Review of PWR modified 75 m^2 Heliostat Modal Test Results

SAND2011-3706P

May 23, 2011

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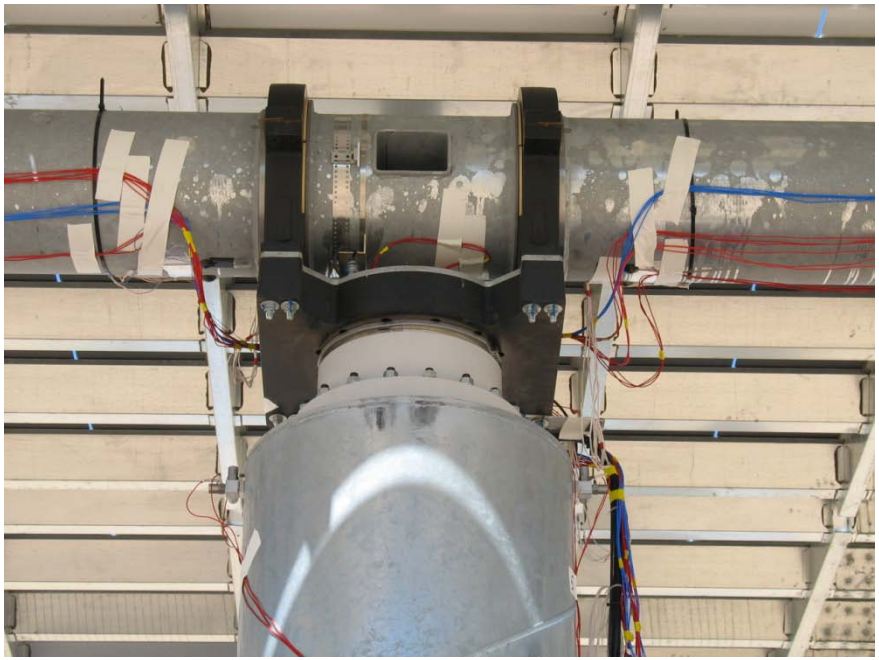


Summary

- Model Correlation
- Model Correlation observations
- Modes List: Hammer and Wind Excited
- Wind Analysis
  - Wind Loading Spectrum
  - Acceleration/Displacement Auto-spectrum
  - Strain response (Torque tube and pedestal)
- Comparison of strain with Nabtesco tests

Analysis Information

- Predicted Modes from:
  - "CSP Heliostat Proposed Accel Locations for In-Situ Wind Response Modeling" by Roland Szabo, Rod Uyekawa and Andy Shiang, PWR Development Stress Group
  - File: heliostat.in.situ.accels.2011.04.13.ppt
  - Section: **Appendix A: 4/2011 75 m2 Heliostat with Traditional Trusses, Mirrors Horizontal, Thicker Horizontal Stiffeners***
  - **Predicted modes provided for stowed configuration (90 degree orientation)**

Model Correlation

- = Comparison of Measured and Predicted Modes
- Notes on actual test unit:
  - Extra weight for structural extensions and hardware from 62.5 to 75 m^2 not modeled (estimated at several hundred lbs)
  - Extra weight for adhesive is likely not modeled
  - **Modeled height of pedestal (i.e. height of pedestal flange above ground level)**

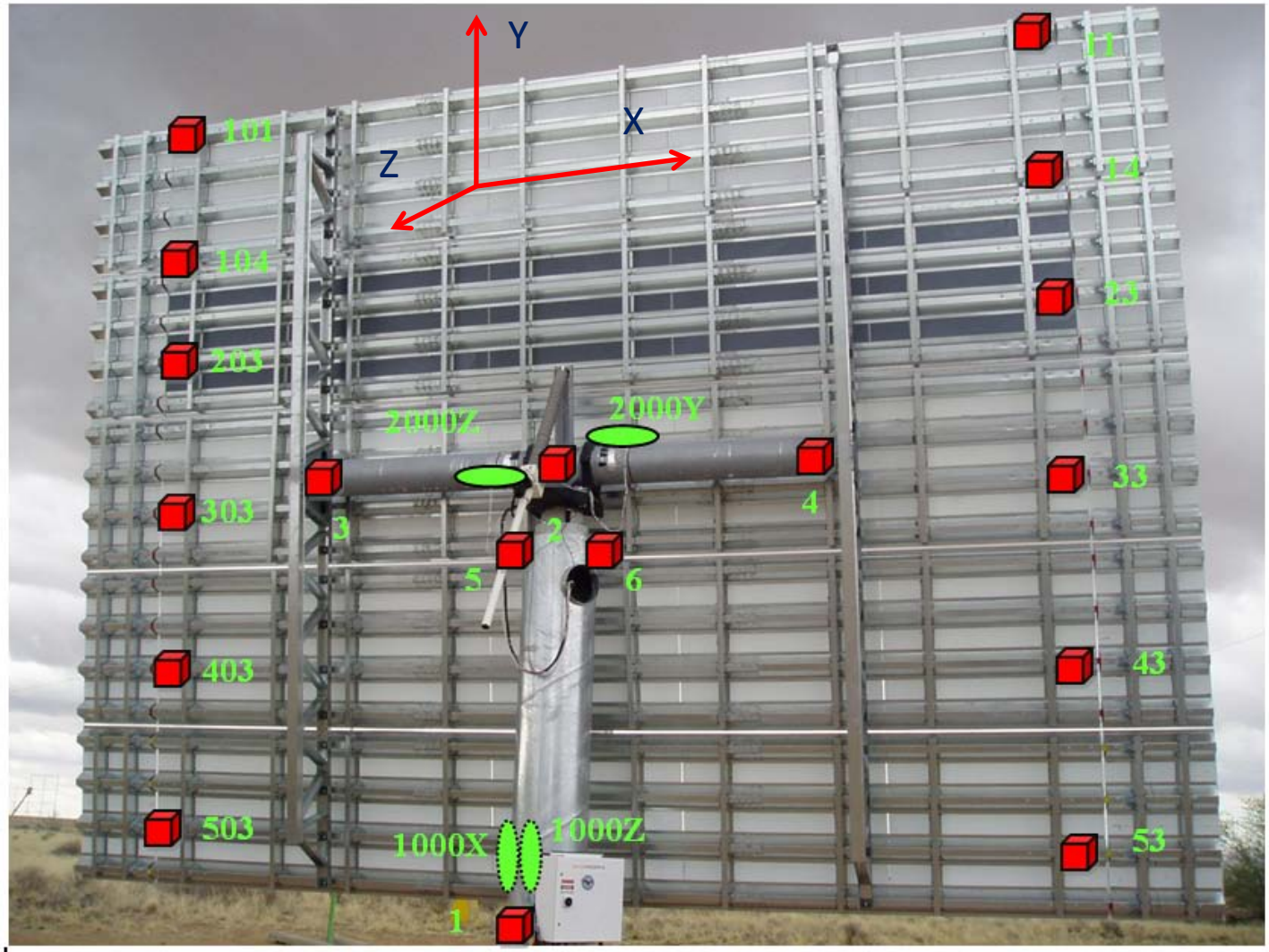
Instrumentation and CS

Coordinate System is “attached” to the mirror frame:

X: along mirror module

Y: chord-wise mirror module

Z: out of plane

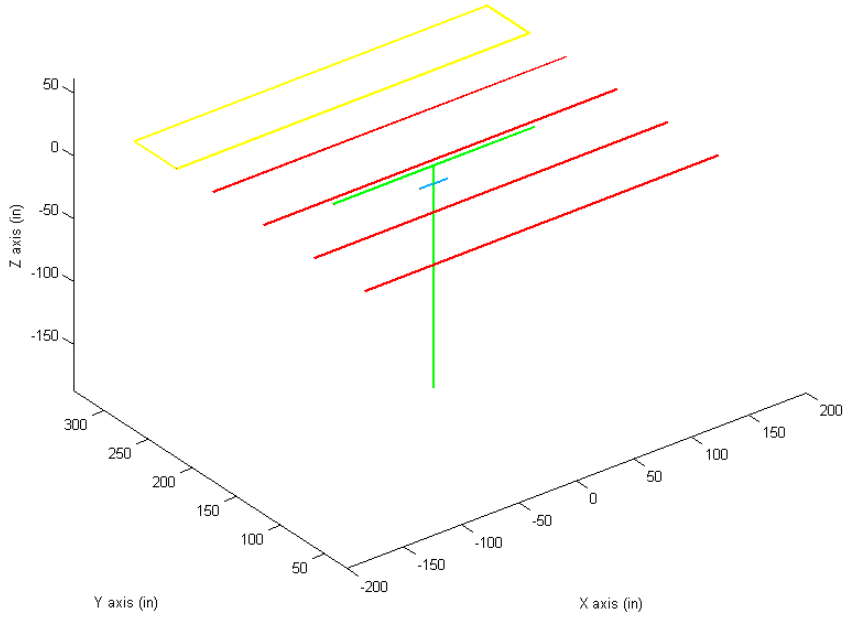


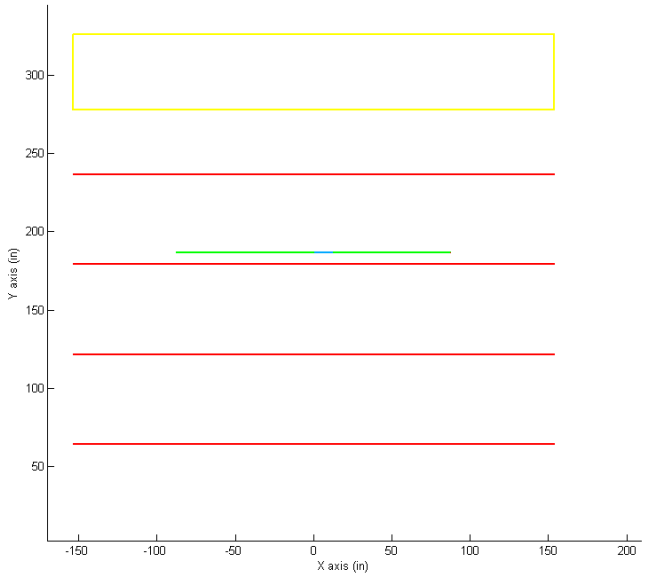
Triaxial accelerometer

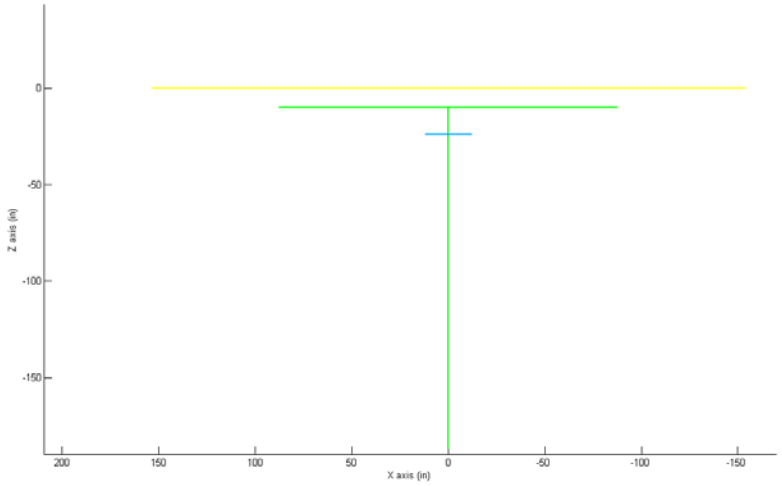
Dynamic strain sensor

Description of Experimental Geometry

Sensors located at vertices







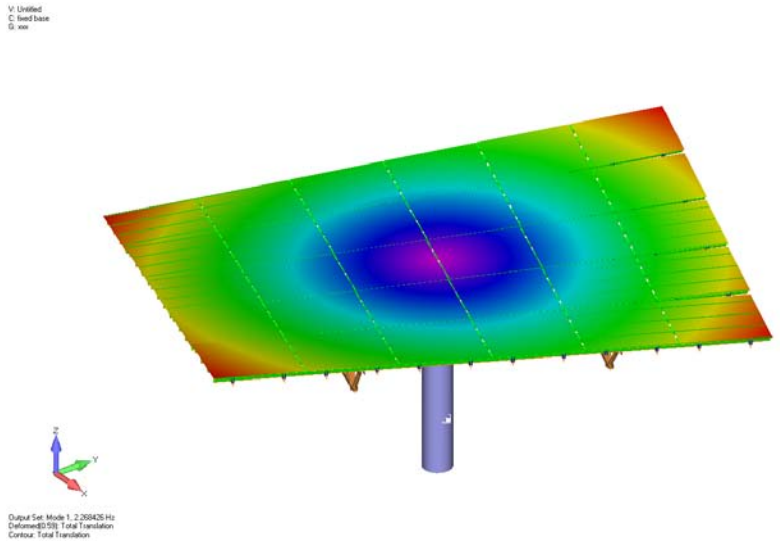
- Upper mirror module (#1): Yellow rectangle (4 corners)
- Mirror modules #2 thru #5: Red lines
- Torque tube and pedestal: Green lines
- Top of pedestal: Blue line

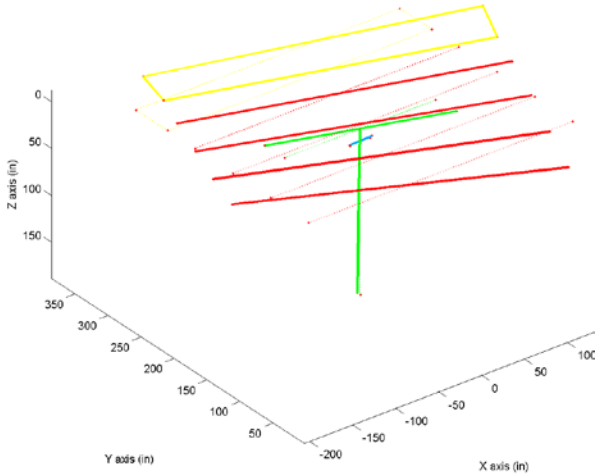
Mode 0
Azimuth Drive Rigid Body (1)

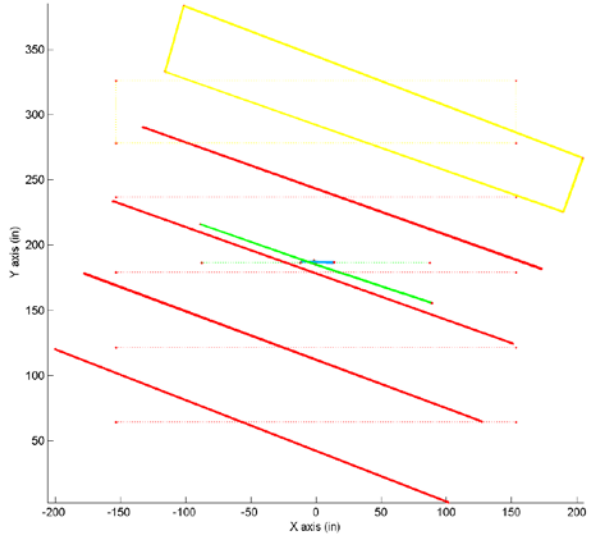
Mode 3
Frequency: 1.425 Hz
Damping: 5.412 %Cr
IDLine 1: Generated from reference 4Y-

1.335, 1.425 Hz

Not Predicted,
but similar shape
to Mode 1

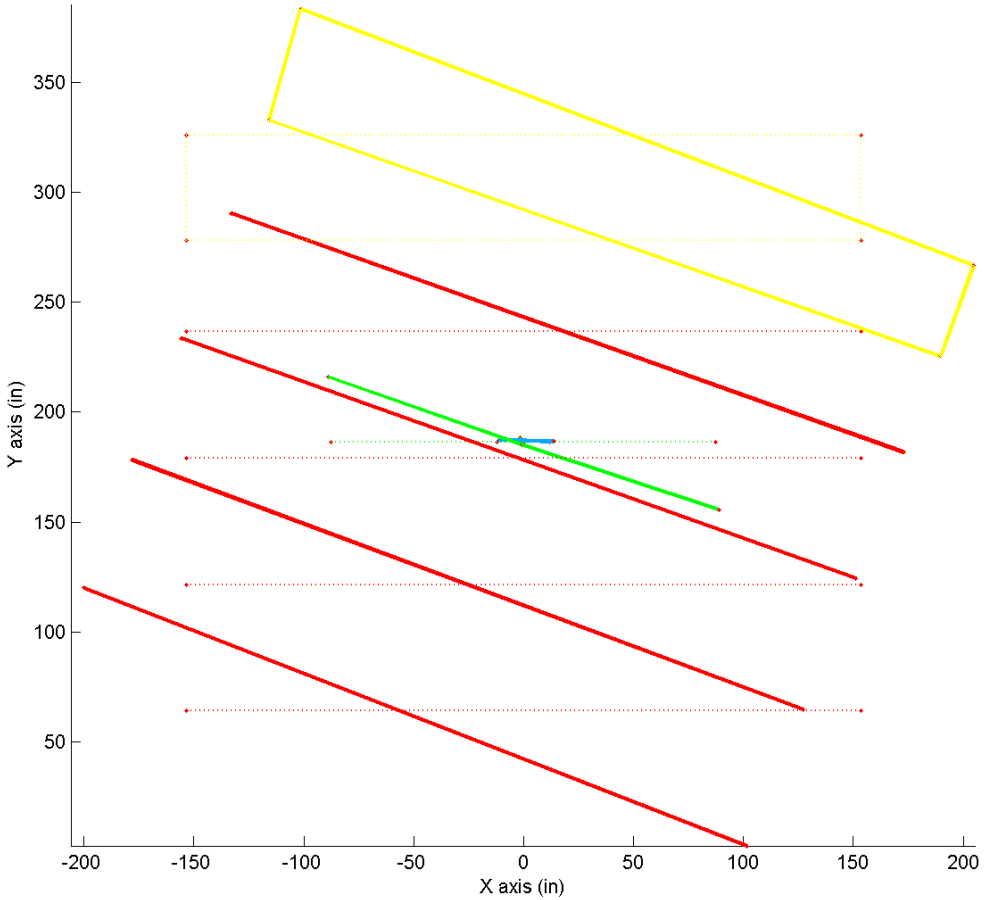






Mode 0
Azimuth Drive Rigid Body (2)
1.335, 1.425 Hz

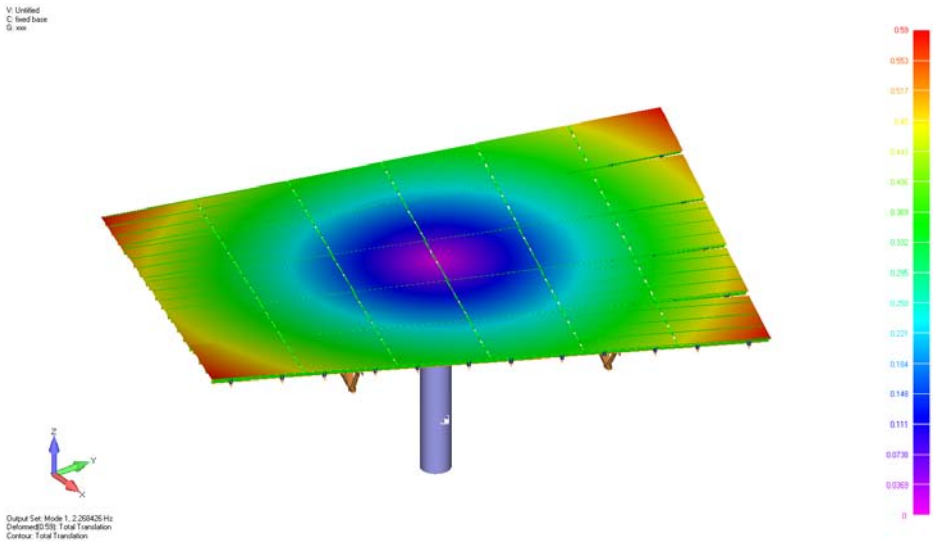
Mode 3
Frequency: 1.425 Hz
Damping: 5.412 %Cr
IDLine 1: Generated from reference 4Y-



Mode 1
Pedestal Twist

2.26 Hz

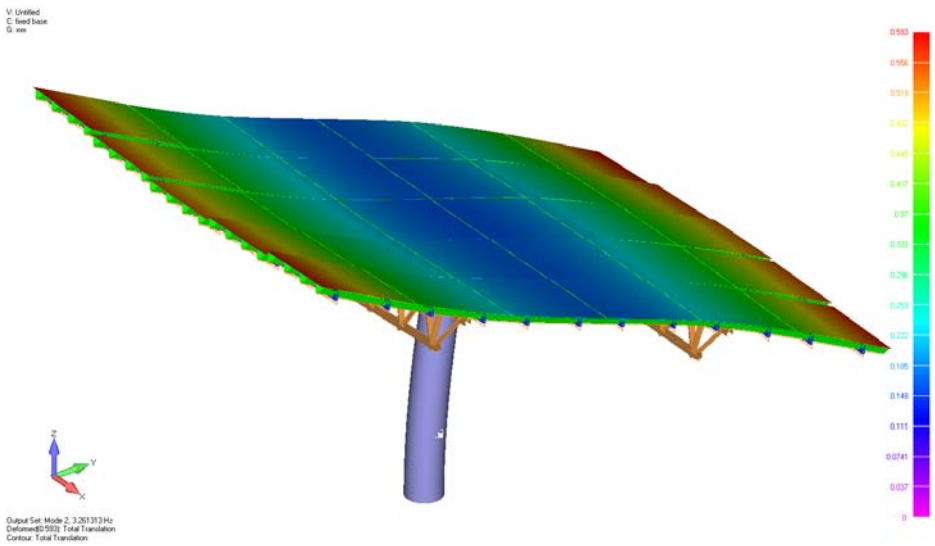
None,
likely present at
higher frequency

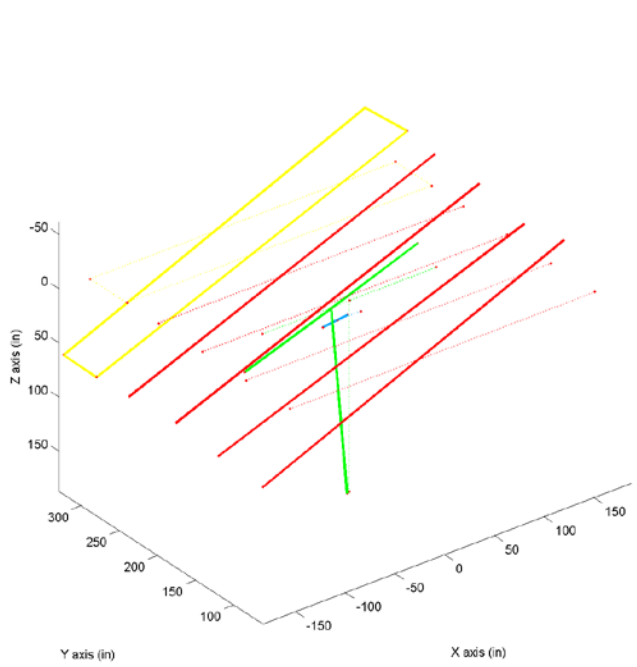


Mode 2
Pedestal Bend (in-line with TT)

3.26 Hz

2.042 Hz

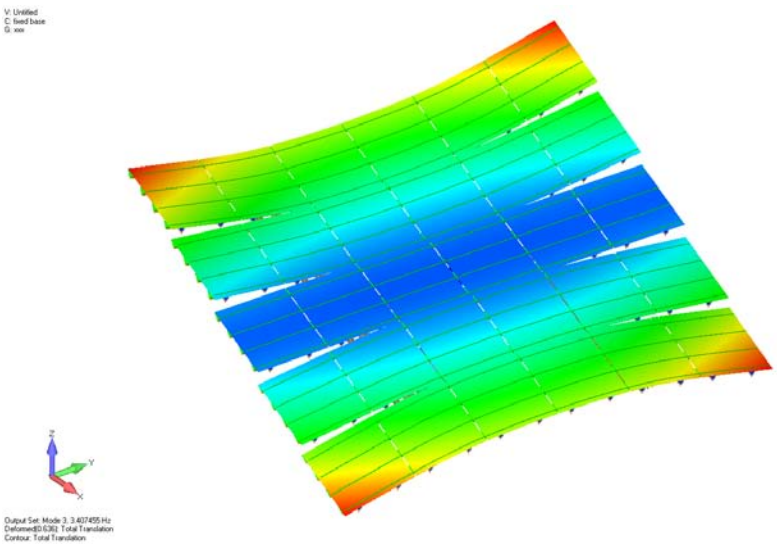


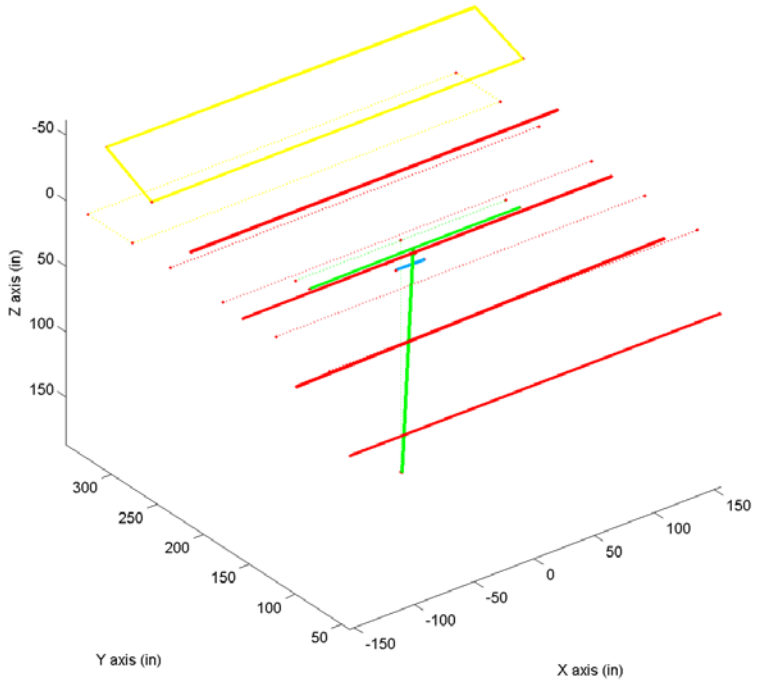


Mode 3
Pedestal Bend (in-line with trusses)

3.34 Hz

2.242 Hz

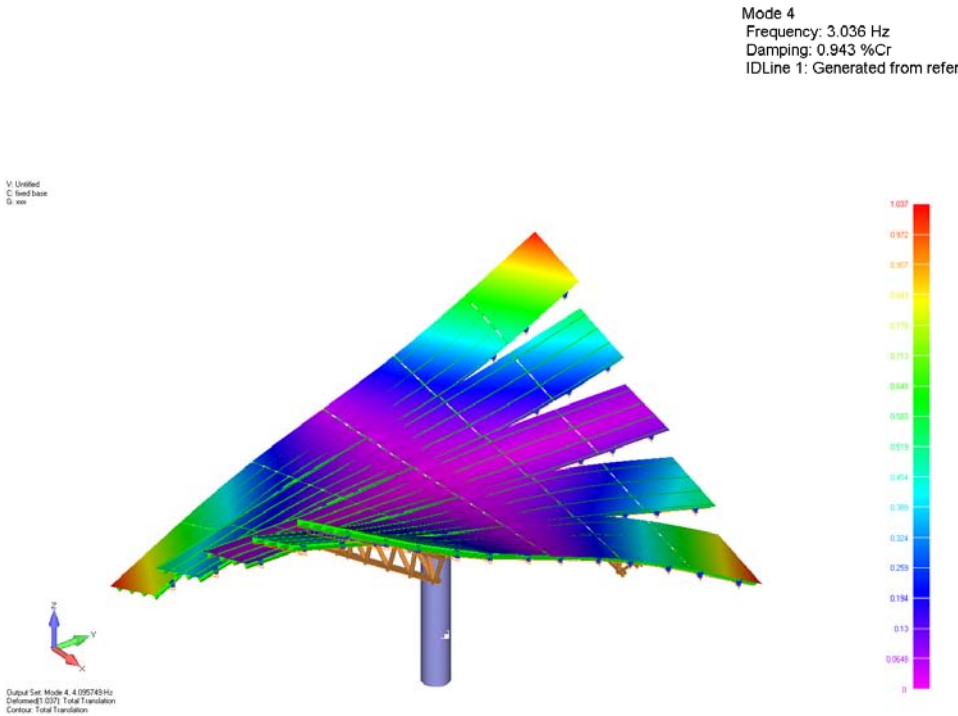


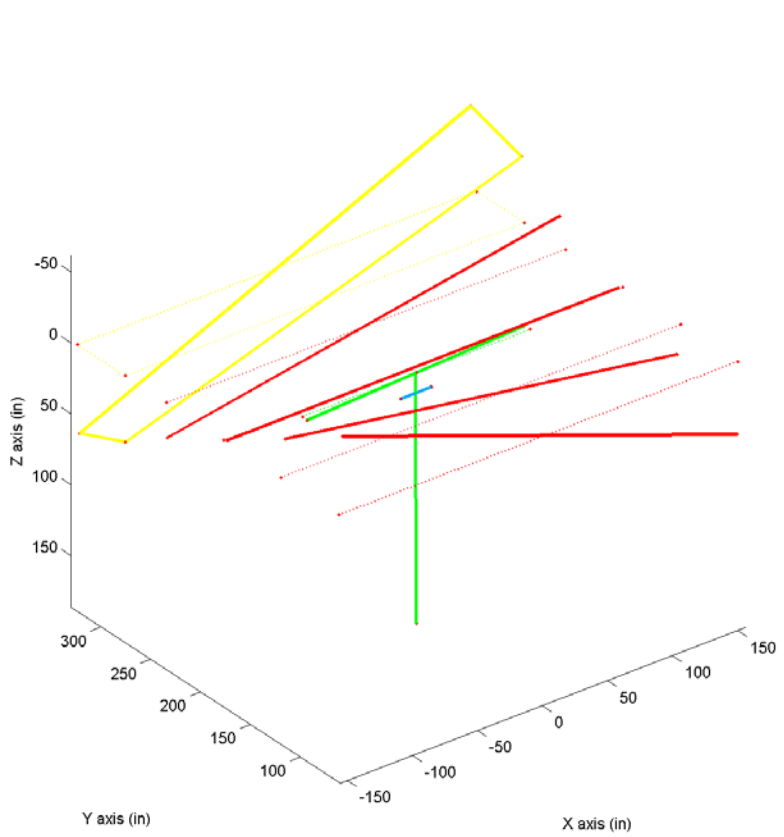


Mode 4
Torque Tube Twist ?

4.09 Hz

3.036 Hz

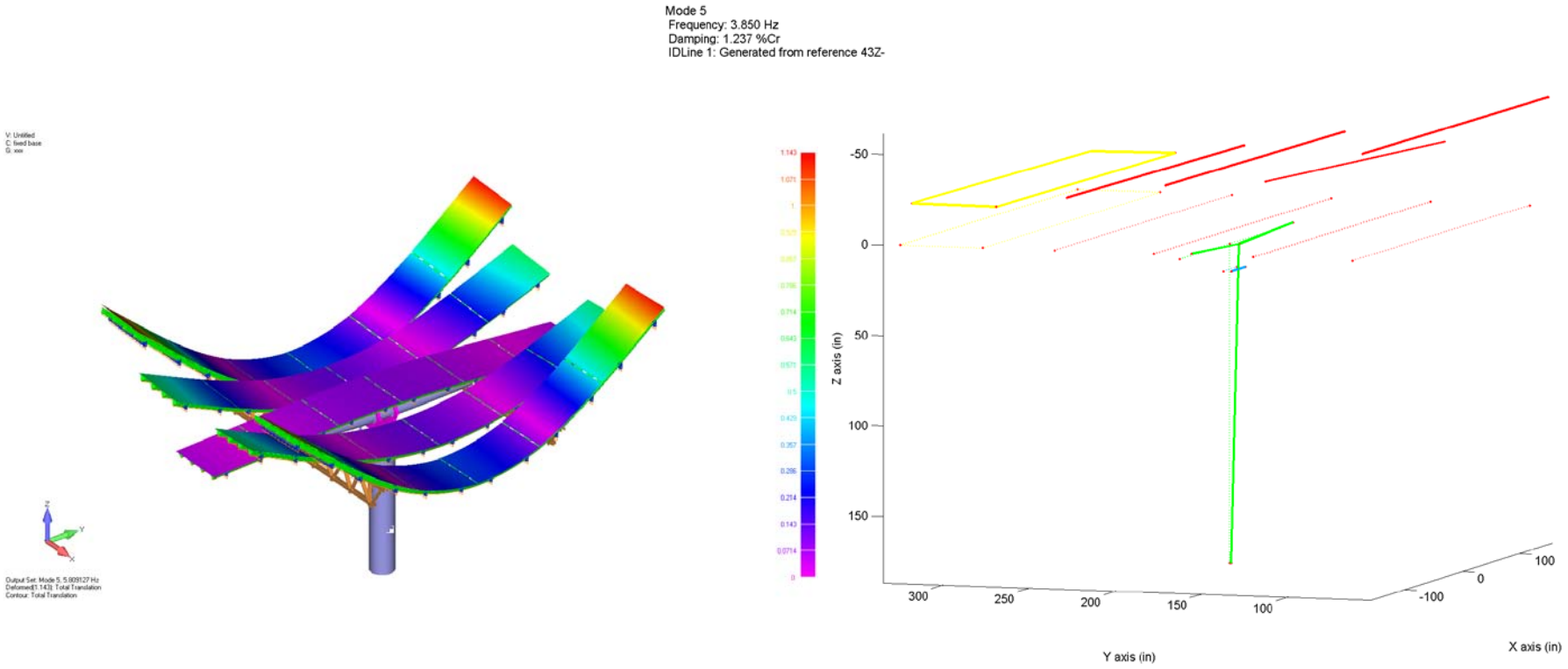




Mode 5
Mirrors OOP Translation #1

5.80 Hz

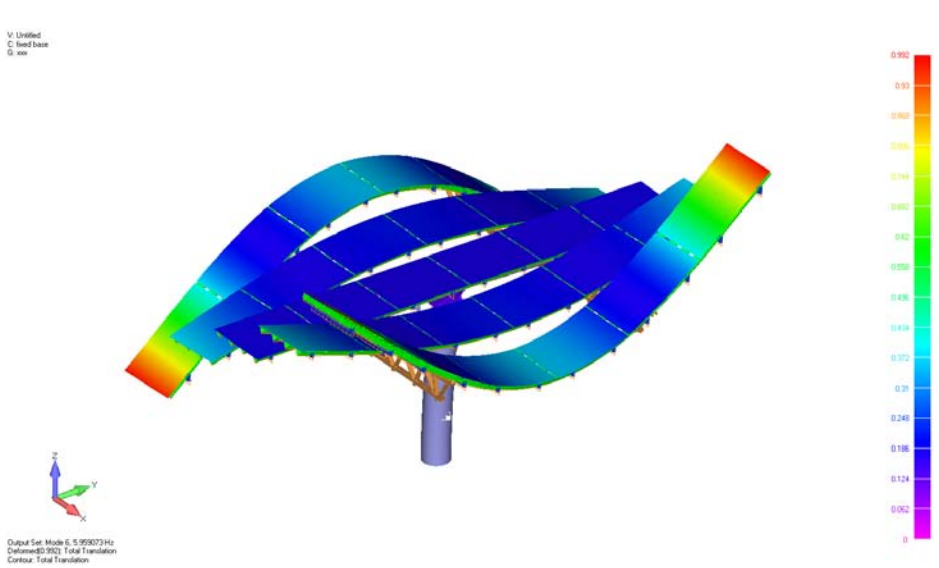
3.850 Hz

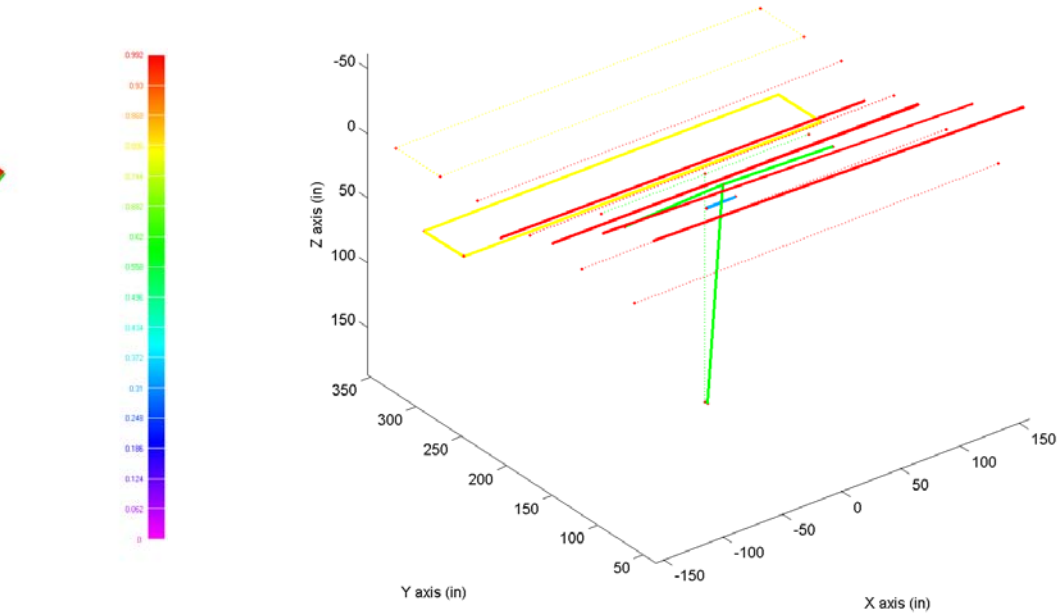


Mode 6
Mirrors OOP Translation #2

5.95 Hz

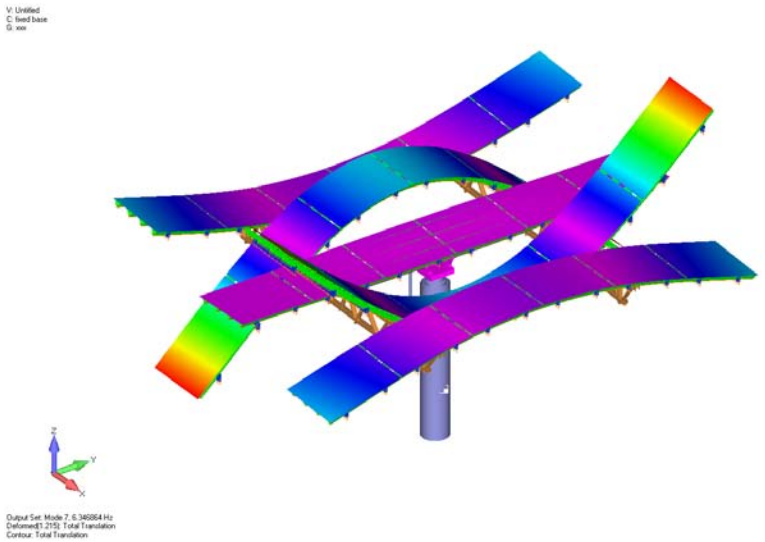
3.879 Hz



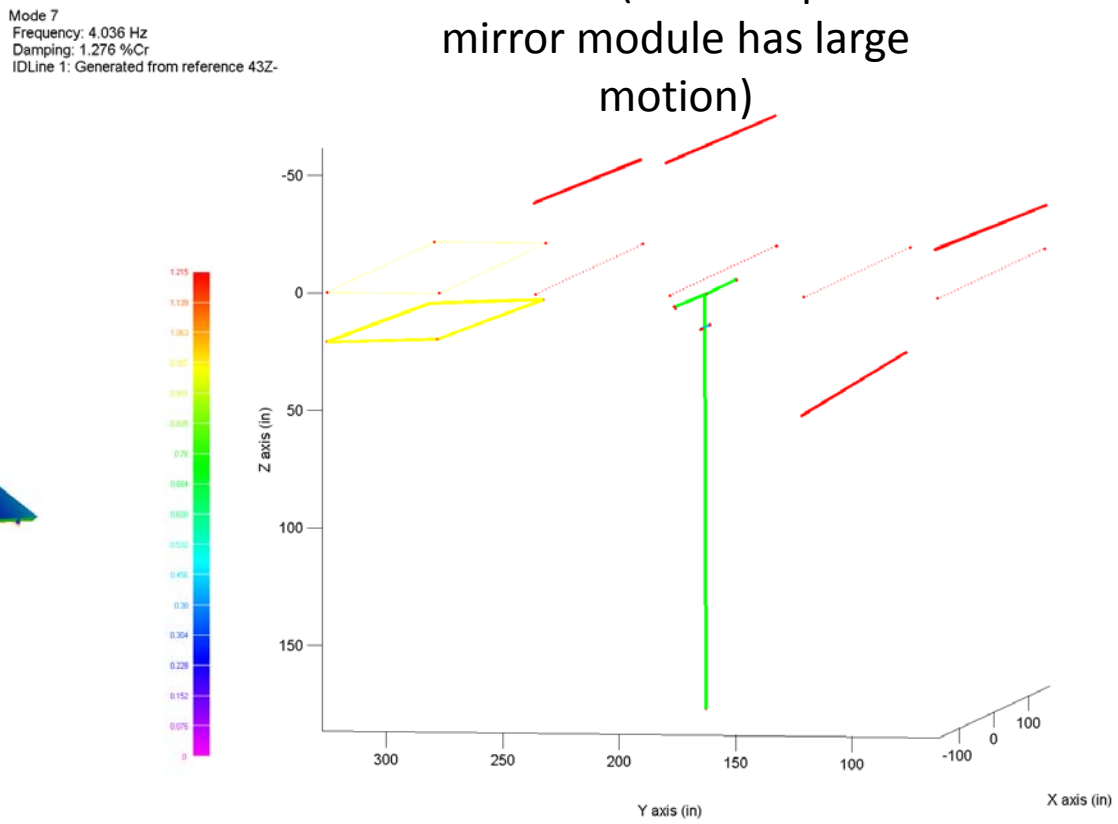


Mode 7
Mirrors OOP Translation #3

6.34 Hz



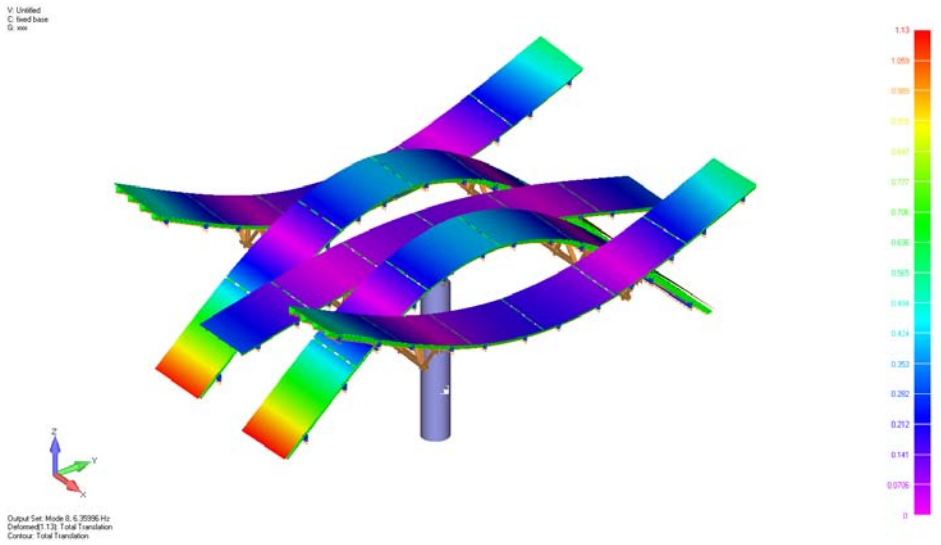
4.036 Hz (note shape 3rd mirror module has large motion)

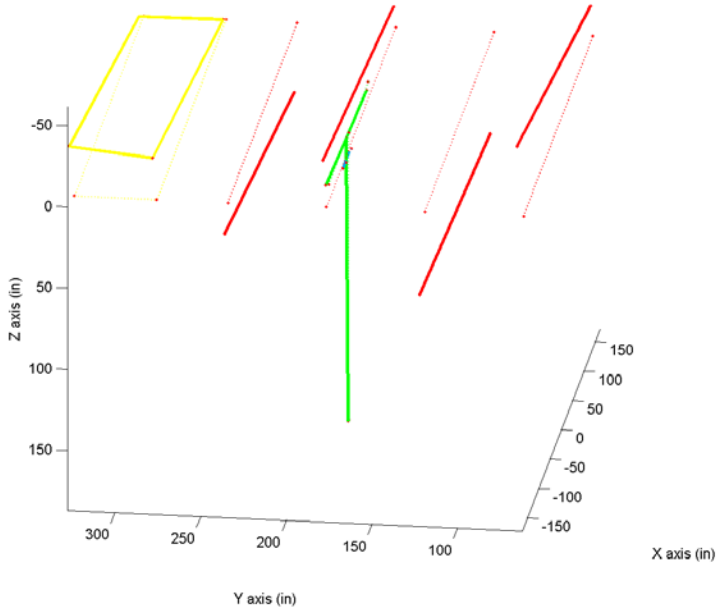


Mode 8
Mirrors OOP Translation #4

6.35 Hz

4.189Hz (note phase of 3rd mirror module)

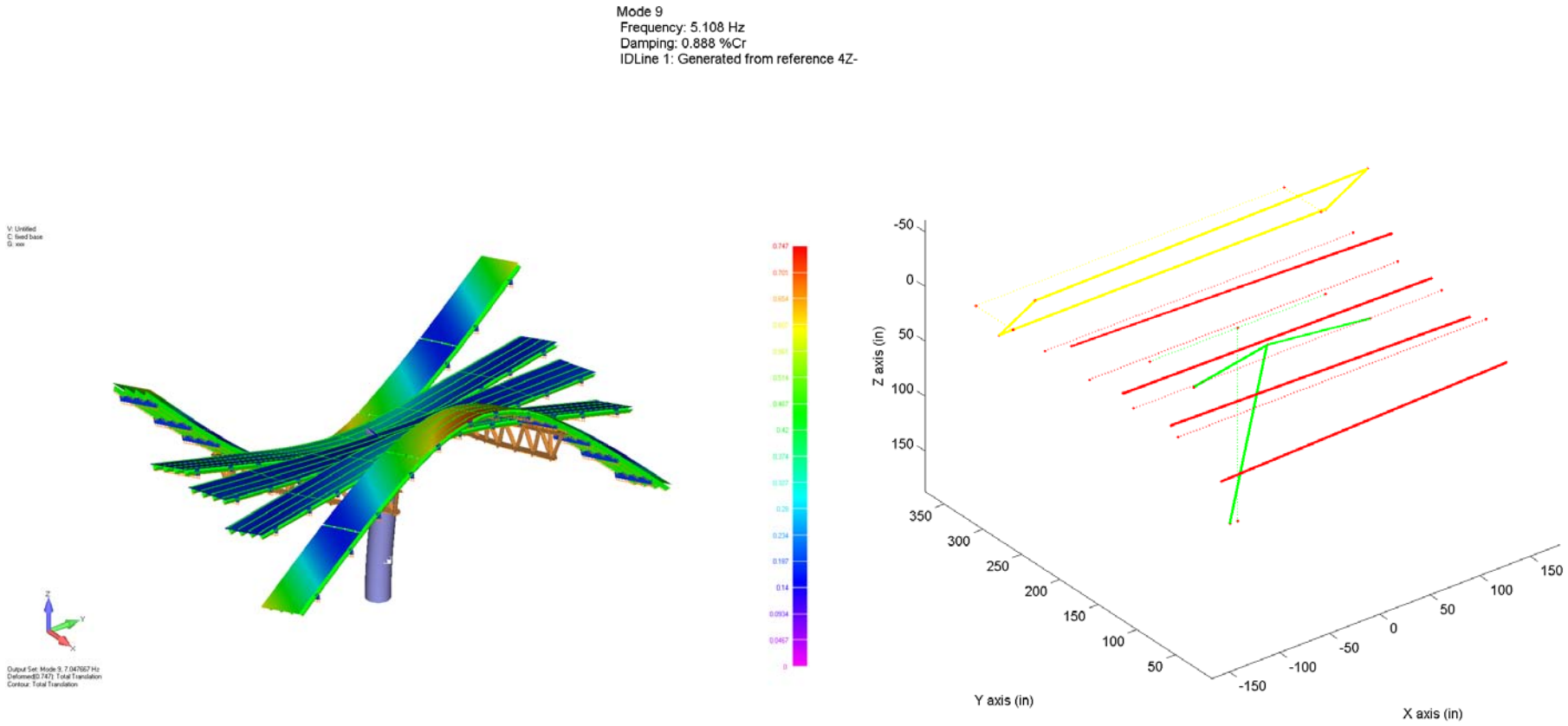




Mode 9
Mirrors OOP Translation #5, truss twist

7.04 Hz

5.108 Hz

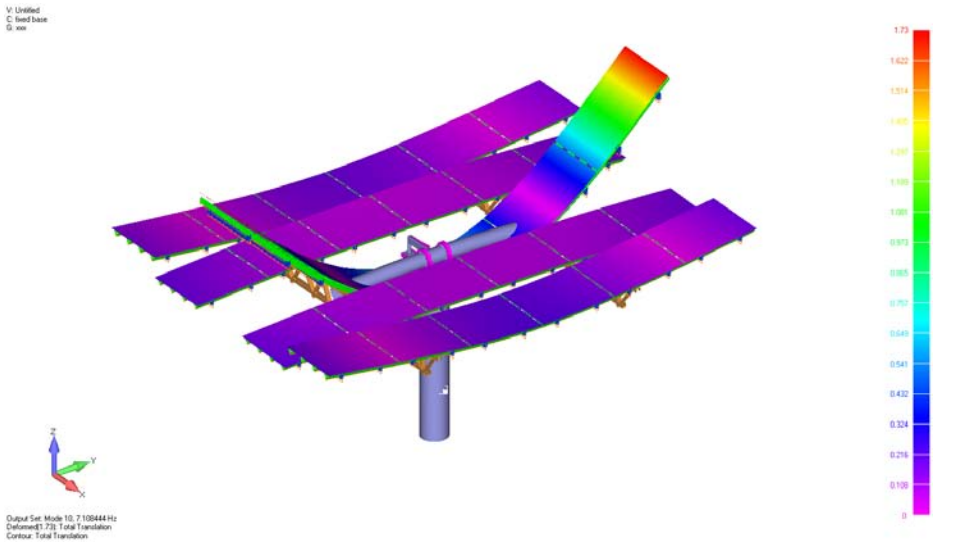


Mode 10

Mirrors OOP Translation #6, TT bend vertical?

7.10 Hz

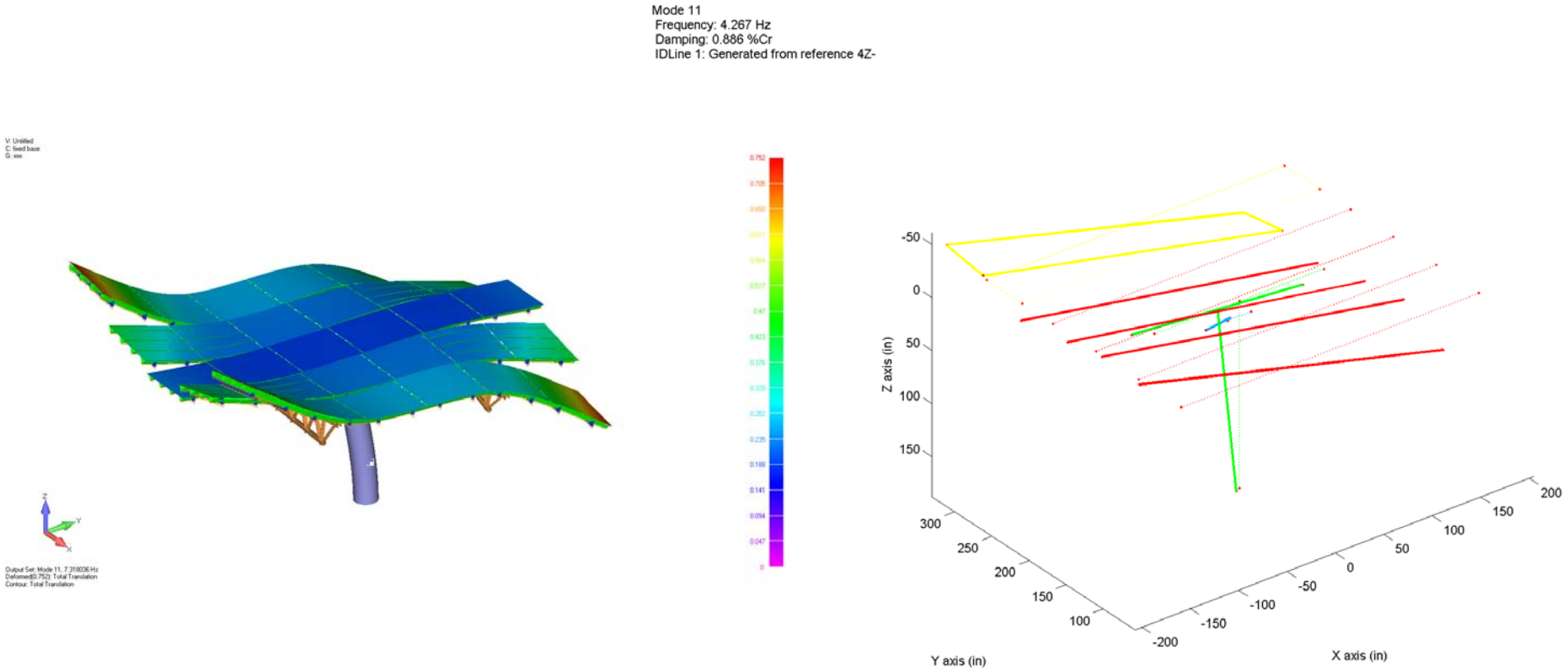
4.189Hz ??



Mode 11
Truss Bend, Mirrors 2nd OOP ?

7.31 Hz

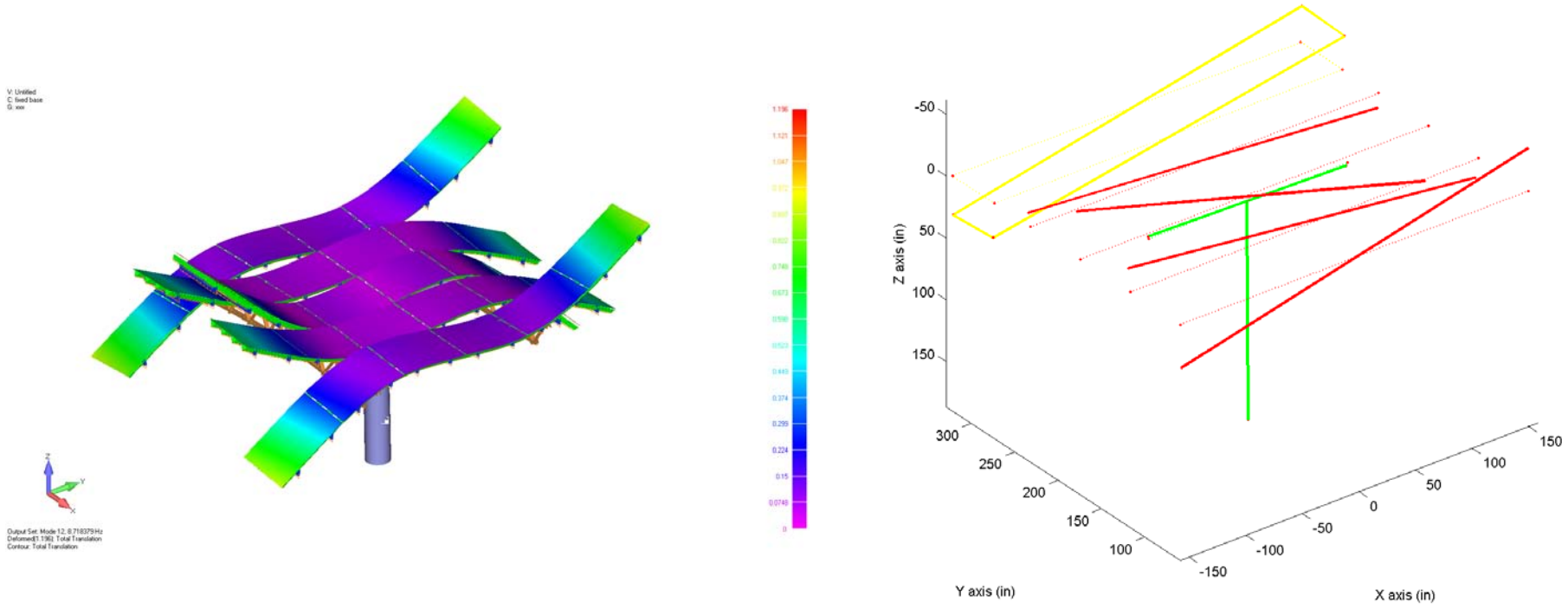
4.267 Hz ???



Mode 12
Mirrors 2nd OOP Translation #1

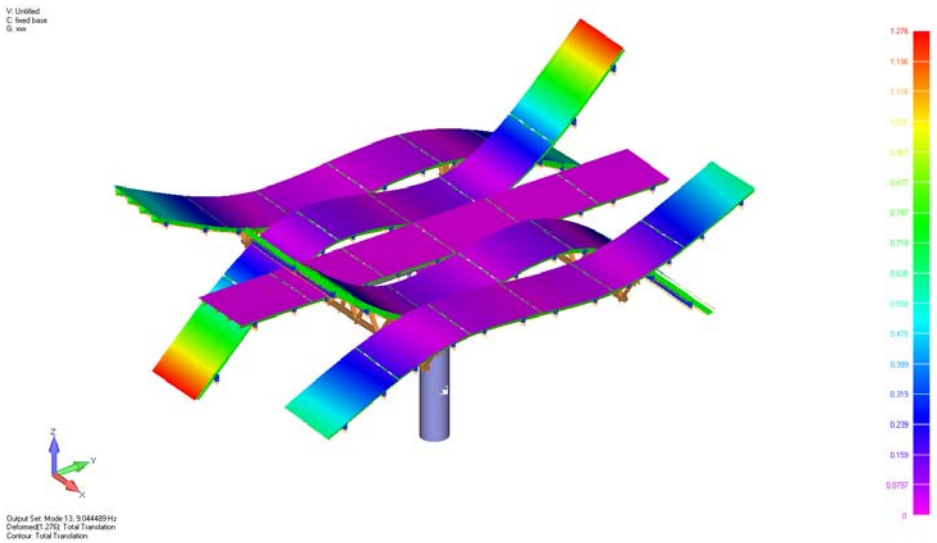
8.71 Hz

5.678 Hz



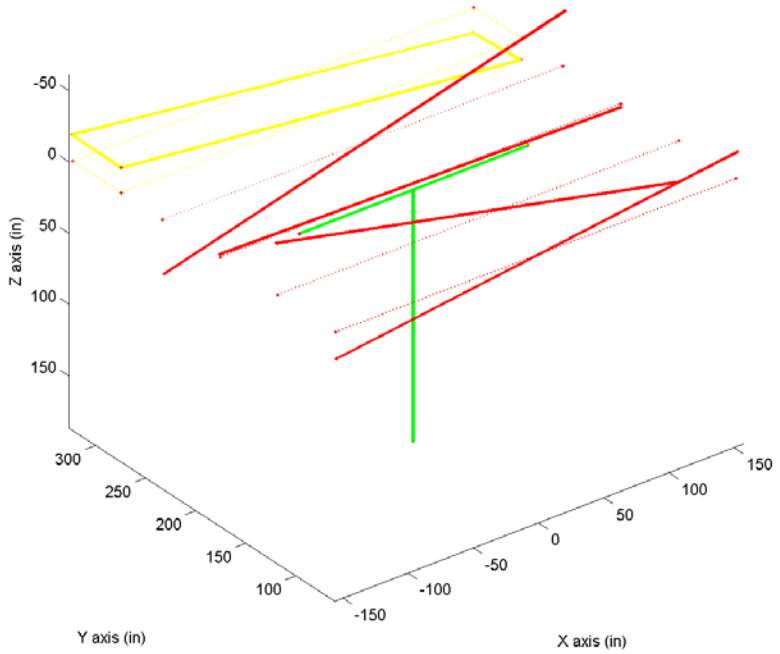
Mode 13
Mirrors 2nd OOP Translation #2

9.04 Hz



Mode 14
Frequency: 5.821 Hz
Damping: 0.785 %Cr
IDLine 1: Generated from reference 11Z-

5.821 Hz

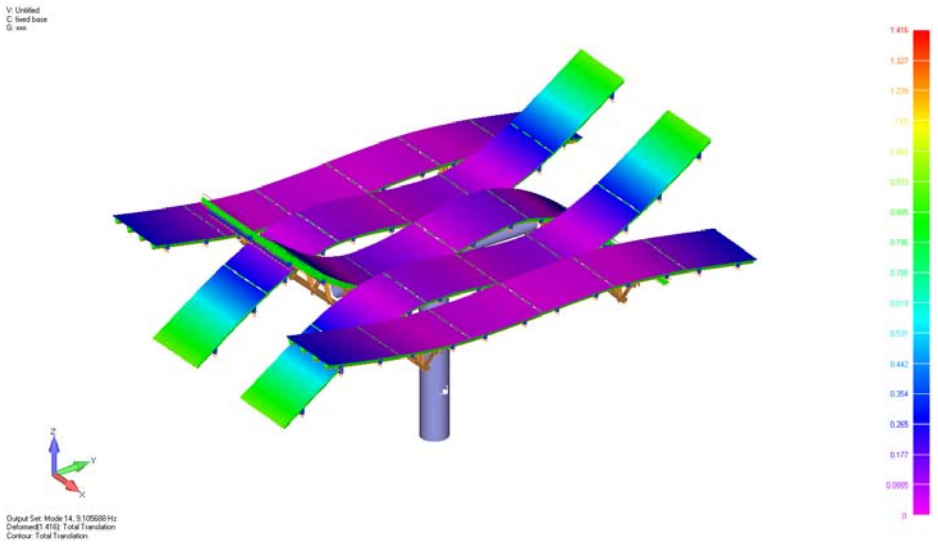


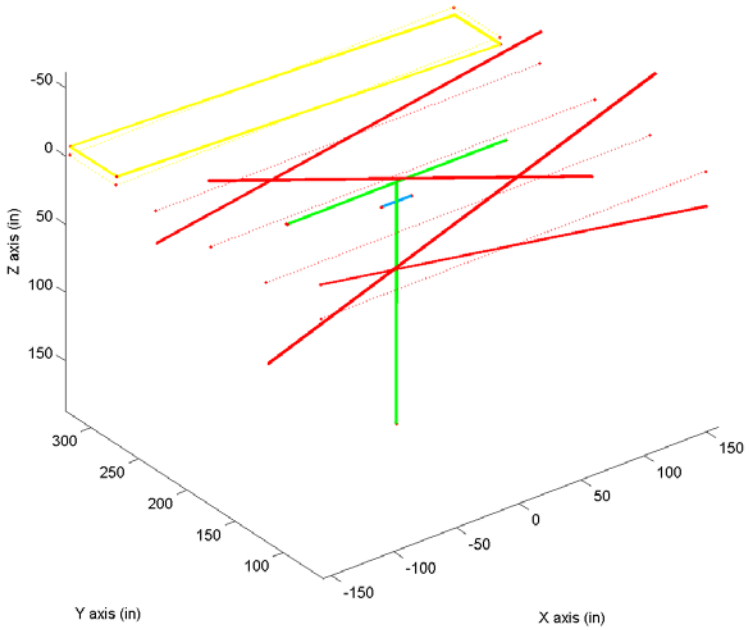
5.730 Hz, 43Z-, run34

Mode 14
Mirrors 2nd OOP Translation #3

9.10 Hz

5.865 Hz

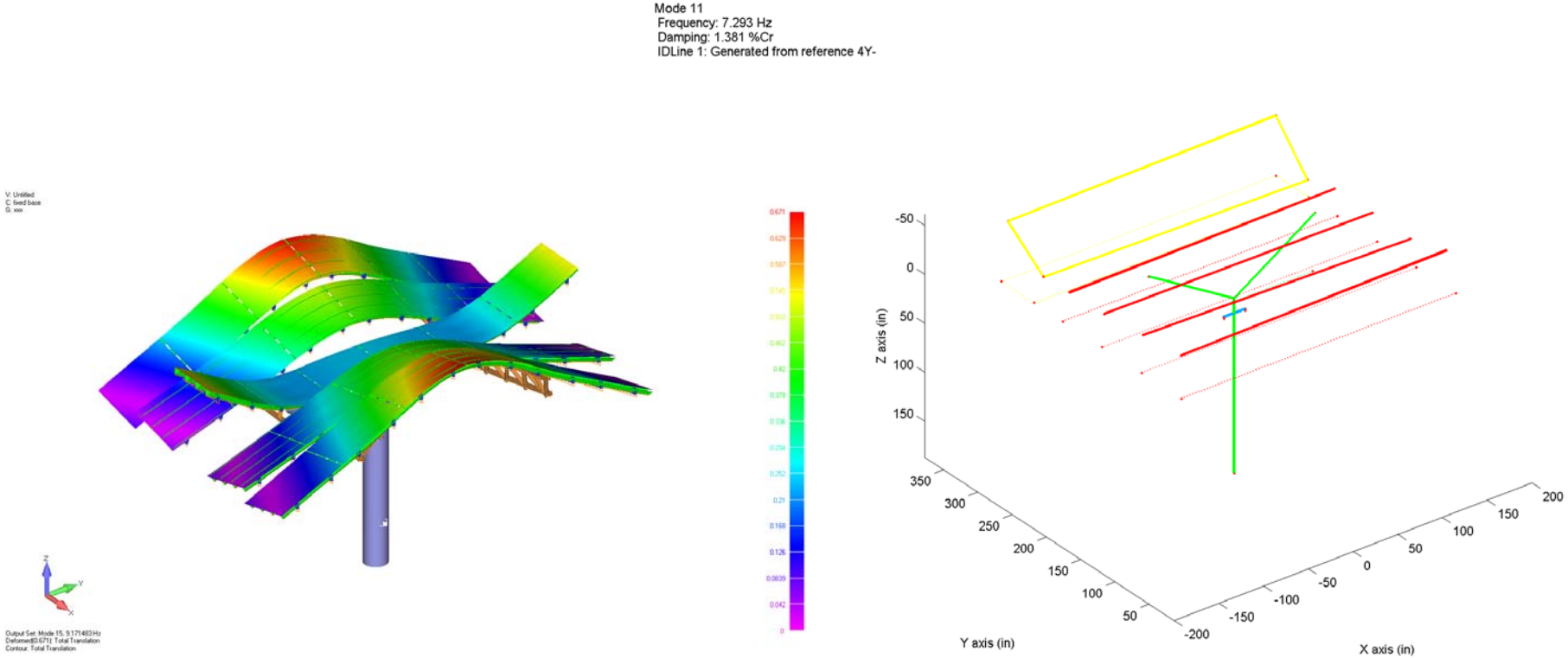




Mode 15
Truss Bend OOP

9.17 Hz

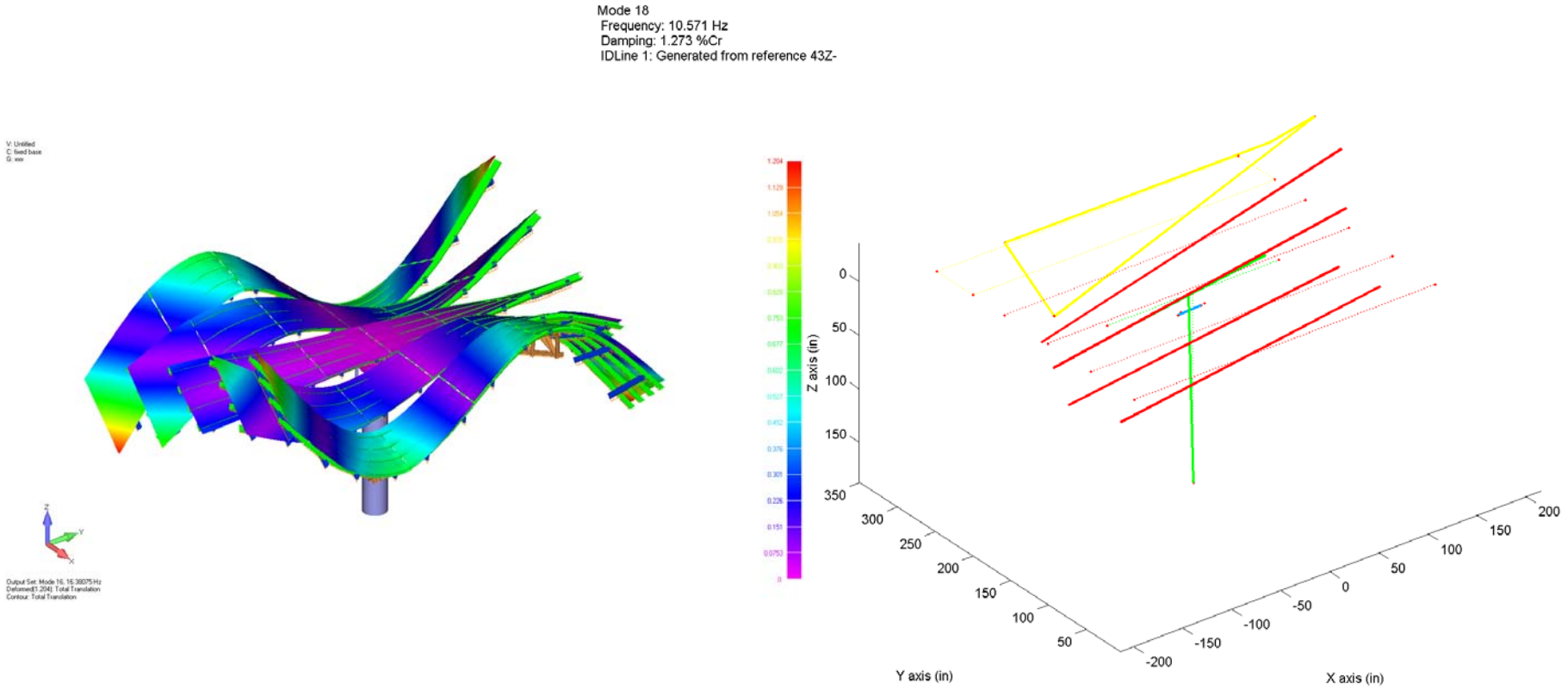
7.293 Hz ???



Mode 16
Truss Twist

16.38 Hz

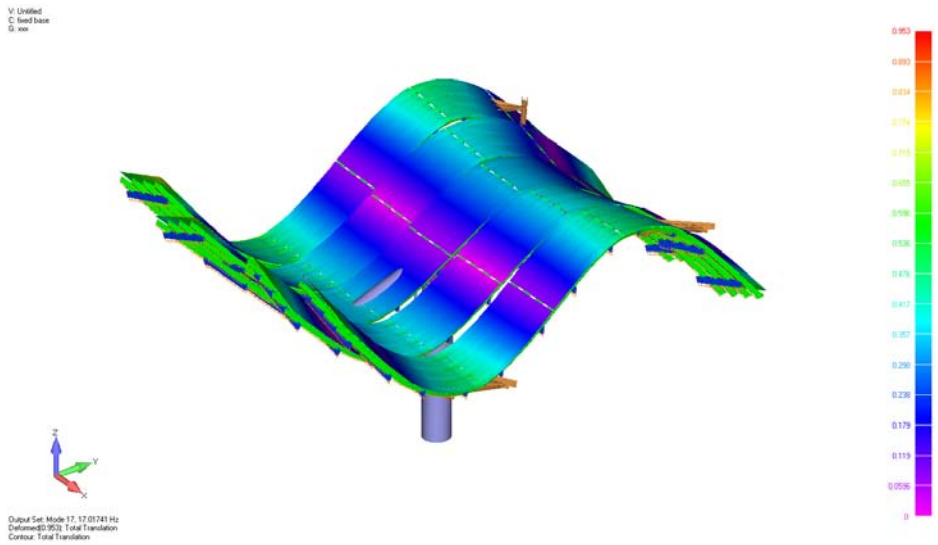
10.571 Hz ???



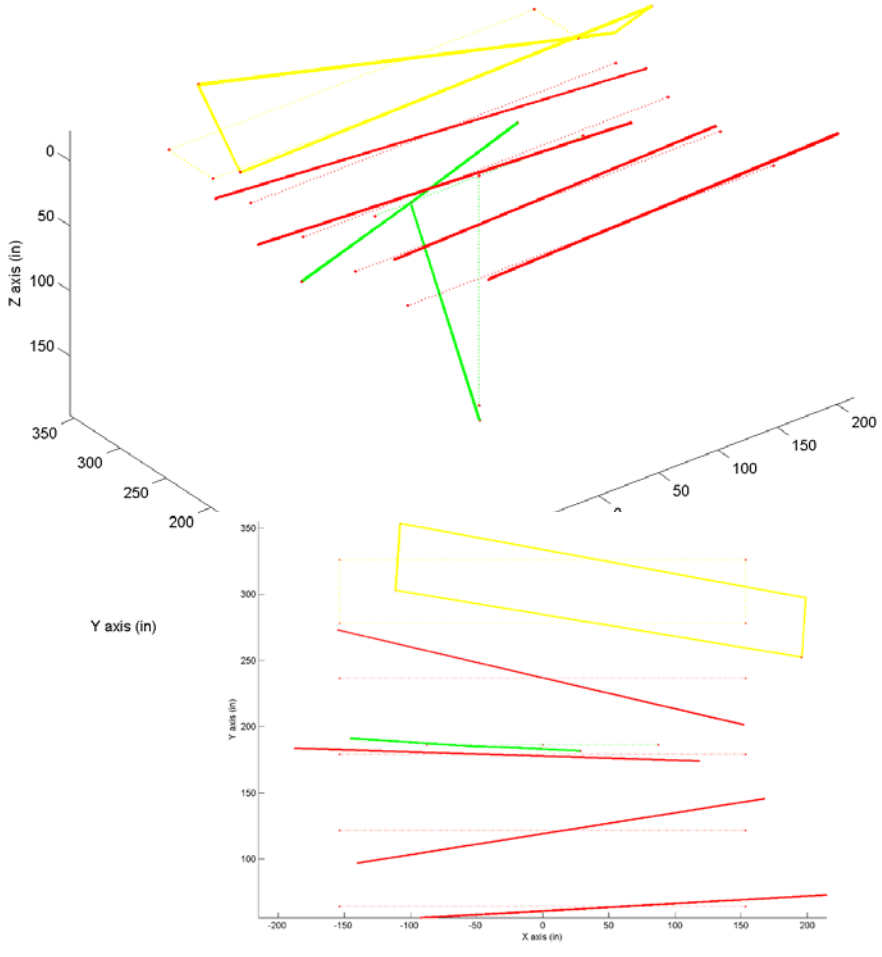
Mode 17
Mirror 2nd OOP, TT rotation, truss bend

Mode 20
Frequency: 11.744 Hz
Damping: 1.800 %Cr
IDLine 1: Generated from reference 4X-

17.01 Hz



11.744 Hz



Modal Parameters (Hammer)

Note: Adjusted frequency is Predicted frequency times 0.64

		Modeled		Measured		
Mode Number	**Mode Description**	**Predicted**	**Adjusted**	**Freq (Hz)**	**Damp (%)**	**Ref.**
0	Azimuth RB	N/A	N/A	1.425	5.412	4Y-, Run11
1	Pedestal Twist	2.26	DNE	DNE	DNE	
2	Pedestal Bend (TT)	3.26	2.09	2.042	1.152	4X-, Run15
3	Pedestal Bend (Truss)	3.34	2.14	2.242	0.786	4Y-, Run11
4	TT Twist	4.09	2.62	3.036	0.943	43Z-, Run34
5	Mirrors OOP Trans #1	5.8	3.71	3.850	1.237	43Z-, Run34
6	Mirrors OOP Trans #2	5.95	3.81	3.879	1.368	4Y-, Run11
7	Mirrors OOP Trans #3	6.34	4.06	4.036	1.276	43Z-, Run34
8	Mirrors OOP Trans #4	6.35	4.06	4.189	0.754	33Z-, Run33
9	Mirrors OOP Trans #5, truss twist	7.04	4.51	5.108	0.888	4Z-, Run05
10	Mirrors OOP Trans #6, TT bend vertical?	7.1	4.54	4.189 ?	0.754	33Z-, Run33
11	Truss Bend, Mirrors 2nd OOP?	7.31	4.68	4.267	0.886	4Z-, Run14
12	Mirrors 2nd OOP Trans #1	8.71	5.57	5.678	0.711	4Z-, Run05
13	Mirrors 2nd OOP Trans #2	9.04	5.79	5.821	0.785	11Z-, Run07
14	Mirros 2nd OOP Trans #3	9.1	5.82	5.865	0.560	43Z-, Run34
15	Truss Bend OOP	9.17	5.87	7.293	1.381	4Y-, Run11
16	Truss Twist	16.38	10.48	10.571	1.273	43Z-, Run34
17	Mirror 2nd OOP, TT rotation, truss bend	17.01	10.89	11.744	1.800	4X-, Run06

Modal Parameters (Wind Excited)

Model Correlation Observations

- Pedestal height has large effect on most modes
- Azimuth drive has enough slop to essentially uncouple pedestal twist from rotation of structure above the drive
- Behavior of 3rd (middle) mirror module is different in several experimental modes
- Extra weight of mirror extensions would appear to most strongly affect mirror modes
- Frequencies dropped by 1 to 1.5% after mirror extension was aligned (on one side)
- 1% damping appears to be a good value for structural damping of all modes

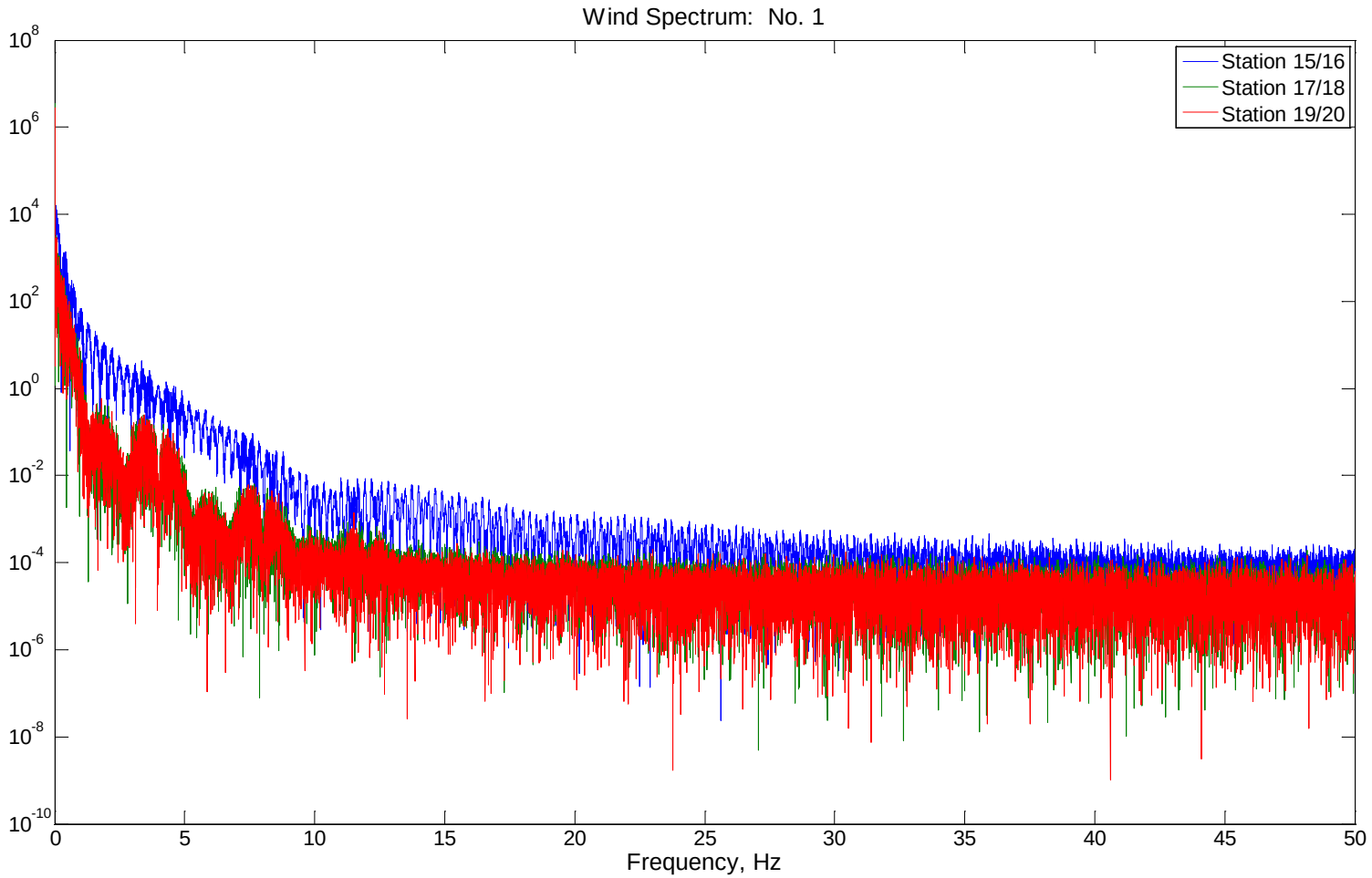
Analysis of Wind Excited Data

- Used to:
  1) Compute frequency spectrum of wind loading (based on earlier Nabtesco testing which was sampled at 100 Hz)
  2) Estimate frequency and damping with wind speed and direction
  3) Measure strain on torque tube and pedestal while “operating” during wind event
  4) Compute displacement for a few locations during wind event

- Only 1) and 2) are addressed in this package

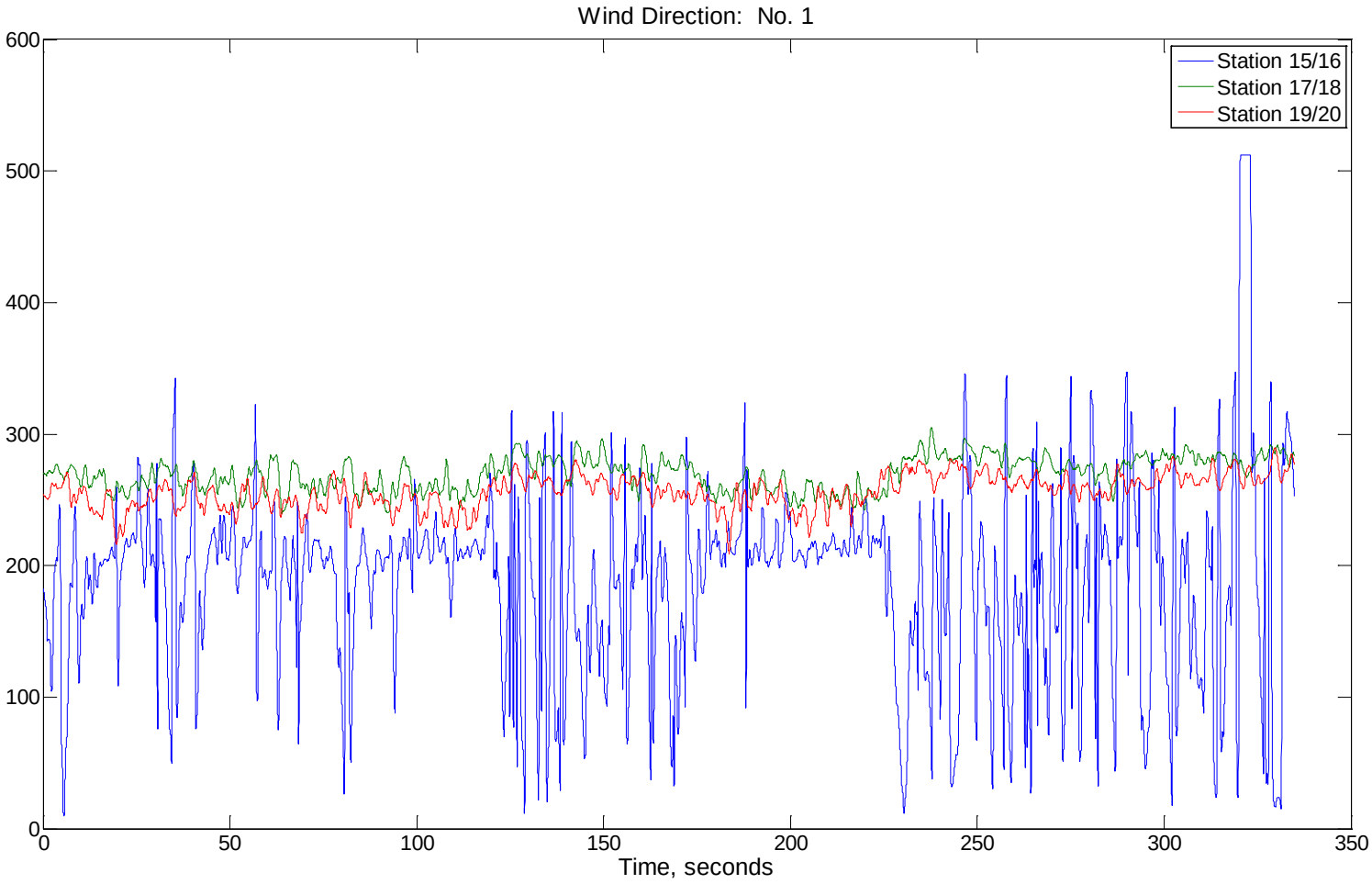
- Response to wind-excitation recorded for 0, 45, and 90 degree orientations with wind direction principally “head-on” and “edge-on” for each orientation (6 total tests)

Nabtesco Wind Data (Set No.1)
Wind Spectrum

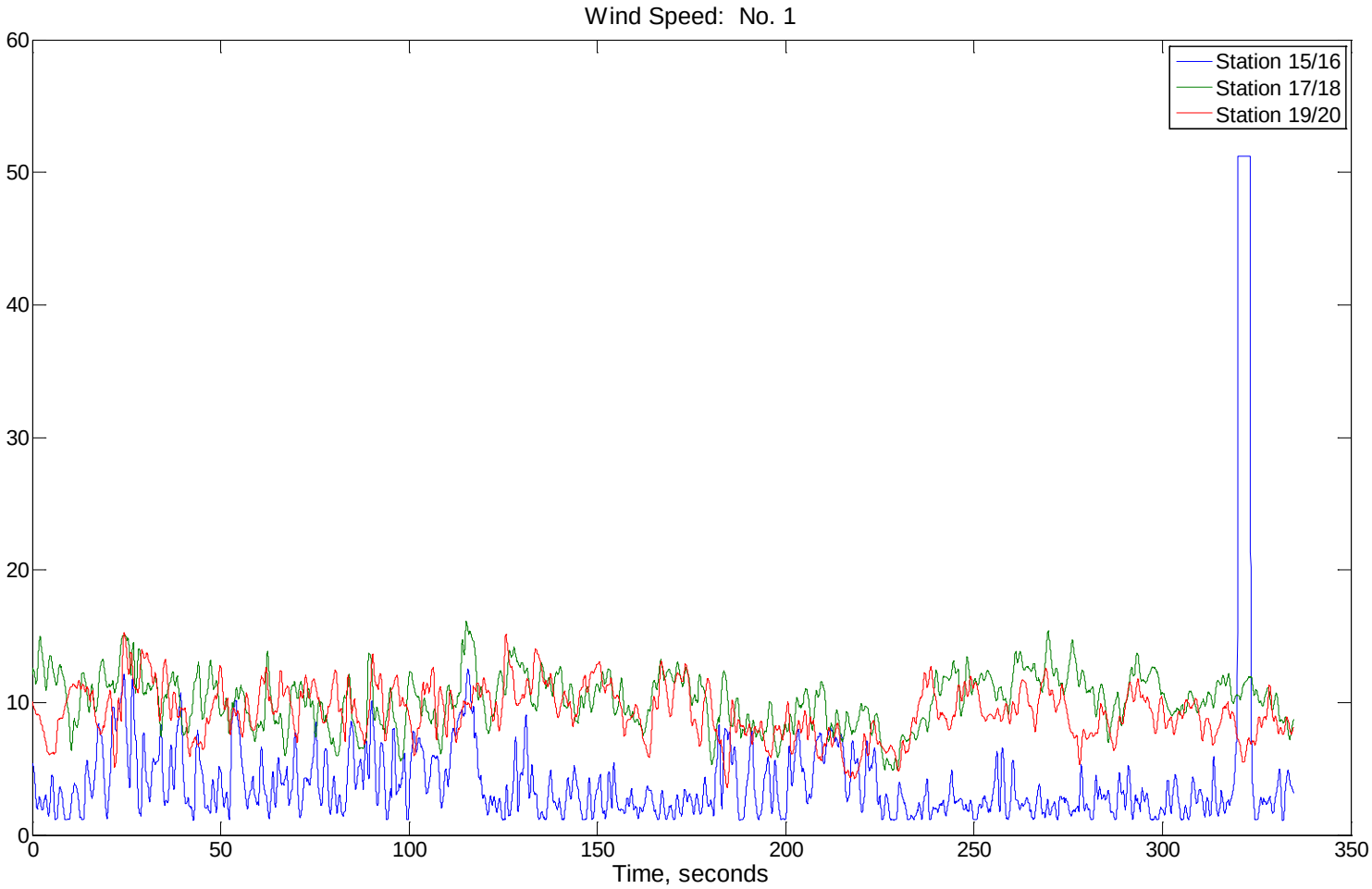


Note: Data not filtered, windowed, or averaged

Nabtesco Wind Data (Set No.1)
Wind Direction



Nabtesco Wind Data (Set No.1)
Wind Speed

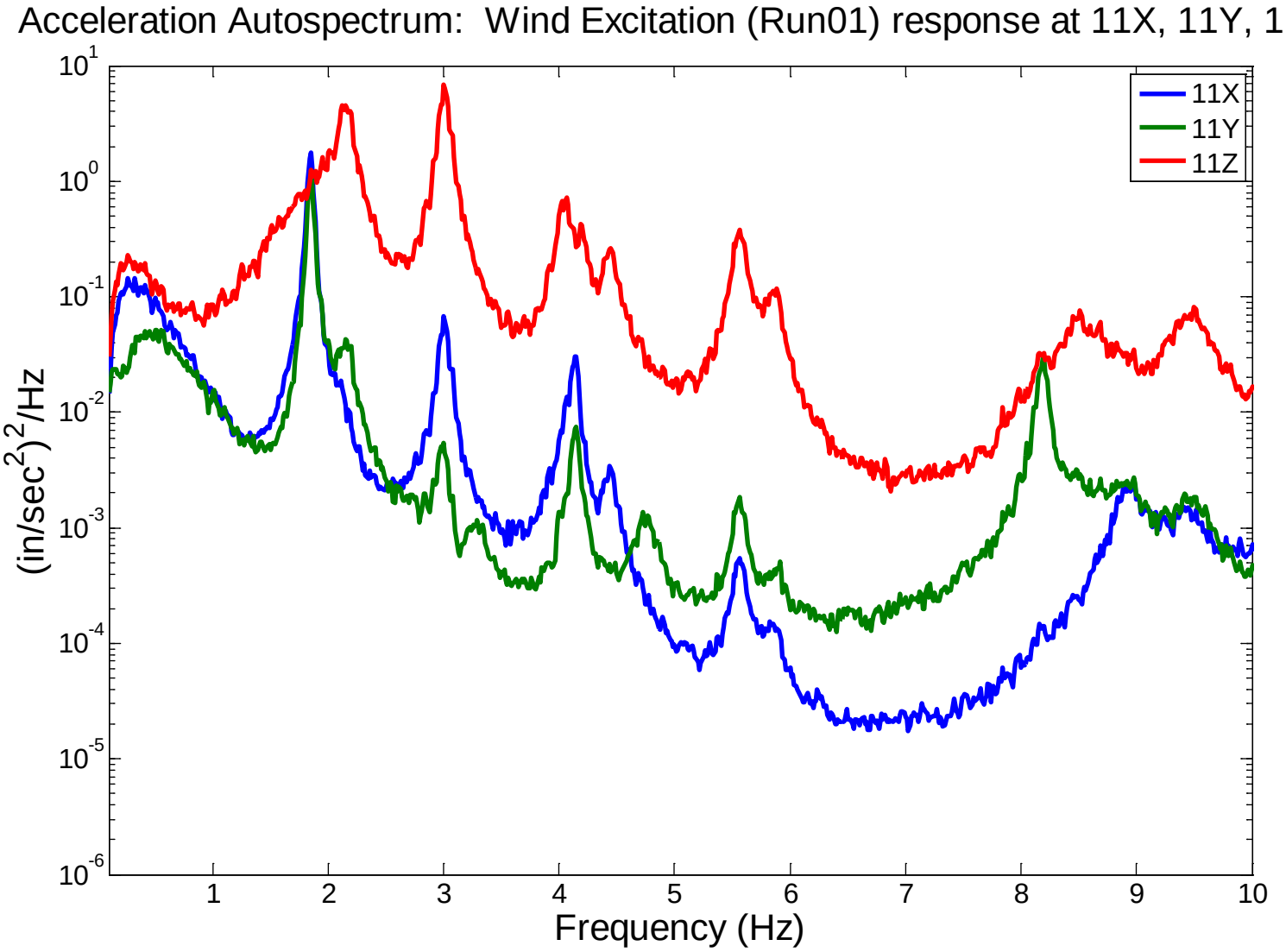


Analysis of Sandia Wind-excited Tests

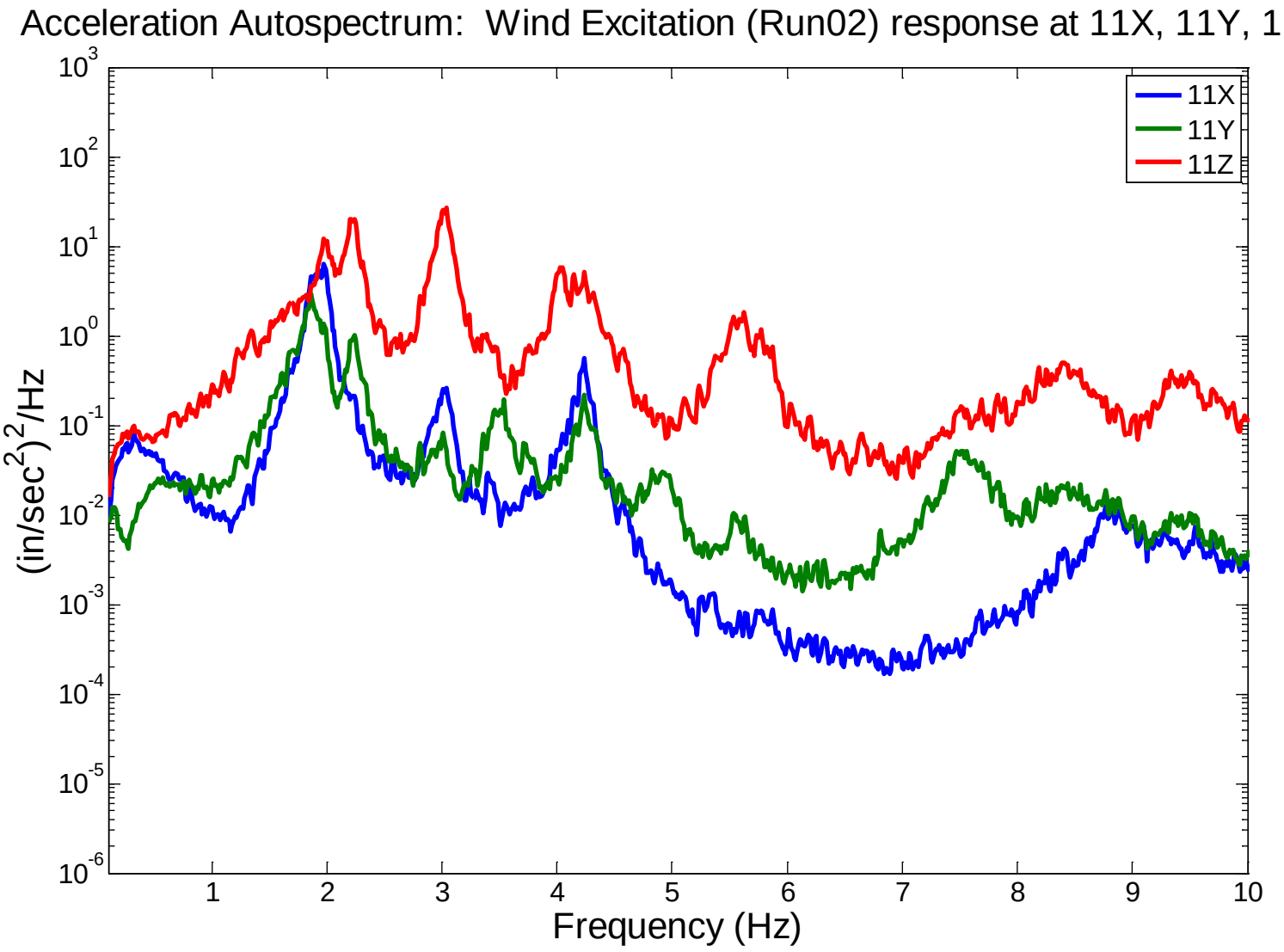
- Wind excited Testing ("head-on" cases)
  - Run01: 0 degree elevation
  - Run02: 45 degree elevation
  - Run03: 90 degree elevation
- Following plots show Auto PSD for X,Y, and Z directions at location #11
  - For acceleration
  - For displacement (= Acceleration Auto PSD divided by omega^4)

Semi-log Plots
0.1 Hz to 10 Hz

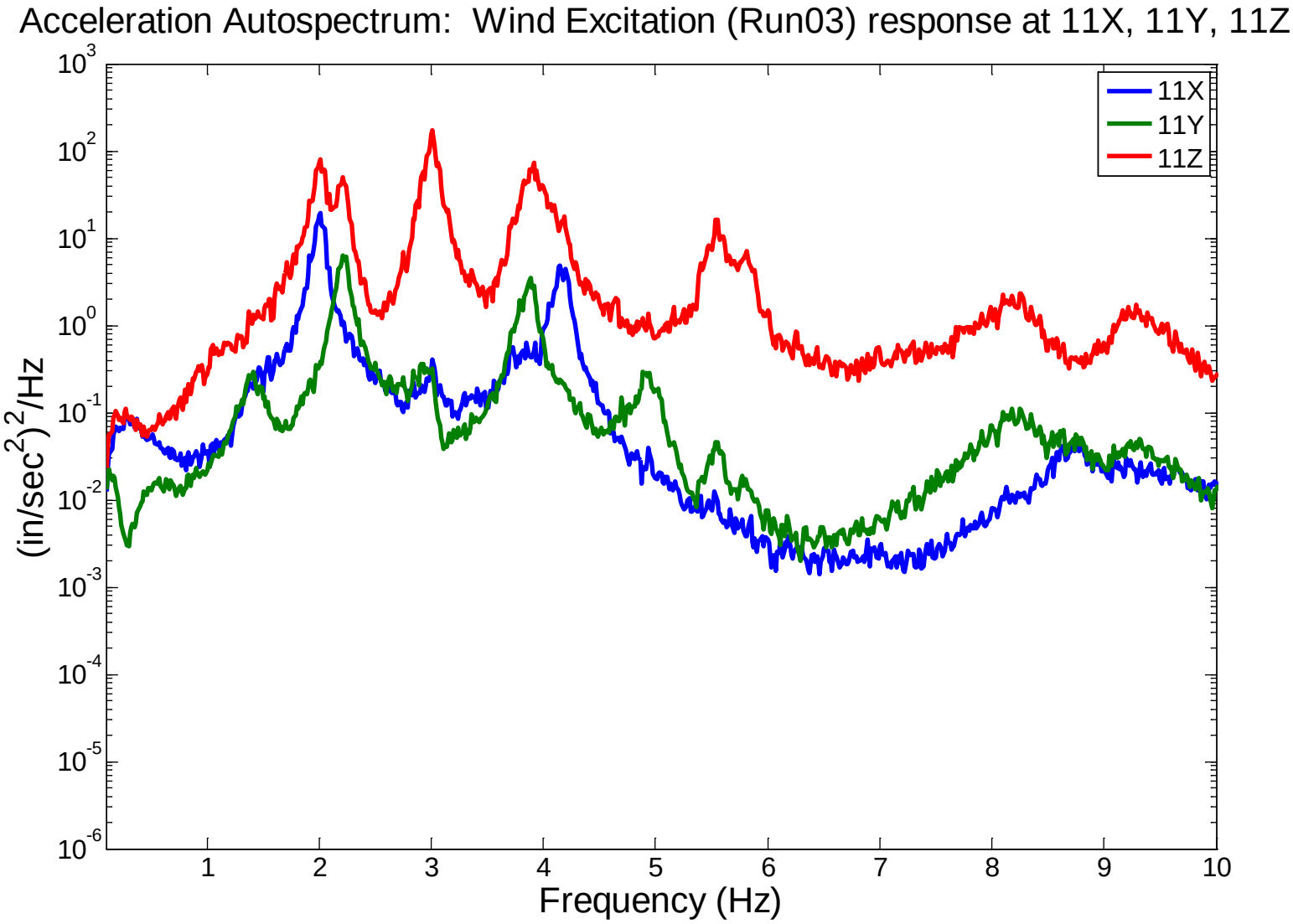
Acceleration Auto-PSD
0 degree



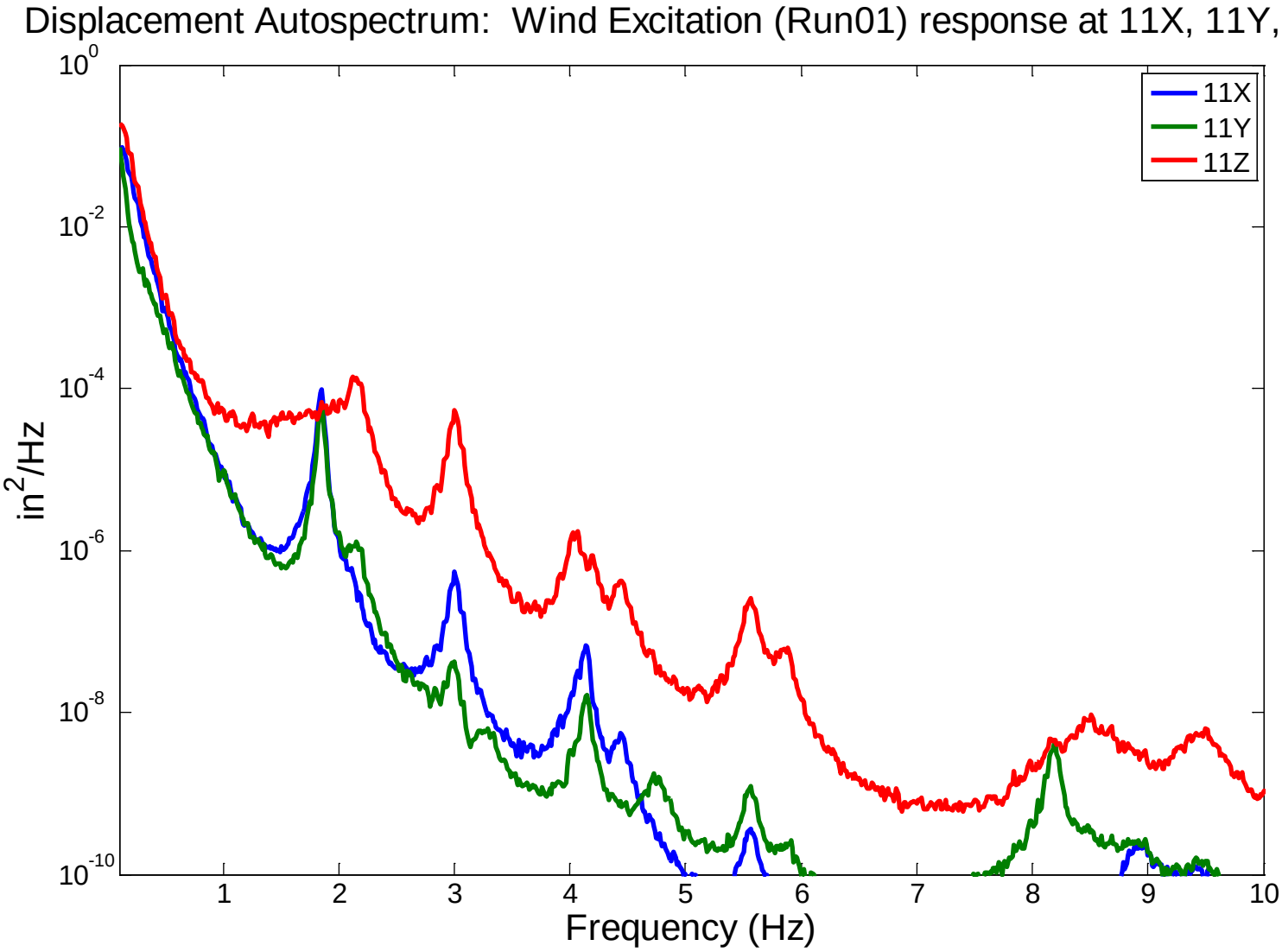
Acceleration Auto-PSD
45 degree



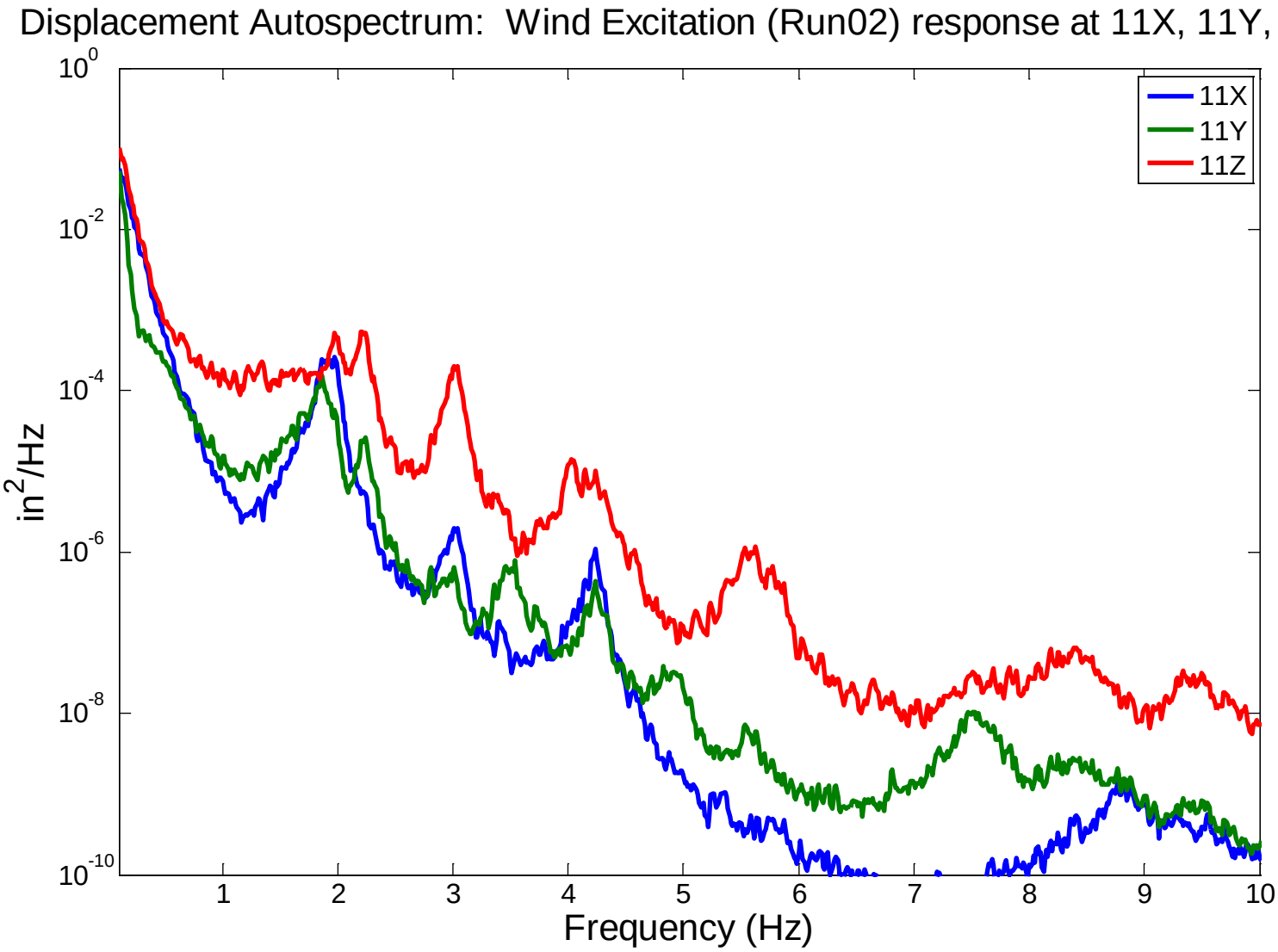
Acceleration Auto-PSD
90 degree



Displacement Auto-PSD
0 degree



Displacement Auto-PSD
45 degree



Displacement Auto-PSD
90 degree