

# Review of PWR modified 75 m<sup>2</sup> Heliostat Modal Test Results

SAND2011-3706P

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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.accel.s.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<sup>2</sup> 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)**

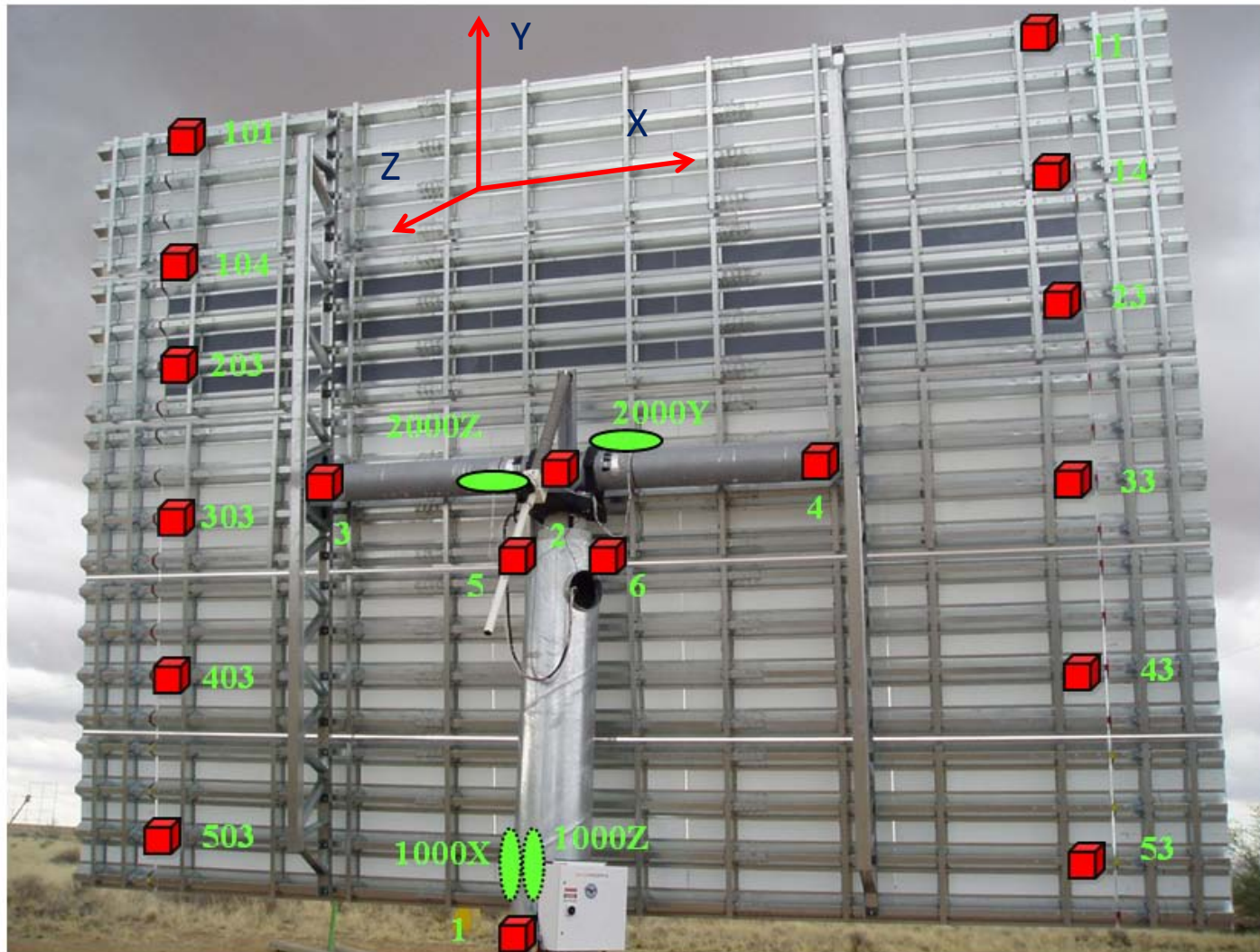
# Instrumentation and CS

Coordinate System is “attached” to the mirror frame:

X: along mirror module

Y: chord-wise mirror module

Z: out of plane



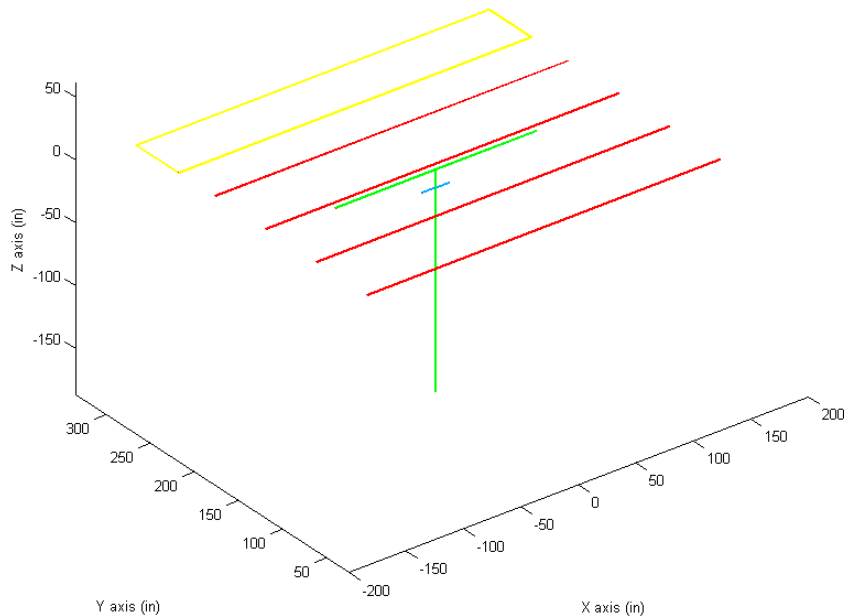
Triaxial  
accelerometer



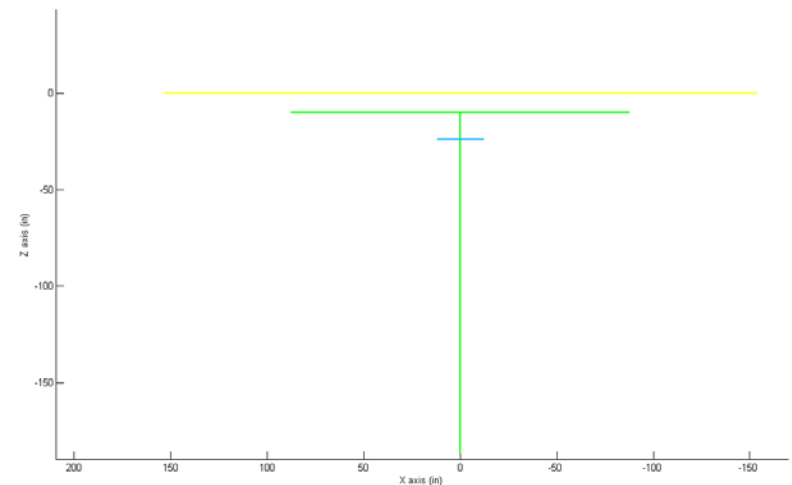
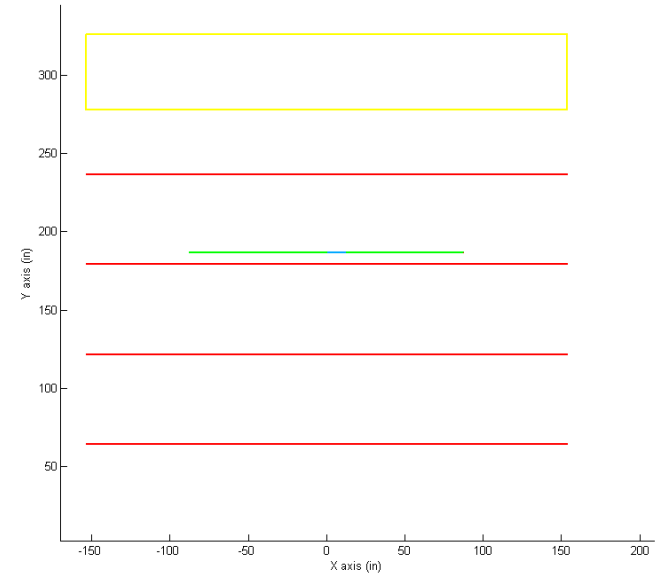
Dynamic strain  
sensor

# 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





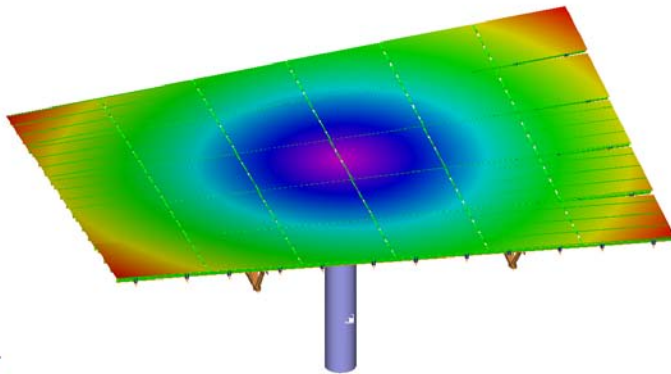
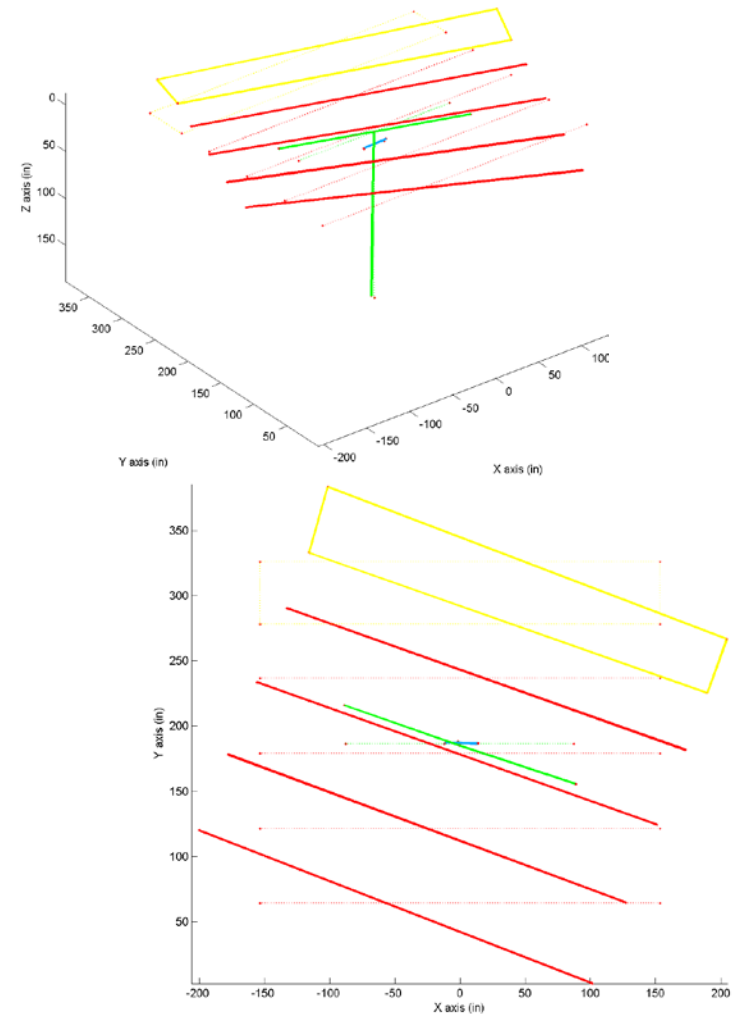
# Mode 0

## 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



V: Unfilled  
C: Fixed base  
G: xov

Output Set: Mode 1, 2.268425 Hz  
Deformed@50% Total Translation  
Contour: Total Translation

# Mode 0

## Azimuth Drive Rigid Body (2)

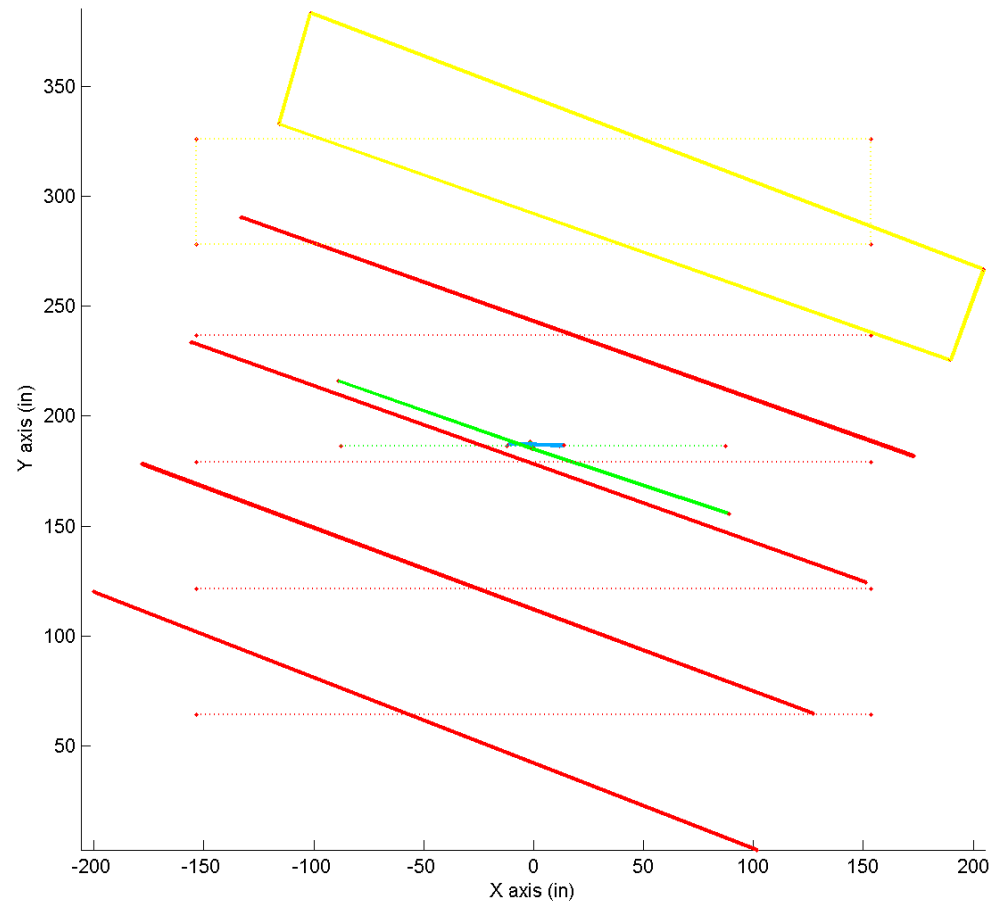
1.335, 1.425 Hz

Mode 3

Frequency: 1.425 Hz

Damping: 5.412 %Cr

IDLine 1: Generated from reference 4Y-



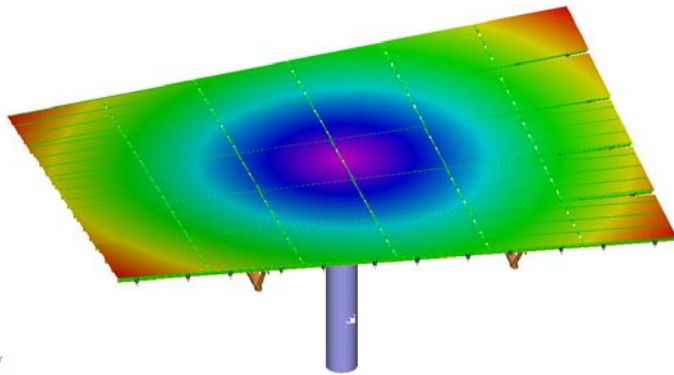
# Mode 1

## Pedestal Twist

2.26 Hz

None,  
likely present at  
higher frequency

V: Unlabeled  
C: Load/State  
G: von



Output Set: Mode 1, 2.26425 Hz  
Defined(S15): Total Translation  
Contour: Total Translation

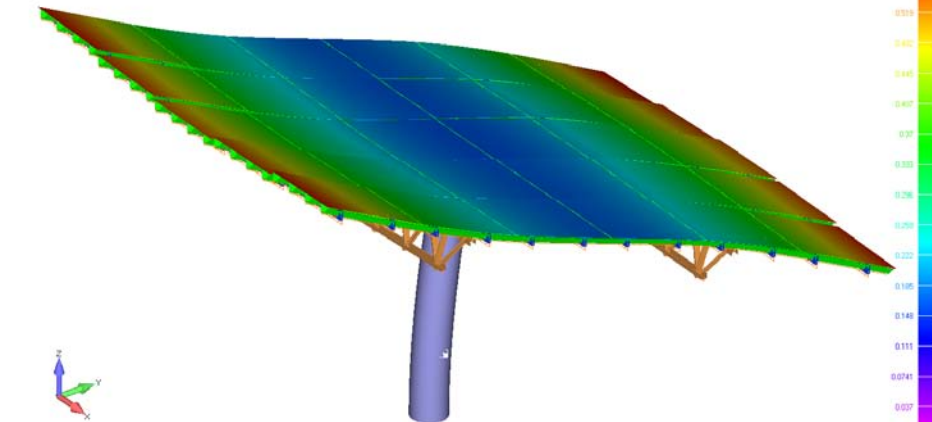


# Mode 2

## Pedestal Bend (in-line with TT)

3.26 Hz

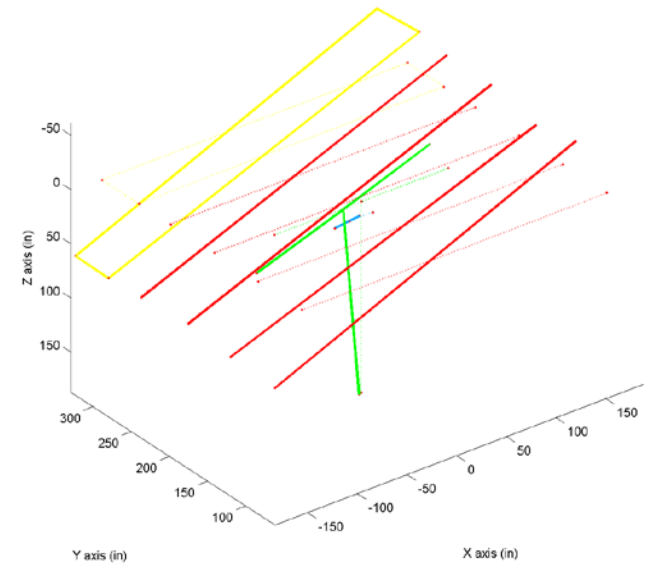
V: Unlabeled  
C: Load/Displacement  
G: von



Output Set: Mode 2, 3.261313 Hz  
Defined: 0.593 Total Translation  
Contour: Total Translation

2.042 Hz

Mode 5  
Frequency: 2.042 Hz  
Damping: 1.152 %Cr  
IDLine 1: Generated from reference 4X-



# Mode 3

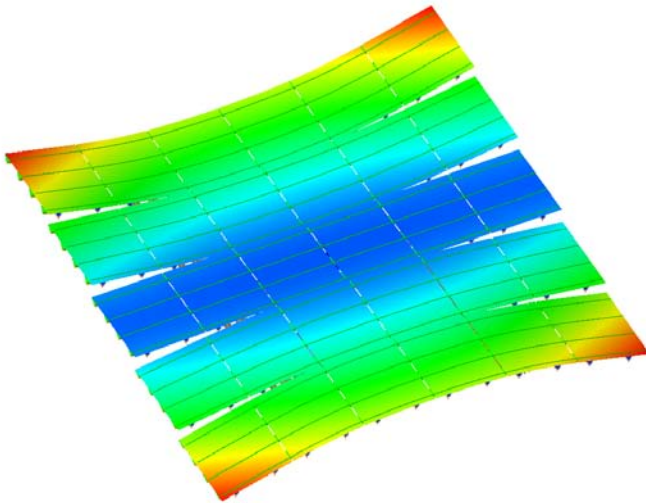
## Pedestal Bend (in-line with trusses)

3.34 Hz

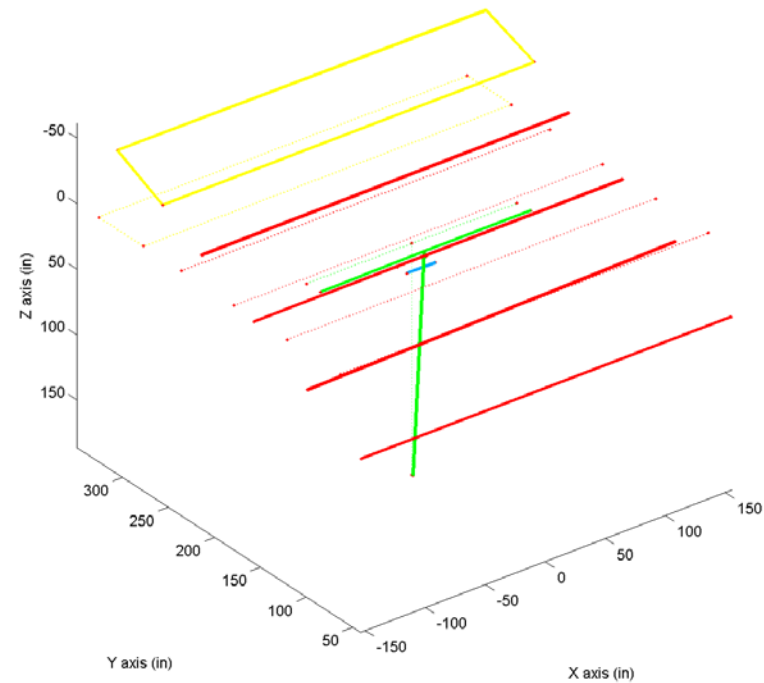
2.242 Hz

Mode 5  
Frequency: 2.242 Hz  
Damping: 0.786 %Cr  
IDLine 1: Generated from reference 4Y-

V: Unlabeled  
C: Load Case  
G: von



Output Set: Mode 3, 3.42745 Hz  
Defined: E1392 Total Translation  
Contour: Total Translation





# Mode 4

## Torque Tube Twist ?

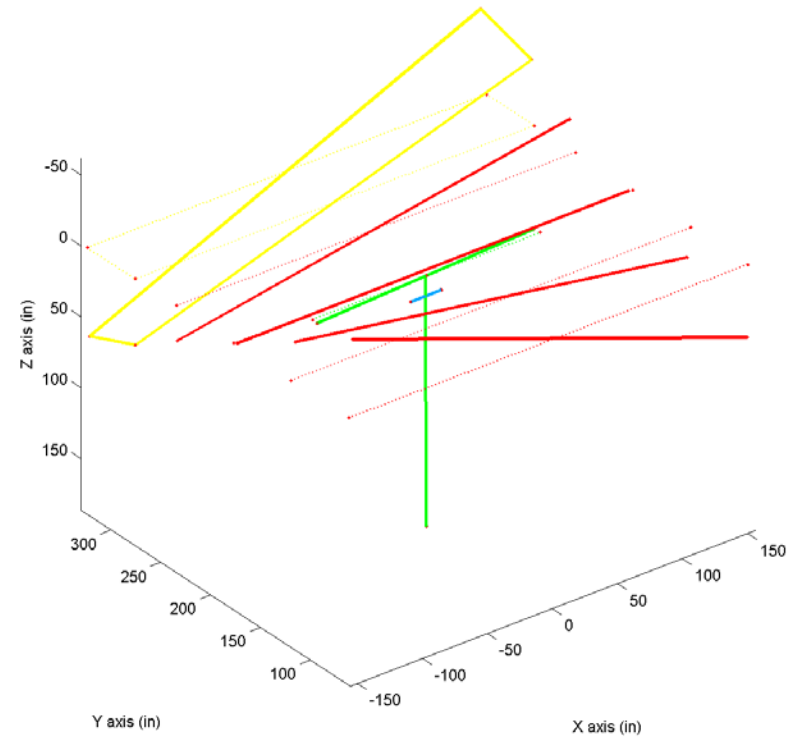
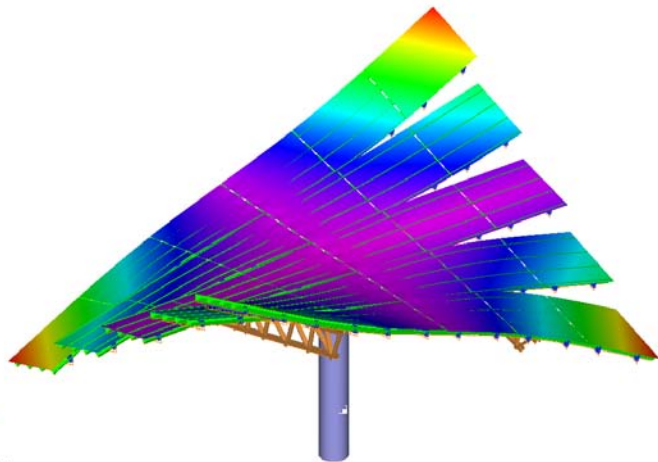
4.09 Hz

3.036 Hz

Mode 4  
Frequency: 3.036 Hz  
Damping: 0.943 %Cr  
IDLine 1: Generated from reference 43Z-

V: Unlabeled  
C: Load/Case  
G: view

Output Set: Mode 4, 4 (0.0746 Hz)  
Definition: (0.07) Total Translation  
Contour: Total Translation



# Mode 5

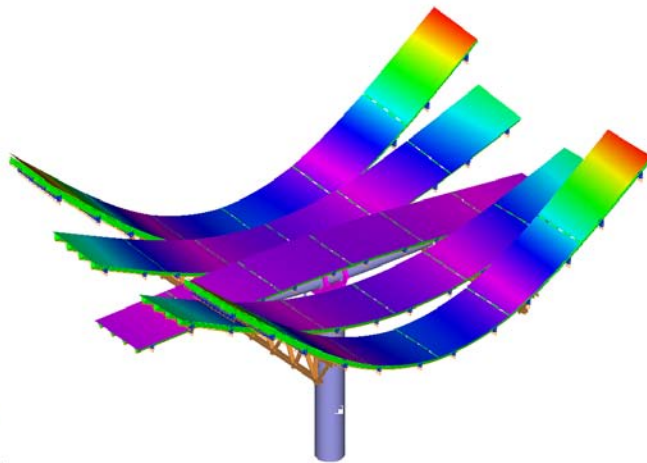
## Mirrors OOP Translation #1

5.80 Hz

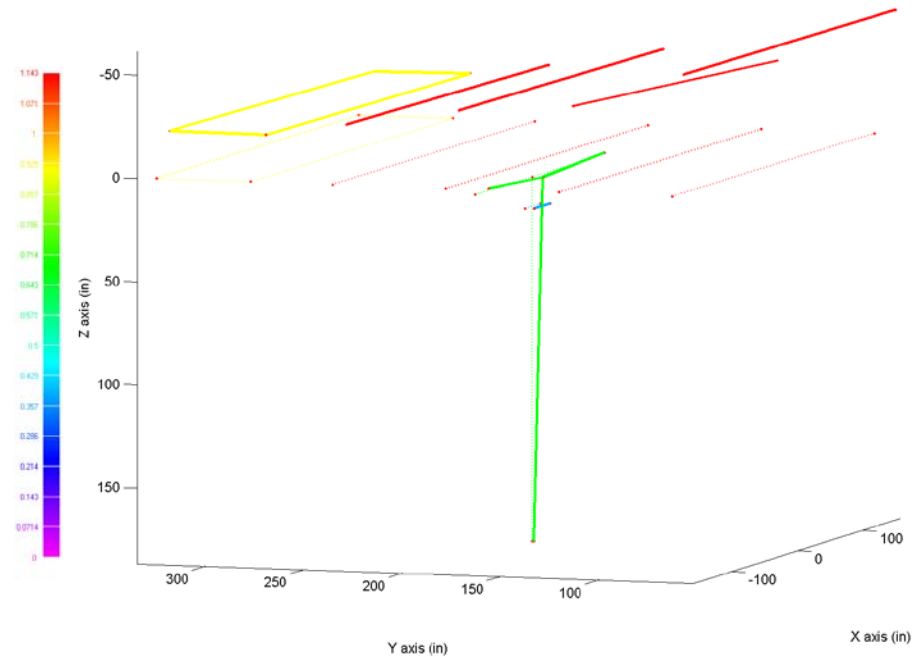
3.850 Hz

Mode 5  
Frequency: 3.850 Hz  
Damping: 1.237 %Cr  
IDLine 1: Generated from reference 43Z-

V: Unlabeled  
C: Load Data  
G: view



Output Set: Mode 5, 3.850 Hz  
Definition: (1.143) Total Translation  
Contour: Total Translation



# Mode 6

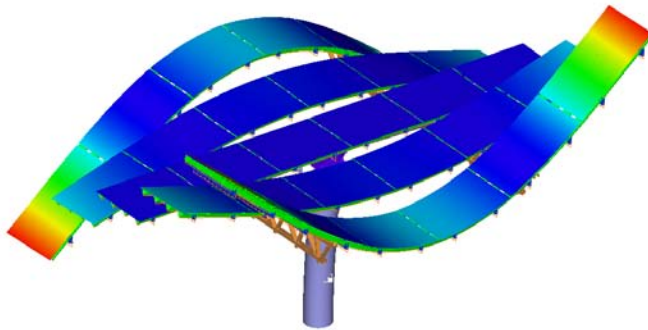
## Mirrors OOP Translation #2

5.95 Hz

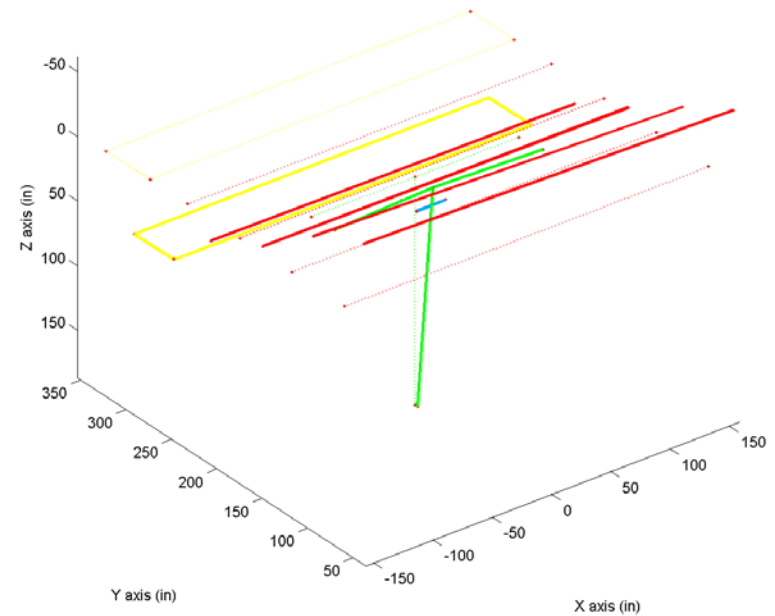
3.879 Hz

Mode 7  
Frequency: 3.879 Hz  
Damping: 1.368 %Cr  
IDLine 1: Generated from reference 4Y-

V: Unlabeled  
C: Load Data  
G: von



Output Set: Mode 6: 5.95073 Hz  
Defined: 1992 Total Translation  
Contour: Total Translation



# Mode 7

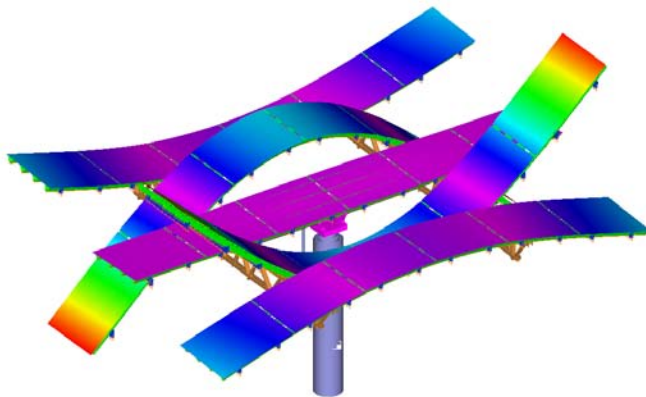
## Mirrors OOP Translation #3

6.34 Hz

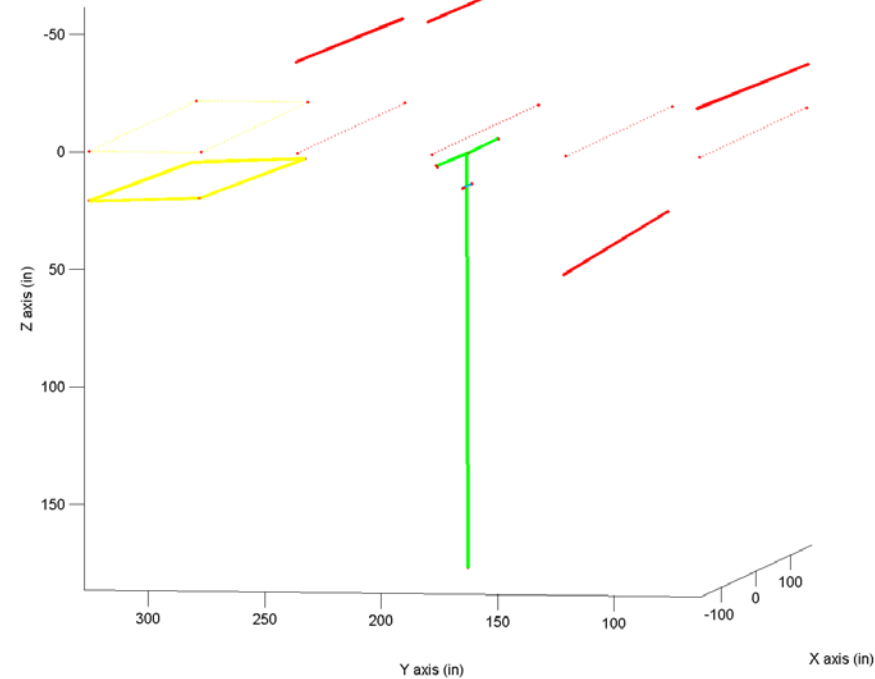
Mode 7  
Frequency: 4.036 Hz  
Damping: 1.276 %Cr  
IDLine 1: Generated from reference 43Z-

4.036 Hz (note shape 3<sup>rd</sup>  
mirror module has large  
motion)

V: Unlabeled  
C: Load Data  
G: view



Output Set: Mode 7, 6.345884 Hz  
Deformed(1.275) Total Translation  
Contour: Total Translation



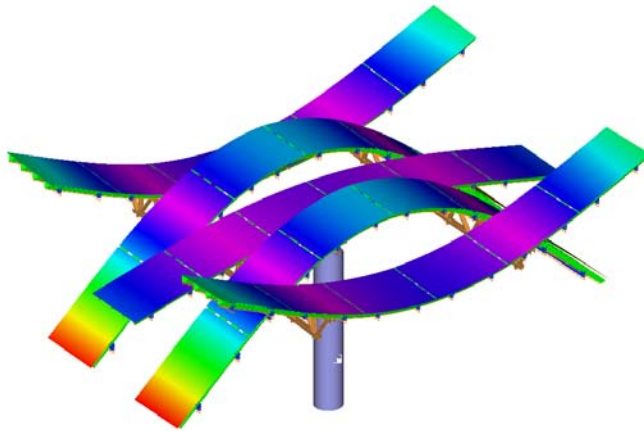
# Mode 8

## Mirrors OOP Translation #4

6.35 Hz

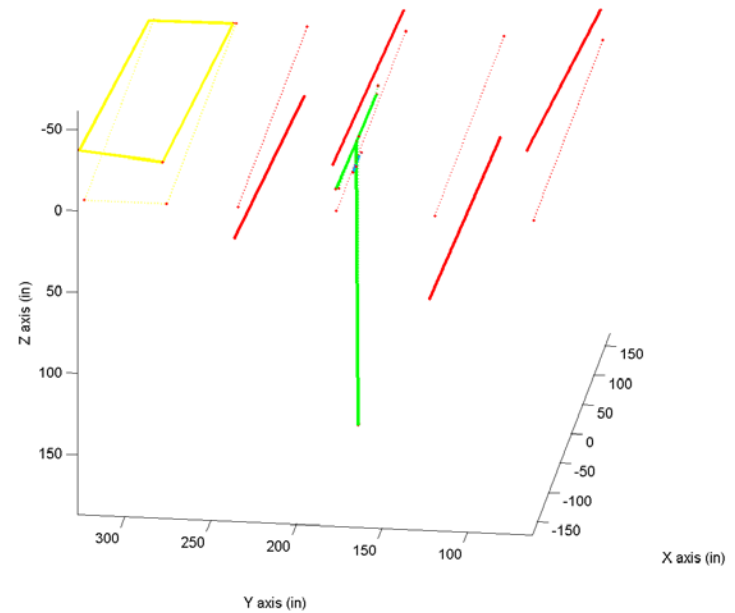
Mode 11  
Frequency: 4.189 Hz  
Damping: 0.754 %Cr  
IDLine 1: Generated from reference 33Z-

V: Unlabeled  
C: Load Case  
G: von



Output Set: Mode 11, 4.189 Hz  
Defined: (1,3) Total Translation  
Contour: Total Translation

4.189 Hz (note phase of  
3<sup>rd</sup> mirror module)





# Mode 9

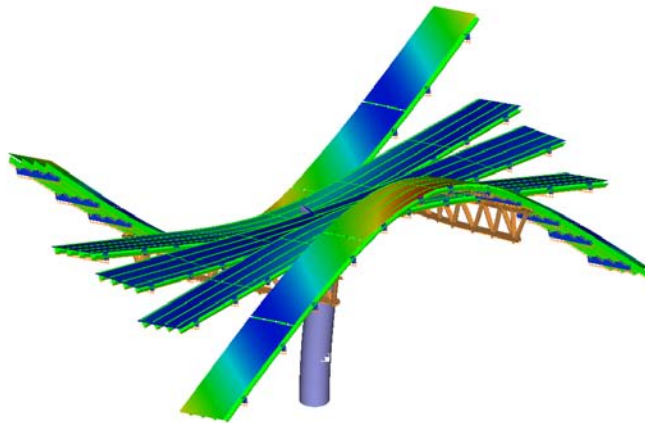
## Mirrors OOP Translation #5, truss twist

7.04 Hz

5.108 Hz

Mode 9  
Frequency: 5.108 Hz  
Damping: 0.888 %Cr  
IDLine 1: Generated from reference 4Z-

V: Unfolded  
C: Load/Displacement  
G: von



# Mode 10

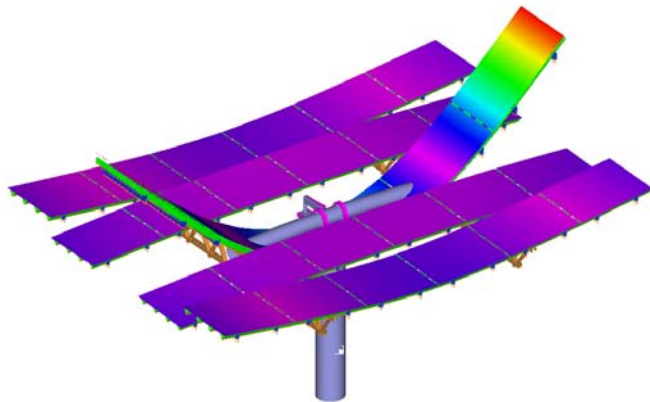
## Mirrors OOP Translation #6, TT bend vertical?

7.10 Hz

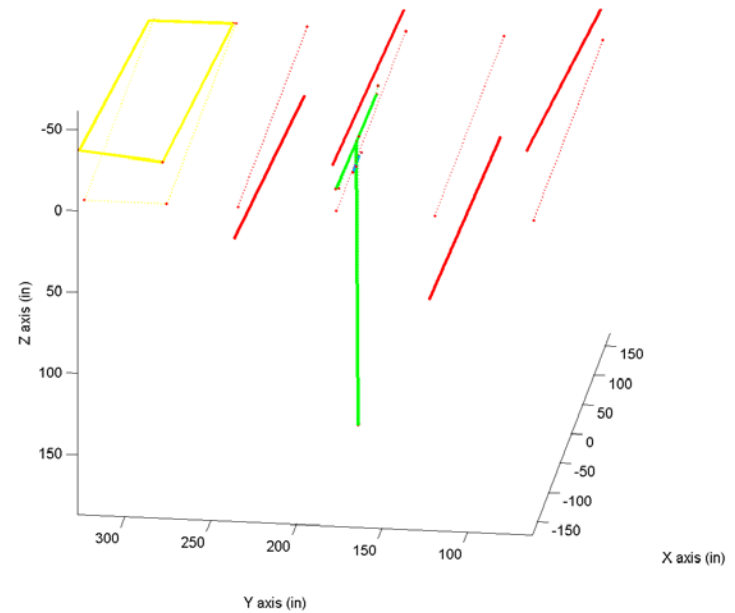
4.189Hz ??

Mode 11  
Frequency: 4.189 Hz  
Damping: 0.754 %Cr  
IDLine 1: Generated from reference 33Z-

V: Unlabeled  
C: Load/Save  
G: view



Output Set: Mode 10, 7.10644 Hz  
Defined: (1.73) Total Translation  
Contour: Total Translation



# Mode 11

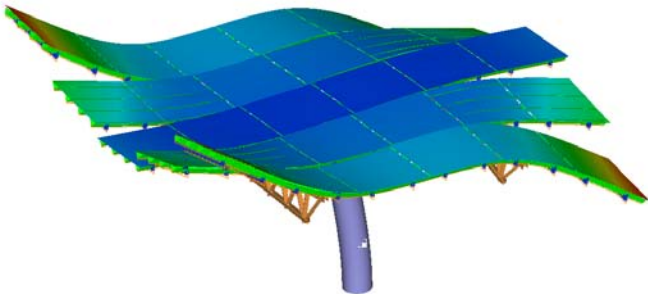
## Truss Bend, Mirrors 2<sup>nd</sup> OOP ?

7.31 Hz

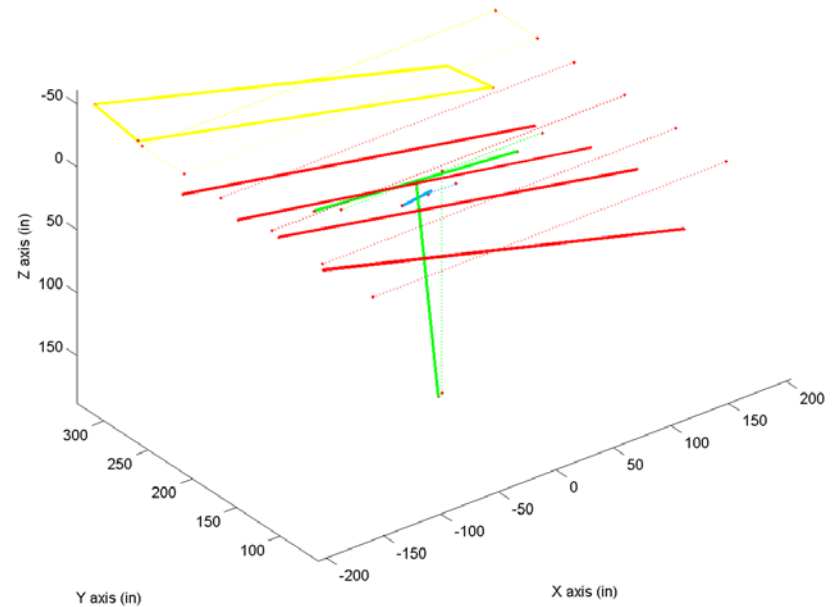
4.267 Hz ???

Mode 11  
Frequency: 4.267 Hz  
Damping: 0.886 %Cr  
IDLine 1: Generated from reference 4Z-

V: Unlabeled  
C: Load Case  
G: view



Output Set: Mode 11, 7.318056 Hz  
Defined: 7523 Total Translation  
Contour: Total Translation



# Mode 12

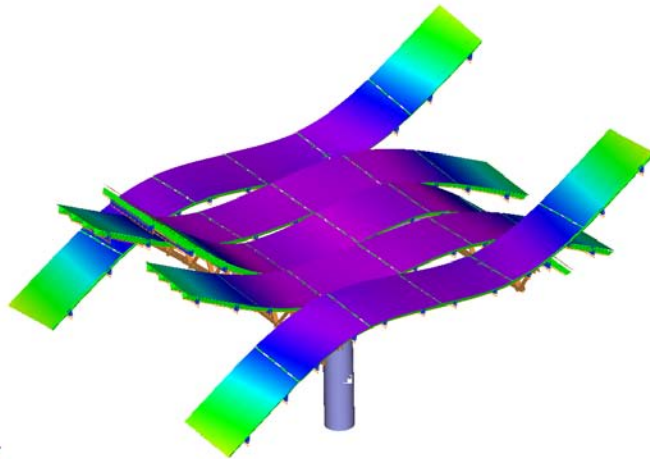
## Mirrors 2<sup>nd</sup> OOP Translation #1

8.71 Hz

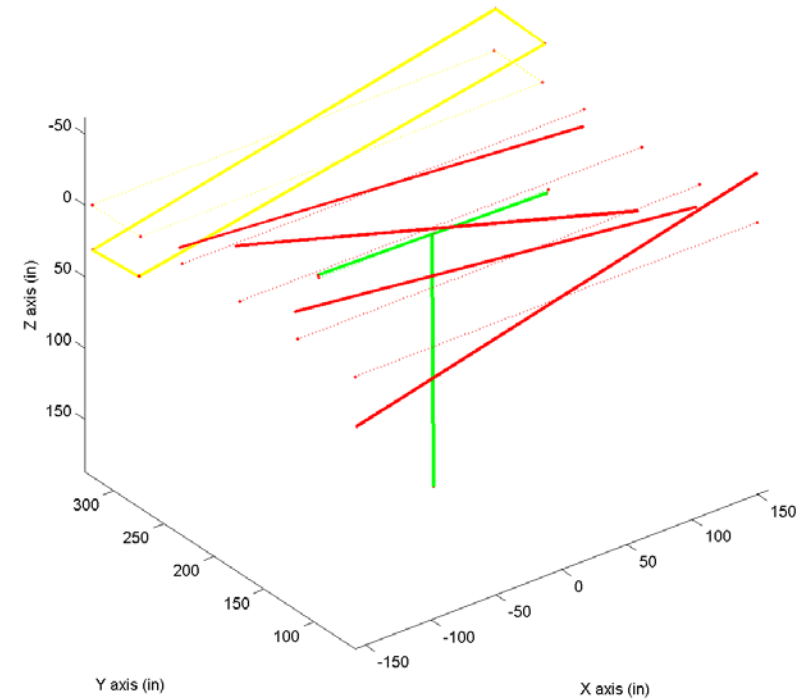
Mode 10  
Frequency: 5.678 Hz  
Damping: 0.711 %Cr  
IDLine 1: Generated from reference 4Z-

5.678 Hz

V: Unlabeled  
C: Load Data  
G: view



Output Set: Mode 12, 8.71839Hz  
Defined: E1190, Total Translation  
Contour: Total Translation



# Mode 13

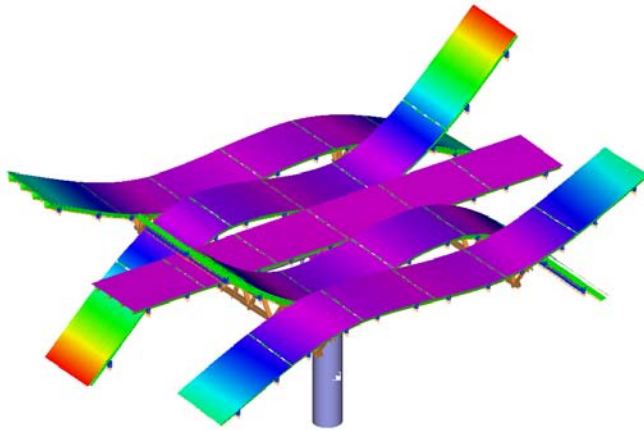
## Mirrors 2<sup>nd</sup> OOP Translation #2

9.04 Hz

V: Unlabeled  
C: Load Case  
G: view

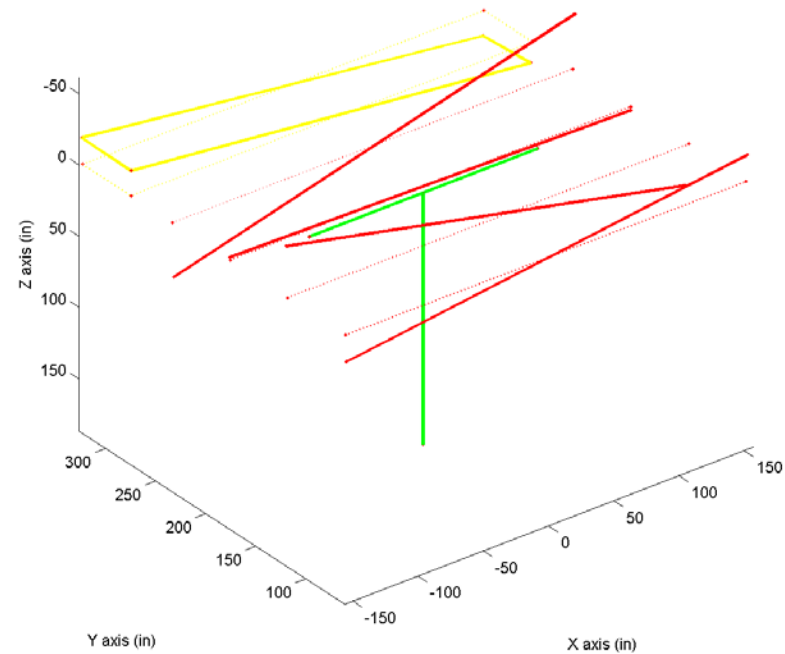


Output Set: Mode 13: 9.044489 Hz  
Defined: 1.270 Total Translation  
Contour: Total Translation



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

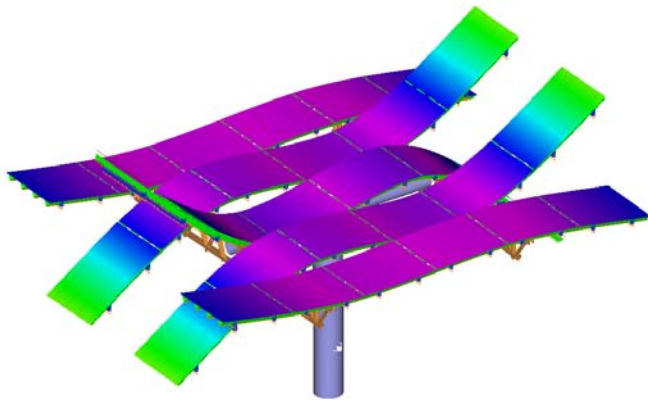
## Mirrors 2<sup>nd</sup> OOP Translation #3

9.10 Hz

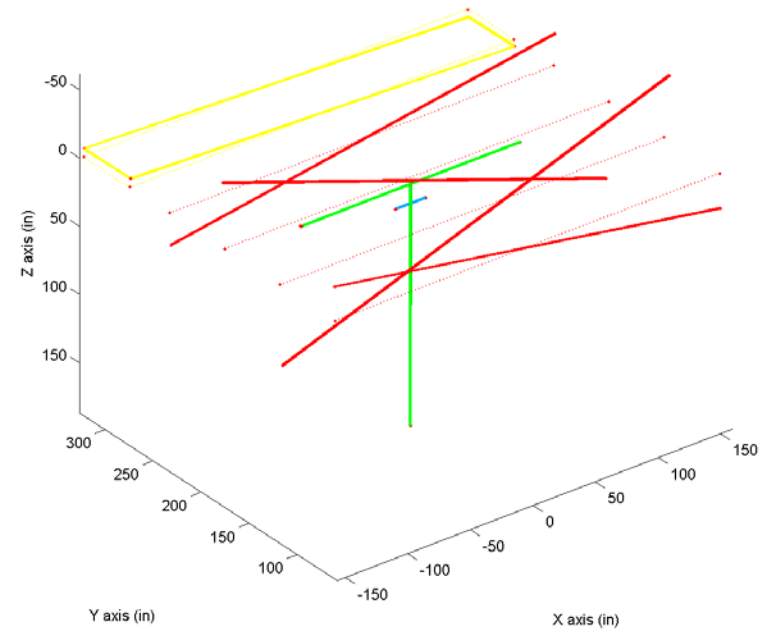
Mode 12  
Frequency: 5.865 Hz  
Damping: 0.560 %Cr  
IDLine 1: Generated from reference 43Z-

5.865 Hz

V: Unlabeled  
C: Load/Save  
G: View



Output Set: Mode 14, 3.109288 Hz  
Defined: E1410 Total Translation  
Contour: Total Translation



# Mode 15

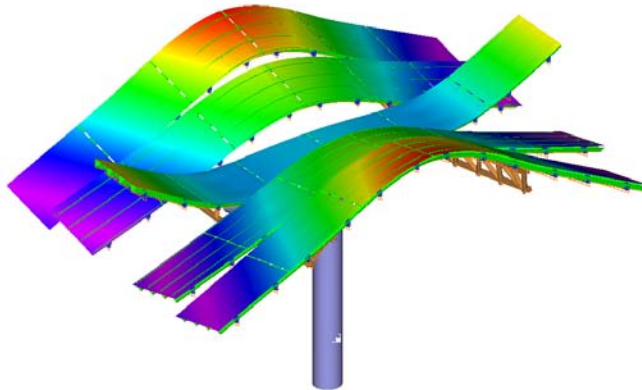
## Truss Bend OOP

9.17 Hz

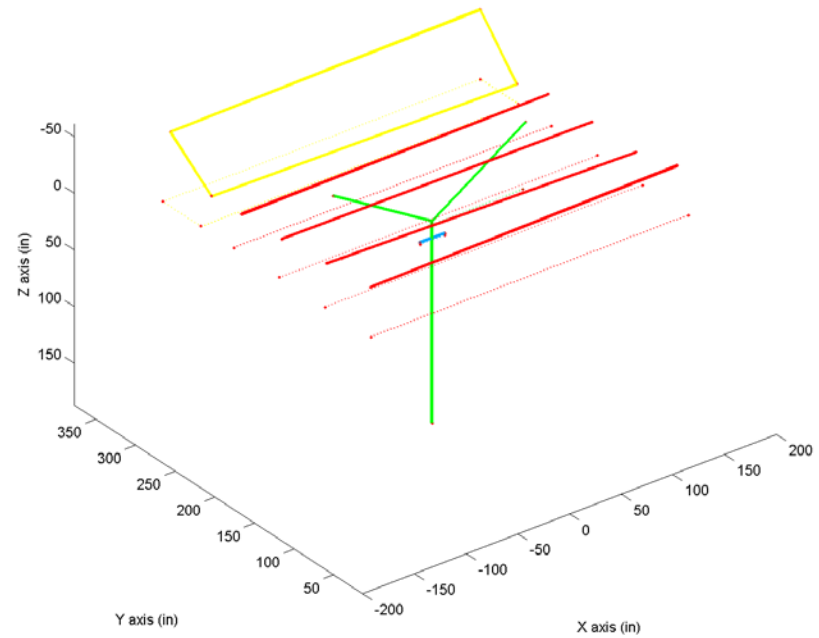
7.293 Hz ???

Mode 11  
Frequency: 7.293 Hz  
Damping: 1.381 %Cr  
IDLine 1: Generated from reference 4Y-

V: Unlabeled  
C: Load Case  
G: View



Output Set: Mode 15, 9.171463Hz  
Definition: (E77) Total Translation  
Contour: Total Translation



# Mode 16

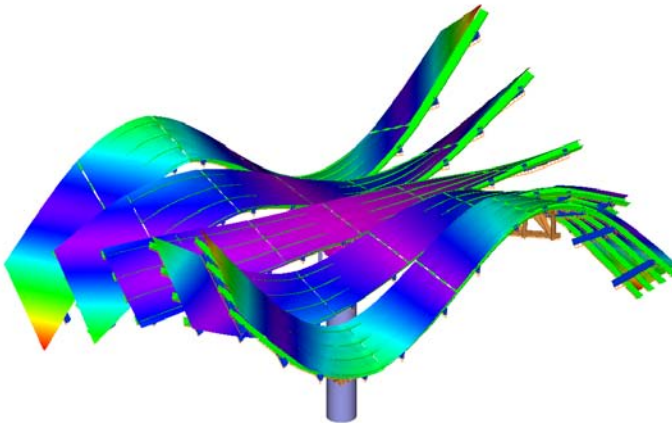
## Truss Twist

16.38 Hz

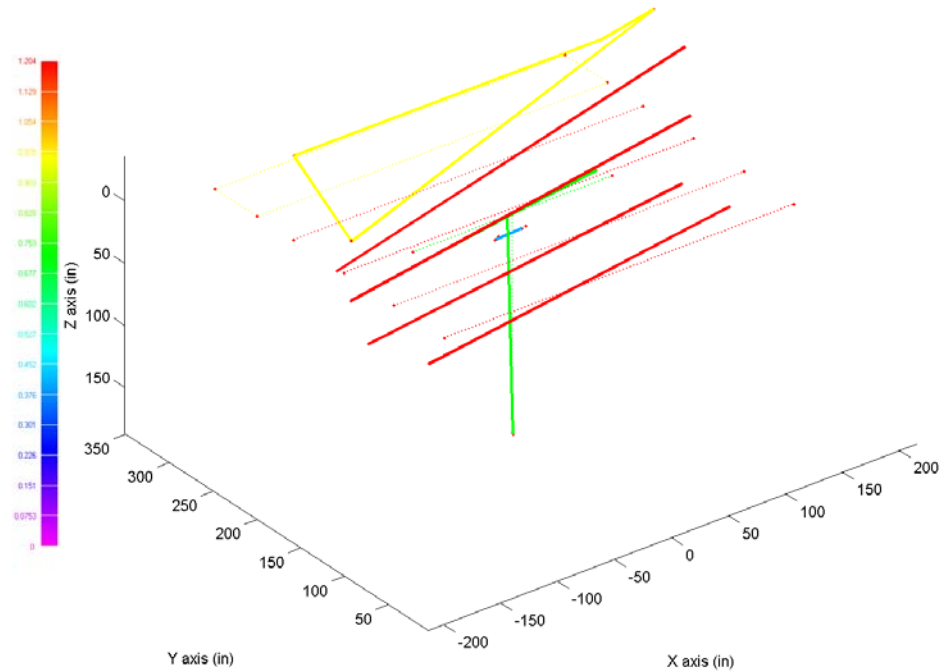
10.571 Hz ???

Mode 18  
Frequency: 10.571 Hz  
Damping: 1.273 %Cr  
IDLine 1: Generated from reference 43Z-

V: Unlabeled  
C: Load/Release  
G: view



Output Set: Mode 16, 16.38275 Hz  
Defined: ET 2040, Total Translation  
Contour: Total Translation



# Mode 17

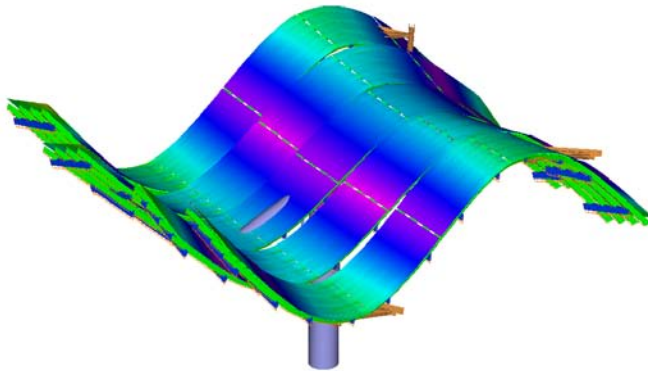
## Mirror 2<sup>nd</sup> OOP, TT rotation, truss bend

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

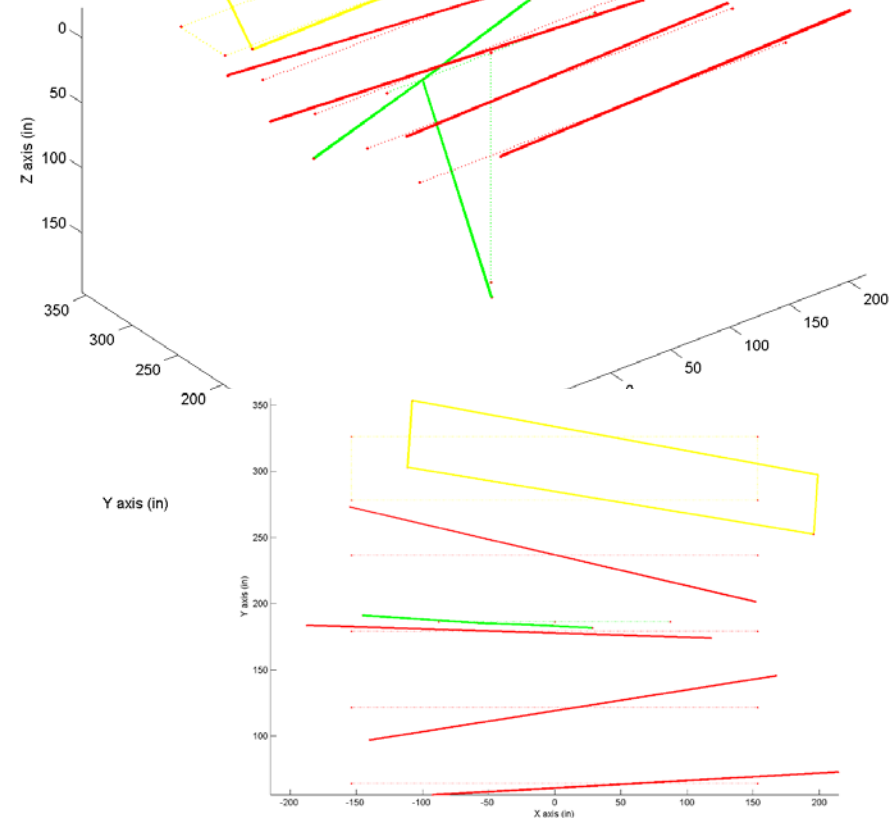
17.01 Hz

11.744 Hz

V: Unlabeled  
C: Solid Base  
G: see



Output Set: Mode 17: 17.01241 Hz  
Deformed: 0.953: Total Translation  
Contour: Total Translation



# 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

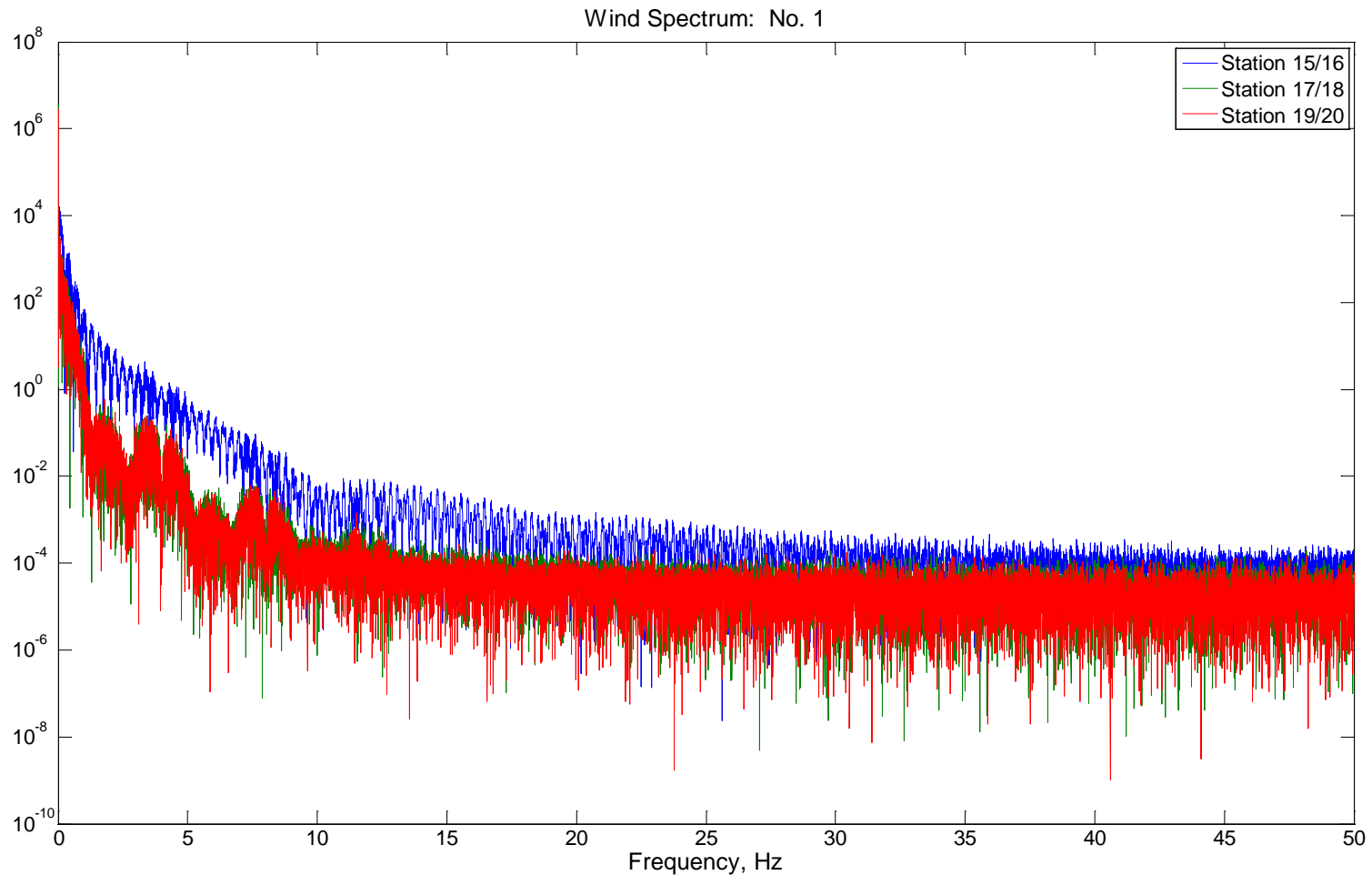
- Pedestal height has large effect on most modes
- Azimuth drive has enough slop to essentially uncouple pedestal twist from rotation of structure above the drive
- Behavior of 3<sup>rd</sup> (middle) mirror module is different in several experimental modes
- Extra weight of mirror extensions would appear 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 )

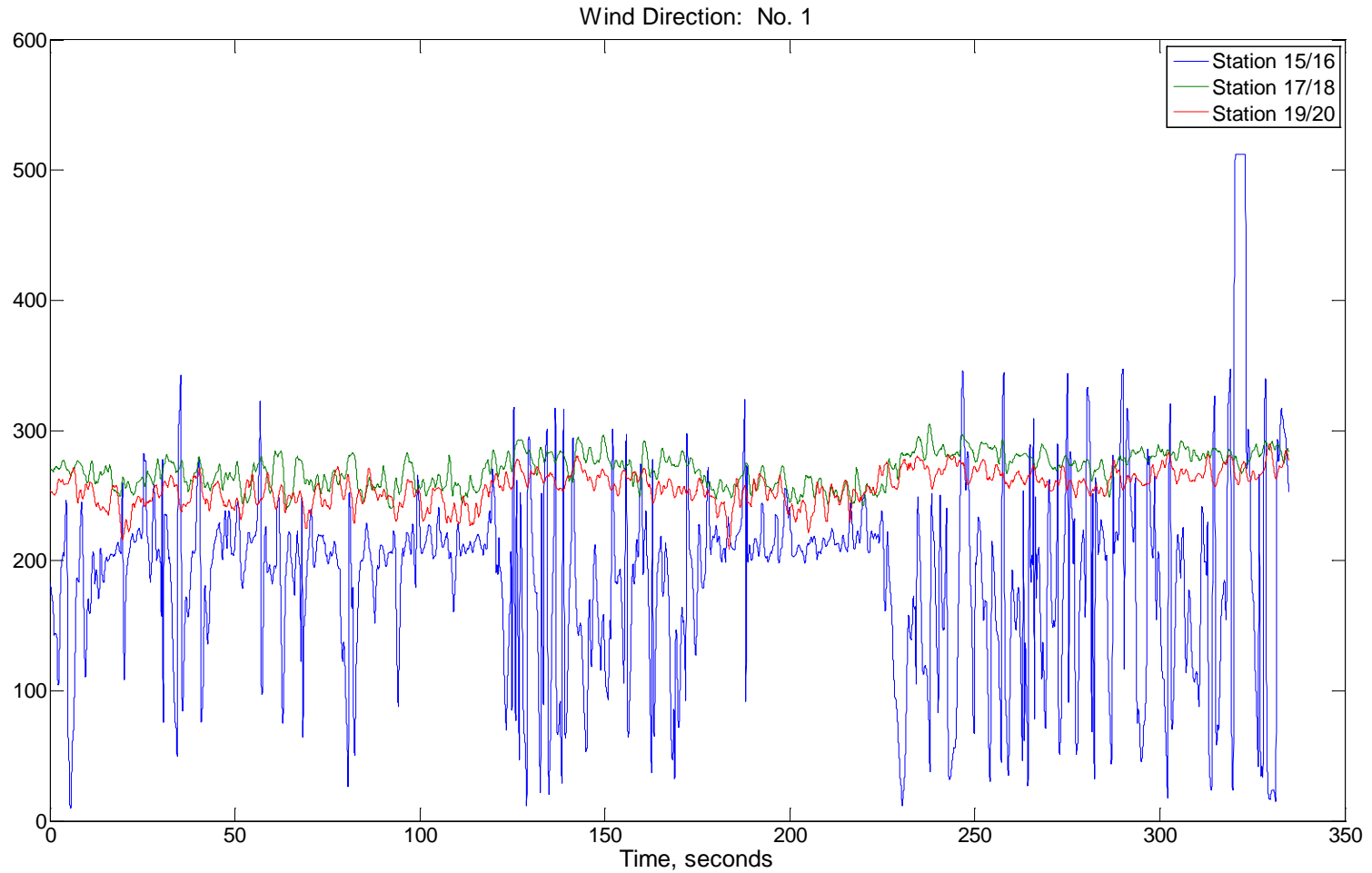
## Wind Spectrum



Note: Data not filtered, windowed, or averaged

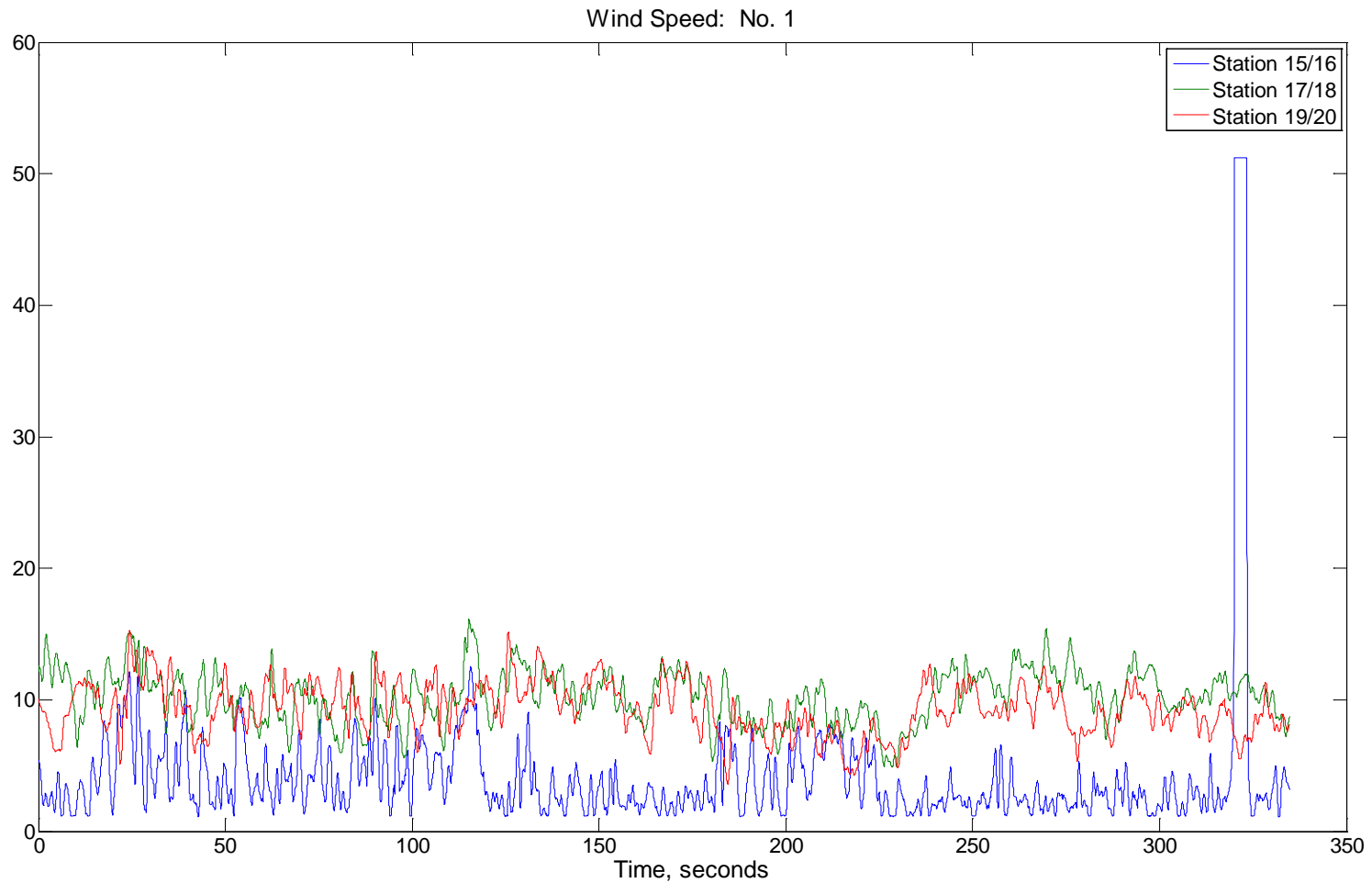
# Nabtesco Wind Data (Set No.1 )

## 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  $\omega^4$ )



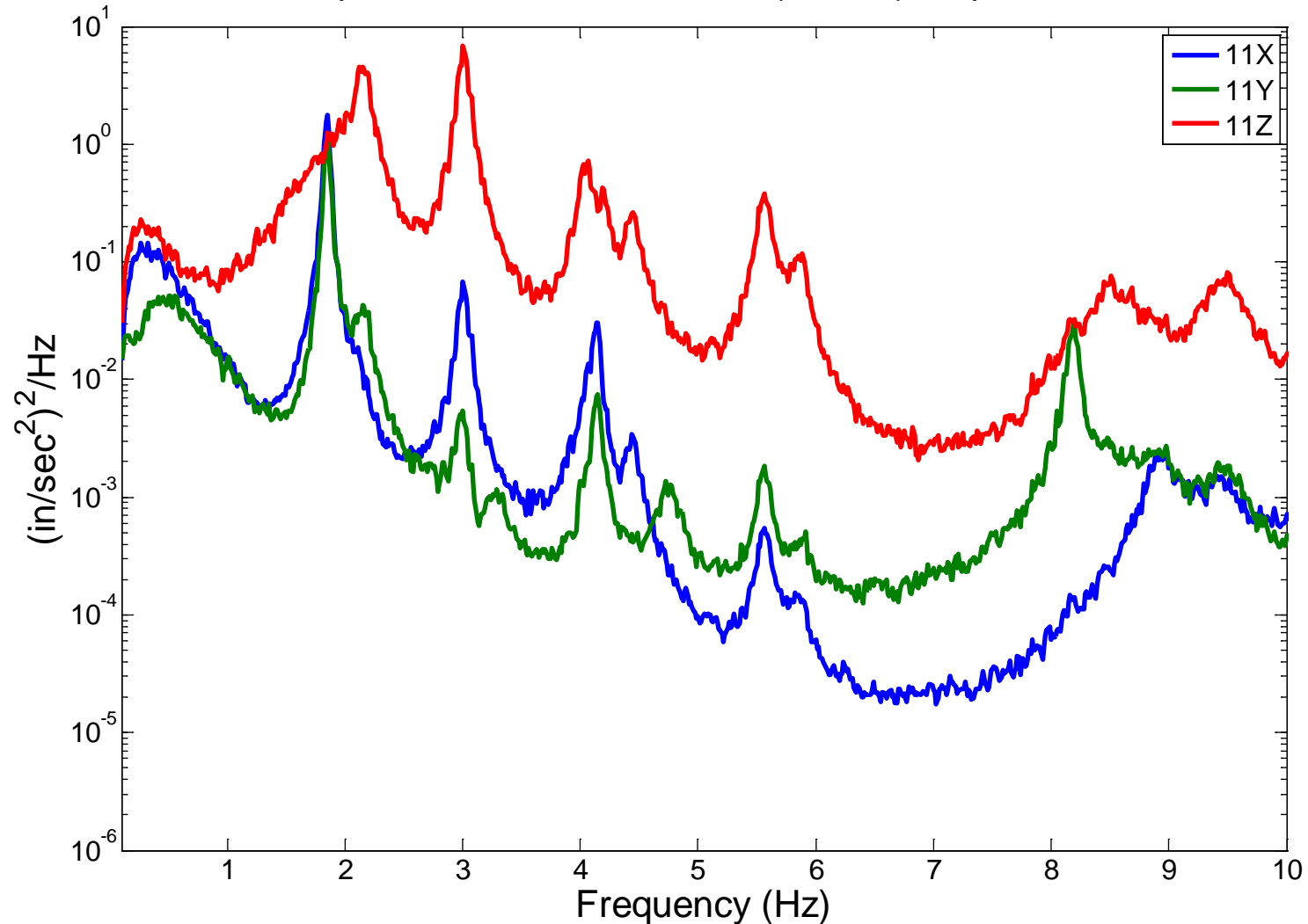
# Semi-log Plots

## 0.1 Hz to 10 Hz

# Acceleration Auto-PSD

## 0 degree

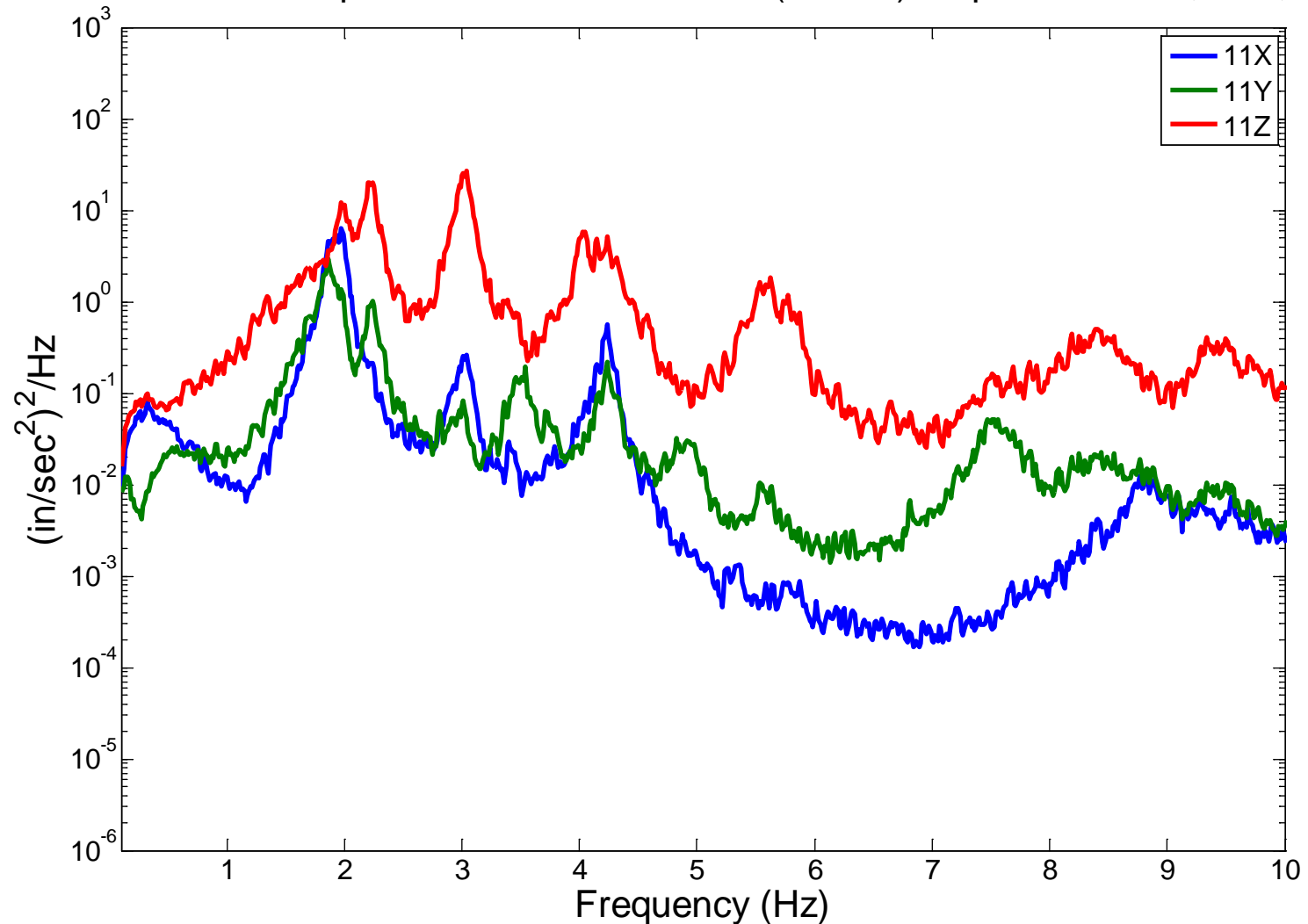
Acceleration Autospectrum: Wind Excitation (Run01) response at 11X, 11Y, 11Z



# Acceleration Auto-PSD

## 45 degree

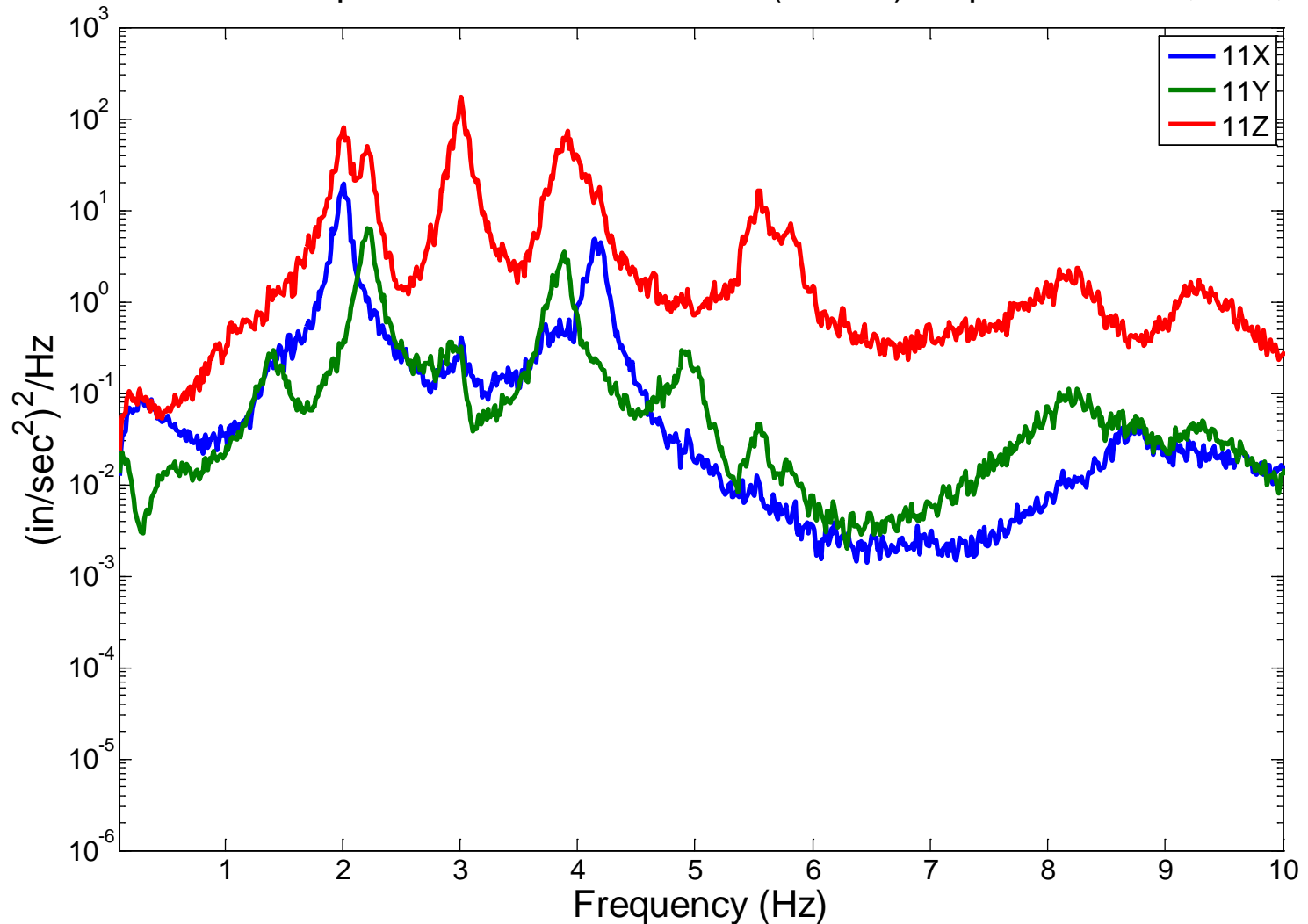
Acceleration Autospectrum: Wind Excitation (Run02) response at 11X, 11Y, 11Z



# Acceleration Auto-PSD

## 90 degree

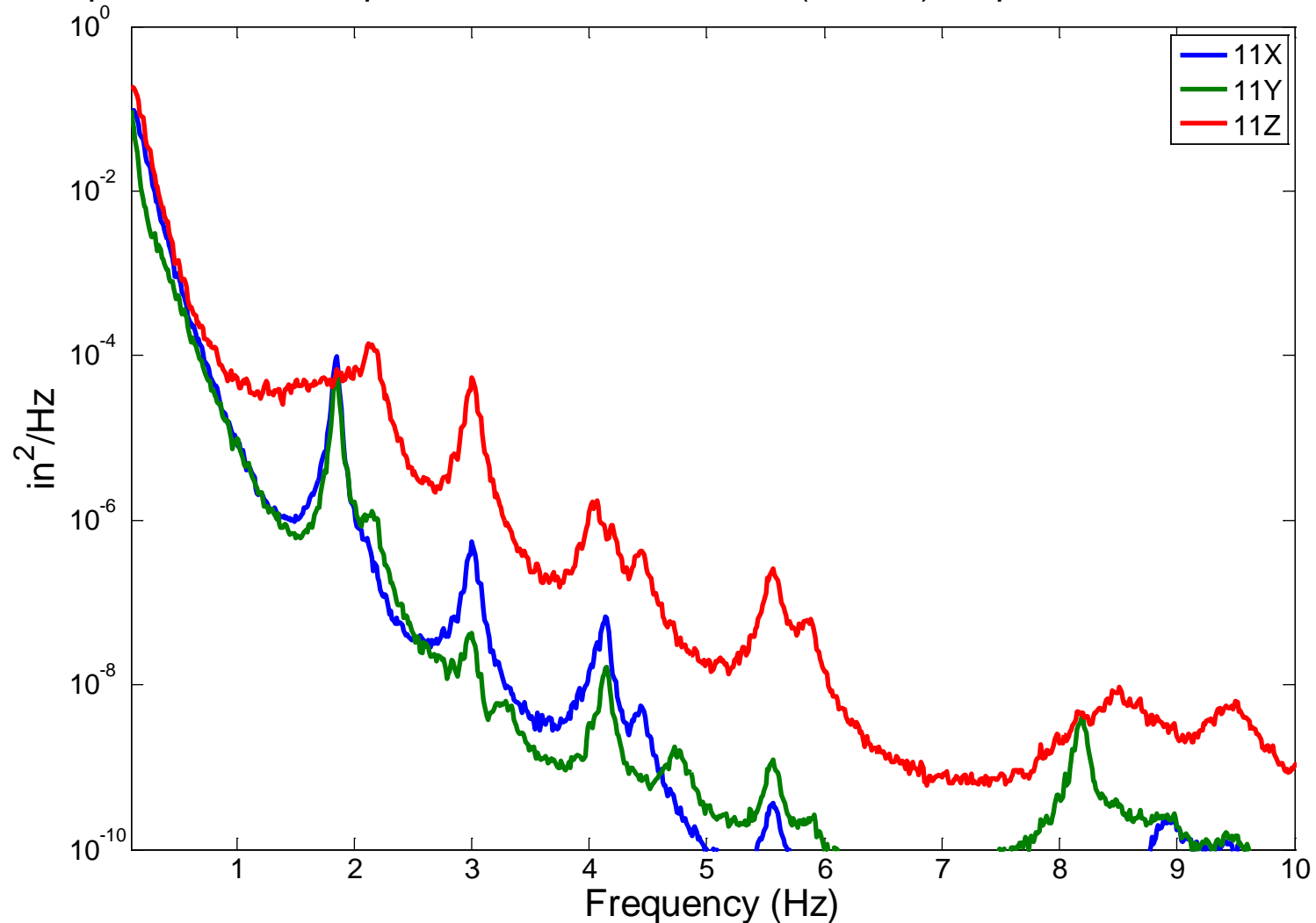
Acceleration Autospectrum: Wind Excitation (Run03) response at 11X, 11Y, 11Z



# Displacement Auto-PSD

## 0 degree

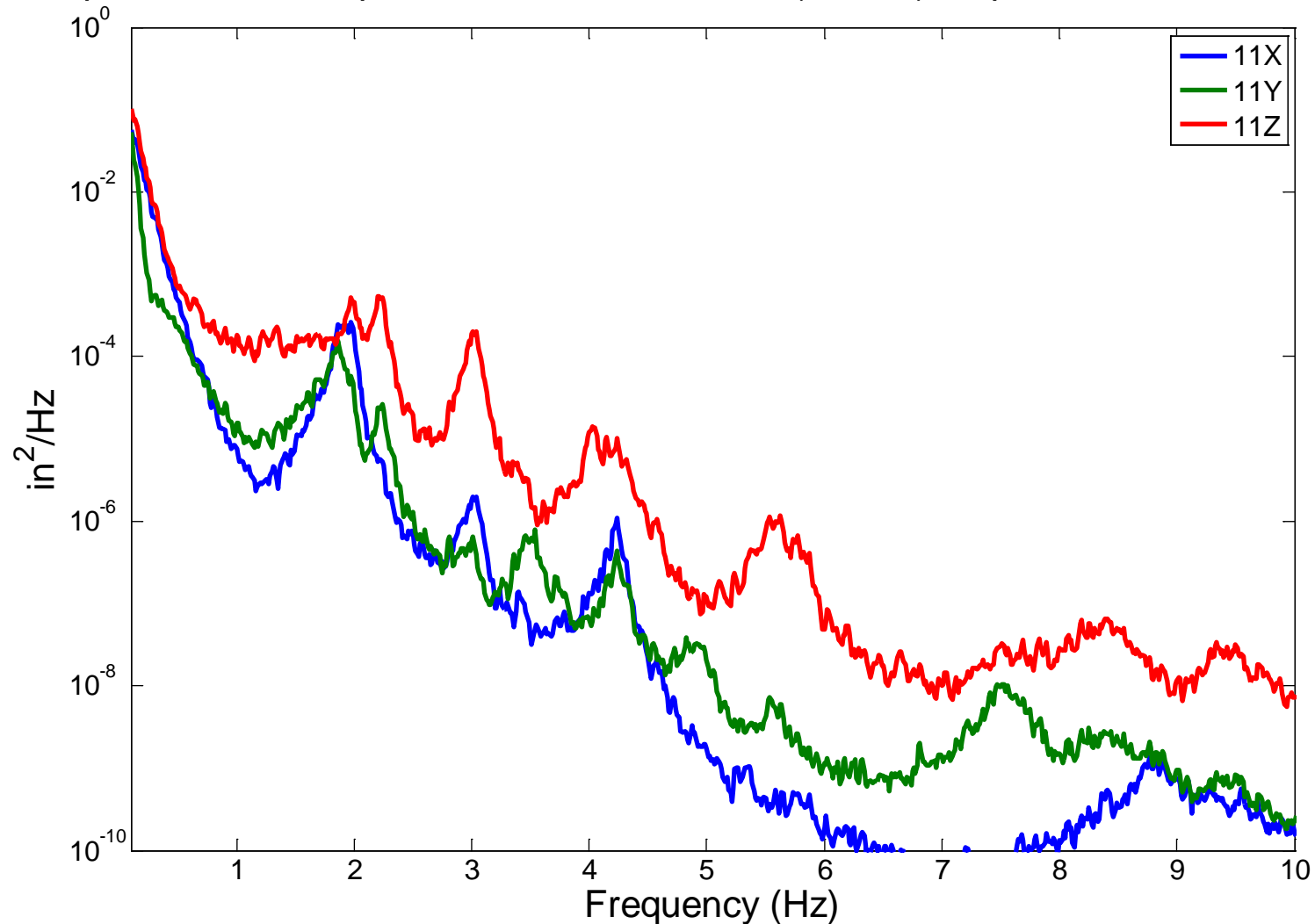
Displacement Autospectrum: Wind Excitation (Run01) response at 11X, 11Y, 11Z



# Displacement Auto-PSD

## 45 degree

Displacement Autospectrum: Wind Excitation (Run02) response at 11X, 11Y, 11Z



# Displacement Auto-PSD

## 90 degree

Displacement Autospectrum: Wind Excitation (Run03) response at 11X, 11Y, 11Z

