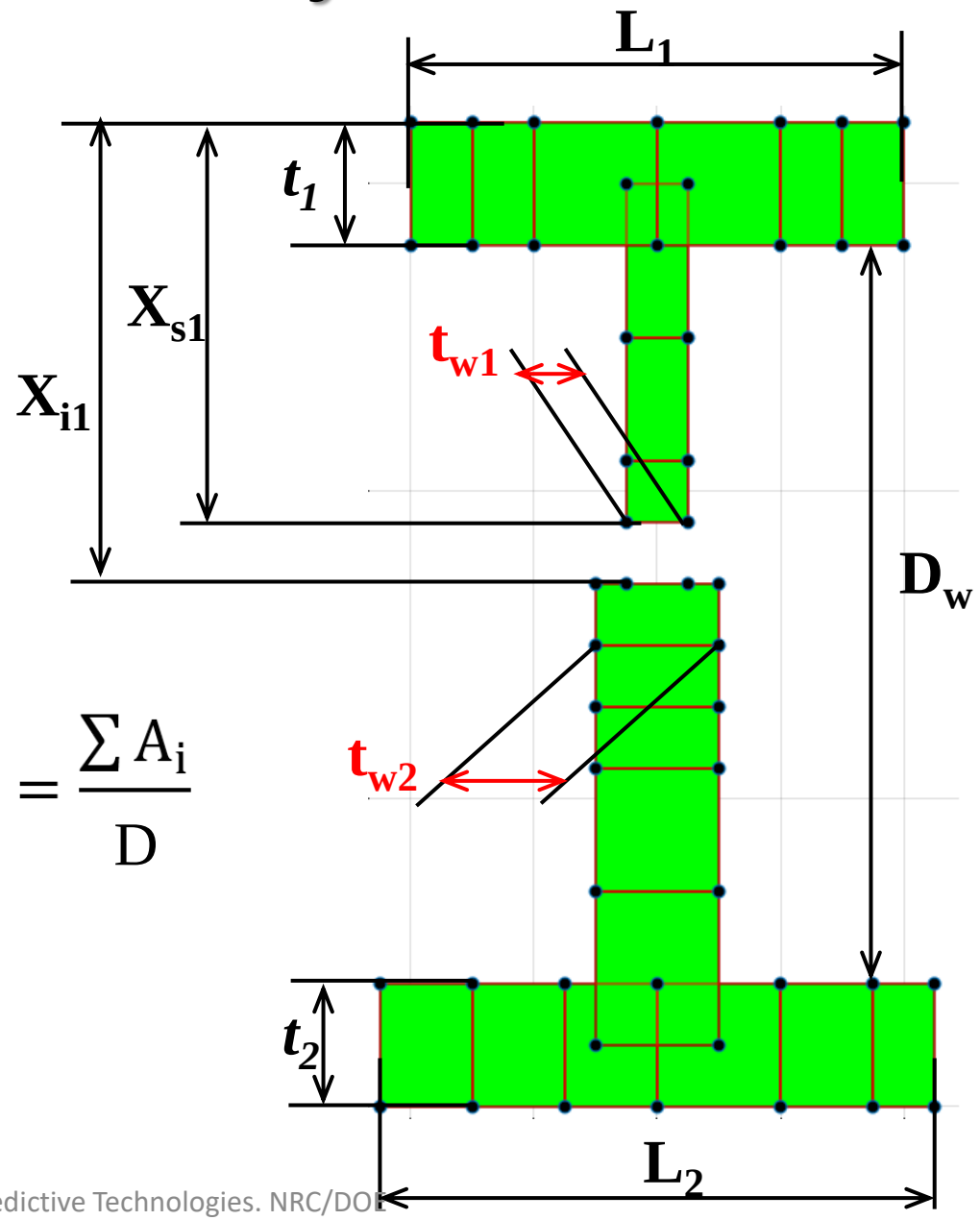
Output files:
The *Section_Data_for_BBC.out* output file produced by the run includes section-cut forces and geometry to be reviewed by the user in Step 6.

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

Examples of Section Geometry Identification



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



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
 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
```

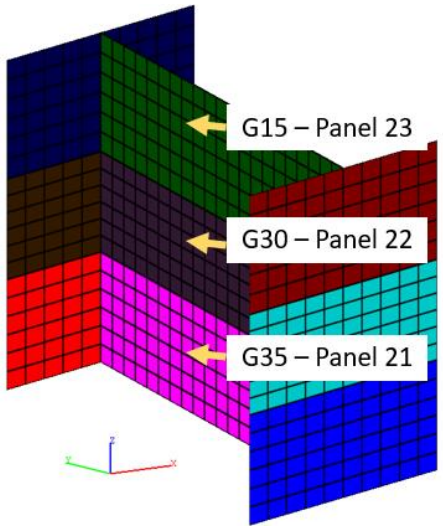
Section_Data_for_BBC.out File from *Section_Cuts_for_BBC Module* (Step5)

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

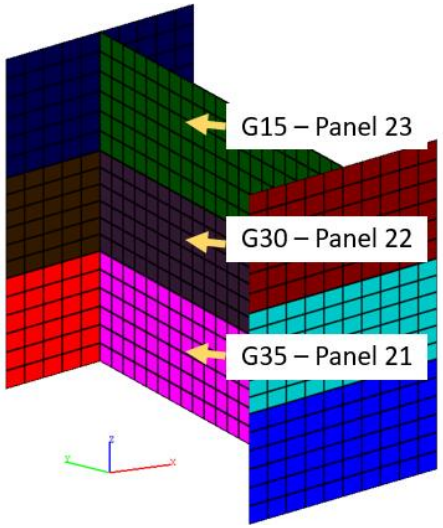
These are parameters shall be input by analyst for each wall submodel for each floor level cross-section

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)

Steps 7-8: Computes Shear and Bending BBCs

BBC_JEAC_4601_2015 Module Run

Step 7 — *Section_BBC_Data.out* file — **(B)**

Step 8 — *BBC Shear.pre & BBC Bending.pre* files — **(UI)**

Steps 9-10: Nonlinear SSI Analysis and Post-Processing

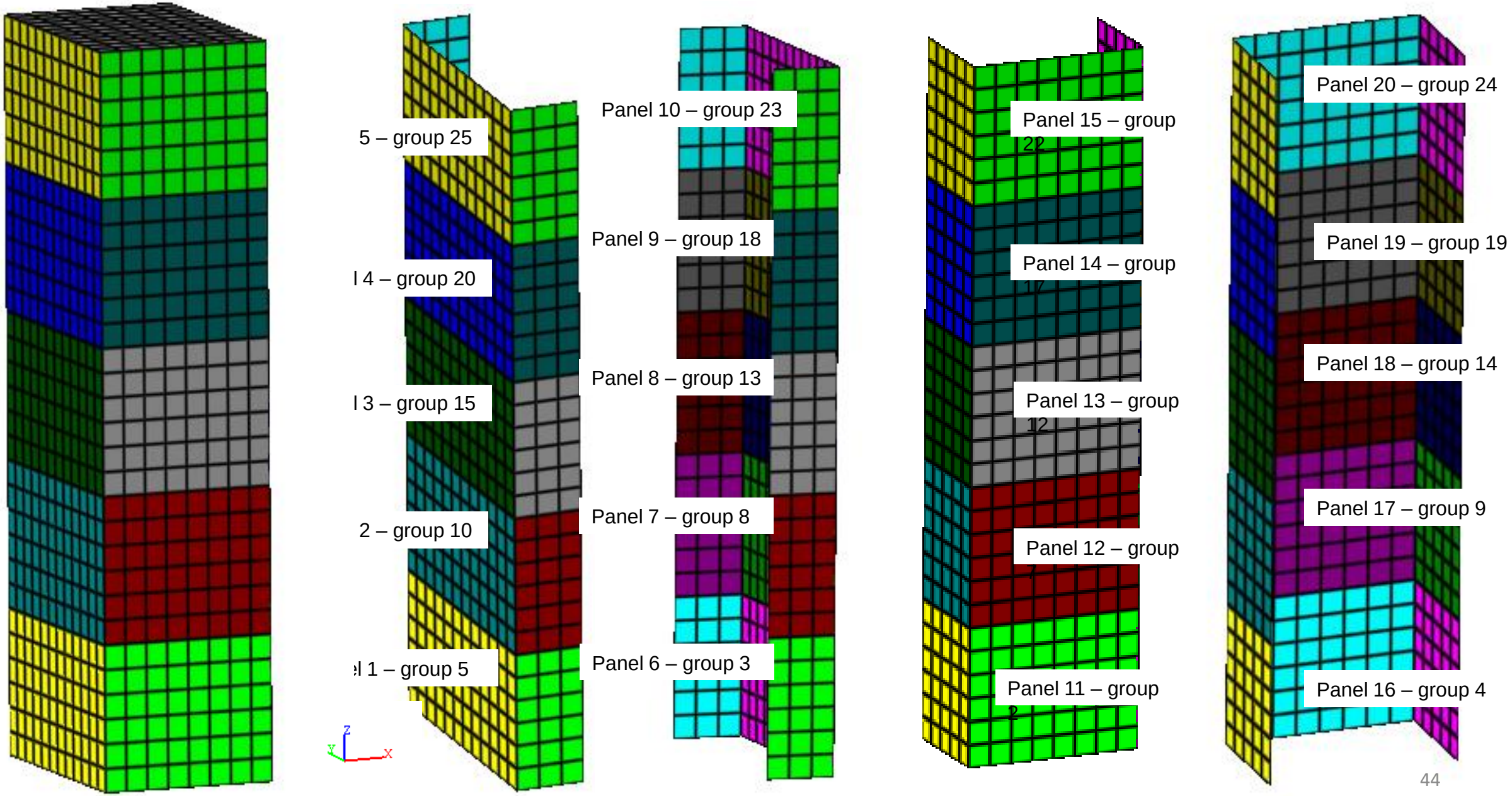
Option NON Nonlinear SSI Analysis (Batch Run)

Step 9 — *Shear and bending effects are combined at each SSI iteration using **COMB_Shear_Bend** Module*

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

Step 10 — **Final SSI Post-Processing** — **(B)** **(UI)**

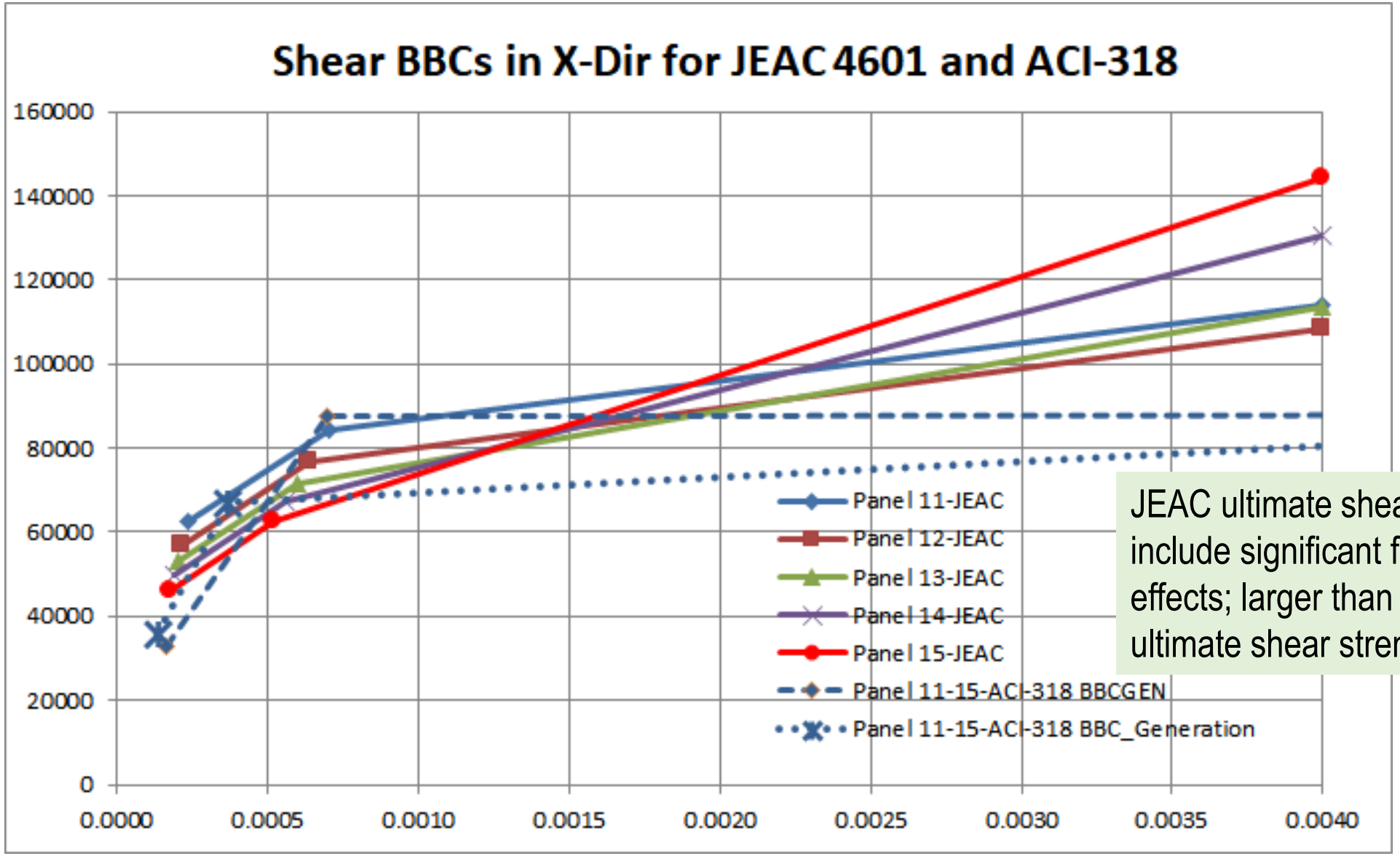
7. Comparative TB Nonlinear Results for US and Japan Practices



Computed Effective Flange Width for ACI-318 and JEAC 4601

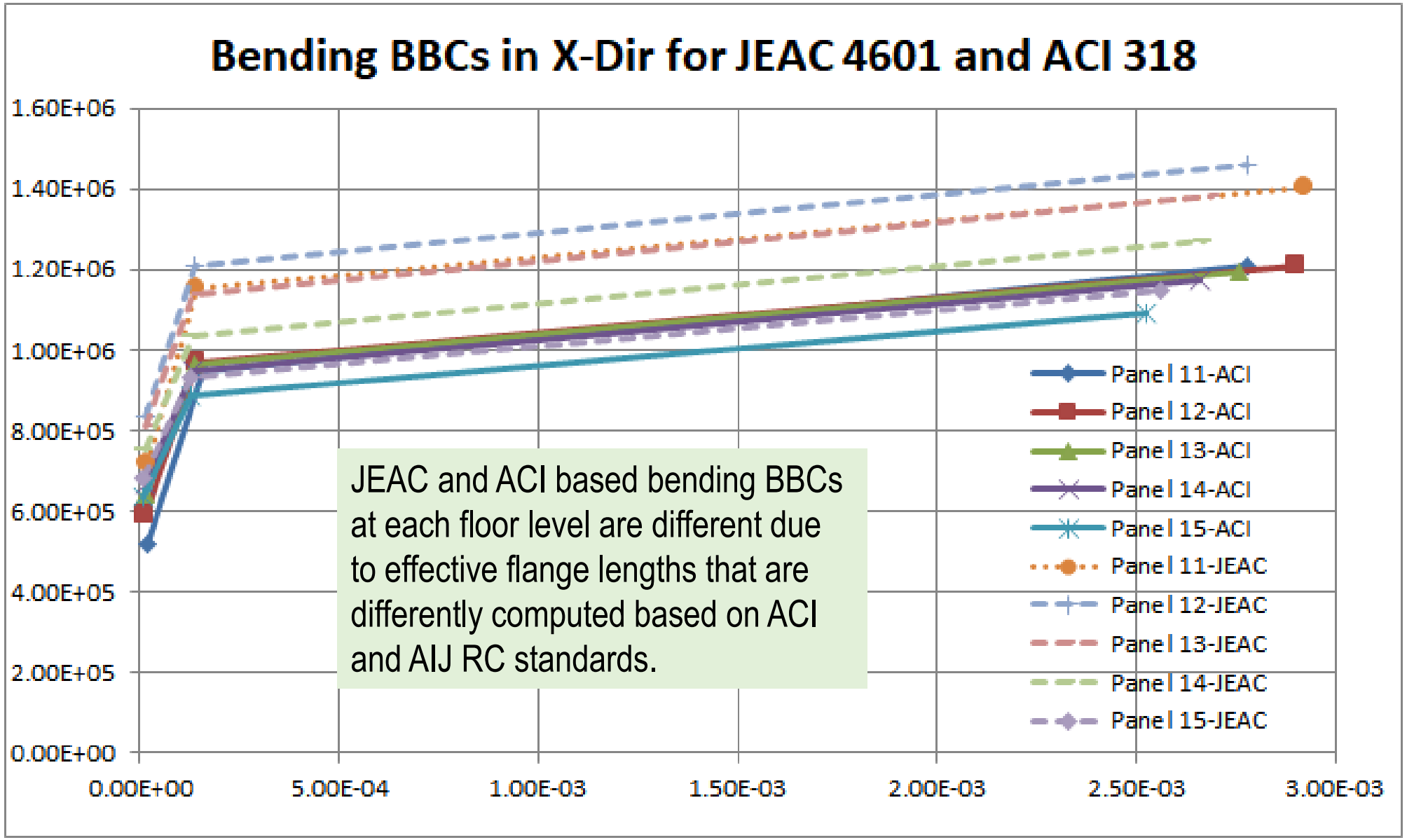
Panel #	Flange 1 L1C (m)		Flange 2 L2C (m)	
	JEAC 4601 2015	ACI 318-14	JEAC 4601 2015	ACI 318-14
1, 6	6.12	3.5	6.12	3.5
2, 7	7.43	5.5	7.43	5.5
3, 8	7.87	7.5	7.87	7.5
4, 9	8.09	8.75	8.09	8.75
5, 10	8.22	8.75	8.22	8.75
11, 16	6.42	3.5	6.42	3.5
12, 17	9.58	5.5	9.58	5.5
13, 18	10.64	7.5	10.64	7.5
14, 19	11.16	9.5	11.16	9.5
15, 20	11.48	10.5	11.48	10.5

Computed Shear BBCs for TB Transverse Walls in X-Dir



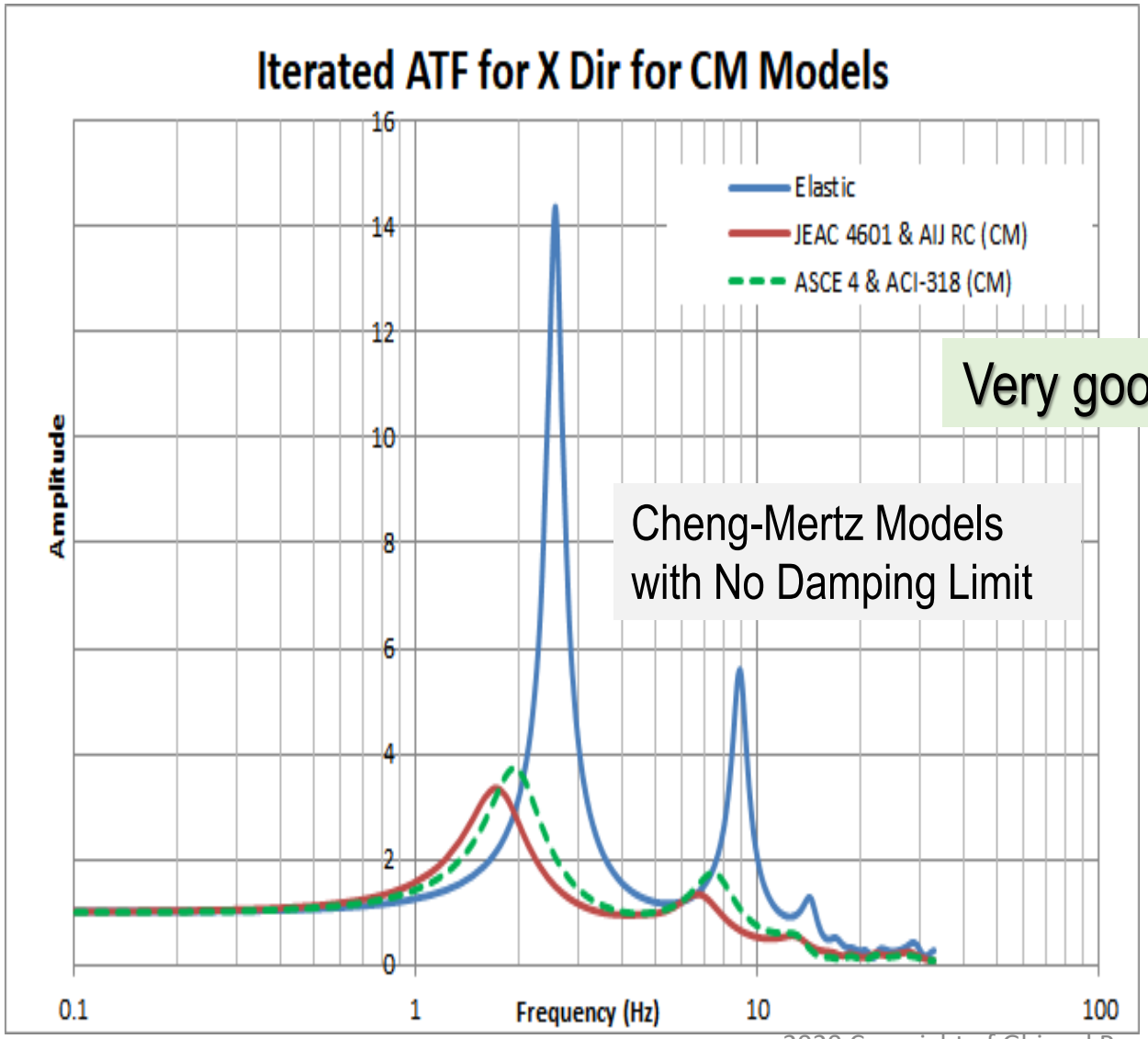
JEAC ultimate shear forces include significant flange effects; larger than ACI-318 ultimate shear strengths.

Computed Bending BBCs for TB Transverse Walls in X-Dir



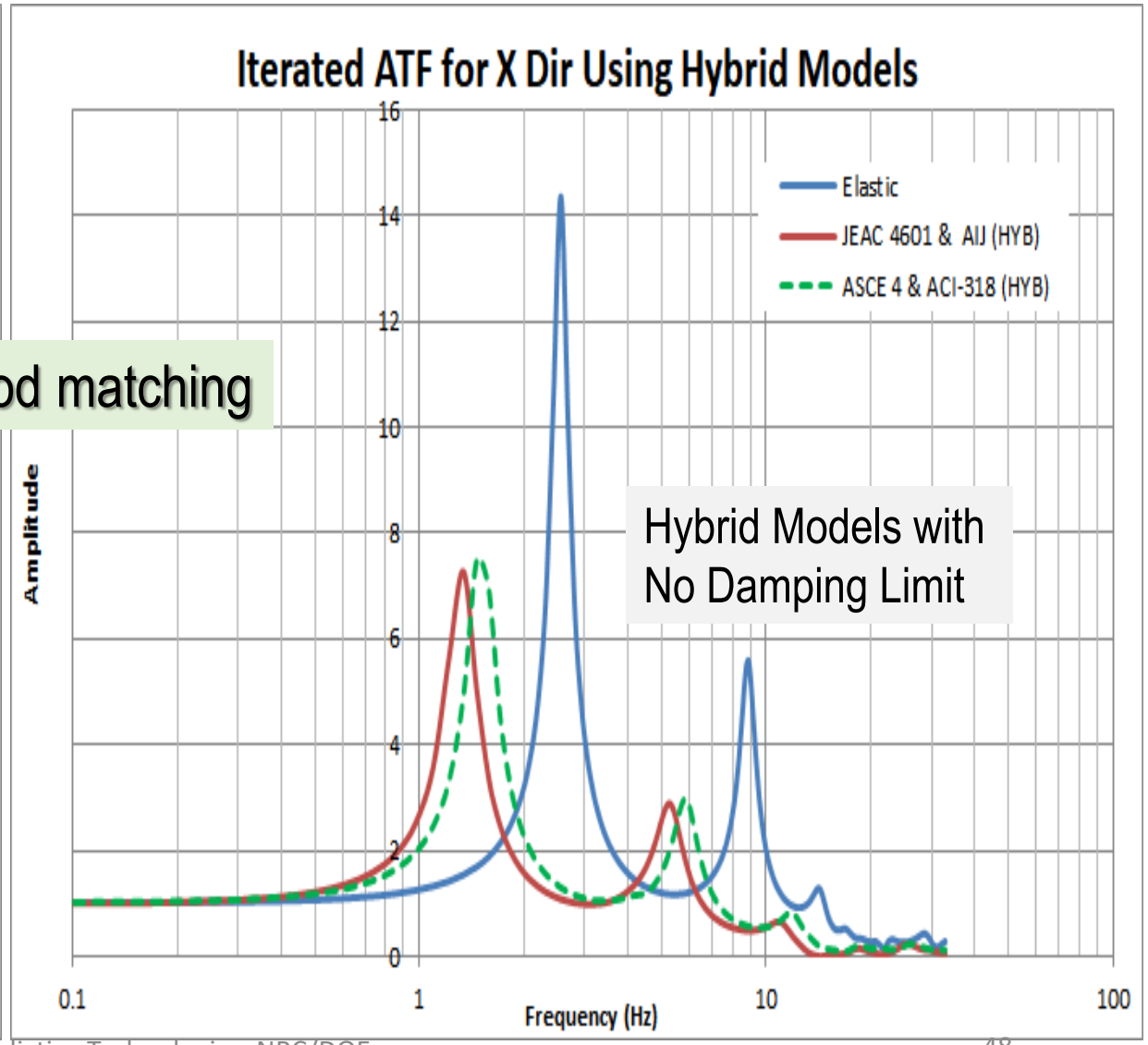
JEAC and ACI based bending BBCs at each floor level are different due to effective flange lengths that are differently computed based on ACI and AIJ RC standards.

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



Cheng-Mertz Models with No Damping Limit

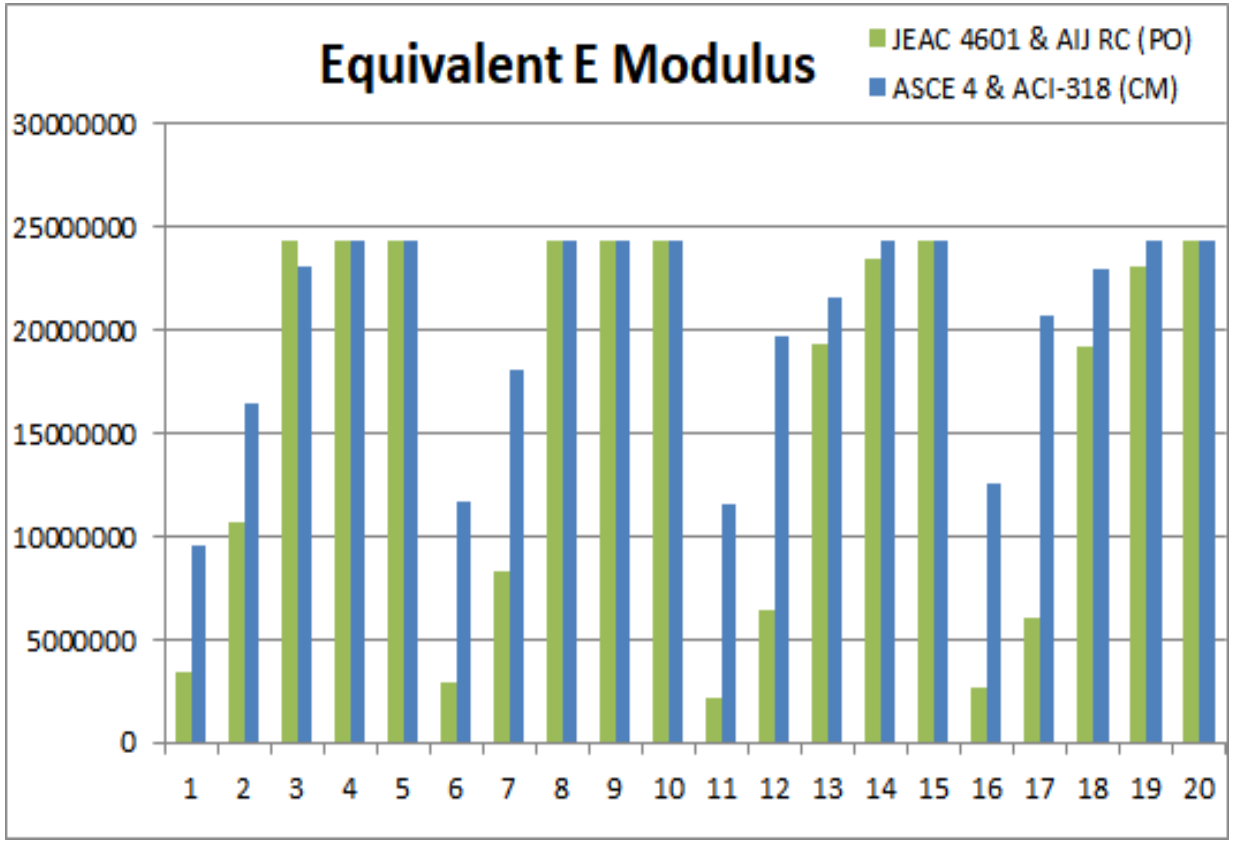
Very good matching

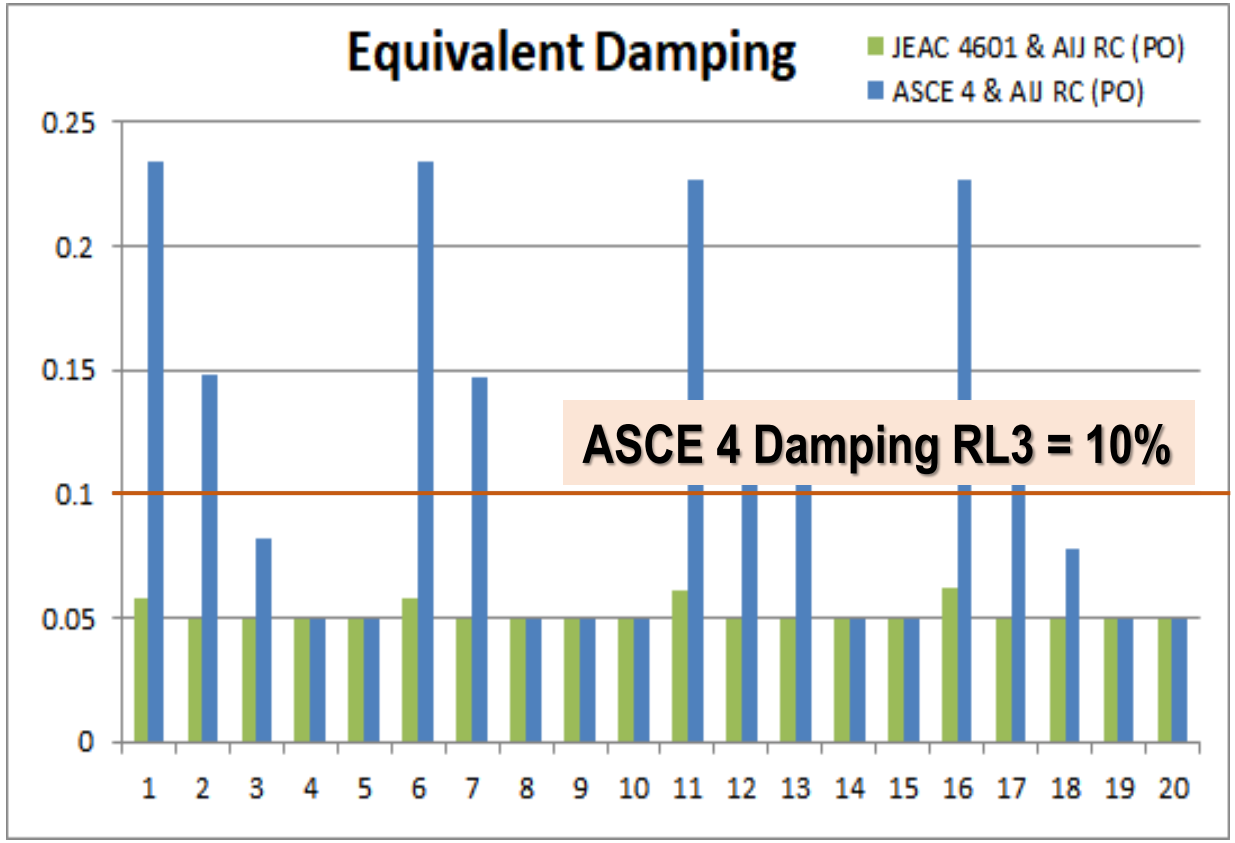


Hybrid Models with No Damping Limit

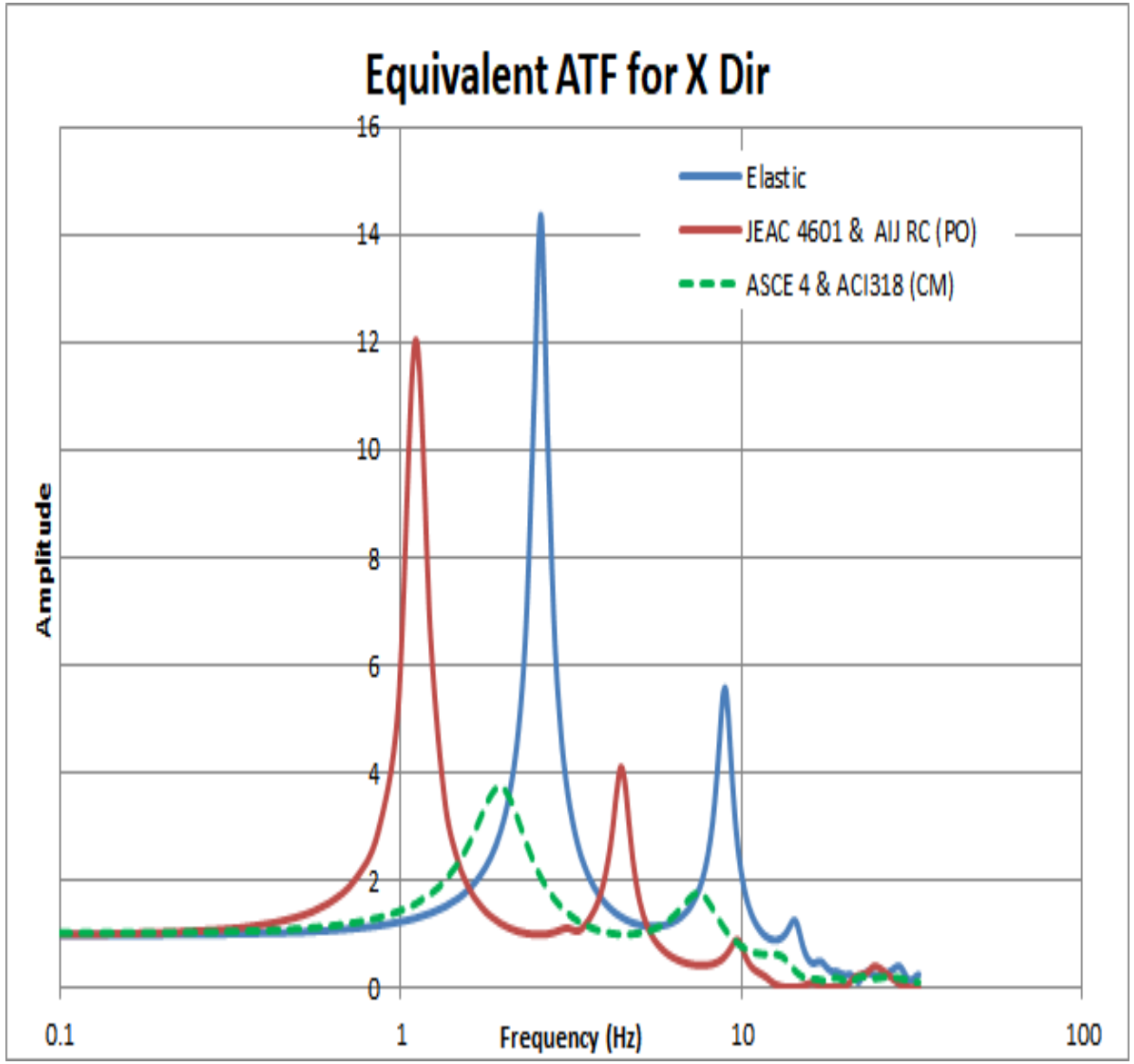
Iterated Walls Stiffness and Damping for 0.70g RG1.60 Input

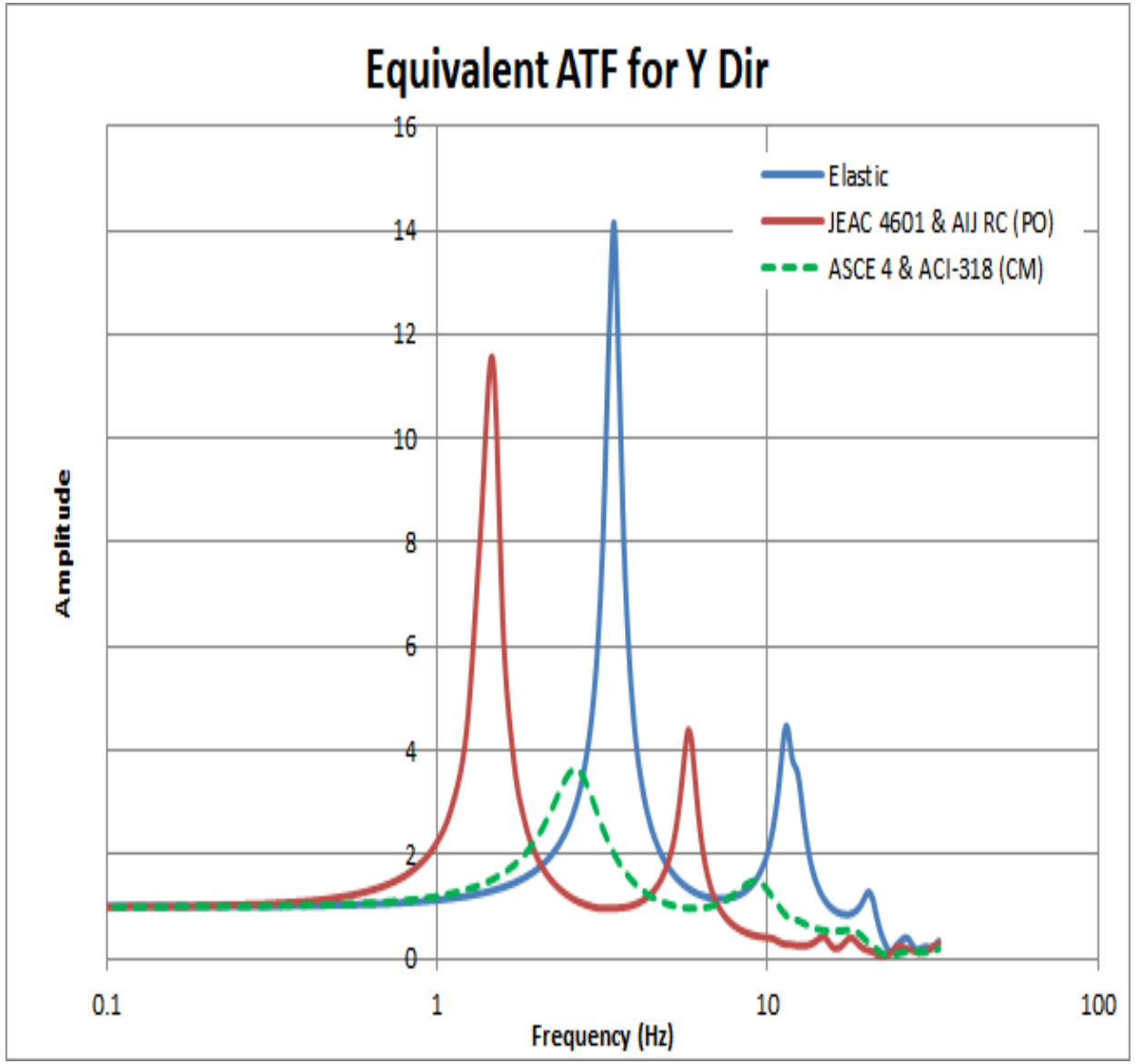
Using JEAC PO Models and CM Models with **No Damping Limit** (directly FEA nonlinear results)



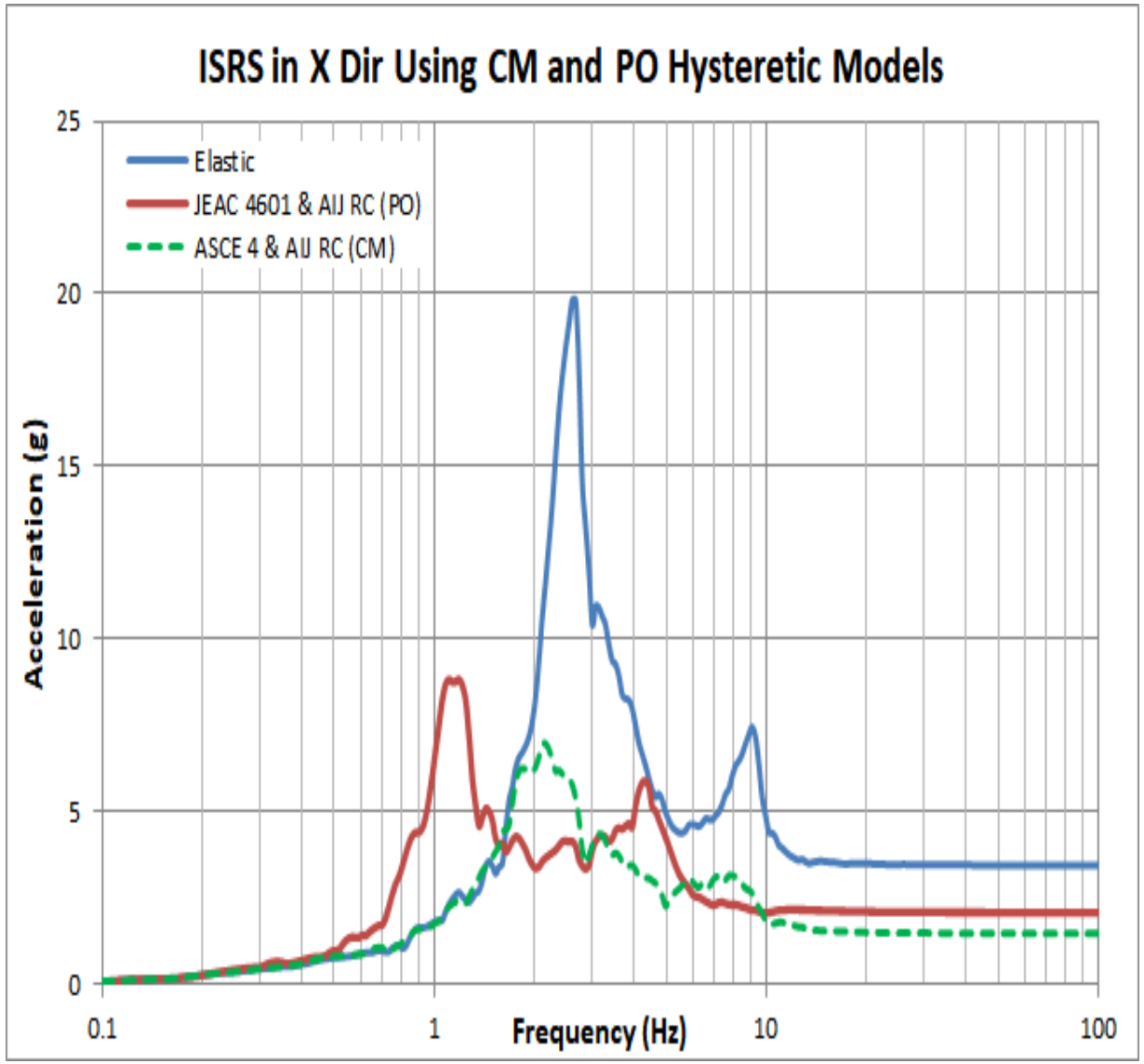


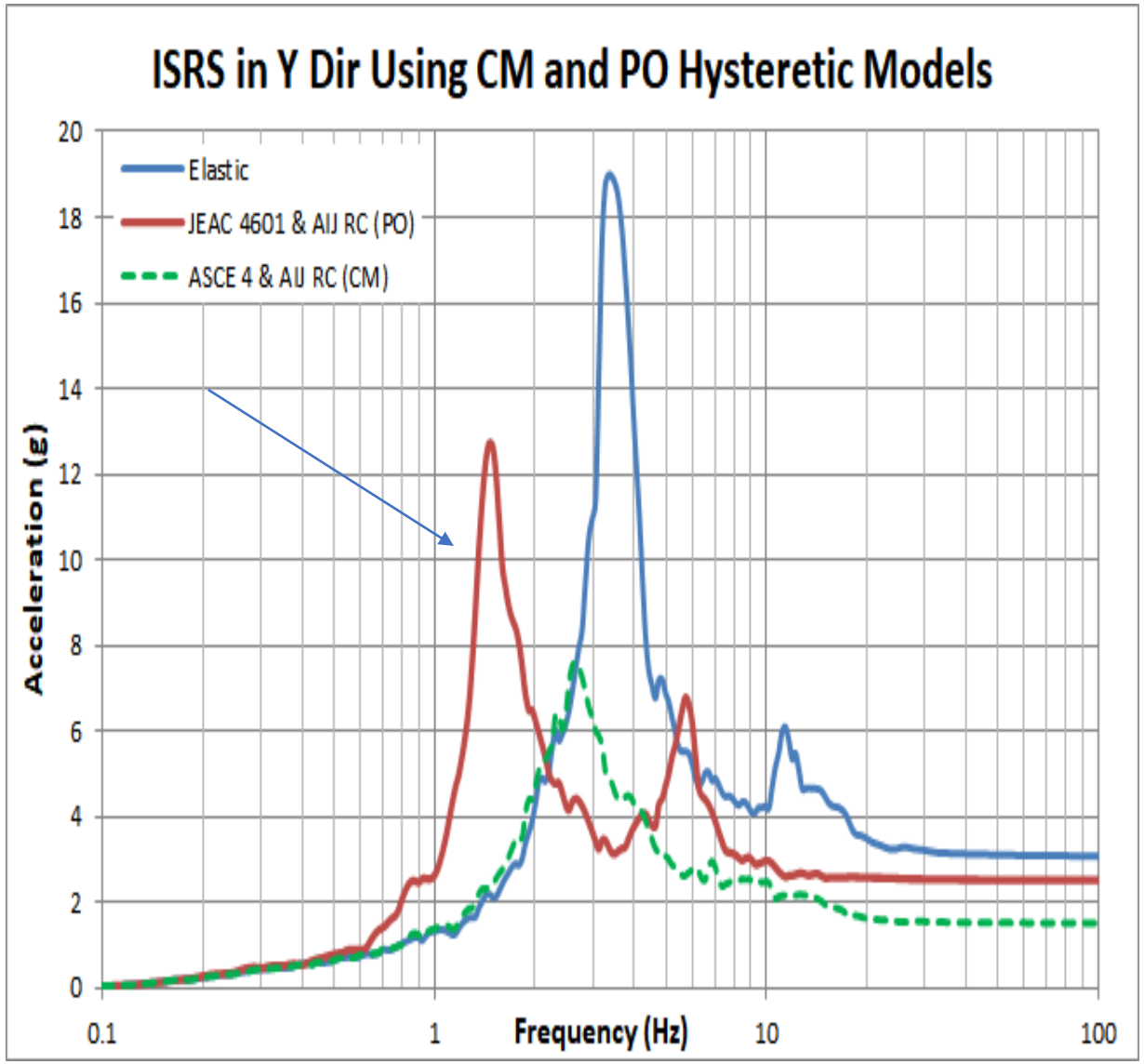
Iterated ATF for JEAC PO Models and CM Models w/ No Damping Limit





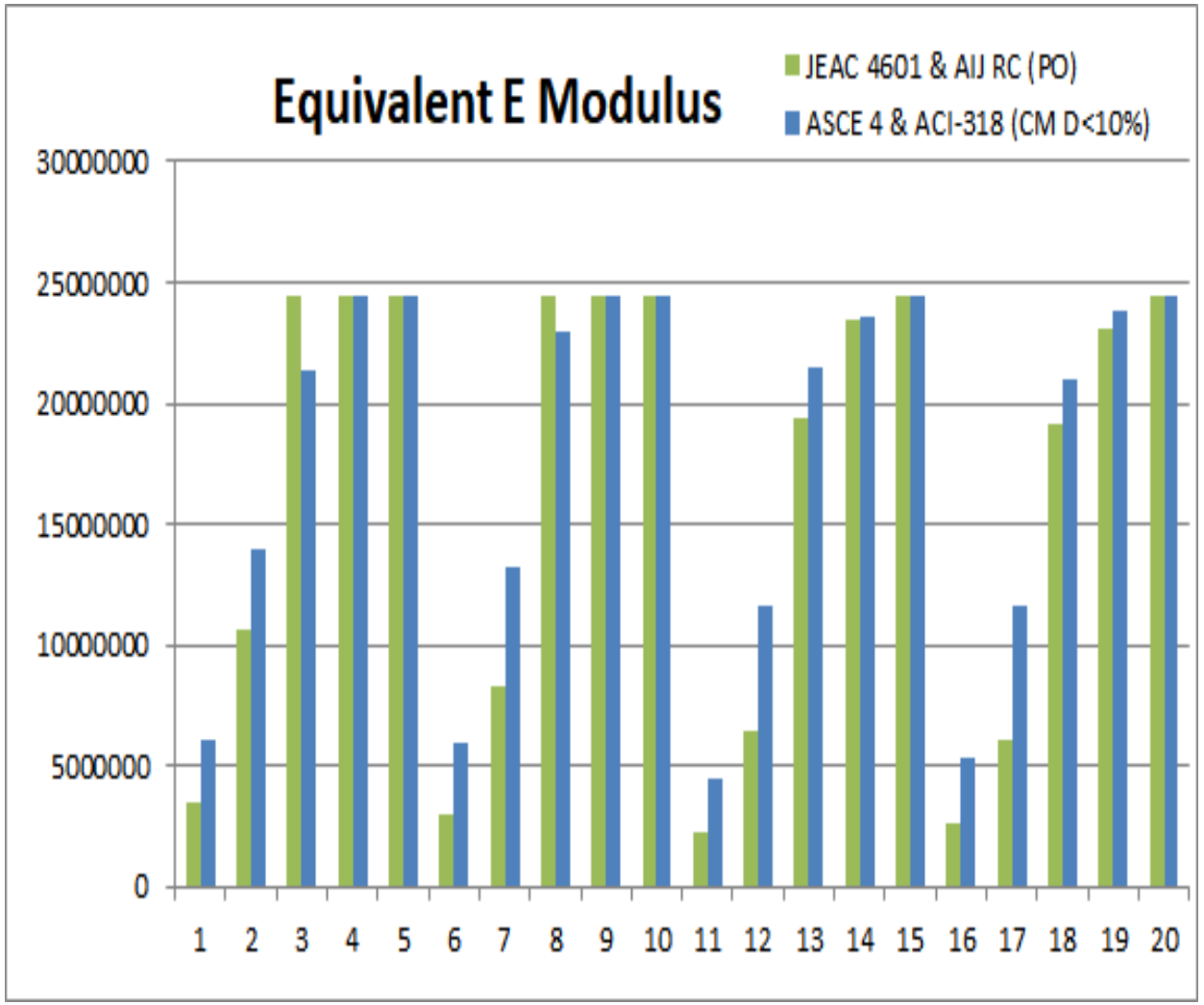
Iterated ISRS for JEAC PO Models and CM Models w/ No Damping Limit)

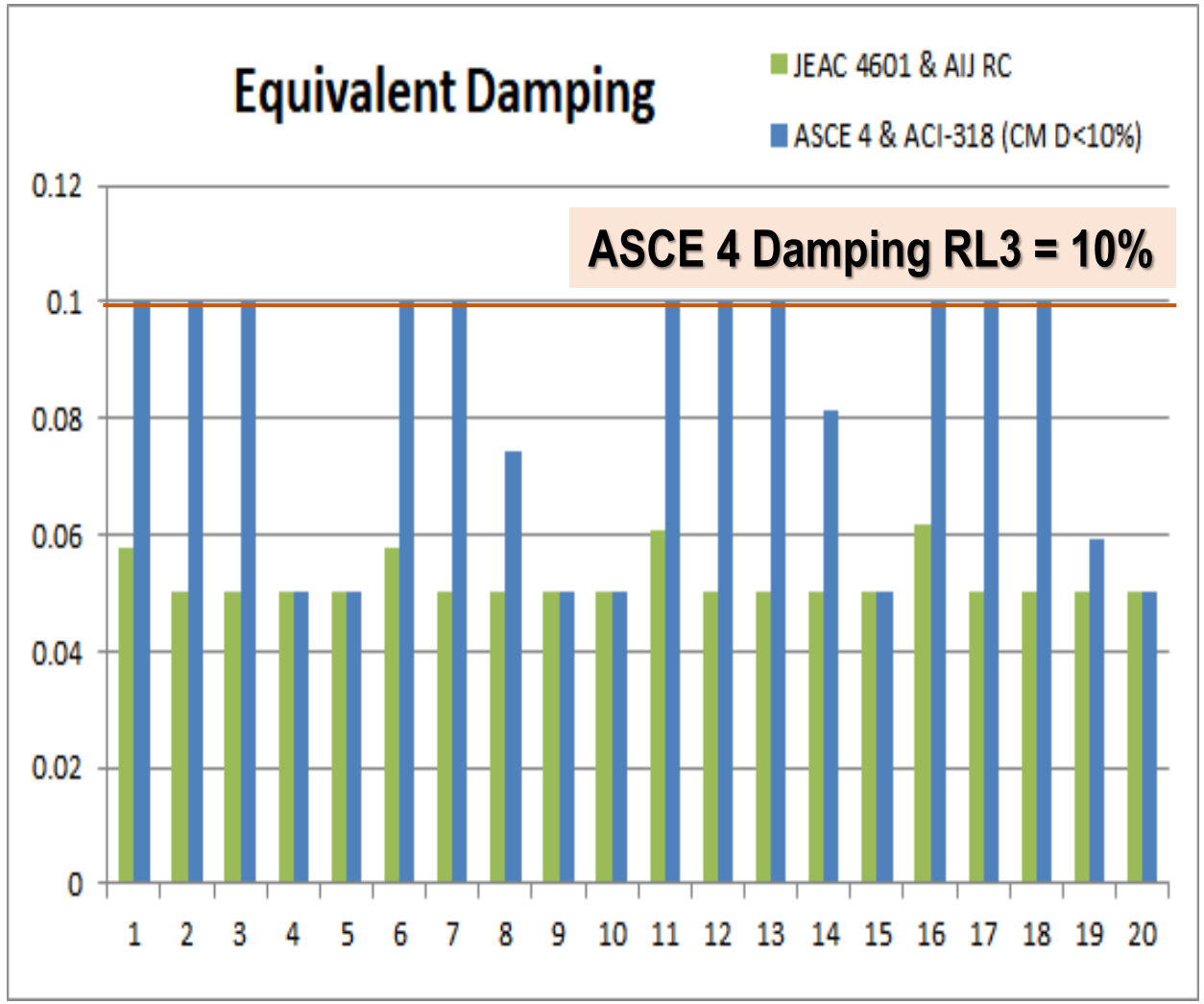




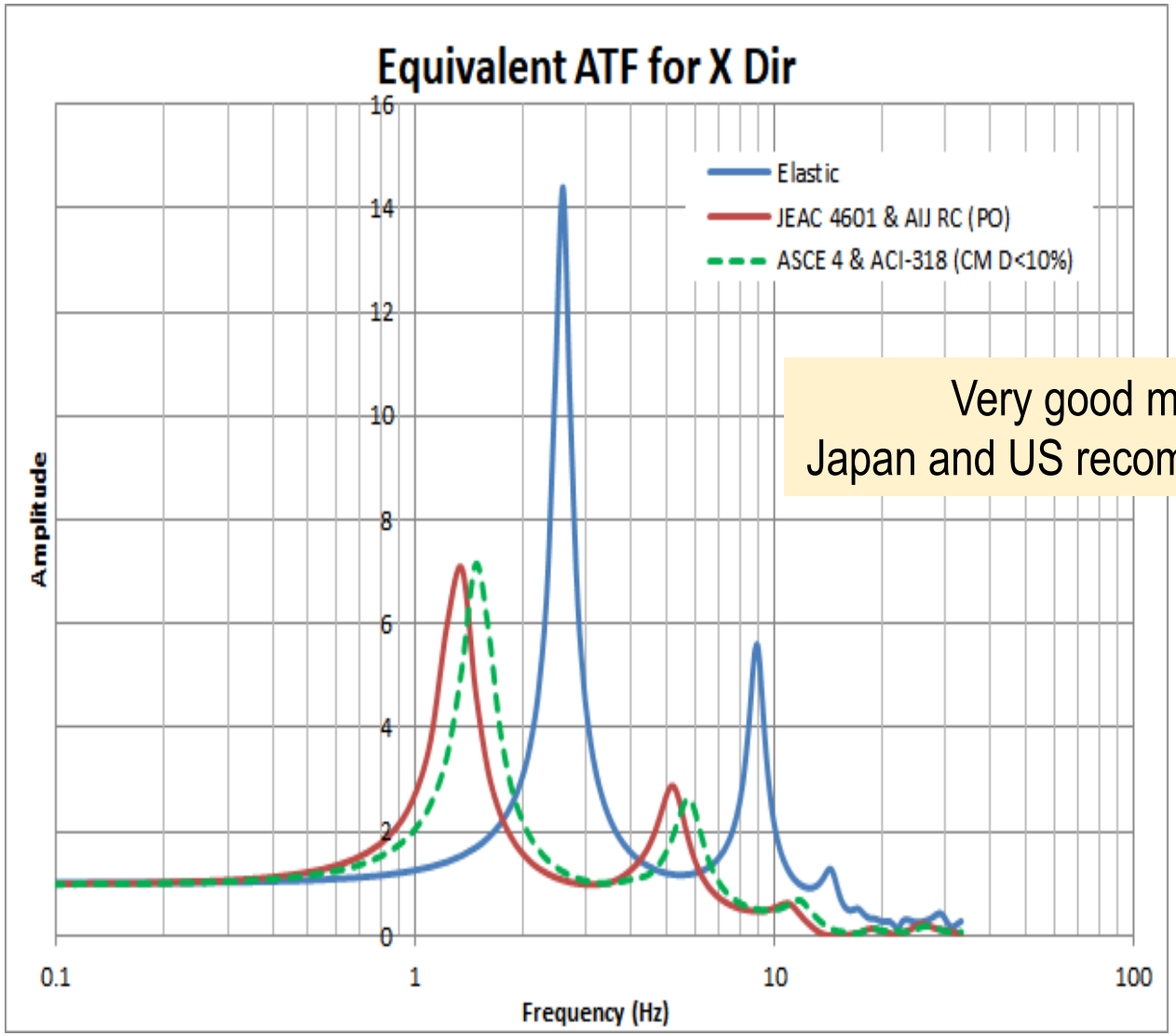
Iterated Walls Stiffness and Damping for 0.70g RG1.60 Input

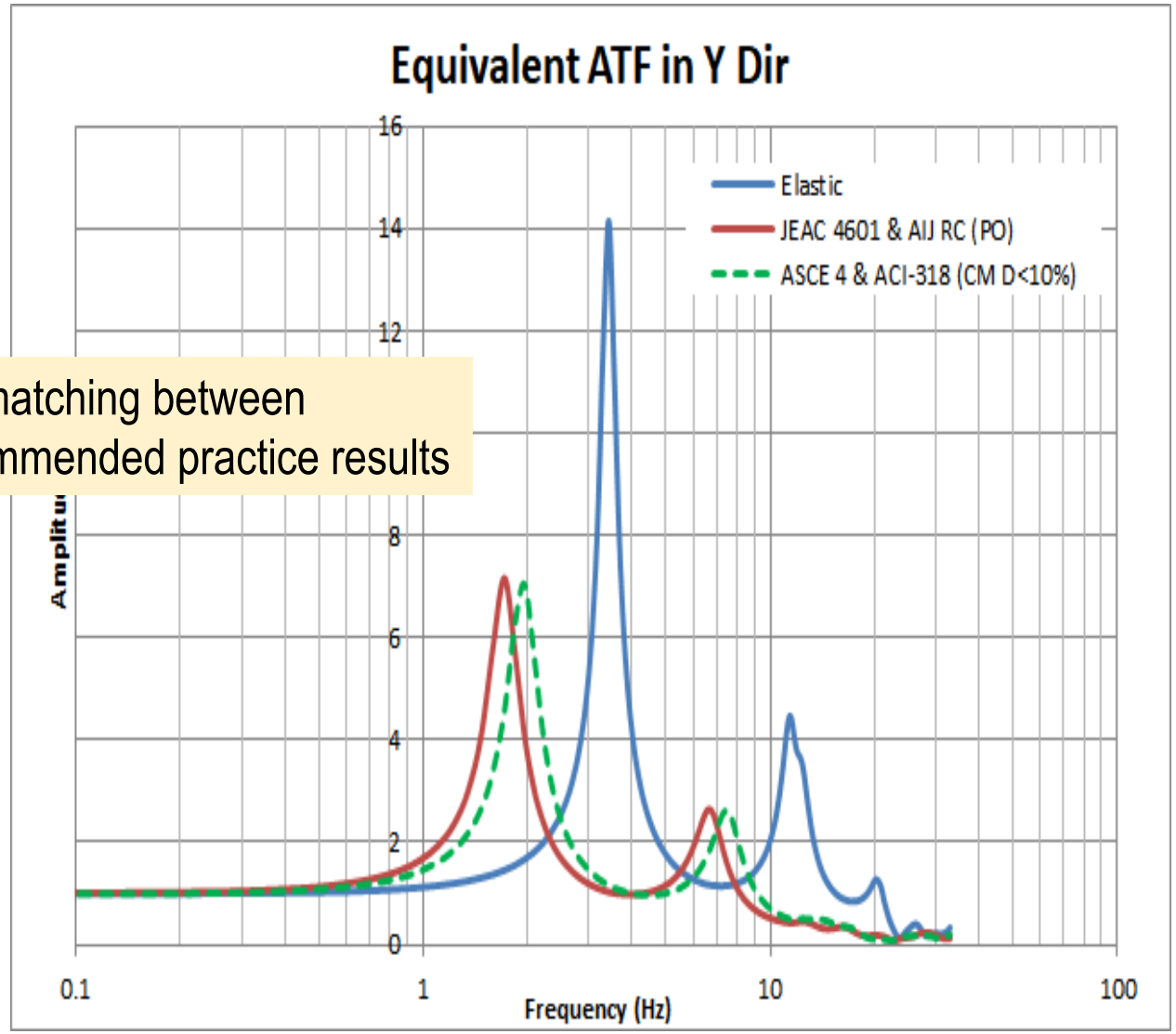
Using JEAC PO and CM Models with **Damping < 10%** per ASCE 4 Section 3 Recommendation





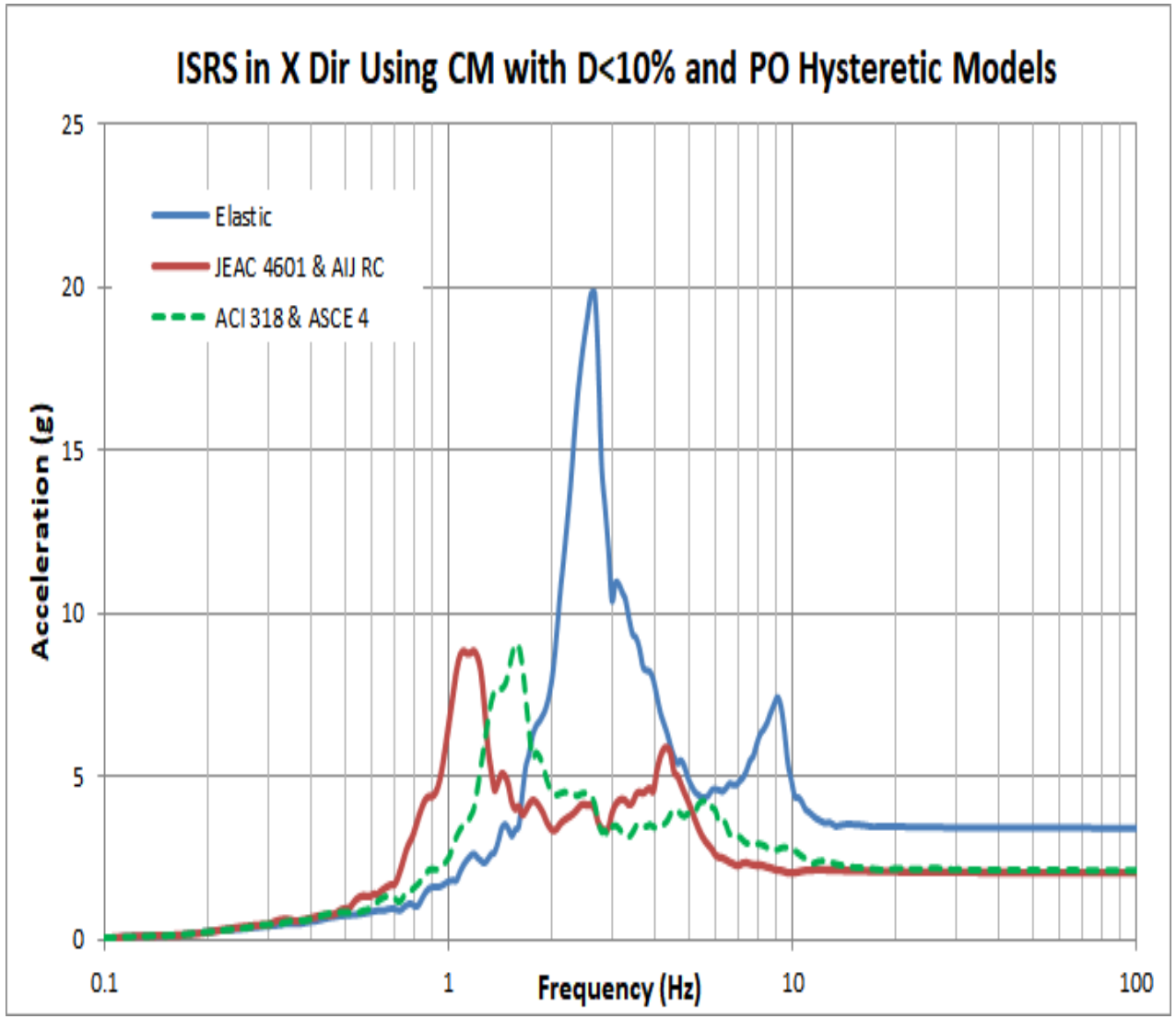
Iterated ATF for JEAC PO Models and CM Models with D<10%

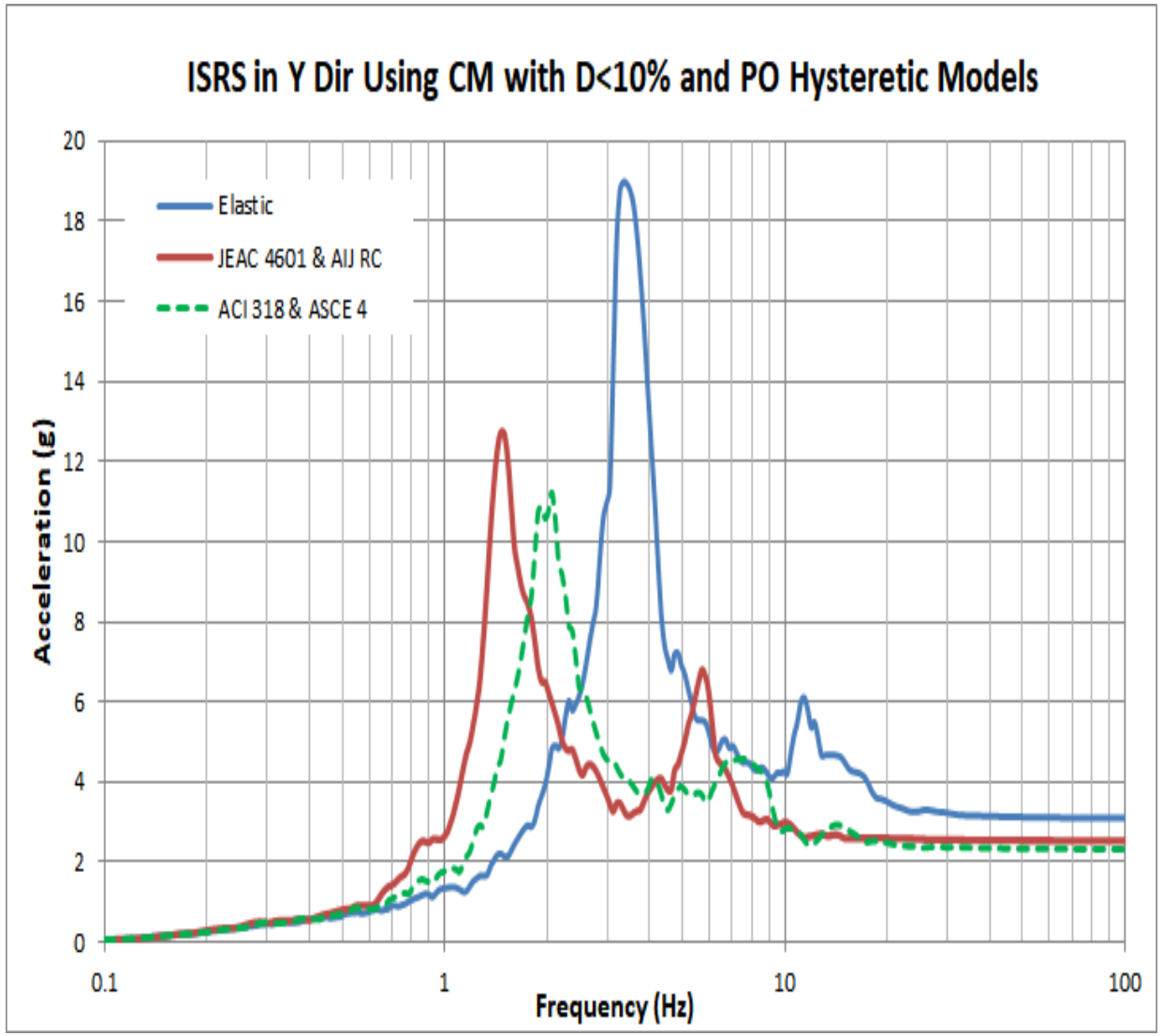




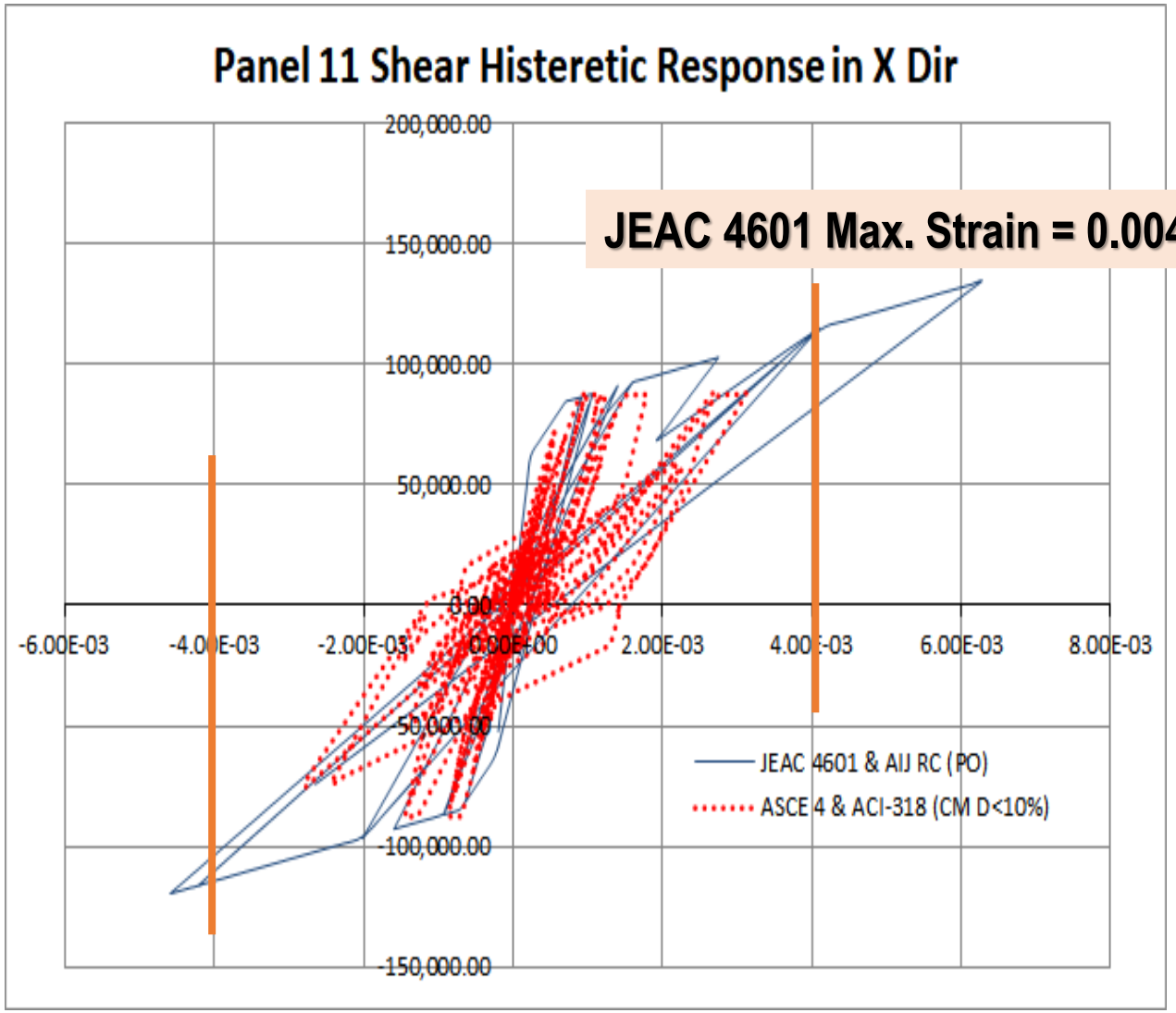
Very good matching between
Japan and US recommended practice results

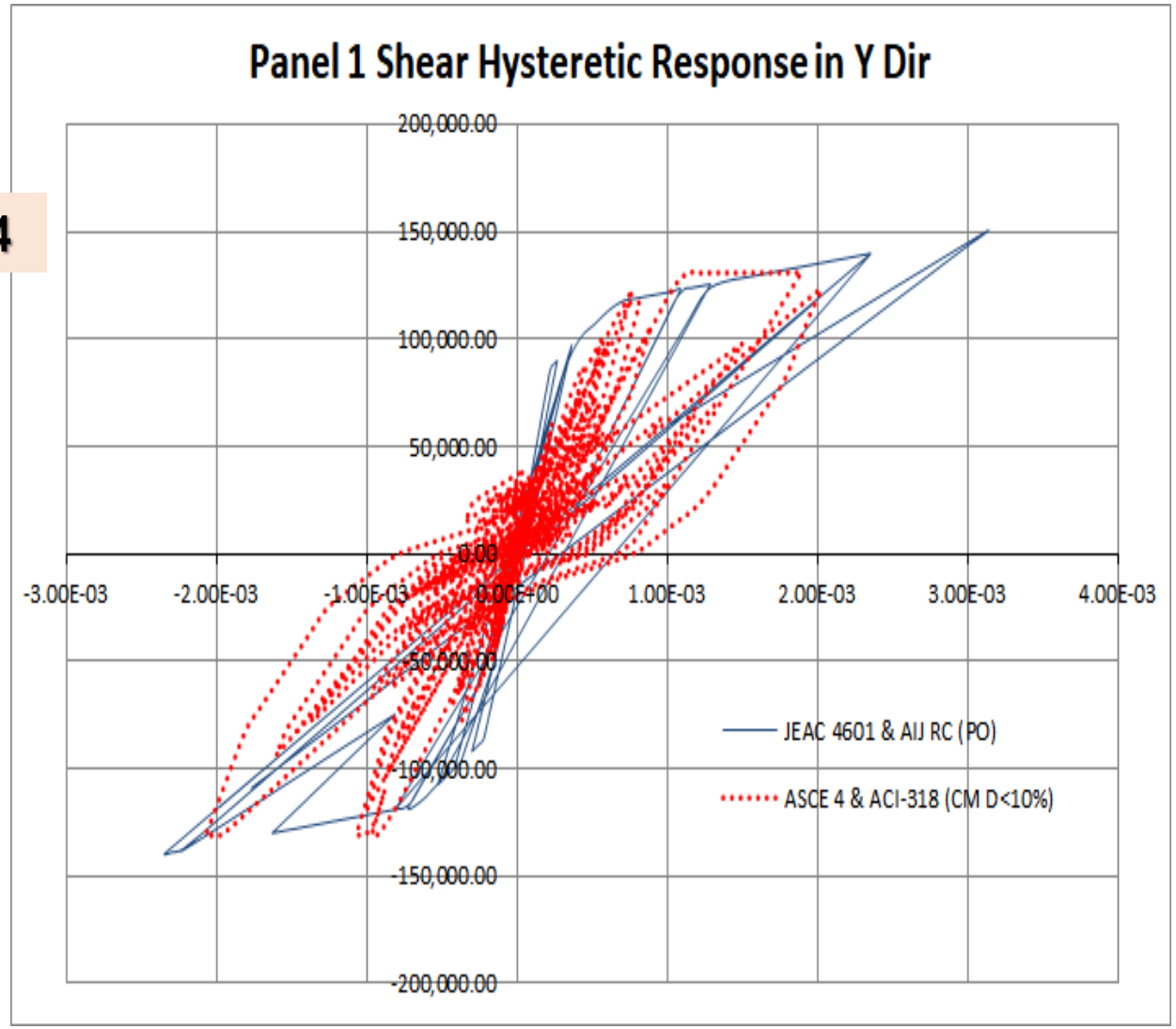
Iterated ISRS for JEAC PO Models and CM Models with D<10%



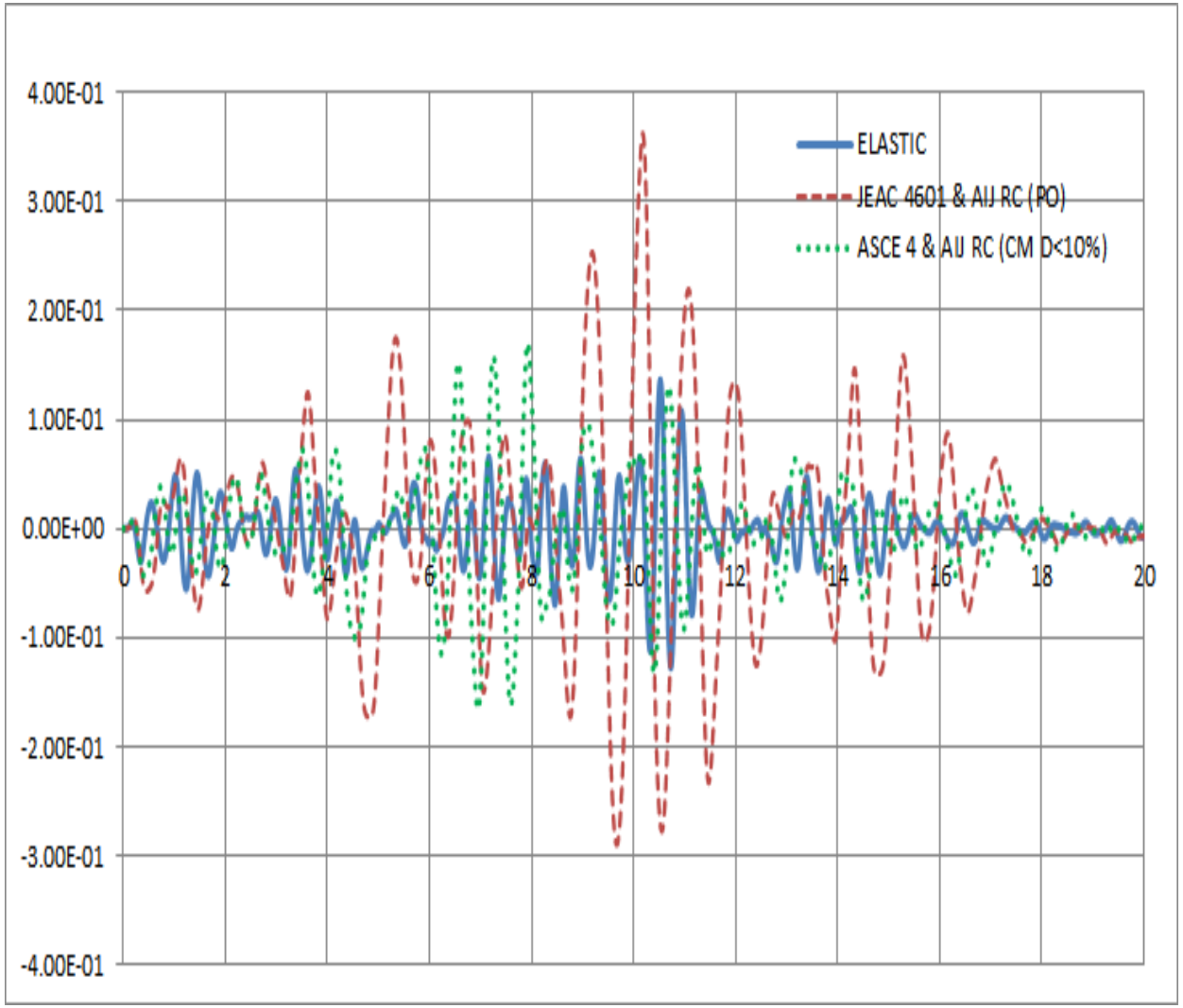


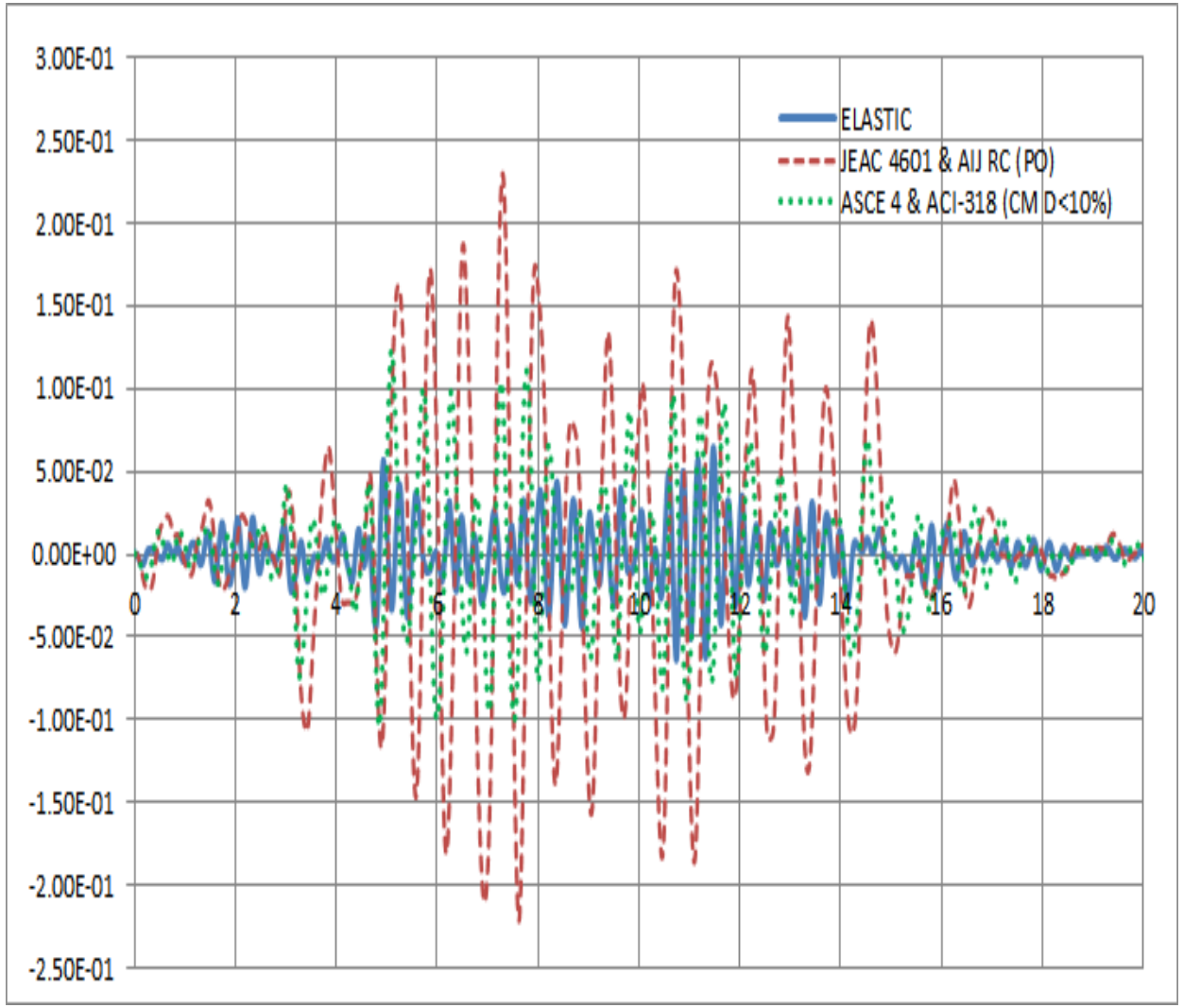
Shear Hysteretic Response for JEAC PO and CM with D<10%





Nonlinear Displacements for X and Y Dir at Top of TB for JEAC PO Models and ASCE 4 CM with D<10%





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.

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End of Part 2

Thank you!