LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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System Dynamics Model of the External Pre-Isolator (EPI) for the Horizontal Access Module (HAM)

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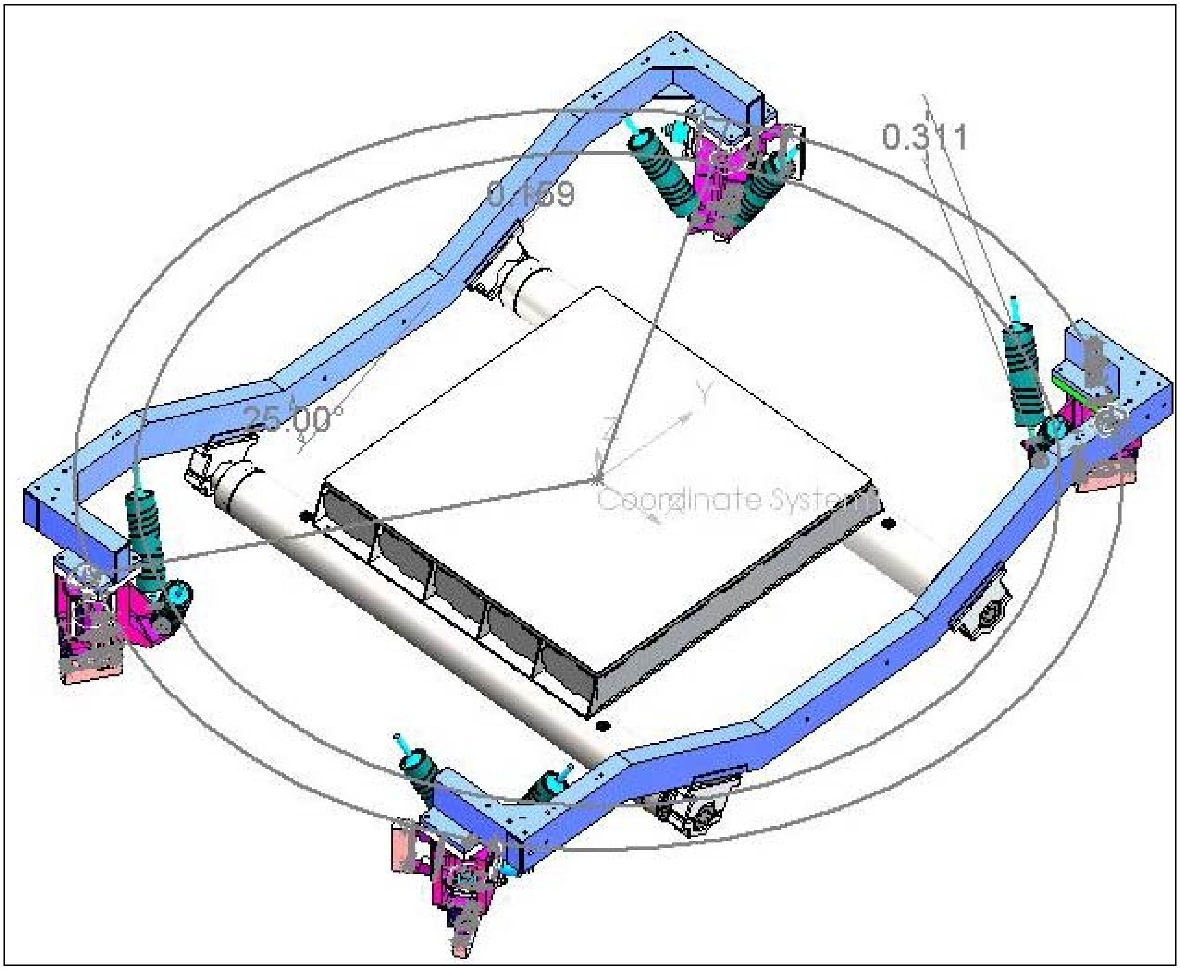
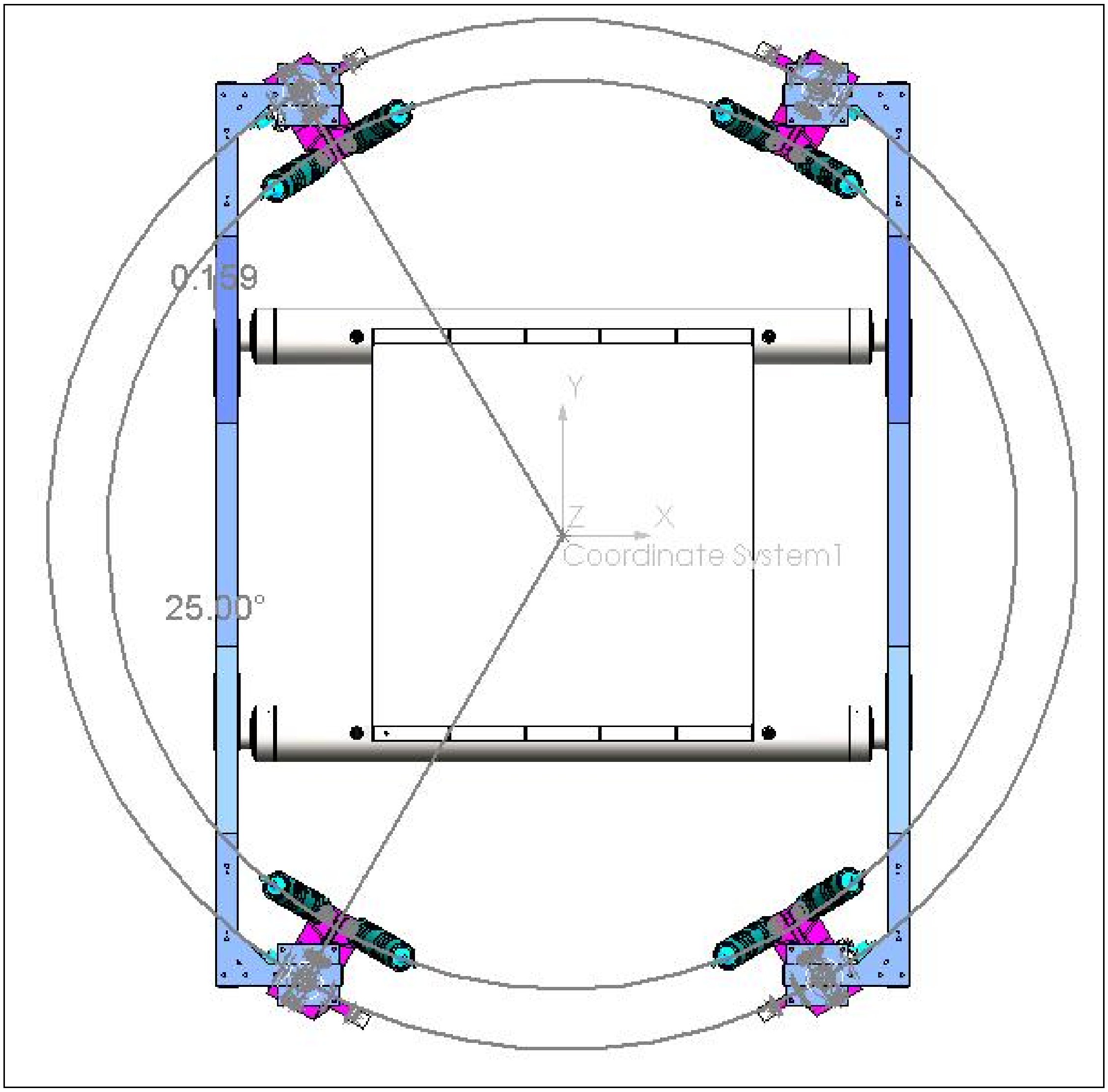
1 Introduction

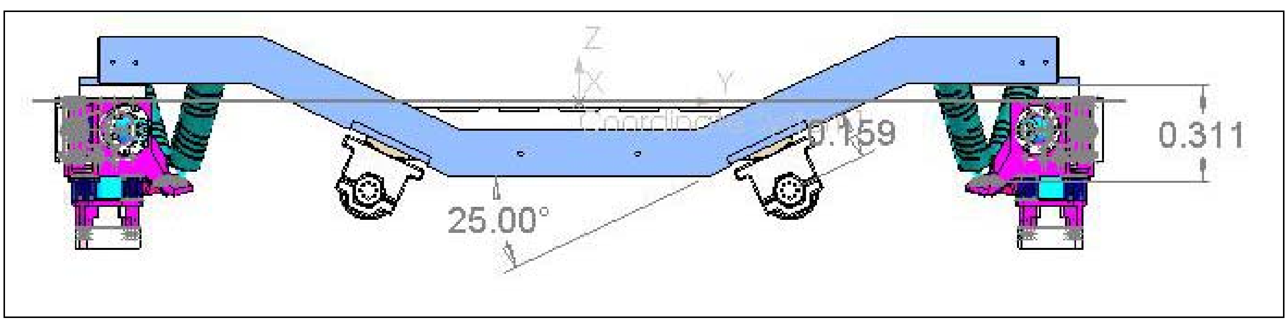
This is an incomplete draft of a technical memo on the electro-Magnetic External Pre-Isolator (MEPI) system. MEPI is similar in dynamics to the Hydraulic EPI (HEPI) system.

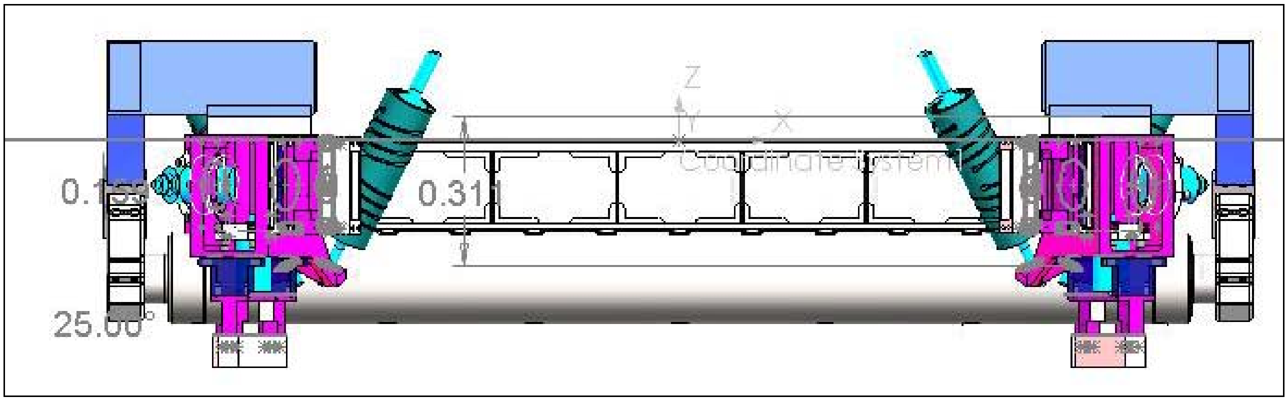
2 Geometry

2.1 CAD

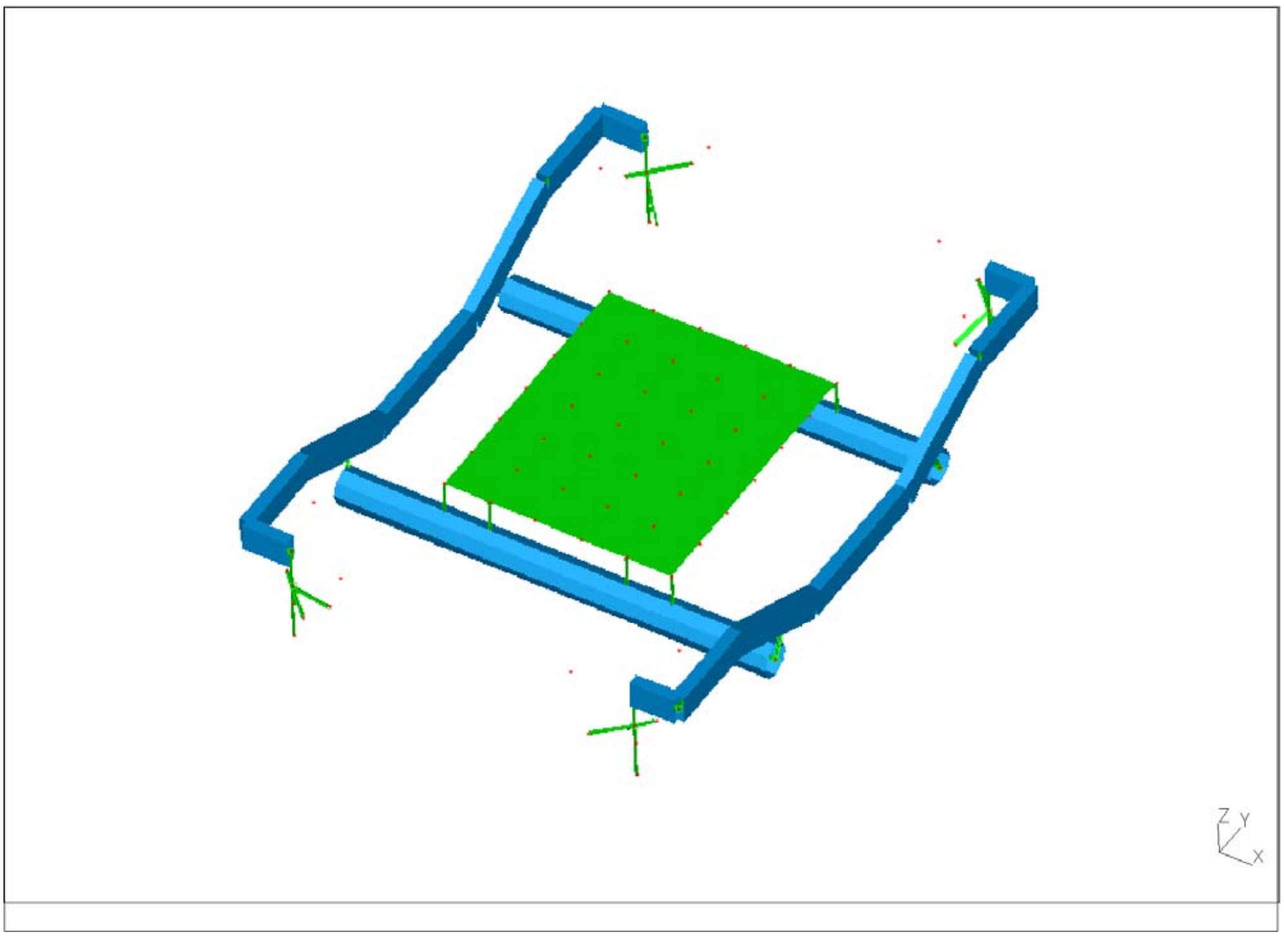


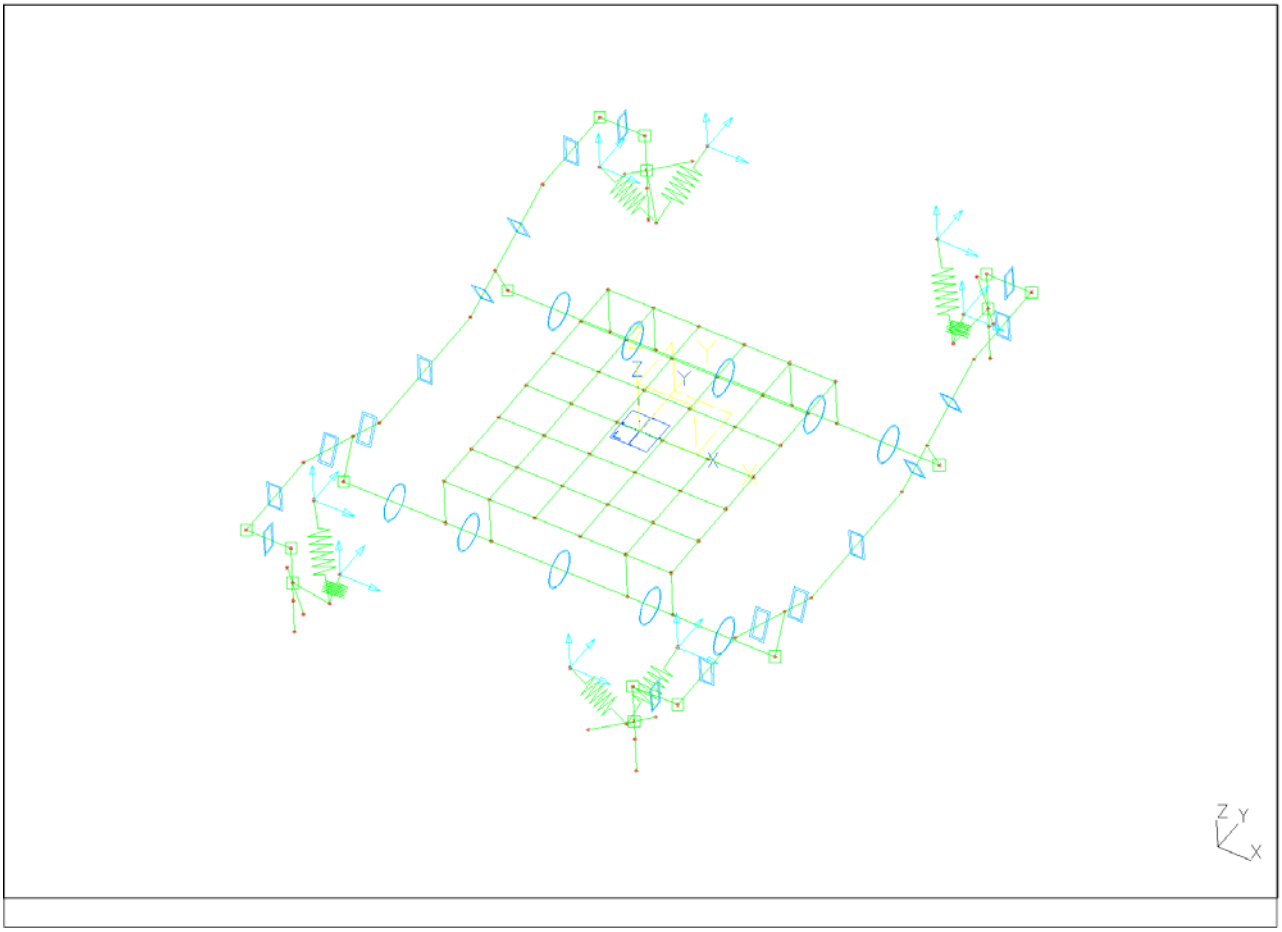

0.159
Y
Z
X
Coordinate System1
25.00°


Z
X
Y
0.159
0.311
25.00°



2.2 Finite Element Model (FEM)

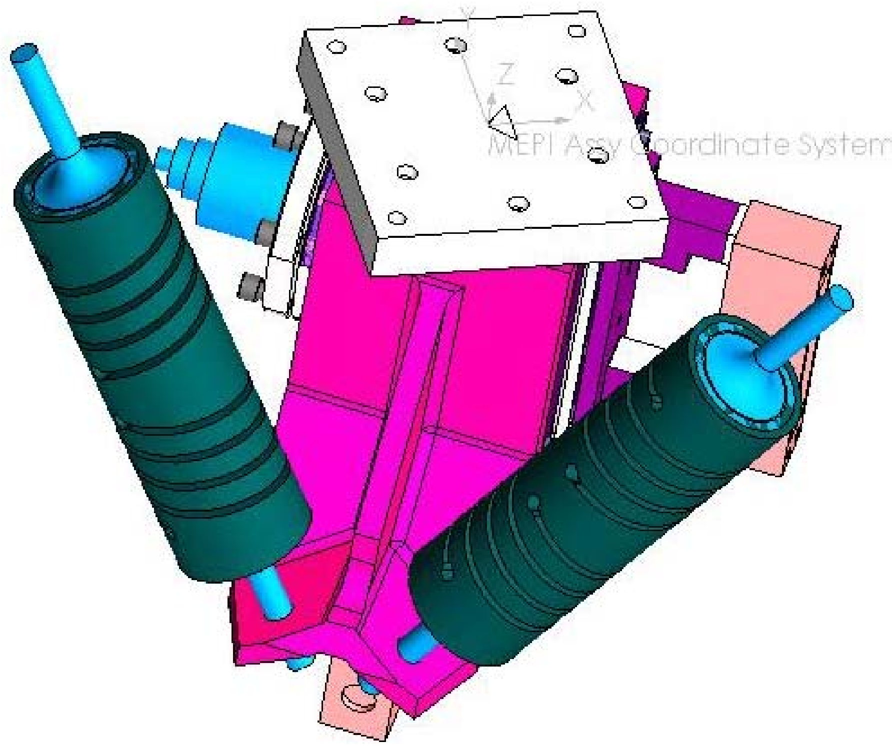


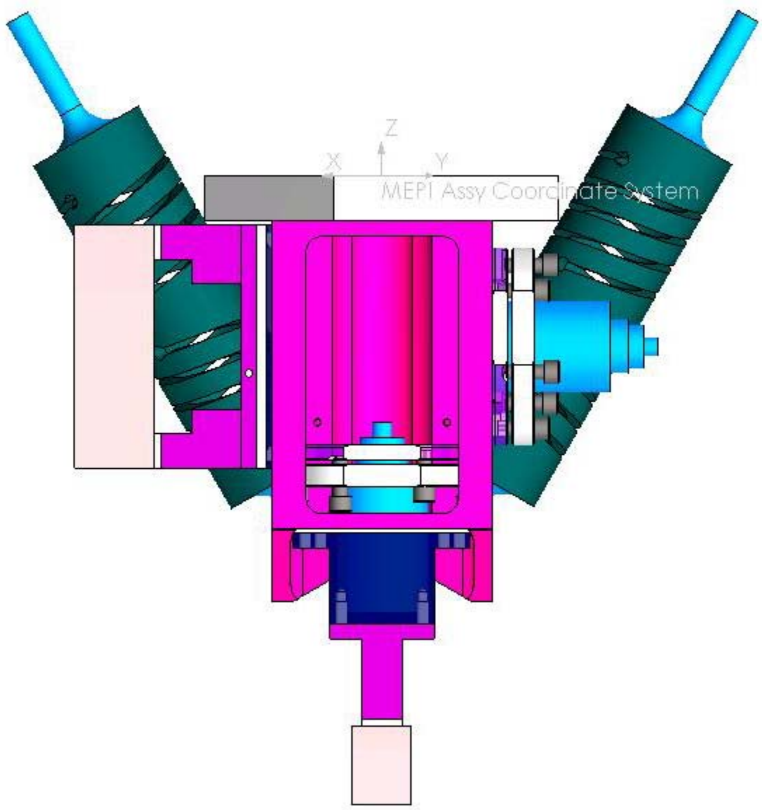


3 Mass Properties

3.1 MEPI Assembly

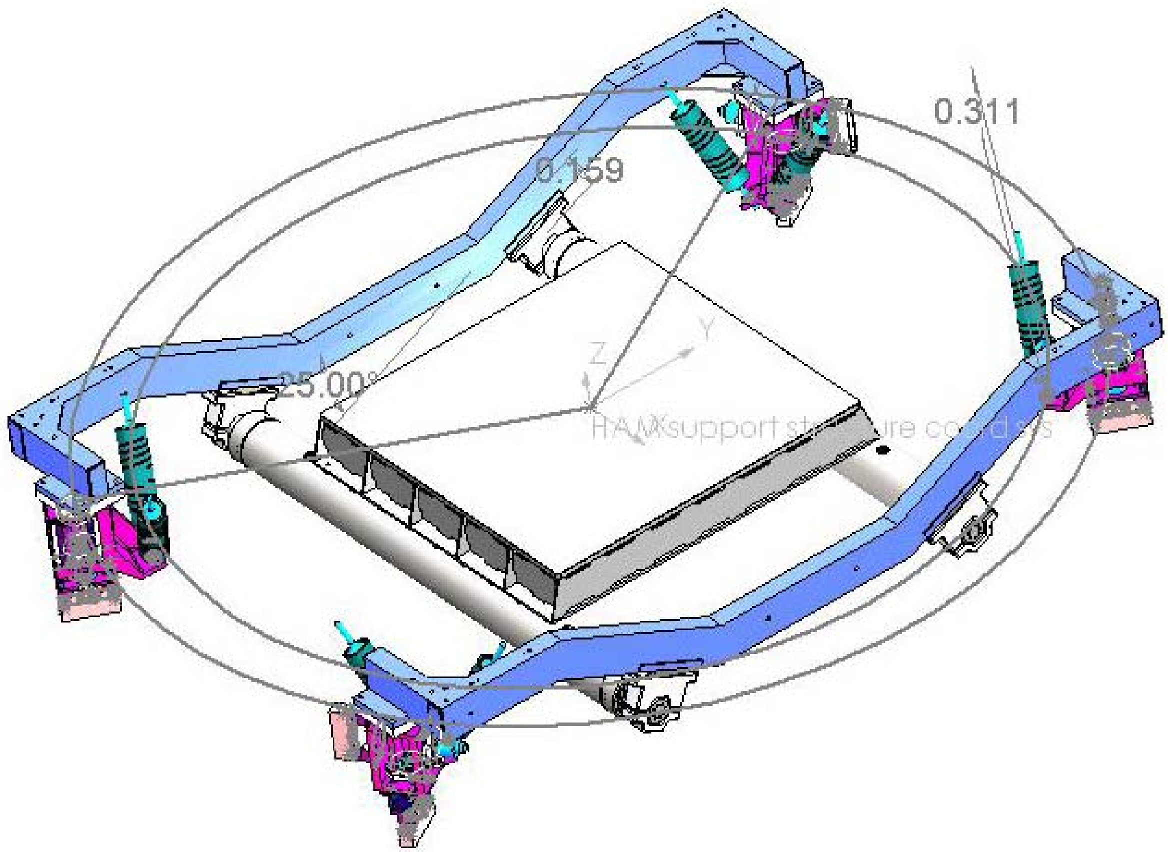
The MEPI assembly with just the stationary components is shown in Figure X. The mass properties for the MEPI assembly is given in Table X. The spring density was set to be ½ of steel to approximate the fact that not all of the mass of the spring participates in the quasi-rigid body modes.


Z
X
MEPI Assy Coordinate System


Z
X
Y
MEPI Assy Coordinate System

Mass properties of EM_assy_stationary_parts_R
Output coordinate System : MEPI Assy Coordinate System
Mass = 109.4561 kilograms
Volume = 0.0155 cubic meters
Surface area = 1.8894 square meters
Center of mass: (meters)
X = -0.0133
Y = -0.0263
Z = -0.1731
Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.
Ix = (-0.0658, -0.1325, 0.9890) Px = 1.8728
Iy = (0.9966, -0.0569, 0.0587) Py = 2.4448
Iz = (0.0485, 0.9896, 0.1358) Pz = 2.4821
Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 2.4424 Lxy = 0.0032 Lxz = -0.0375
Lyx = 0.0032 Lyy = 2.4713 Lyz = -0.0799
Lzx = -0.0375 Lzy = -0.0799 Lzz = 1.8860
Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.
Ixx = 5.7993 Ixy = 0.0413 Ixz = 0.2138
Iyx = 0.0413 Iyy = 5.7718 Iyz = 0.4182
Izx = 0.2138 Izy = 0.4182 Izz = 1.9809

3.2 MEPI and Support Structure Assembly



Mass properties of HAM_support_assy
Output coordinate System : HAM support structure coord sys
Mass = 1122.550 kilograms
Volume = 0.196 cubic meters
Surface area = 30.285 square meters
Center of mass: (meters)
X = 0.000
Y = 0.000
Z = -0.107
Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.

Ix = (0.002, -1.000, 0.000)	Px = 907.574
Iy = (1.000, 0.002, 0.000)	Py = 1488.929
Iz = (0.000, 0.000, 1.000)	Pz = 2347.401

Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 1488.927	Lxy = -1.105	Lxz = -0.000
Lyx = -1.105	Lyy = 907.576	Lyz = -0.000
Lzx = -0.000	Lzy = -0.000	Lzz = 2347.401

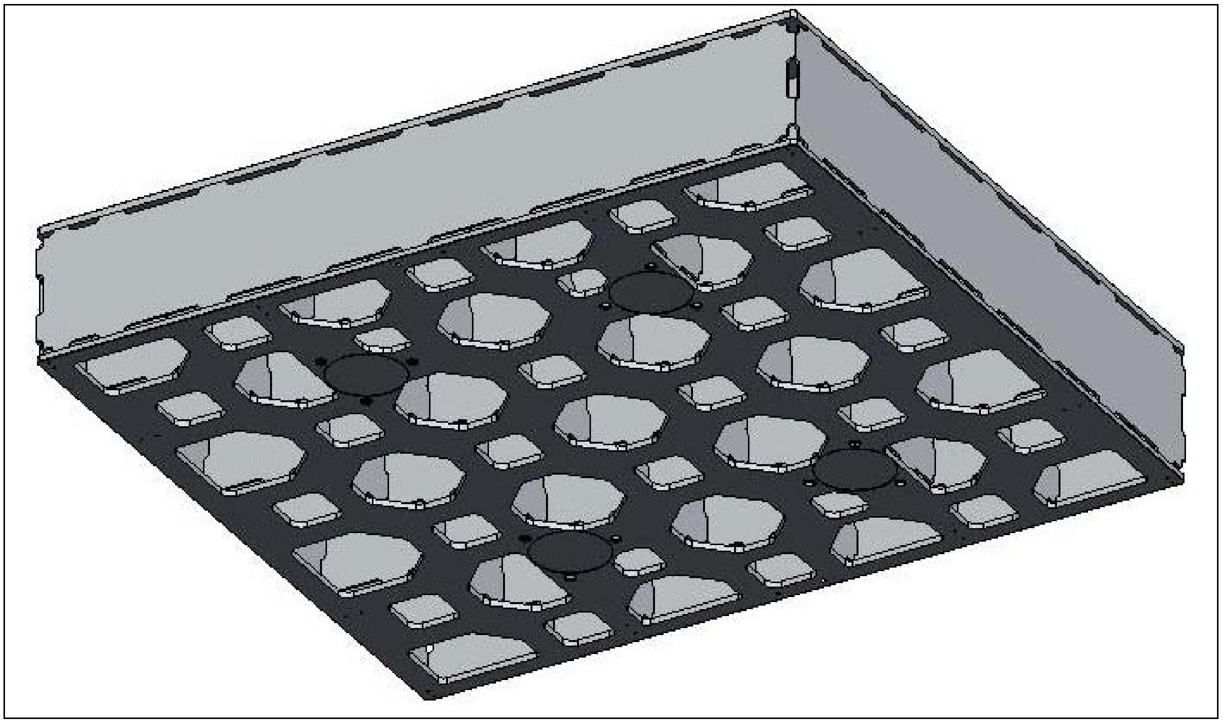
Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.

Ixx = 1501.707	Ixy = -1.105	Ixz = -0.000
Iyx = -1.105	Iyy = 920.357	Iyz = -0.000
Izx = -0.000	Izy = -0.000	Izz = 2347.401

3.3 Stack

3.3.1 Optics Table

The Optics Table coordinate system is parallel to global system and centered on the bottom face of the table, with Xtable = Xglobal, Ytable = Zglobal and Ztable = -Yglobal



Mass properties of HAM Optics Table Assy
Output coordinate System : -- default --
Mass = 381.461 kilograms
Volume = 0.138 cubic meters
Surface area = 27.255 square meters
Center of mass: (meters)
X = -0.000
Y = 0.208
Z = -0.000
Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.

Ix = (1.000, -0.000, -0.002)	Px = 105.142
Iy = (-0.002, 0.000, -1.000)	Py = 128.132
Iz = (0.000, 1.000, 0.000)	Pz = 219.975

Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.

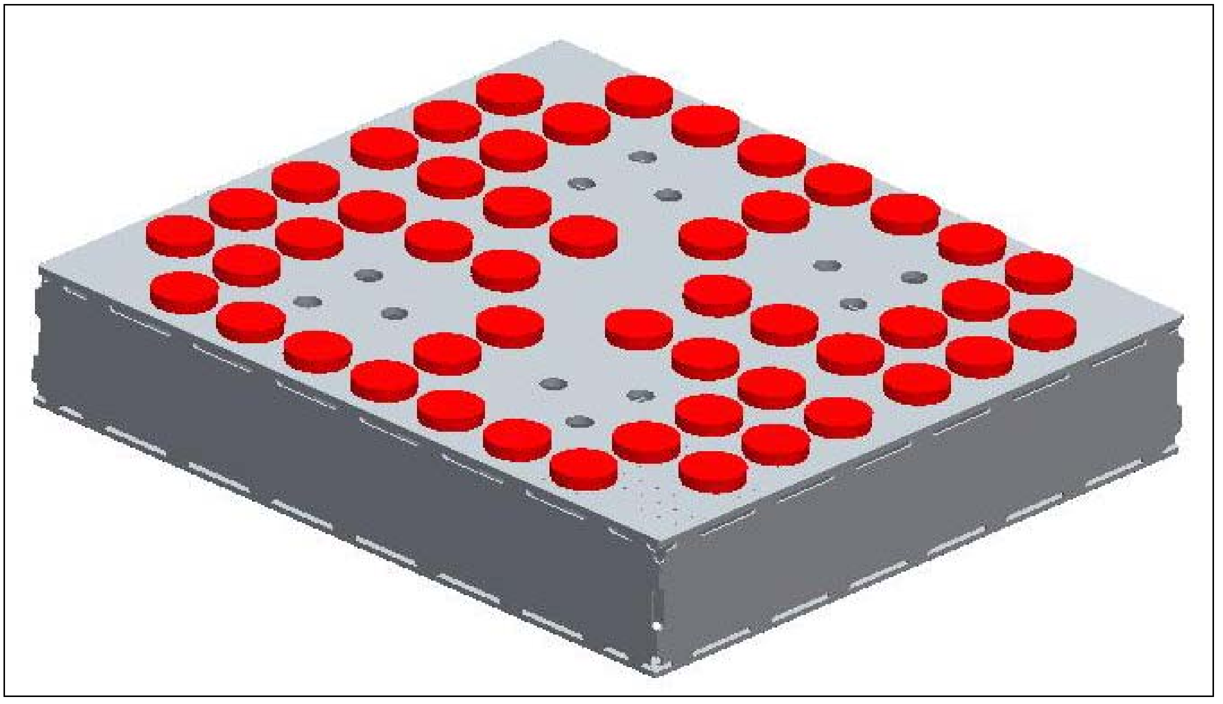
Lxx = 105.142	Lxy = -0.010	Lxz = -0.050
Lyx = -0.010	Lyy = 219.975	Lyz = -0.008
Lzx = -0.050	Lzy = -0.008	Lzz = 128.132

Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.

Ixx = 121.638	Ixy = -0.026	Ixz = -0.050
Iyx = -0.026	Iyy = 219.975	Iyz = -0.023
Izx = -0.050	Izy = -0.023	Izz = 144.629

3.3.2 Optics Table with Payload

Optics table with 50 counter-weights, each weighing 10 pounds, evenly distributed over the top of the optics table.



Mass properties of HAM Optics Table Mass Study
Output coordinate System : -- default --
Mass = 609.105 kilograms
Volume = 0.167 cubic meters
Surface area = 29.840 square meters
Center of mass: (meters)
X = -0.000
Y = 0.263
Z = -0.000
Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.

Ix = (1.000, -0.000, -0.001)	Px = 162.249
Iy = (-0.001, 0.000, -1.000)	Py = 202.247
Iz = (0.000, 1.000, 0.000)	Pz = 344.997

Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 162.249	Lxy = -0.005	Lxz = -0.050
Lyx = -0.005	Lyy = 344.997	Lyz = -0.005
Lzx = -0.050	Lzy = -0.005	Lzz = 202.247

Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.

Ixx = 204.348	Ixy = -0.026	Ixz = -0.050
Iyx = -0.026	Iyy = 344.997	Iyz = -0.023
Izx = -0.050	Izy = -0.023	Izz = 244.346

3.3.3 Isolation Leg Element 1

Coordinate system is centered on the lower face of the cylindrical mass.

Mass properties of legelement1-coil
Output coordinate System : -- default --
Density = 8027.17 kilograms per cubic meter
Mass = 179.42 kilograms
Volume = 0.02 cubic meters
Surface area = 0.60 square meters
Center of mass: (meters)
X = 0.00
Y = 0.06
Z = 0.00
Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.
Ix = (0.00, 0.00, 1.00) Px = 2.97
Iy = (1.00, 0.00, 0.00) Py = 2.97
Iz = (0.00, 1.00, 0.00) Pz = 5.53
Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 2.97	Lxy = 0.00	Lxz = 0.00
Lyx = 0.00	Lyy = 5.53	Lyz = 0.00
Lzx = 0.00	Lzy = 0.00	Lzz = 2.97

Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.

Ixx = 3.58	Ixy = 0.00	Ixz = 0.00
Iyx = 0.00	Iyy = 5.53	Iyz = 0.00
Izx = 0.00	Izy = 0.00	Izz = 3.58

3.3.4 Isolation Leg Element 2

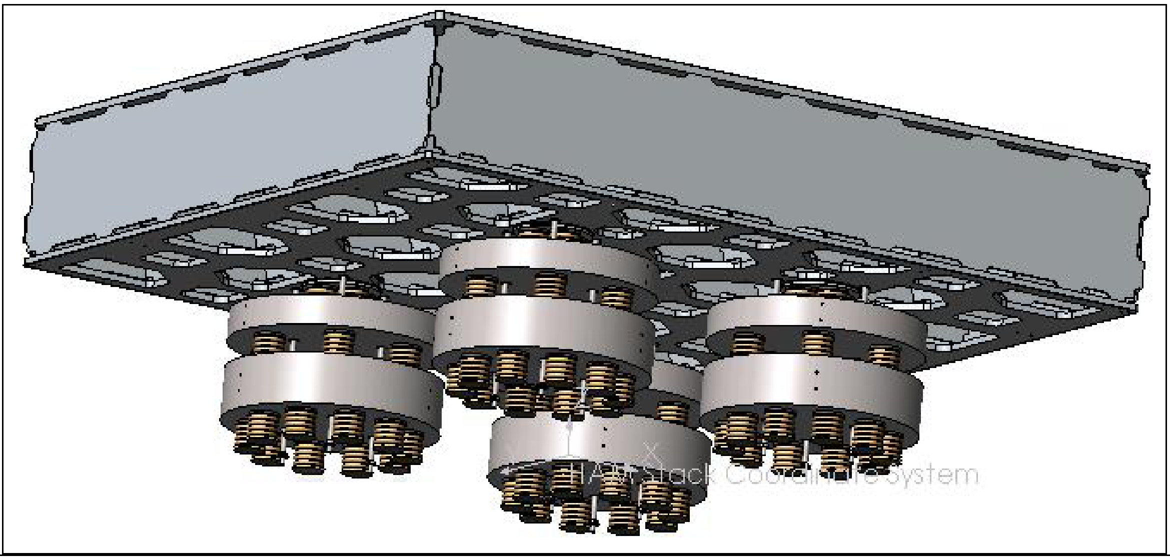
Coordinate system is centered on the lower face of the cylindrical mass.

Mass properties of legelement2-coil
Output coordinate System : -- default --
Density = 8027.17 kilograms per cubic meter
Mass = 106.52 kilograms
Volume = 0.01 cubic meters
Surface area = 0.51 square meters
Center of mass: (meters)
X = 0.00
Y = 0.03
Z = 0.00
Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.
Ix = (0.00, 0.00, 1.00) Px = 1.69
Iy = (1.00, 0.00, 0.00) Py = 1.69
Iz = (0.00, 1.00, 0.00) Pz = 3.29
Moments of inertia: (kilograms * square meters)

Taken at the center of mass and aligned with the output coordinate system.
Lxx = 1.69 Lxy = 0.00 Lxz = 0.00
Lyx = 0.00 Lyy = 3.29 Lyz = 0.00
Lzx = 0.00 Lzy = 0.00 Lzz = 1.69
Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.
Ixx = 1.81 Ixy = 0.00 Ixz = 0.00
Iyx = 0.00 Iyy = 3.29 Iyz = 0.00
Izx = 0.00 Izy = 0.00 Izz = 1.81

3.3.5 Isolation Stack Assembly

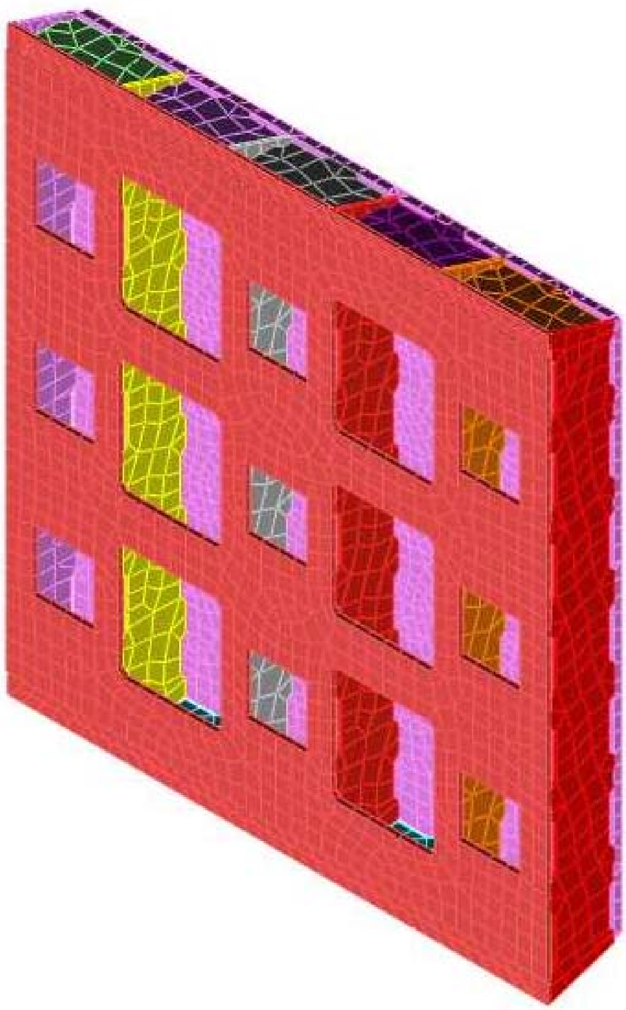
The coordinate system for the assembly is parallel to the global axes and centered on the top of the support table.

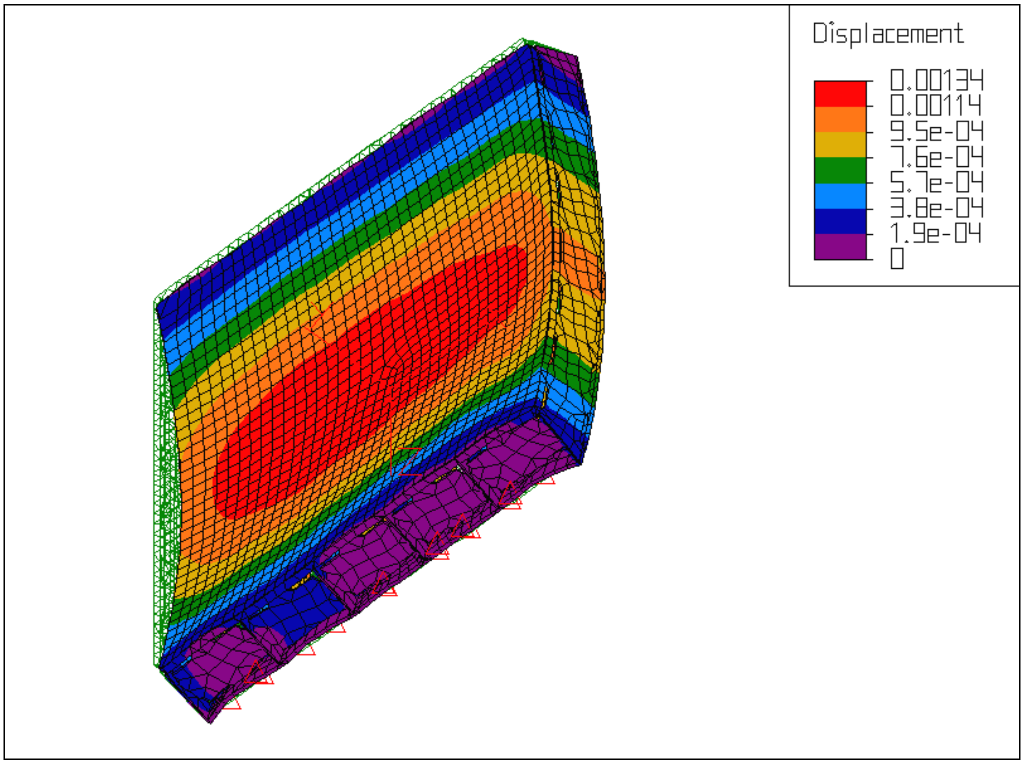


Mass properties of HAM-top-stack-with-coil springs
Output coordinate System : HAM Stack Coordinate System
Mass = 1558.153 kilograms
Volume = 0.301 cubic meters
Surface area = 34.728 square meters
Center of mass: (meters)
X = -0.000
Y = 0.000
Z = 0.280
Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.
Ix = (-0.001, -1.000, -0.000) Px = 353.501
Iy = (1.000, -0.001, -0.000) Py = 412.440
Iz = (0.000, -0.000, 1.000) Pz = 638.121
Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 412.440 Lxy = 0.050 Lxz = -0.034
Lyx = 0.050 Lyy = 353.501 Lyz = 0.030
Lzx = -0.034 Lzy = 0.030 Lzz = 638.121
Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.
Ixx = 534.355 Ixy = 0.050 Ixz = -0.057
Iyx = 0.050 Iyy = 475.416 Iyz = 0.049

Izx = -0.057	Izy = 0.049	Izz = 638.121

4 Support Table Stiffness



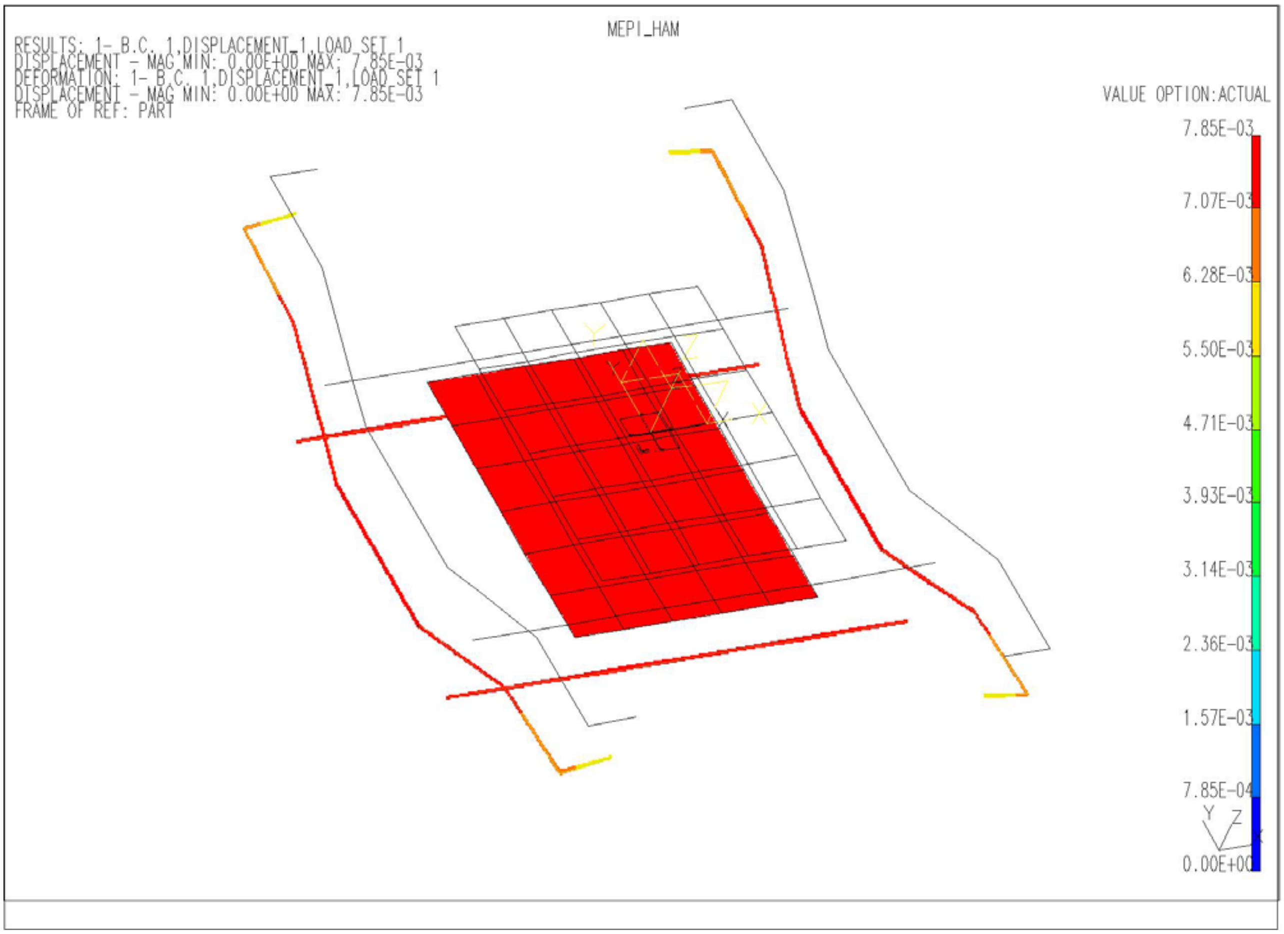


5 Joint Stiffness

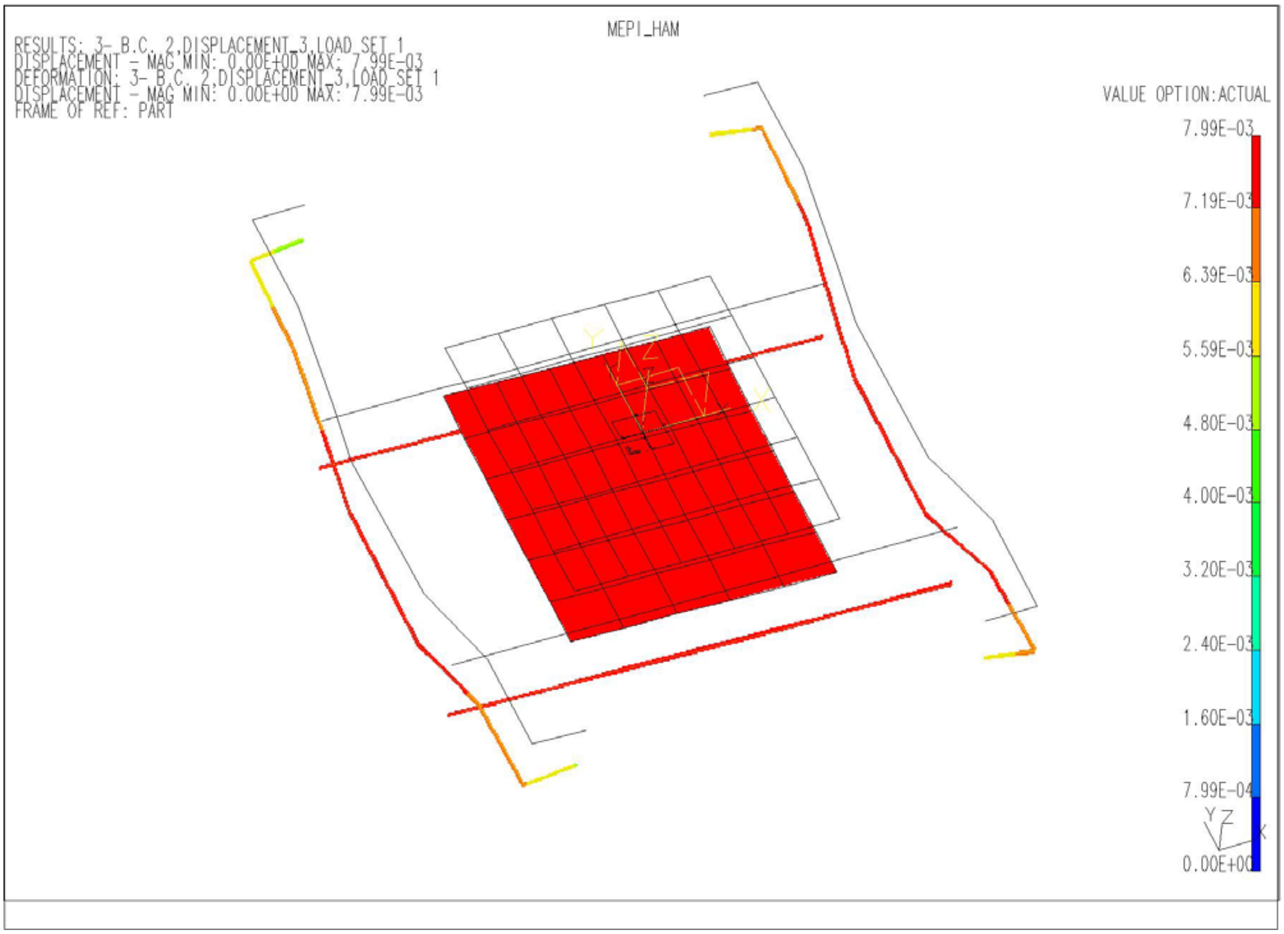
6 Spring Stiffness

7 Static Compliance

With the entire stack weight added, the maximum static deflection is 7.85 mm (0.31 in) as shown in figure x. Note also in Figure X that elastic deflection of the cross beams contribute about 2 mm of the total vertical deflection, the balance being from the V-springs.

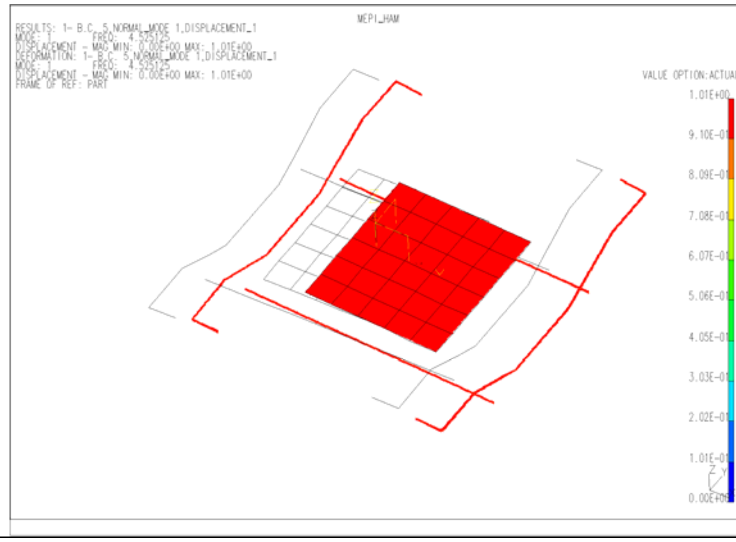
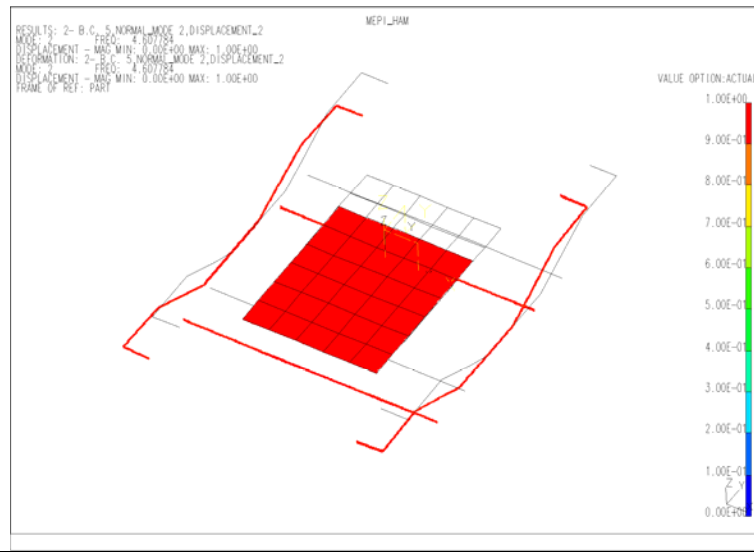
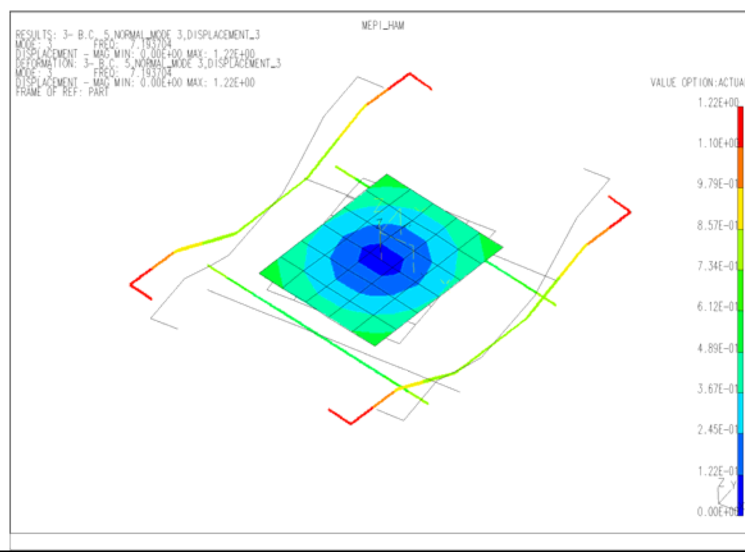


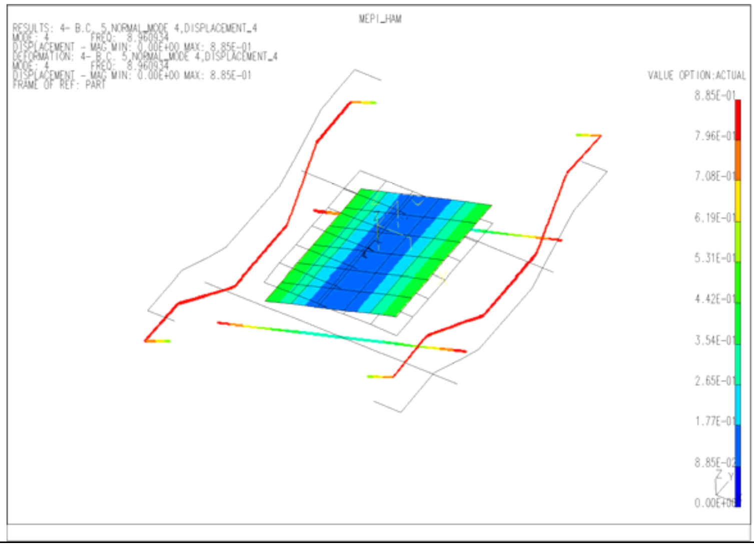
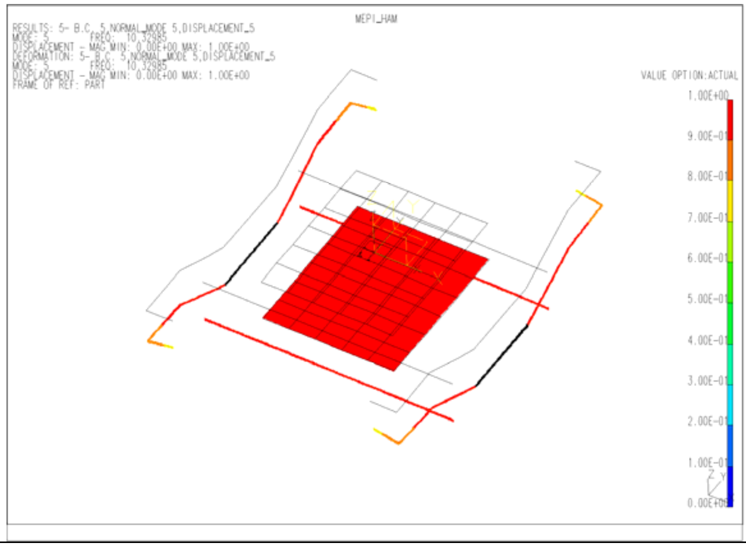
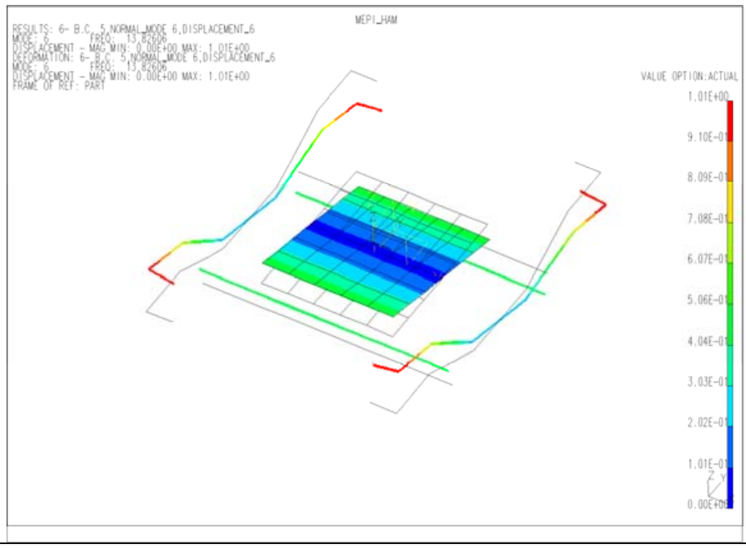
When the top of one spring is pulled up 1 mm, the resulting deflection pattern is shown in Figure X. The load redistribution is calculated to be as shown in the following Table.

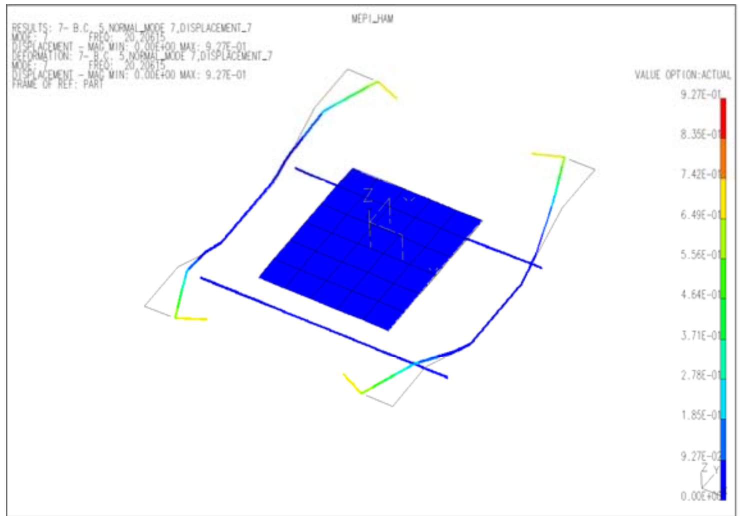
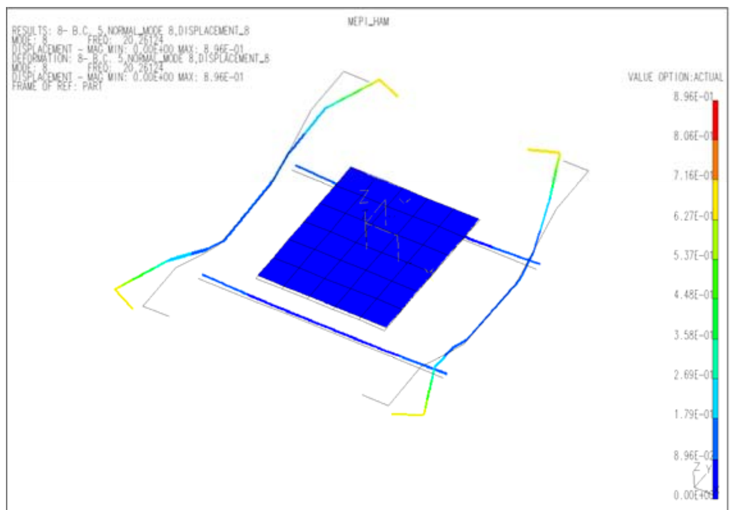
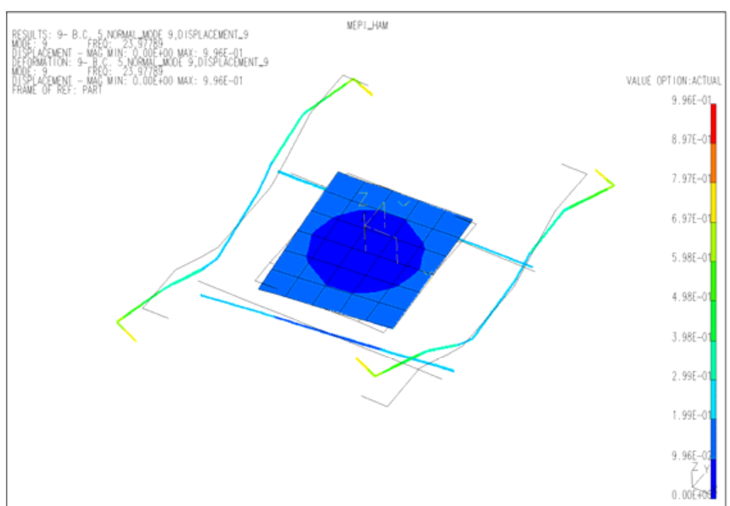


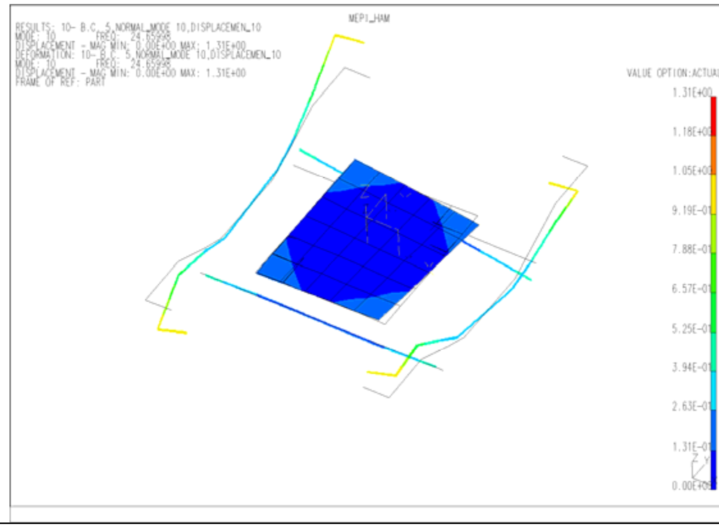
8 Modal Analysis

Mode #, Frequency	Mode Shape

Mode 1 4.5 Hz translation in X, roll about Y	
Mode 2 4.6 Hz Translation in Y, roll about X	
Mode 3 7.2 Hz Yaw about Z	

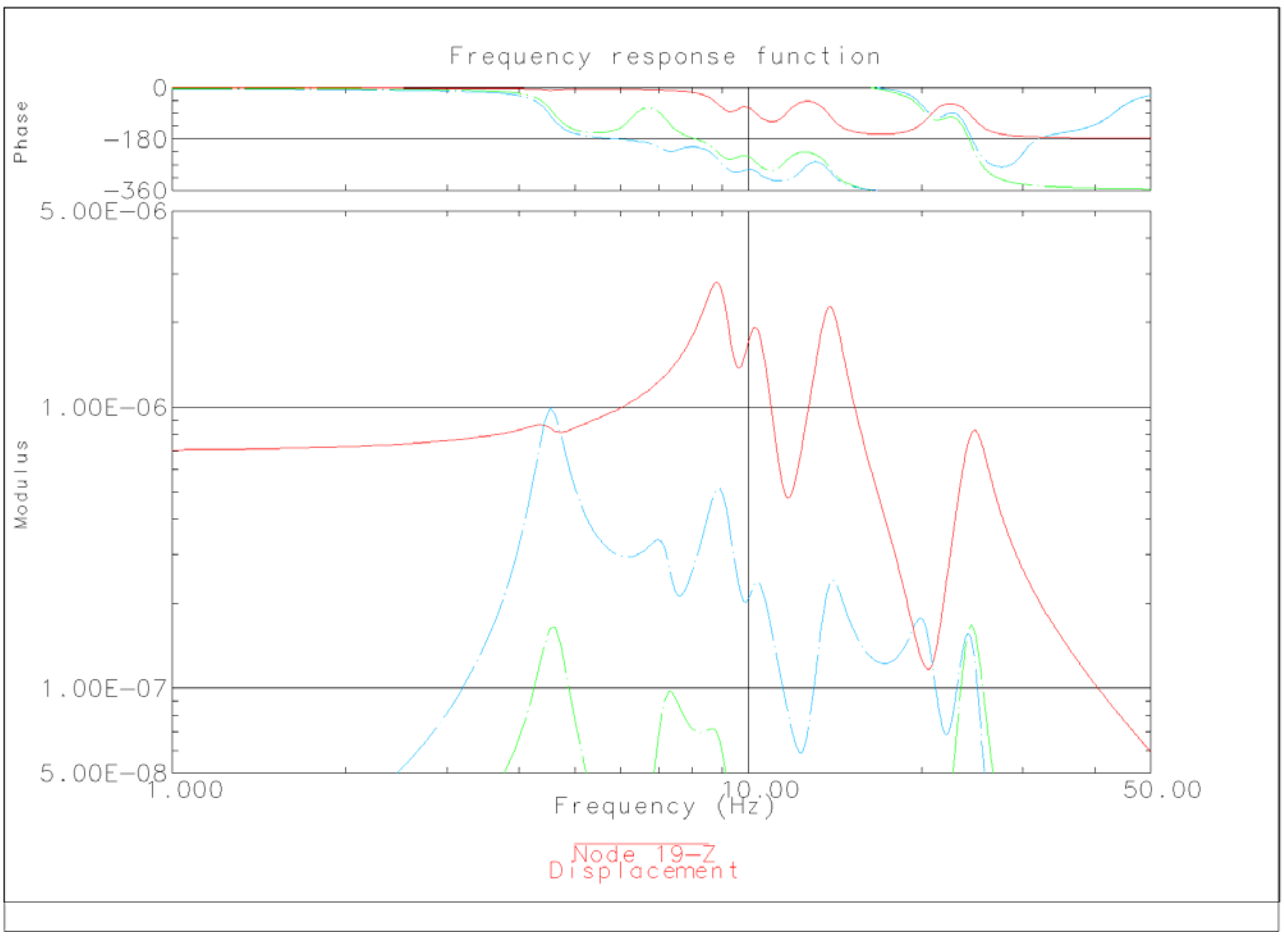
Mode 4 9.0 Hz Roll about Y	
Mode 5 10.3 Hz Translation in Z (Heave)	
Mode 6 13.8 Hz Vertical Crossbeam Bending and support table roll about X	

Mode 7 20.2 Hz Symmetric horizontal crossbeam bending	
Mode 8 20.2 Hz Anti-symmetric horizontal crossbeam bending	
Mode 9 24.0 Hz Crossbeam bending and support table yaw about Z	

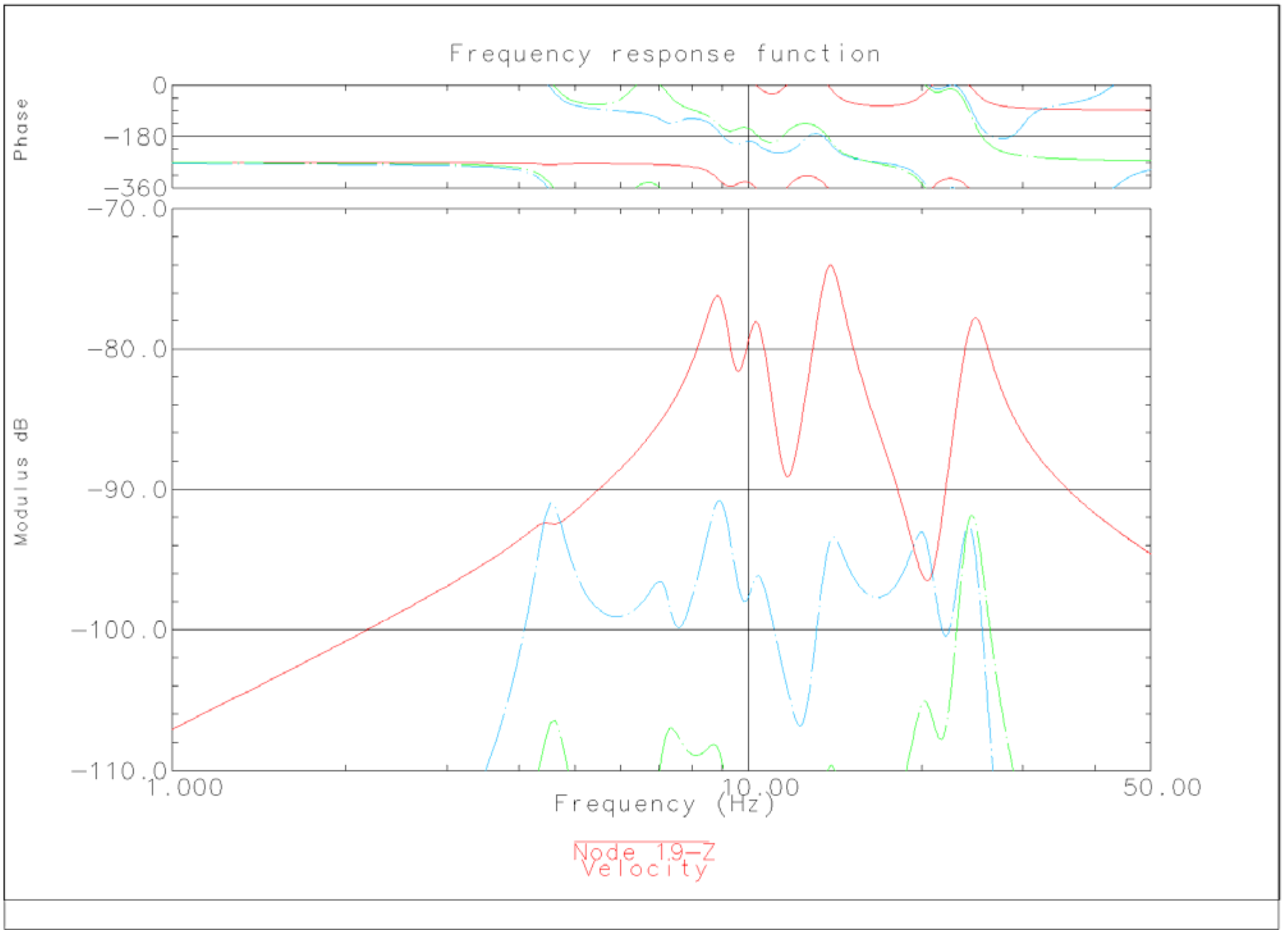
Mode 10 24.7 Hz Crossbeam bending and support table bending	

9 Transfer Functions

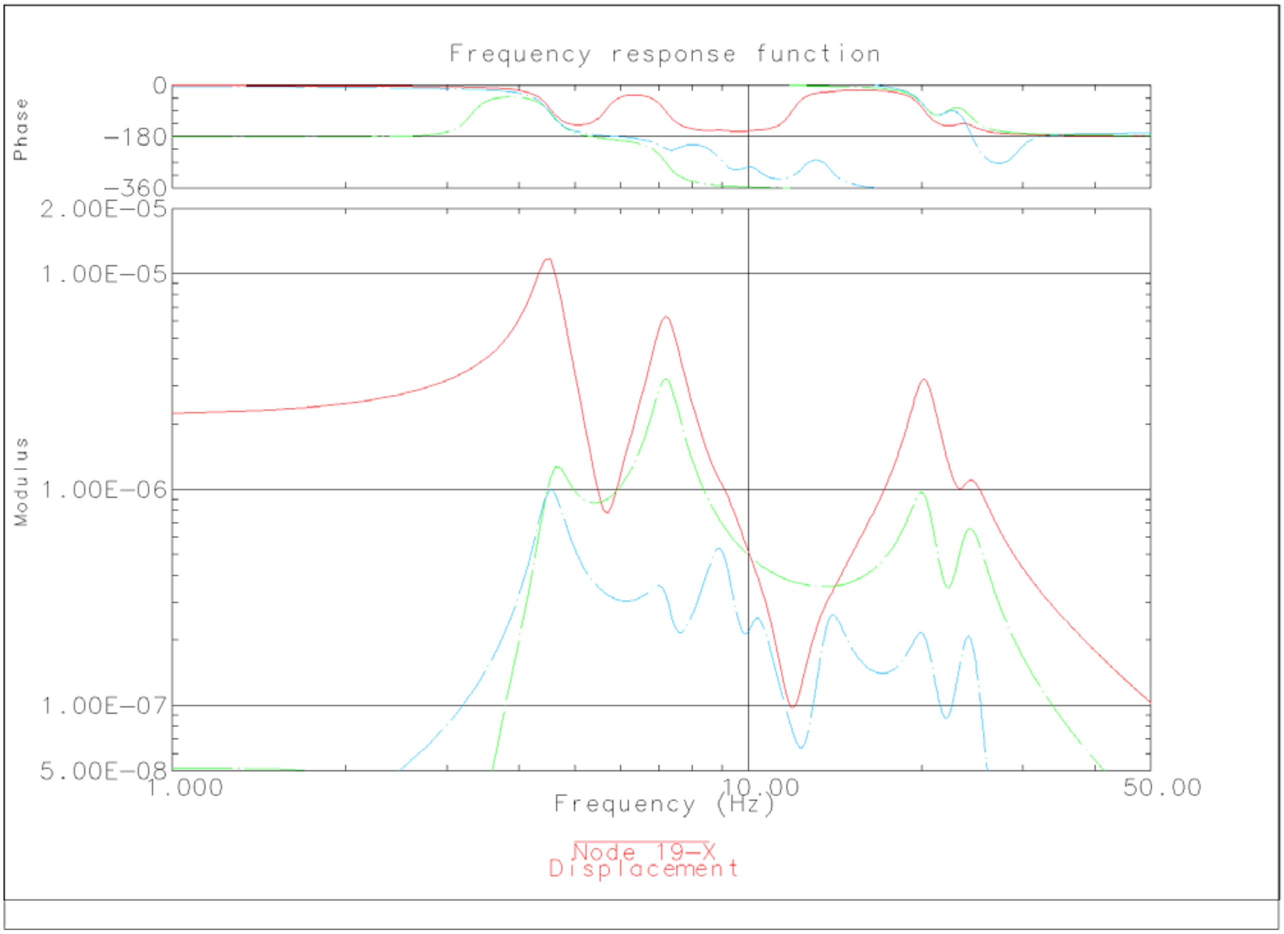
Force at N24 Z-direction, Displacement Response at N19 (same Pier)



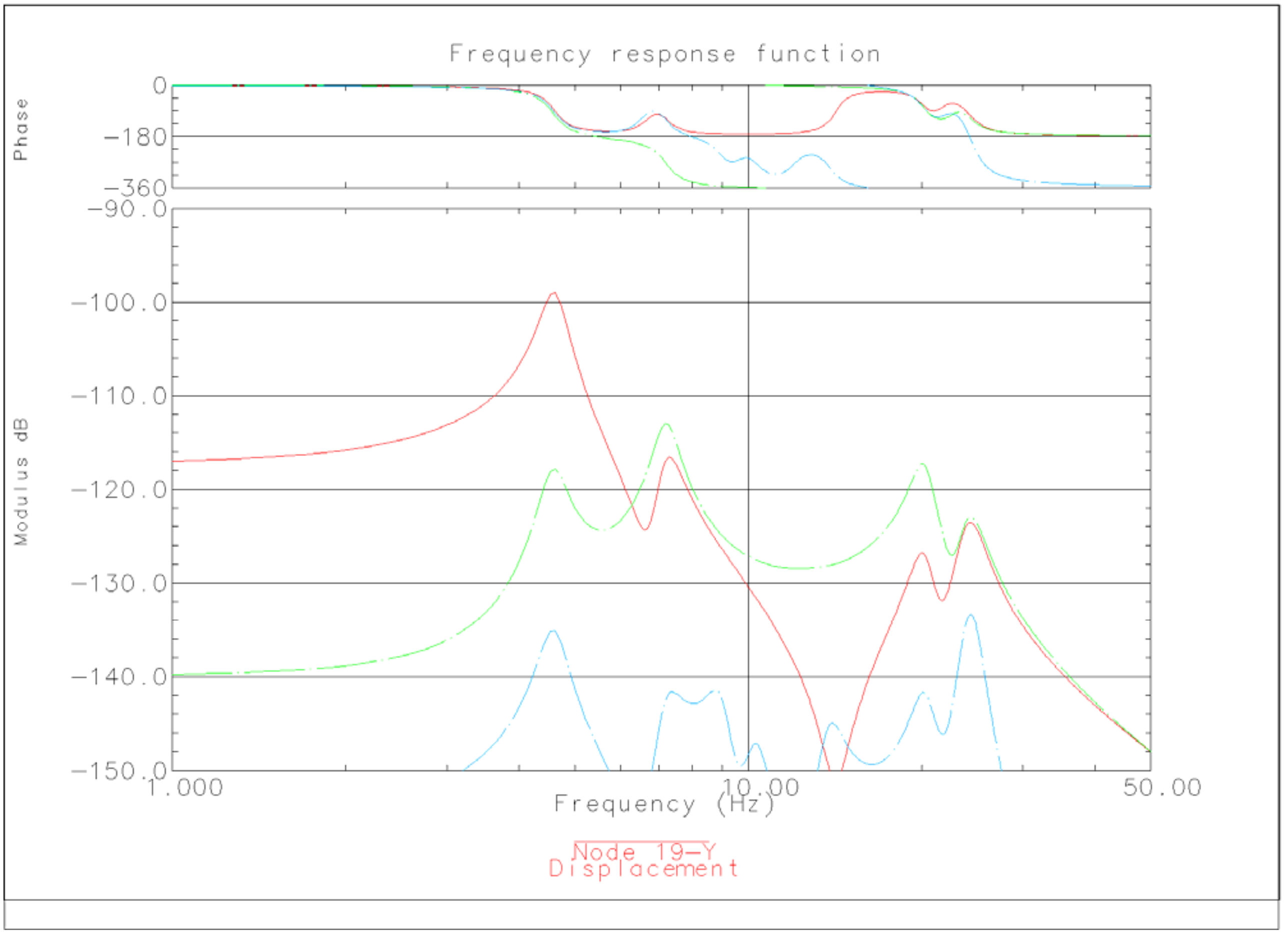
Force at N24 Z-direction, Velocity Response at N19 (same Pier)



Force at N24 X-direction, Displacement Response at N19 (same Pier)



Force at N24 Y-direction, Displacement Response at N19 (same Pier)



Force at N24 Y-direction, Velocity Response at N19 (same Pier)