MEscope Application Note 32

Modal Sensitivity to Joint Stiffness

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-4600 Advanced Modal Analysis** and **VES-5000 SDM** options. Without these options, you can still carry out the steps in this App Note using the **AppNote32** project file. These steps might also require a more recent release date of MEscope.

APP NOTE 32 PROJECT FILE

- To retrieve the Project for this App Note, **click here** to download **AppNote32.zip**

This Project file contains ***numbered Hotkeys & Scripts*** for carrying out the steps of this App Note.

- ***Hold down*** **the Ctrl key** and ***click*** **on a Hotkey** to display its Script window

STRUCTURAL DYNAMICS MODIFICATION (SDM)

SDM has become a practical tool for improving the engineering designs of mechanical systems. It provides a very quick and inexpensive approach for investigating the effects of design modifications to a structure, thus eliminating the need for costly prototype fabrication and testing.

MODAL MODEL

SDM is unique in that it works directly with a **modal model** of the structure, either an **Experimental Modal Analysis (EMA) modal model**, a **Finite Element Analysis (FEA) modal model**, or a **Hybrid modal model** consisting of both **EMA** and **FEA** mode shapes. **EMA** mode shapes are extracted from experimental data and are referred to as **EMA** mode shapes. **FEA** mode shapes are extracted from a finite element computer model and are referred to as **FEA** mode shapes.

A **modal model** is a set of ***properly scaled*** mode shapes.

SDM assumes that the mode shapes are scaled to **Unit Modal Masses, called UMM** mode shapes.

They are referred to an **UMM** mode shapes. A **modal model** preserves the mass and elastic properties of the structure, and therefore represents its dynamic properties.

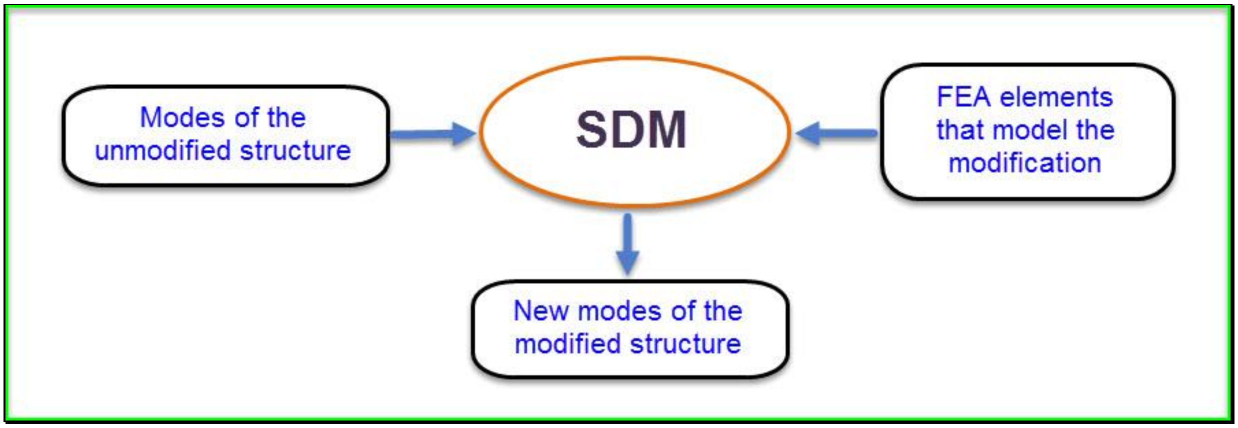
DESIGN MODIFICATIONS

Once the dynamic properties of an ***unmodified*** structure are defined in the form of its **modal model**, **SDM** can be used to predict the dynamic effects of certain kinds of mechanical design modifications to the structure. These modifications can be as simple as point mass, linear spring, or linear damper ***additions to*** or ***removals from*** the structure, or more complex modifications that are modeled using **FEA** elements such as plates (membranes) and solid elements.

SDM is computationally ***very efficient***.

SDM solves an ***eigenvalue problem in modal space***, whereas **FEA** mode shapes are obtained by solving an ***eigenvalue problem in physical space***

Another advantage of **SDM** is that the **modal model** of the ***unmodified*** structure only has to contain data ***for the*** **DOFs (points and directions)** ***where the modification elements are attached*** to the structure. **SDM** then provides a new **modal model** of the modified structure, as depicted below.



SDM *Input-Output Diagram*

MODAL SENSITIVITY ANALYSIS

It is a well-known fast that the ***modes of a structure are very sensitive*** to changes in its physical properties.

Mode shapes are solutions to differential equations of motion, which are defined in terms of the physical mass, stiffness, and damping properties of the structure.

The mode shapes also ***reflect the boundary conditions*** of the structure. For example, the mode shapes of a cantilever beam are quite different from the mode shapes of the same beam with free-free boundary conditions.

Because of its computational speed, **SDM** can be utilized to repetitively solve in a few seconds for the mode shapes of ***thousands of potential user-defined physical modifications***. In MEscope, this is called **Modal Sensitivity Analysis**.

USING SDM TO MODEL JOINT STIFFNESS

In **App Note 30**, **SDM** is used to model the attachment of a RIB stiffener to the aluminum Plate shown in the figures below. The dimensions of the Plate are 20 inches (508 mm) by 25 inches (635 mm) by 3/8 inches (9.525 mm) thick. The dimensions of the RIB are 3 inches (76.2 mm) by 25 inches (635 mm) by 3/8 inches (9.525 mm) thick.

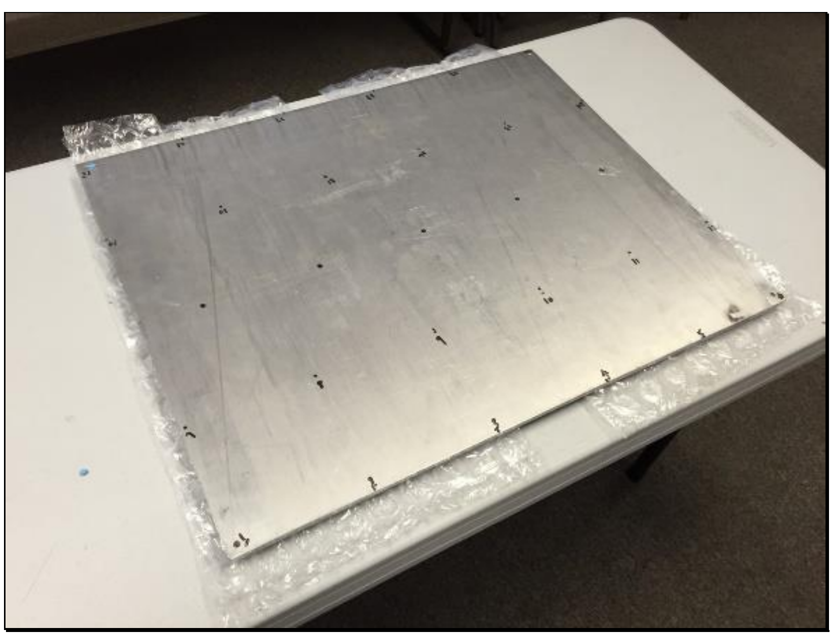
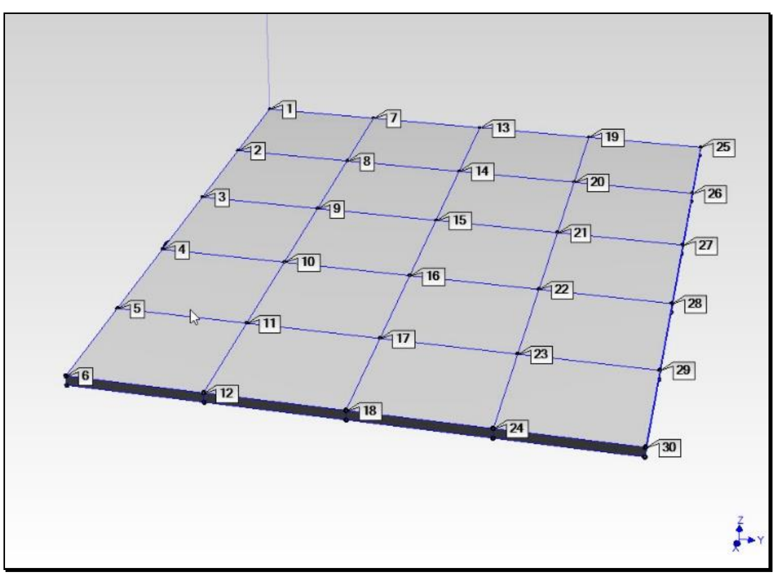


Figure 1A. Aluminum Plate without RIB

Figure 1B. RIB and Cap Screws

Figure 1C. Plate with RIB Stiffener Attached



*Impact Test Points to Obtain **EMA** Plate Modes*

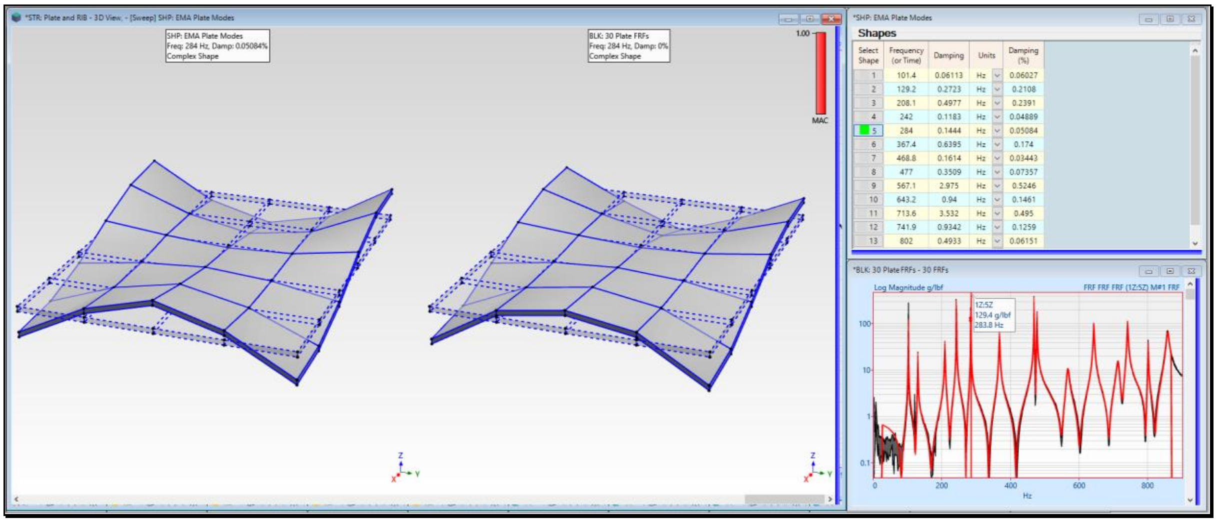
STEP 1 - EMA MODE SHAPES OF THE PLATE

- ***Press*** **Hotkey 1 EMA Plate Mode Shapes**

FRFs were calculated from data acquired during a Roving Impact Test on the Plate shown above, by impacting it in the vertical direction at 30 points. The Plate was supported on bubble wrap in a ***semi-free-free condition*** on a tabletop.

In this step, the **EMA** modal shapes of the Plate are estimated by curve fitting the FRFs of the Plate. A curve fit function overlaid on one of the FRFs is shown below. Each mode shape has 30 **DOFs** (1Z through 30Z).

First the FRFs are curve fit and then side-by-side animation of each **EMA** mode shape and its ***closest matching*** **ODS** is begun, as shown below.



*Animated Display of Each **EMA** Mode Shape of the Plate & its Closest Matching **ODS**.*

- *Click* on a **Select Shape** button to display a mode shape and its ***closest matching*** **ODS**
- Scroll through the FRFs to display each **red curve fit function** overlaid on its FRF

STEP 2 - FEA MODE SHAPES OF THE PLATE

- ***Press*** **Hotkey 2 FEA Plate Mode Shapes**

An **FEA** model of the Plate was created in MEscope using ***80 FEA Plate (membrane) elements***. The following properties of **FEA** plates were used,

Young's modulus of elasticity: 1E+07 lbf/in^2 (or 6.895E+04 N/mm^2)

Density: 0.101 lbm/in^3 (or 2.796E-06 kg/mm^3)

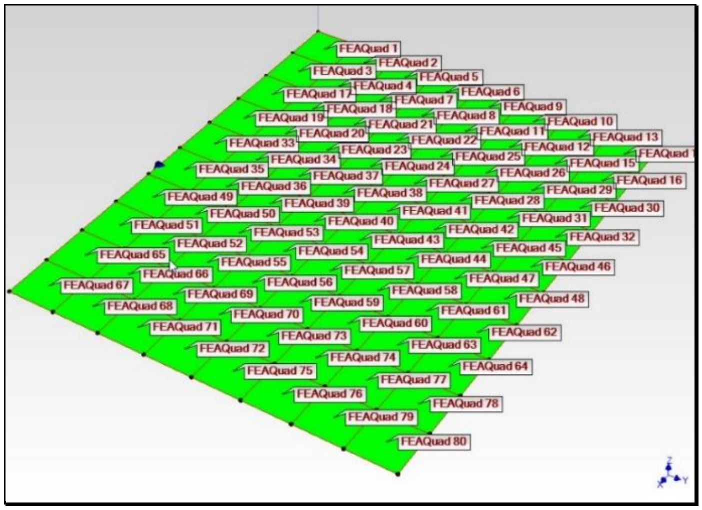
Poisson's Ratio: 0.33

Plate thickness: 0.375 in (or 9.525 mm)

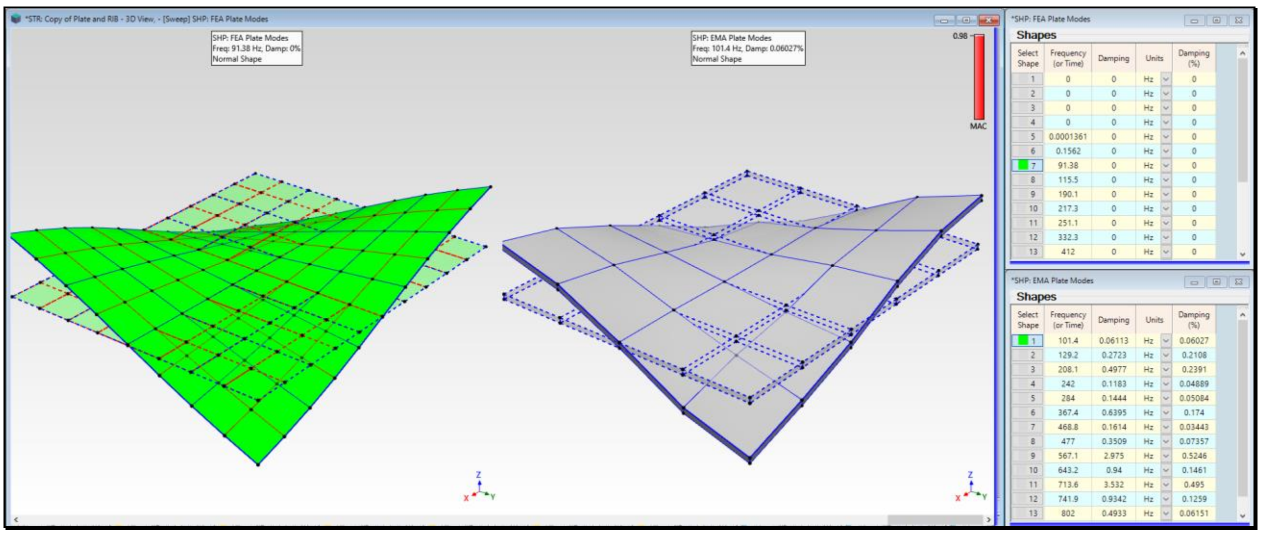
The **FEA** model shown below has a grid of 99 points (or nodes) and 80 **FEA** Quad Plate elements.

When this **Hotkey 2 is** ***pressed***, 20 **FEA** mode shapes (***6 rigid-body & 14 flexible-body mode shapes***), of the Plate are calculated. Then side-by-side animation of each **FEA** mode shape and ***its closest matching*** **EMA** mode shape is begun.

- *Click* on a **Select Shape** button to display an **FEA mode shape** and its ***closest matching*** **EMA mode shape**



***FEA** model with 80 **FEA** Quad Plate Elements*



*Animated Display of Closest Matching Pair of **FEA** & **EMA** Mode Shapes of the Plate.*

MODE SHAPE COMPARISON

The animation will sweep through a display of the **FEA** mode shapes, starting with **Shape 7**.

The ***first six*** **FEA** modes have ***rigid-body mode shapes***.

Modes **7 through 20** have ***flexible-body mode shapes***, and each of them ***closely matches in order*** with an **EMA** mode shape.

Each **FEA** mode shape has **594 DOFs (3 translational & 3 rotational DOFS)** for each of the 99 Points on the **FEA** model.

The **FEA** mode shapes are **UMM** mode shapes, and therefore they are a **modal model** of the Plate.

The **Modal Assurance Criterion** (**MAC**) value in the ***upper right corner*** of the display indicates how ***closely matched*** each pair of mode shapes is. The ***worst-case pair*** of mode shapes has **MAC ➔ 0.98**. These **MAC** values indicate ***close correlation*** between the **FEA** & **EMA** mode shapes for ***matching*** **translational DOFs (1Z through 30Z)**.

MODAL FREQUENCY COMPARISON

The modal frequencies of the matching **FEA** & **EMA** mod shape pairs are listed in the Table below.

Each **FEA** mode shape ***has a lower frequency*** than the frequency of its ***closest matching*** **EMA** mode shape.

The higher **EMA** modal frequencies mean that the actual aluminum Plate ***has greater stiffness*** than the **FEA** model. In **App Note 29, FEA Model Updating** is used to ***modify the physical properties*** of the **FEA** Plate model so that its ***modal frequencies more closely match*** the **EMA** frequencies.

Shape Number	EMA Frequency (Hz)	EMA Damping (Hz)	FEA Frequency (Hz)	MAC
1	101.5	0.04487	91.38	0.98
2	129.1	0.264	115.5	0.99
3	208.1	0.4977	190.1	0.99
4	242.0	0.1089	217.3	0.99
5	284.0	0.1444	251.1	0.99
6	367.5	0.6455	332.3	0.98
7	468.7	0.1659	412.0	0.98
8	477.0	0.3509	424.3	0.99
9	567.1	2.979	495.7	0.99
10	643.2	0.9498	563.6	0.99
11	713.6	3.583	625.9	0.98
12	741.9	0.9449	653.6	0.99
13	802.0	0.4814	688.7	0.98
14	858.6	3.087	756.6	0.98

EMA *&.* ***FEA*** *Mode Shapes for the Plate without RIB*

HYBRID MODAL MODEL OF THE PLATE

To correctly model the stiffness between the Plate & RIB when they are attached together, a **modal model** of each stand-alone sub-structure is required.

Each matching pair of **FEA** & **EMA** mode shapes for the Plate was highly correlated (their **MAC** values are high). Therefore, a **hybrid modal model** was created for the Plate. Each hybrid mode shape can be created by assigning the frequency & damping of each ***closely matching*** **EMA** mode shape to each **FEA** mode shape.

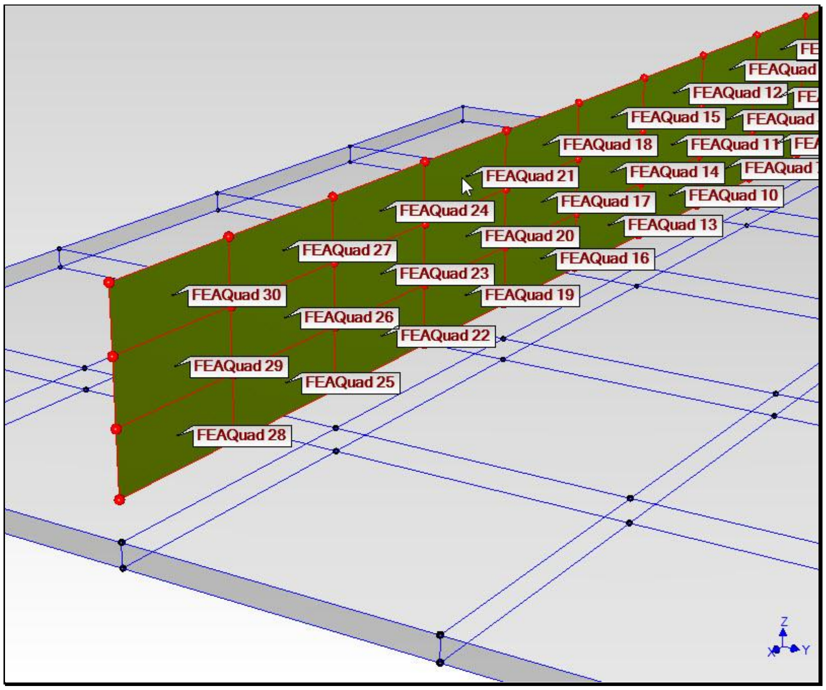
A **hybrid modal model** assigns the modal frequency & damping of each ***closely matching*** **EMA** mode shape to each **FEA** mode shape.

In most cases, **EMA** mode shapes have ***more accurate modal frequencies*** than **FEA** mode shapes, and they ***always include modal damping***.

Damping is difficult to model, so most **FEA models** ***do not damping in them***. Hence, their **FEA** mode shapes have no modal damping. But **FEA** mode shapes have both **translational & rotational DOFs**, whereas **EMA** mode shapes ***only have*** **translational DOFs**

Using **hybrid modal model**s for both the Plate and the RIB more accurately models their stand-alone dynamics.

Using a **hybrid modal model** for each stand-along substructure, **SDM** will more accurately model the attachment of the RIB to the Plate ***using stiff* 6 DOF *springs to model the six cap screws*** that were used to attach the real-world structures together.



*RIB **FEA** Model with Quad Plate Elements*

HYBRID MODAL MODEL OF THE RIB

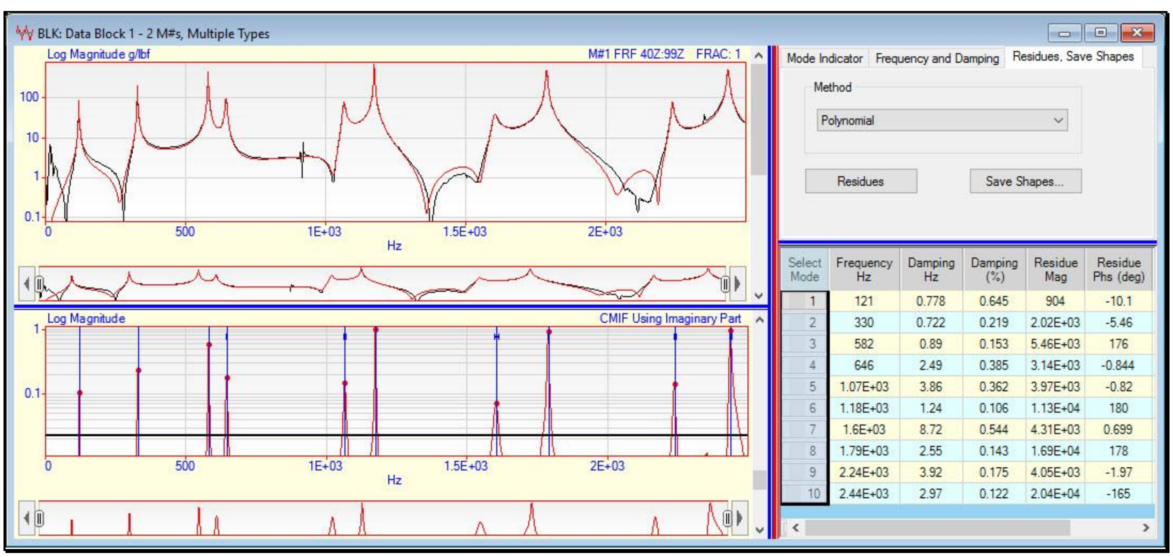
An **FEA** model of the RIB in a free-free condition (no fixed boundaries) was created using **30 FEA** Quad Plate elements, as shown above. The frequencies of the first 16 **FEA** modes of the RIB are listed in table below. Because it has free-free boundary conditions, the ***first six* modes** of the **FEA** model are ***rigid-body* mode shapes** with zero frequency**.**

To obtain its **EMA** modal frequencies & damping, the RIB ***was impacted once***, and the resulting FRF was curve fit. The curve fit of the FRF measurement is shown in the figure below. The resulting **EMA** modal frequencies & damping are listed in the Table below, and were used to create the **hybrid modal model** of the RIB.

The **EMA** modal frequencies of the RIB ***are higher than*** the **FEA** modal frequencies, for the same reasons as those discussed for the Plate mode shapes. Assuming that the **EMA** modal frequency & damping are more accurate, they were combined with the **FEA** mode shapes of the RIB to create the **hybrid modal model** of the RIB.

Shape Number	FEA Frequency (Hz)	EMA Frequency (Hz)	EMA Damping (Hz)
1	0		
2	0		
3	0		
4	0		
5	0		
6	0		
7	117	121	0.778
8	315	330	0.722
9	521	582	0.89
10	607	646	2.49
11	987	1.07E+03	3.86
12	1.07E+03	1.18E+03	1.24
13	1.45E+03	1.6E+03	8.72
14	1.67E+03	1.79E+03	2.55
15	1.99E+03	2.24E+03	3.92
16	2.32E+03	2.44E+03	2.97

RIB Modal Frequencies & Damping



Curve Fit of a RIB FRF.

SUBSTRUCTURE MODAL MODEL IN BLOCK DIAGONAL FORMAT

To use **SDM** to calculate the new modes of the RIB attached to the Plate, the **hybrid modal model** of the RIB must be added to the **hybrid modal model** of the Plate to create a new modal model of the entire ***unmodified*** **structure**.

When the **modal model** of the RIB is added to the **modal model** of the Plate, the unique numbering of the points on both the RIB and Plate creates a **modal model** in **block diagonal format**. In **block diagonal format**, the mode shapes of the Plate have ***zero valued shape components*** for **DOFs** on the RIB. Likewise the mode shapes for the RIB have ***zero valued shape components*** for the **DOFs** of the Plate.

> The Plate **modal model** contains **14** mode shapes with **594 DOFs** (**297 translational & 297 rotational DOFs)**.
>
> The RIB **modal model** contains **16** mode shapes, including ***6 rigid-body*** mode shapes, with **264 DOFs (132 translational & 132 rotational DOFs)**.

We have already seen that 14 pairs of **EMA** & **FEA** mode shapes of the Plate were ***strongly correlated*** based upon their ***high*** **MAC values**. The only significant difference between the **EMA** & **FEA** mode shapes was their modal frequencies. A **hybrid modal model** of the Plate was created by ***replacing the frequency & damping of each flexible-body*** **FEA** mode shape with the modal frequency & damping of its ***matching*** **EMA** mode shape, obtained from an impact test.

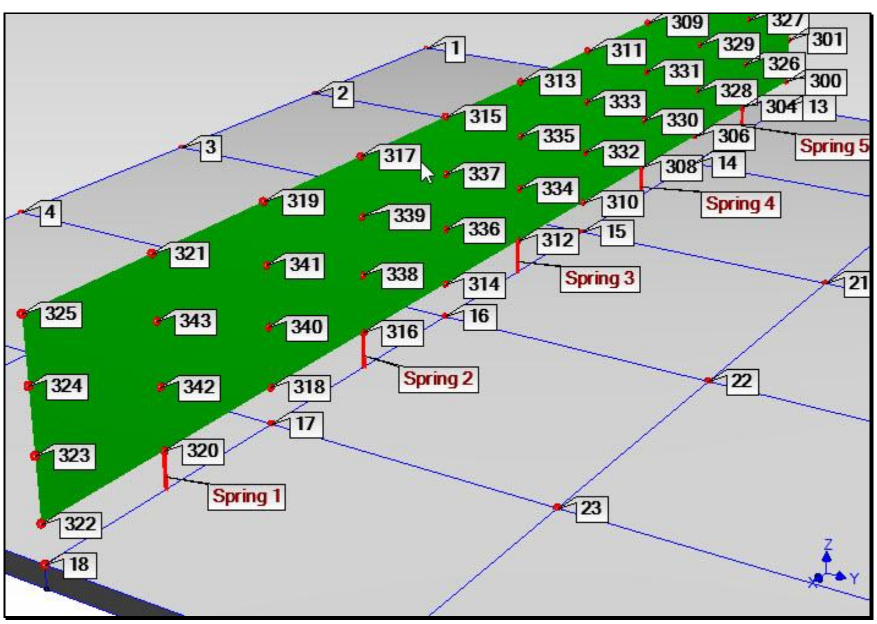
A **hybrid modal model** of the RIB was also created by ***replacing the frequency & damping*** *of each* ***flexible-body*** **FEA** mode shape with the **EMA** frequency & damping estimated by curve fitting a single FRF obtained from an impact test of the RIB.

Since the RIB will be attached to the Plate as a free-body in space, its ***rigid-body*** **mode shapes** ***must be included*** in its **modal model** to correctly model its free-body dynamics.

To perform sub-structuring with SDM, the mode shapes of the two ***unmodified*** substructures must be saved in a single Shape Table in ***block diagonal*** **format**.

To add the mode shapes of the RIB to the mode shapes of the Plate, the Points on the RIB are ***numbered with higher numbers*** than the points on the Plate.

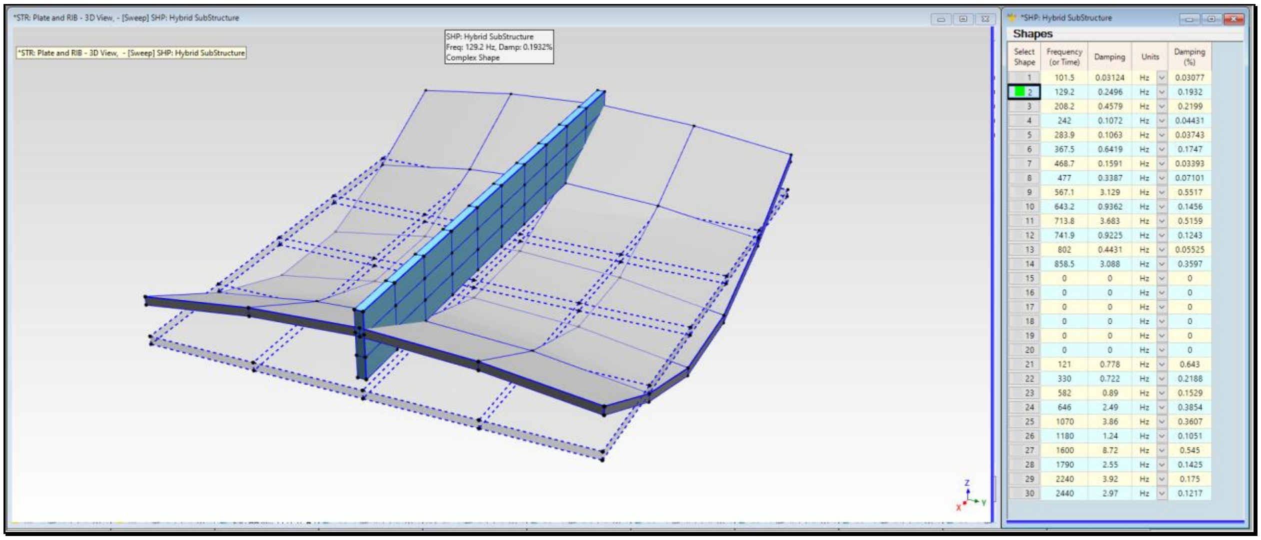
Different Point numbers of each sub-structure ensure that their mode shapes will be saved in the same Shape Table in ***block diagonal*** **format**.



Point numbers of the RIB and Plate

STEP 3 - SUBSTRUCTURE MODAL MODEL

- **Press Hotkey 3 Substructure Modal Model**



*Display of a Mode Shape From the Substructure **Modal Model***

The substructure modal model contains **30** mode shapes with **858 DOFs (429 translational & 429 rotational DOFs**).

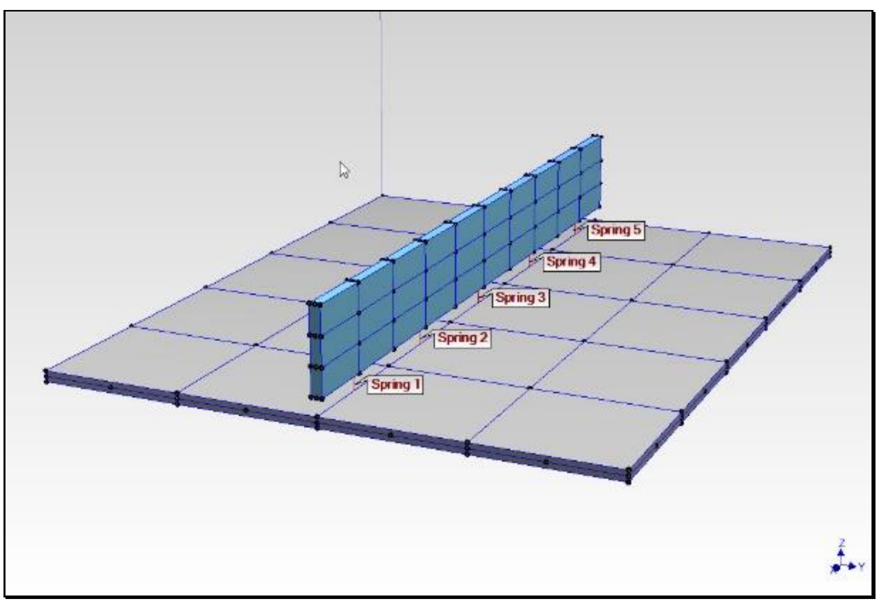
- ***Click*** on a **Select Shape** button to display its mode shape

MODELING THE JOINT STIFFNESS

The actual RIB stiffener was attached to the actual Plate using five cap screws, shown in Figure 1B. When the RIB is attached to the Plate, both ***translational forces & torsional moments*** are applied between the two sub-structures. Both stiffness forces must be modeled to represent the Plate with the RIB stiffener attached to it.

The joint stiffness was modeled using 6-DOF **FEA** springs located at the five cap screw locations, shown below.

Each 6-DOF FEA spring contains three translational DOFs & three rotational DOFs.



*6-DOF **FEA** Springs Used to Model the Cap Screws*

The 6-DOF **FEA** springs were given the following stiffnesses,

Translational stiffness: 1 E+06 lbs/in (1.75E+05 N/mm)

Torsional stiffness: 1 E+06 in-lbs/degree (1.75E+05 mm-N/degree)

The spring stiffnesses were ***arbitrarily chosen as large values*** to model a tight fastening of the RIB to the Plate with the cap screws.

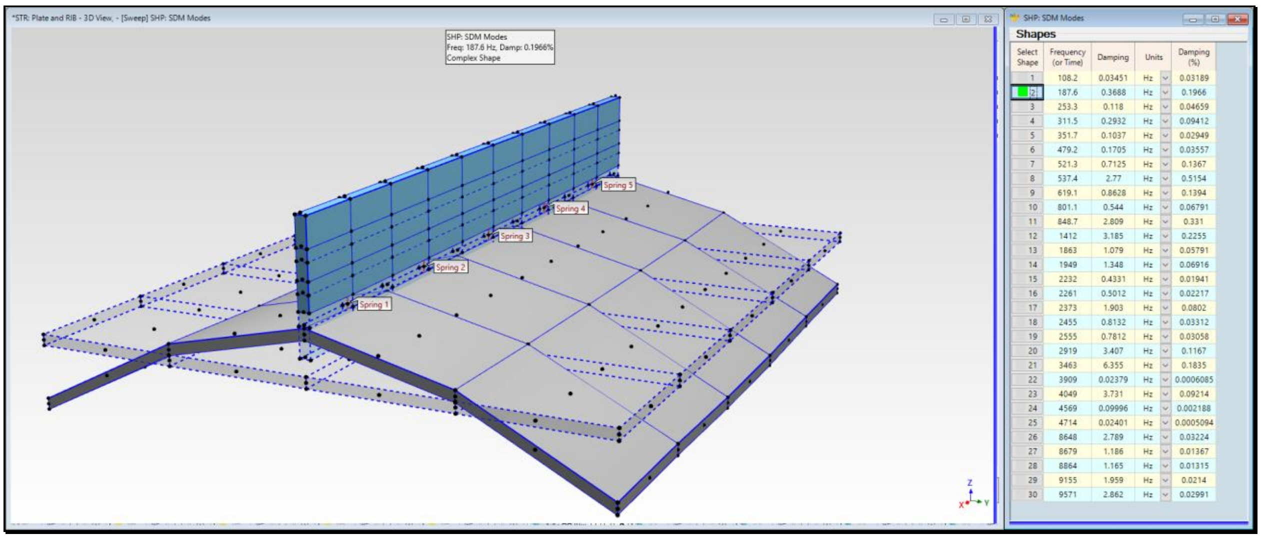
STEP 4 - SDM MODE SHAPES OF THE PLATE & RIB

- ***Press*** **Hotkey 4 SDM Mode Shapes**

The mode shapes of the Plate & RIB calculated by **SDM** are displayed in sweep animation, shown below.

The mode shapes of five modes (**108 Hz, 253 Hz, 479 Hz, 619 Hz, & 801 Hz**) clearly ***reflect the torsional stiffness forces*** transmitted between the RIB and the Plate.

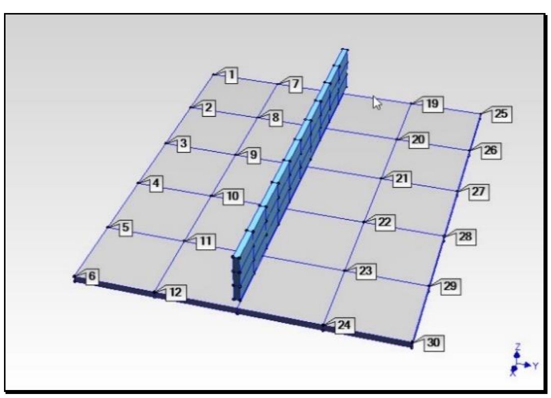
Both the RIB and Plate are flexing in unison because torsional stiffness was created between them by the five 6-DOF springs that modeled the cap screws.



Display of an SDM Mode Shape of the RIB Attached to the Plate.

EMA MODE SHAPES OF THE PLATE & RIB

To validate the SDM mode shapes, the actual Plate with the RIB attached was impacted tested using a Roving Impact test. The Plate was impacted at 24 points in the **(vertical) Z-direction** to gather enough **EMA** shape components to uniquely compare the **EMA** mode shapes with the **SDM** mode shapes.



Impact Points on Plate with RIB

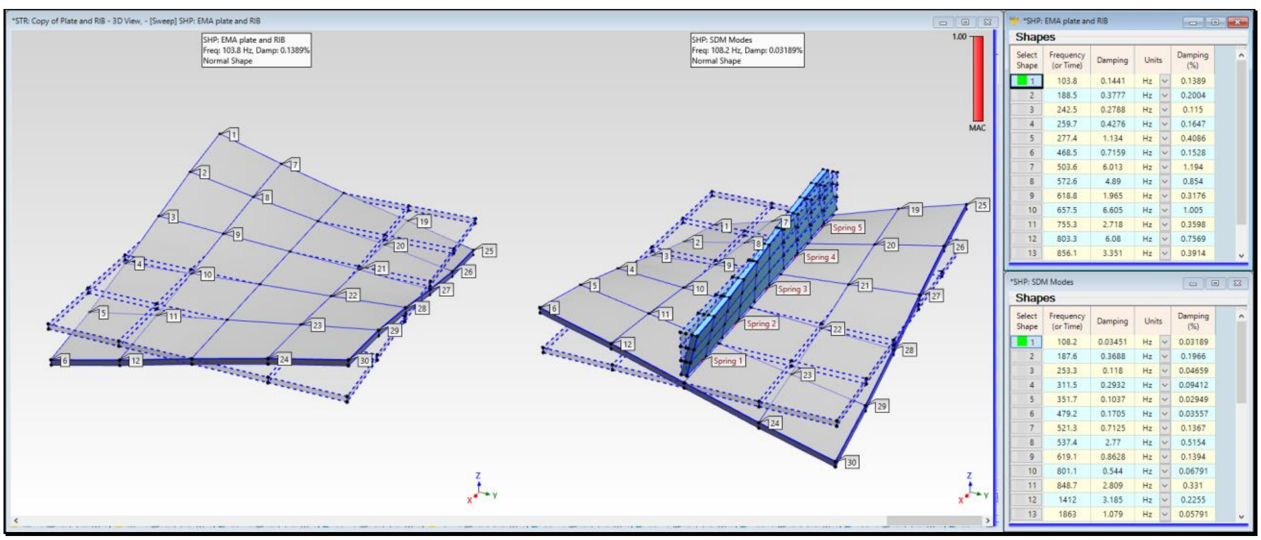
STEP 5 - EMA MODE SHAPES OF THE PLATE & RIB

- ***Press Hotkey* 5 EMA vs. SDM Mode Shapes**

The Table below shows the **EMA & SDM** mode shape pairs and their **MAC** values.

Shape Pair	EMA Frequency (Hz)	EMA Damping (Hz)	SDM Frequency (Hz)	SDM Damping (Hz)	MAC
1	103.8	0.1441	108.2	0.03451	1.00
2	188.5	0.36	187.6	0.3688	0.99
3	242.5	0.2623	253.3	0.118	0.99
4	259.7	0.3783	311.5	0.2932	0.98
5	277.4	1.164	351.7	0.1037	0.97
6	468.6	0.7687	479.2	0.1705	0.98
7	503.6	6.035	521.3	0.7125	0.97
8	572.6	4.953	537.4	2.77	0.98
9	618.8	1.828	619.1	0.8628	0.87
10	657.5	6.541	801.1	0.544	0,95

***EMA & SDM** Mode Shape Pairs for the Plate & RIB*



EMA Versus SDM Mode Shape.

Impact Points on Plate with RIB STEP 6 - MODAL SENSITIVITY ANALYSIS

- ***Press* Hotkey 6 Modal Sensitivity**

When **Hotkey 6 is *pressed***, the **Modal Sensitivity Analysis** window is opened.

In **Modal Sensitivity Analysis**, **SDM** is used to ***calculate many solutions*** using different amounts of cap screw **translational & rotational stiffness.** This is done to answer the question,

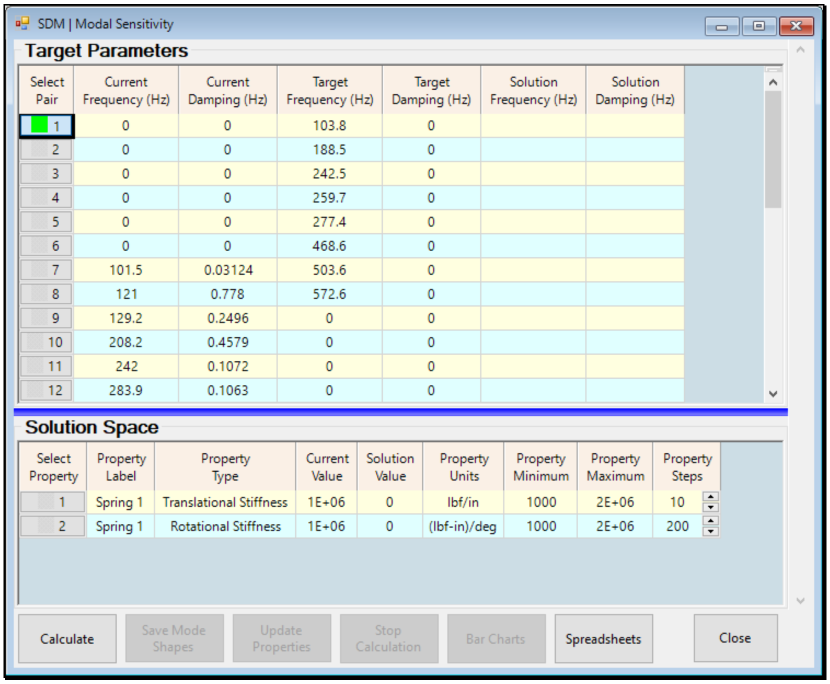
> **"How sensitive are the modes of the Plate & RIB to the stiffness of the cap screws, which are modeled with 6-DOF springs?"**

TARGET MODE SHAPES

The **SDM | Modal Sensitivity** window is shown below. It contains two spreadsheets. The **upper spreadsheet** lists the frequencies of the 30 modes of the **sub-structure modal model**. This **modal model** contains the mode shapes of both the Plate without the RIB, and the modes of the free-body RIB, stored in block-diagonal format.

Since the first mode of the Plate & RIB (**EMA = 103.8 Hz, SDM = 108.2 Hz**) involves twisting of both the Plate and the RIB, it is affected by both the translational & rotational stiffnesses of the springs.

Therefore, a **Modal Sensitivity Analysis** can be done **using only the EMA = 104 Hz mode as a Target Frequency** for the **SDM** solutions.



Select Pair	Current Frequency (Hz)	Current Damping (Hz)	Target Frequency (Hz)	Target Damping (Hz)	Solution Frequency (Hz)	Solution Damping (Hz)
1	0	0	103.8	0		
2	0	0	188.5	0		
3	0	0	242.5	0		
4	0	0	259.7	0		
5	0	0	277.4	0		
6	0	0	468.6	0		
7	101.5	0.03124	503.6	0		
8	121	0.778	572.6	0		
9	129.2	0.2496	0	0		
10	208.2	0.4579	0	0		
11	242	0.1072	0	0		
12	283.9	0.1063	0	0		

Select Property	Property Label	Property Type	Current Value	Solution Value	Property Units	Property Minimum	Property Maximum	Property Steps
1	Spring 1	Translational Stiffness	1E+06	0	lbf/in	1000	2E+06	10
2	Spring 1	Rotational Stiffness	1E+06	0	(lbf-in)/deg	1000	2E+06	200

Modal Sensitivity window with First Shape Pair Selected

The ***selected*** Target Frequency will be compared with the ***first modal frequency of each* SDM solution**.

The **SDM** solution with its ***first frequency closest to* 103.8 Hz** is ranked as the best solution.

SOLUTION SPACE

Solution spaces of stiffness for both the translational & rotational stiffnesses of the five **FEA** springs are defined in the **lower spreadsheet**.

Each stiffness has a range of values from **Minimum Property =1000 to Maximum Property = 2E+06**

The **Translational Stiffness** solution space has **10 Steps** between its Minimum & Maximum Property

The **Rotational Stiffness** solution space has **200 Steps** between its Minimum & Maximum Property

Modal sensitivity calculates an **SDM** solution using a property value from each property in its solution space.

The solution space has **10 x 200 ➔ 2000 solutions** in it.

SDM will solve for new modes using all combinations of the solution space values of the two stiffnesses. Because of the speed of **SDM**, all solutions are **calculated and ranked in a few seconds**.

- ***Select*** the **first shape pair** in the **upper spreadsheet**, as shown above
- ***Press*** the **Calculate** button at the bottom of the Modal Sensitivity window

The Modal Sensitivity window below shows the results **after 2000 solutions have be calculated and ranked**.

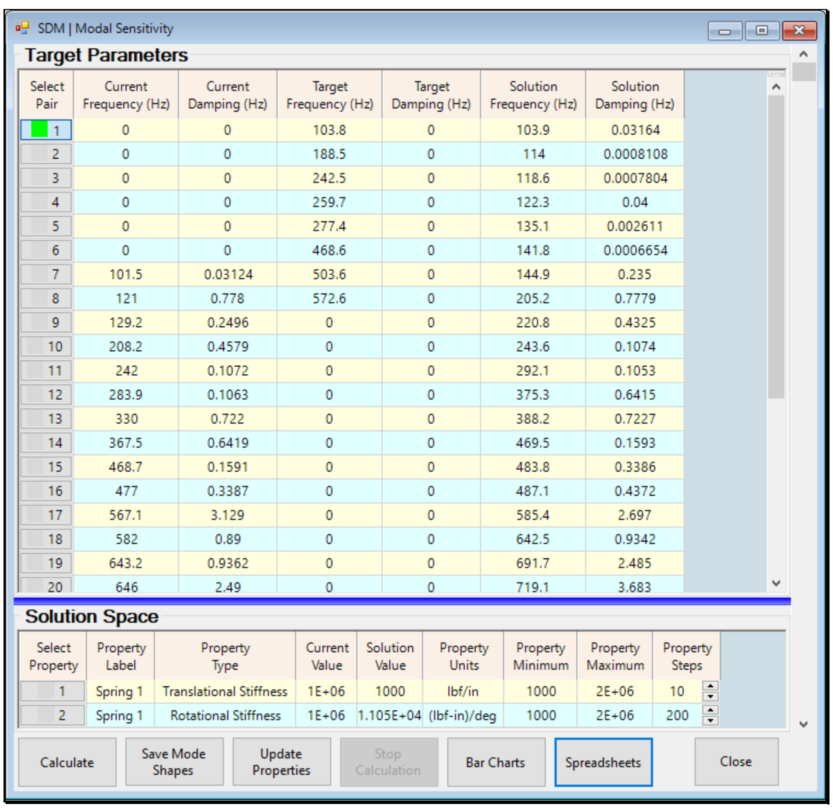
The mode shapes of the ***best solution*** are displayed in the **upper spreadsheet**

The stiffness values used to calculate the ***best solution*** are displayed in the **lower spreadsheet**

These stiffnesses are ***far less than the stiffnesses*** that were originally used **(1E+06)**

However, the figure below also shows that these lower stiffnesses resulted in ***much lower* frequencies** for the higher frequency modes compared with the **EMA** modal frequencies.

Since the first mode has a torsional mod shape involving both the Plate and RIB, less rotational stiffness was also required to create this mode shape.



Select Pair	Current Frequency (Hz)	Current Damping (Hz)	Target Frequency (Hz)	Target Damping (Hz)	Solution Frequency (Hz)	Solution Damping (Hz)
1	0	0	103.8	0	103.9	0.03164
2	0	0	188.5	0	114	0.0008108
3	0	0	242.5	0	118.6	0.0007804
4	0	0	259.7	0	122.3	0.04
5	0	0	277.4	0	135.1	0.002611
6	0	0	468.6	0	141.8	0.0006654
7	101.5	0.03124	503.6	0	144.9	0.235
8	121	0.778	572.6	0	205.2	0.7779
9	129.2	0.2496	0	0	220.8	0.4325
10	208.2	0.4579	0	0	243.6	0.1074
11	242	0.1072	0	0	292.1	0.1053
12	283.9	0.1063	0	0	375.3	0.6415
13	330	0.722	0	0	388.2	0.7227
14	367.5	0.6419	0	0	469.5	0.1593
15	468.7	0.1591	0	0	483.8	0.3386
16	477	0.3387	0	0	487.1	0.4372
17	567.1	3.129	0	0	585.4	2.697
18	582	0.89	0	0	642.5	0.9342
19	643.2	0.9362	0	0	691.7	2.485
20	646	2.49	0	0	719.1	3.683

Select Property	Property Label	Property Type	Current Value	Solution Value	Property Units	Property Minimum	Property Maximum	Property Steps
1	Spring 1	Translational Stiffness	1E+06	1000	lbf/in	1000	2E+06	10
2	Spring 1	Rotational Stiffness	1E+06	1.105E+04	(lbf-in)/deg	1000	2E+06	200

Best Solution (Target Frequency = 103.8 Hz)

The modal frequencies of the **EMA** & **SDM** solution modes are compared in the Table below. The first mode pair matches in frequency, but the frequencies of the rest of the modes do not match. Likewise, the **MAC** value of the first pair shows a good match of mode shapes, while the **MAC** values of the rest of the mode shape pairs indicates a poor match of mode shapes.

- ***Press*** the **Close** button on the Modal Sensitivity window

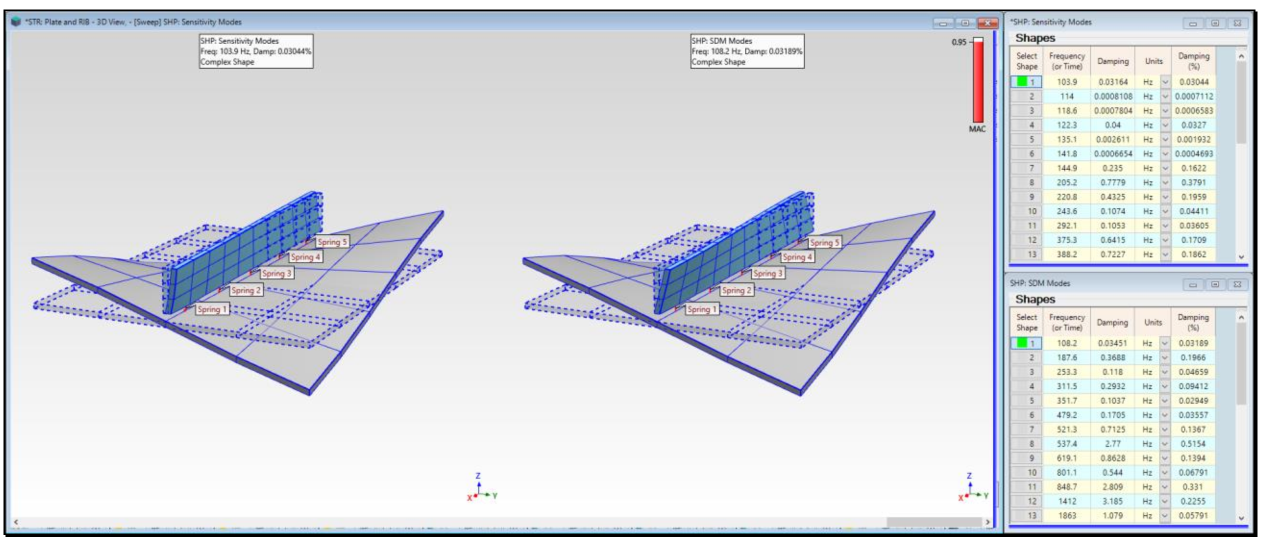
Shape Pair	EMA Frequency (Hz)	EMA Damping (Hz)	SDM Frequency (Hz)	SDM Damping (Hz)	MAC
1	103.8	0.1441	103.9	0.03164	0.95
2	188.5	0.36	114.0	0.0008108	0.00
3	242.5	0.2623	118.6	0.0007804	0.01
4	259.7	0.3783	122.3	0.04	0.00
5	277.4	1.164	135.1	0.002611	0.00
6	468.6	0.7687	141.8	0.0006654	0.05
7	503.6	6.035	144.9	0.235	0.00
8	572.6	4.953	205.2	0.7779	0.00
9	618.8	1.828	103.9	0.03164	0.00
10	657.5	6.541	114.0	0.0008108	0,05

EMA *vs.* ***SDM*** *mode shapes (Trans Stiff = 1000, Rot Stiff = 1.10E4)*

STEP 7 - NEW VERSUS OLD MODE SHAPES

To compare the mode shapes from before the stiffness reduction of the five **FEA** springs to the mode shapes after the stiffness reductions,

- ***Press*** **Hotkey 7 New vs. Old Mode Shapes**



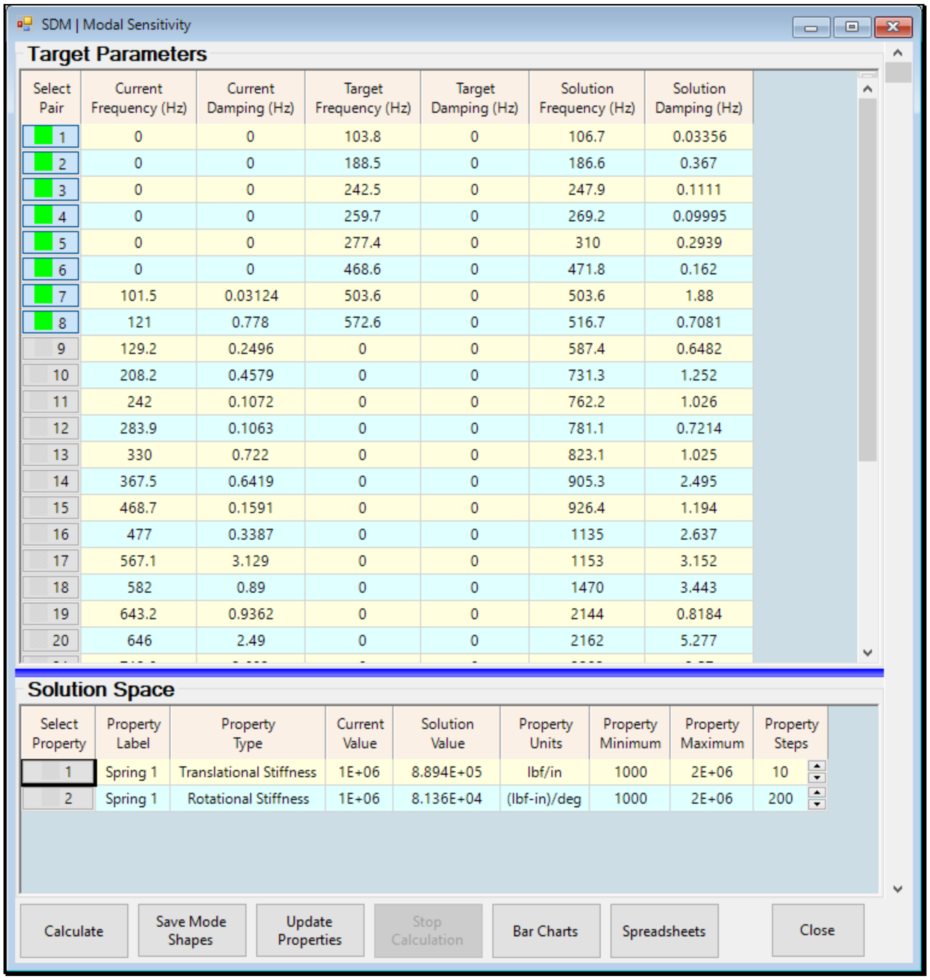
New Versus Old Mode Shape With One Target Frequency.

Only the **first mode shape pair** correlates well with **MAC = 0.95**. Using only one target modal frequency is not sufficient in this case.

USING EIGHT TARGET MODAL FREQUENCIES

When eight target modal frequency pairs are selected, the results will be much better.

- ***Press* Hotkey 6 Modal Sensitivity *again***
- ***Select* the first eight shape pairs in the upper spreadsheet, as shown above**
- ***Press* the Calculate button at the bottom of the Modal Sensitivity window**



Select Pair	Current Frequency (Hz)	Current Damping (Hz)	Target Frequency (Hz)	Target Damping (Hz)	Solution Frequency (Hz)	Solution Damping (Hz)
1	0	0	103.8	0	106.7	0.03356
2	0	0	188.5	0	186.6	0.367
3	0	0	242.5	0	247.9	0.1111
4	0	0	259.7	0	269.2	0.09995
5	0	0	277.4	0	310	0.2939
6	0	0	468.6	0	471.8	0.162
7	101.5	0.03124	503.6	0	503.6	1.88
8	121	0.778	572.6	0	516.7	0.7081
9	129.2	0.2496	0	0	587.4	0.6482
10	208.2	0.4579	0	0	731.3	1.252
11	242	0.1072	0	0	762.2	1.026
12	283.9	0.1063	0	0	781.1	0.7214
13	330	0.722	0	0	823.1	1.025
14	367.5	0.6419	0	0	905.3	2.495
15	468.7	0.1591	0	0	926.4	1.194
16	477	0.3387	0	0	1135	2.637
17	567.1	3.129	0	0	1153	3.152
18	582	0.89	0	0	1470	3.443
19	643.2	0.9362	0	0	2144	0.8184
20	646	2.49	0	0	2162	5.277

Select Property	Property Label	Property Type	Current Value	Solution Value	Property Units	Property Minimum	Property Maximum	Property Steps
1	Spring 1	Translational Stiffness	1E+06	8.894E+05	lbf/in	1000	2E+06	10
2	Spring 1	Rotational Stiffness	1E+06	8.136E+04	(lbf-in)/deg	1000	2E+06	200

Best Solution with Eight Target Frequencies

When the calculation is completed,

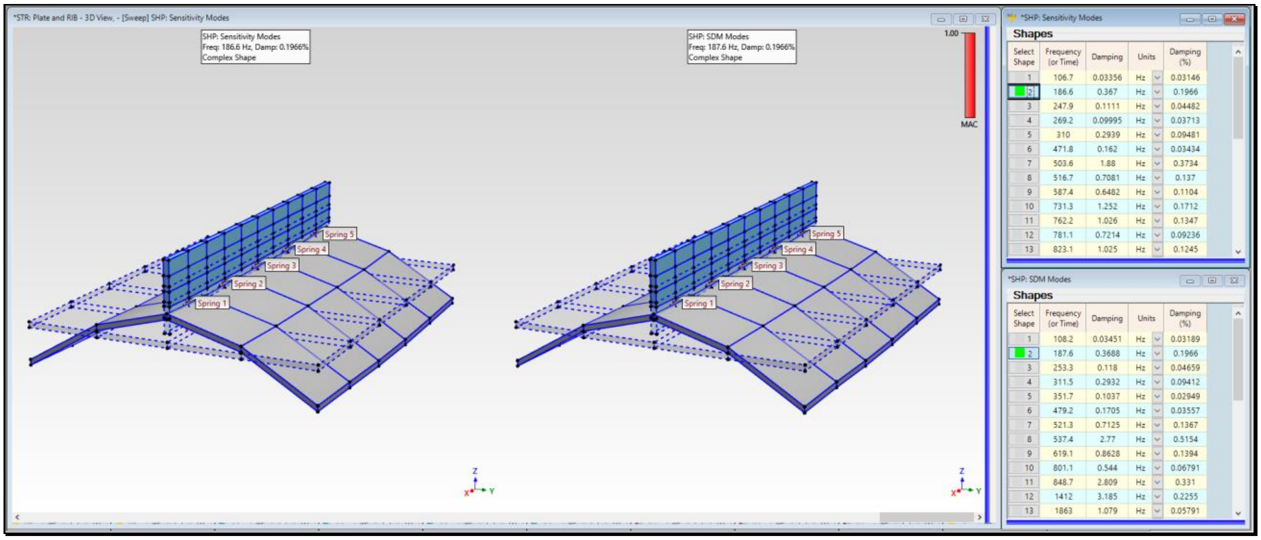
- ***Press* Save Mode Shapes followed by the Close button *again***

The figure above also shows the best solution the ***eight* EMA Target Frequencies *are selected***.

> The ***best solution*** Translational & Rotational stiffnesses ***are still significantly less*** than the original stiffnesses ➔ **1E+06**

- ***Press* Hotkey 7 New vs. Old Mode Shapes *again***

Using ***far less stiffness***, the frequencies & mode shapes of the ***first eight* modes *match very well*** with the mode shapes obtained with the original stiffnesses ➔ **1E+06**



Old Versus New Mode Shape With Eight Target Frequencies.

STEP 8 - REVIEW STEPS

To review the steps of this App Note

- ***Press* Hotkey 8 Review Steps**