MEscope Application Note 33

Calculating ODS-FRFs with Multiple Reference Responses

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-3600 Advanced Signal Processing** option. Without this option, you can still carry out the steps in this App Note using the **AppNote33** project file. These steps might also require a ***more recent release date*** of MEscope.

APP NOTE 33 PROJECT FILE

- To retrieve the Project for this App Note, **click here** to download **AppNote33.zip**

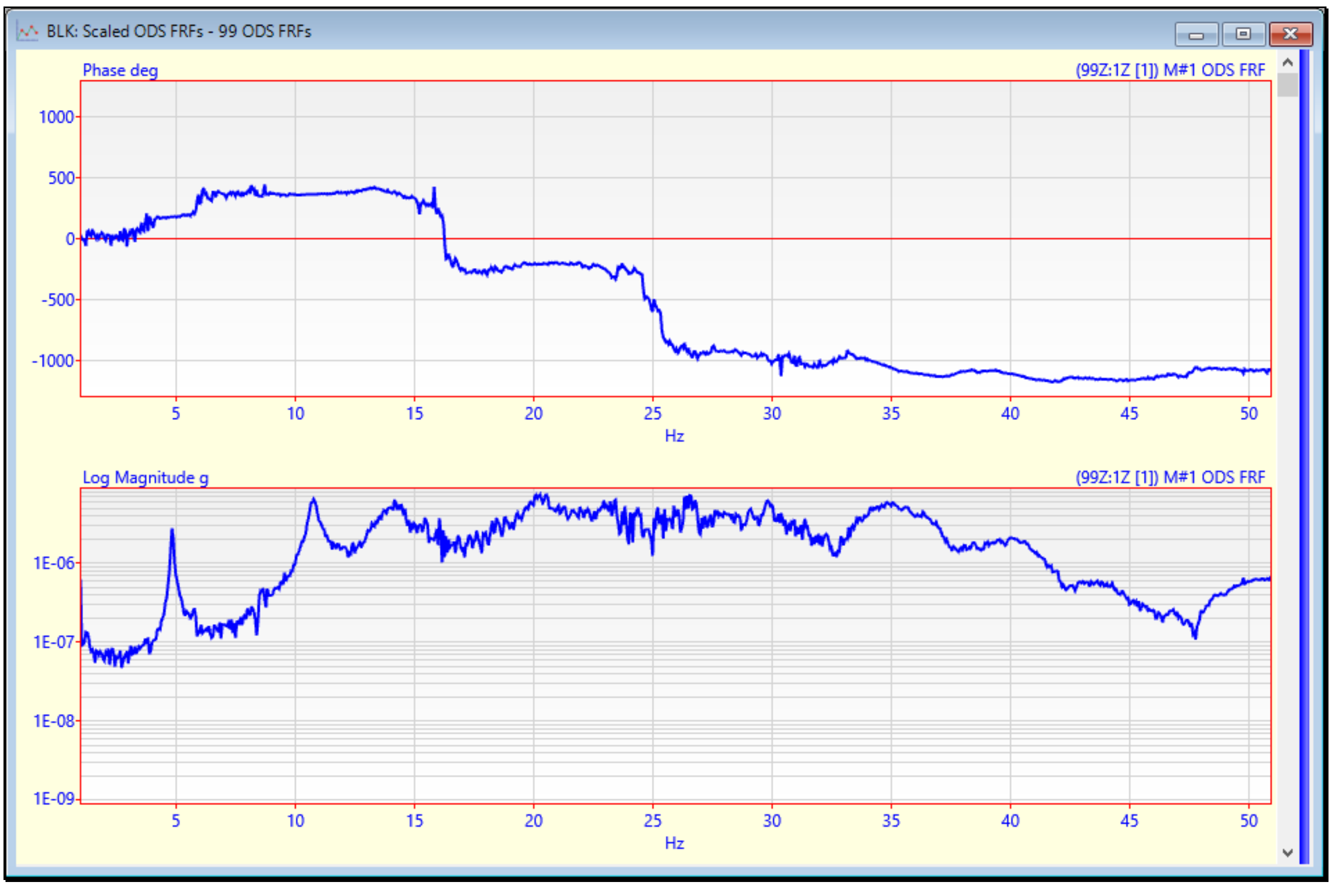
This Project file contains ***numbered Hotkeys & Scripts*** for carrying out the steps of this App Note.

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

WHAT IS AN ODS-FRF?

An **ODS-FRF** is ***complex*** valued function of frequency that has ***magnitude*** & ***phase***, like an **FRF**.

An **ODS-FRF** is created by combining the **Auto spectrum** of the ***roving*** response with the **phase** of the **Cross spectrum** between the ***roving*** response and a ***(fixed) reference*** response.



*Log Magnitude and Phase of an **ODS-FRF**.*

ADVANTAGES OF AN ODS-FRF

An **ODS-FRF** is a ***true measure*** of the response (***in engineering units***) of a machine or structure at each frequency

An **ODS-FRF** contains ***peaks at resonant frequencies***

A set of **ODS-FRF**s can be used to ***extract operating deflection shapes*** (**ODS's**) of a machine

A set of **ODS-FRF**s can be curve fit to estimate **operating mode shapes** (**OMA** mode shapes)

The **ODS-FRF** provides the response (in displacement, velocity, or acceleration units) for each measured Point & direction together with the phase relative to a Reference response.

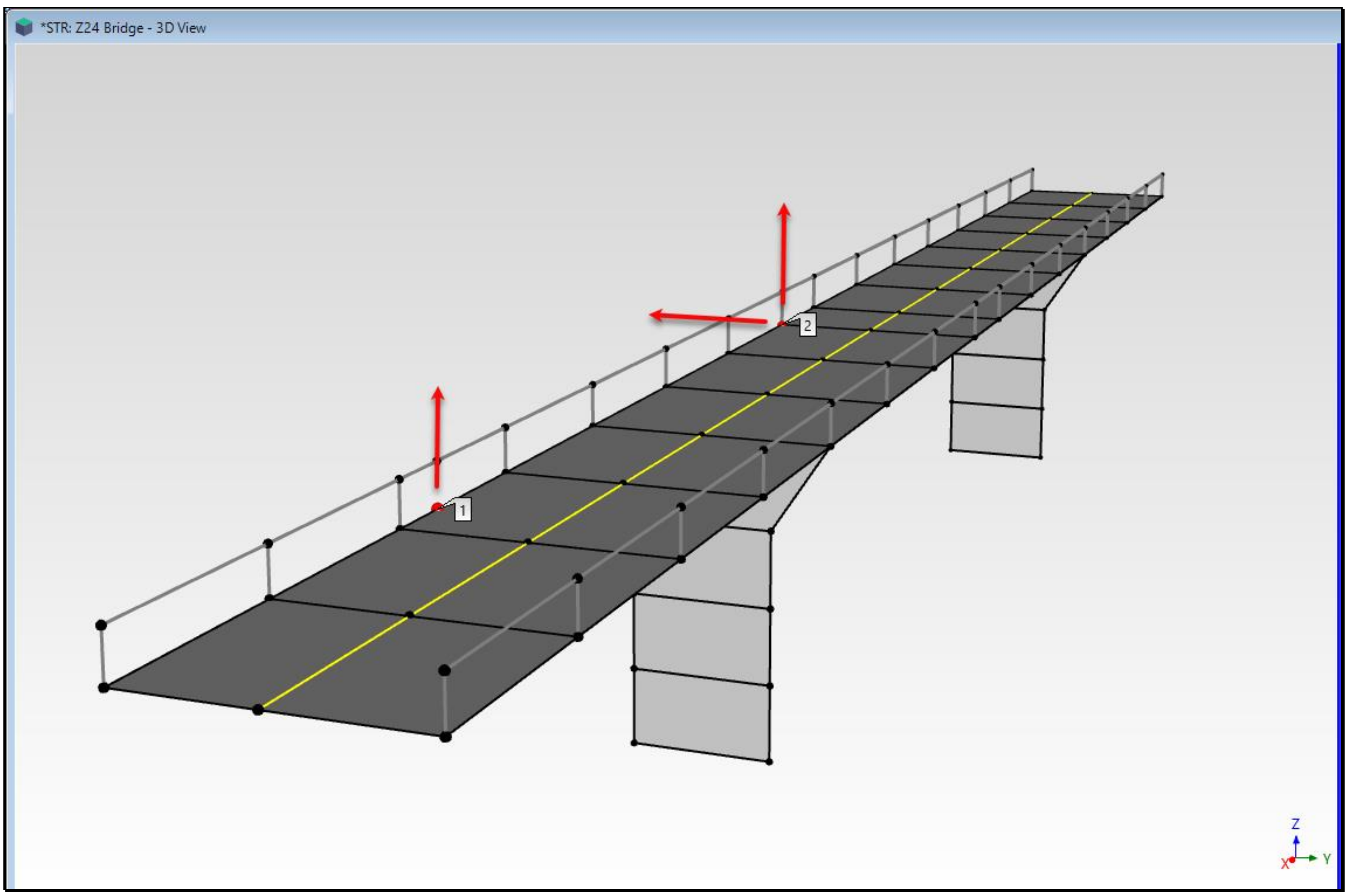
An **ODS** displayed from a set of **ODS-FRFs** is the ***actual magnitude*** of the measured response in engineering units, together with the ***correct phase*** relative to all other responses.

When the **DeConvolution** window is applied to a set of **ODS-FRF**s, operating mode shapes, called OMA mode shapes, can be estimated using **FRF-based curve fitting** on the windowed **ODS-FRF**s.

CALCULATING ODS-FRFS

ODS-FRFs can be calculated in several different ways,

1. From response **time waveforms**
2. From response **Auto & Cross spectra**
3. From a **Transmissibility Chain** seeded with a response **Auto spectrum**



*Z-24 Bridge Showing Three Reference Accelerometer **DOFs**.*

CALCULATING ODS-FRFS FROM AUTO & CROSS SPECTRA

Auto & Cross spectrum measurements were calculated from data acquired by impacting a bridge, the model of which is shown in the figure above.

The impact forces ***were not measured***

Because there were not enough data acquisition channels to ***simultaneously acquire*** all the bridge responses, the data was acquired in ***nine (9) Measurement Sets***.

All responses in each Measurement Set were ***simultaneously acquired***

Three (fixed) Reference acceleration responses were acquired in each Measurement Set

75 unique Roving accelerometer responses were acquired in the ***9 Measurement Sets***

The three Reference accelerometer **DOFs** (**1Z, -2Y, 2Z**) are indicated in the figure above.

NINE MEASUREMENT SETS

If an **M# DOF** of acquired data also contains a **Measurement Set [number]**, then each Measurement Set of data is processed independently of the others to calculate **ODS-FRFs**.

This Project contains 9 Data Block files (**BLK: APSs XPSs [1]** ***through*** **BLK: APSs XPSs [9]**). Each Data Block contains a separate Measurement Set of Auto & Cross spectra. Each Measurement Set contains the following,

Auto spectra of ***three Reference*** responses

Auto spectra for several ***unique Roving*** responses

Cross spectra between each ***Roving*** response and the ***three Reference*** responses

To calculate **ODS-FRF**s, each **M#** must be designated as either an **Input** or an **Output**.

All **Reference response Auto spectra** are designated as **Inputs** in the **Input Output** column of the **M#s** spreadsheet

All **Roving response Auto spectra** are designated as **Outputs** in the **Input Output** column of the **M#s** spreadsheet

All **Cross spectra** are designated as **Cross** in the **Input Output** column of the **M#s** spreadsheet

CHECKING THE DOFS IN MEASUREMENT SET [1]

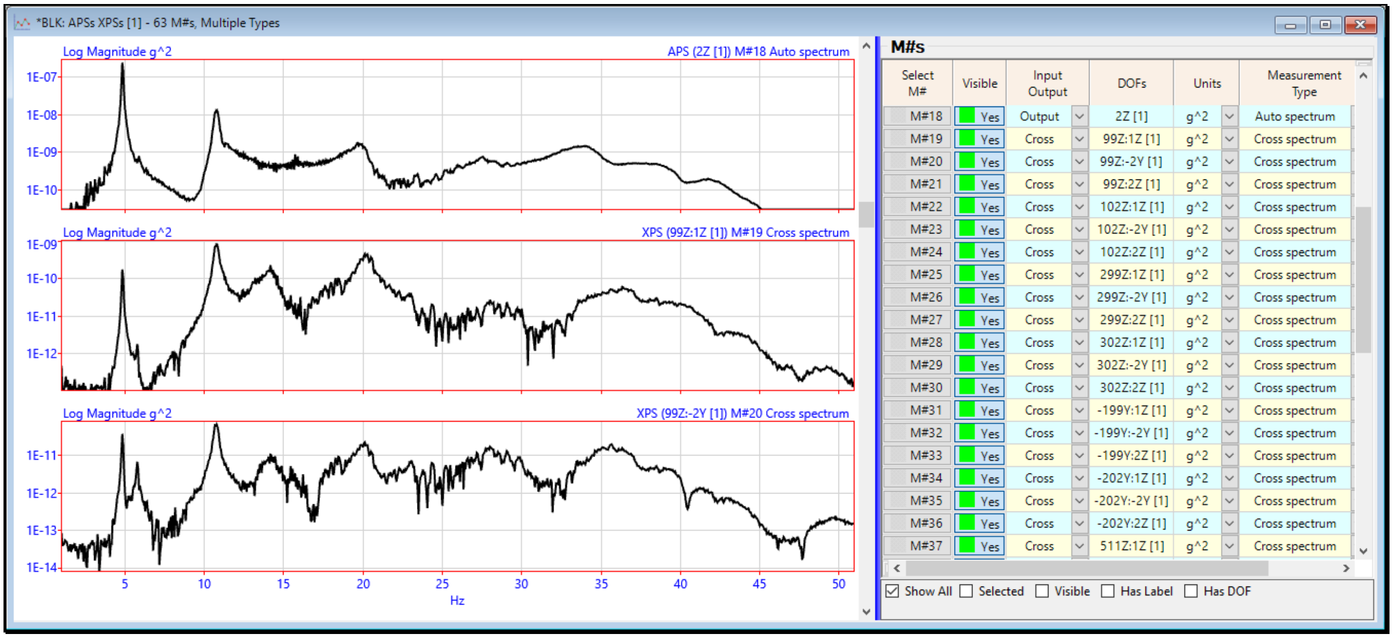
- Open the **BLK: APSs XPSs [1]** window
- ***Drag*** the **vertical blue splitter bar** ***to the left*** to display the **M#s** spreadsheet, as shown below

There are **63 M#s** in this Data Block.

Auto spectra for **3 Reference responses**(**1Z, -2Y** & **2Z**) designated as **Inputs** in the **Input Output** column

Auto spectra for **15 Roving responses** designated as **Outputs** in the **Input Output** column

45 Cross spectra (**15 roving DOFs** x **3 reference DOFs**) designated as **Cross** in the **Input Output** column



Data Block with Auto & Cross spectra for Measurement Set [1].

Each Data Block (**BLK: APSs XPSs [2]** through **BLK: APSs XPSs [9]**) also contains Auto & Cross spectra. Each of the nine Data Blocks contains,

Auto spectra for the **3 Reference DOFs** (**1Z, -2Y & 2Z**)

Auto spectra for several ***unique*** **Roving DOFs**

Cross spectra between each ***Roving*** **&** ***Reference*** **DOF pair**

STEP 1 - CALCULATING THE ODS-FRFs

- ***Press*** **Hotkey 1 Calculate the ODS-FRFs**

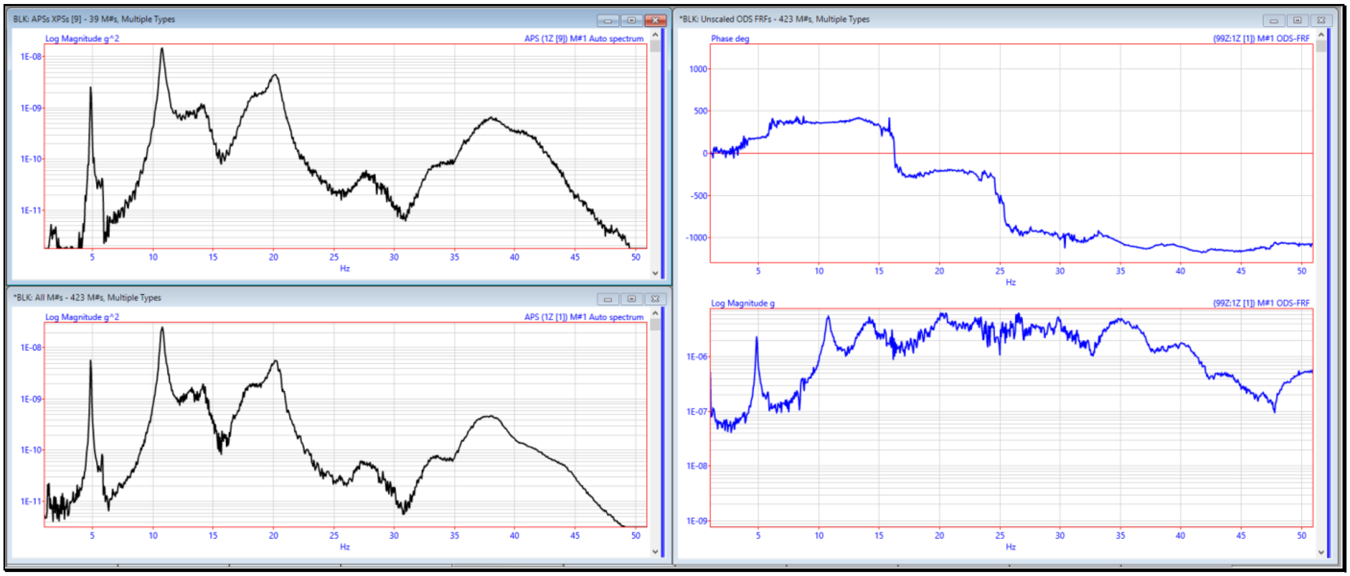
The **Transform | ODS-FRFs** command requires that all Auto & Cross spectra be stored in ***one or two*** Data Blocks.

When **Hotkey 1 is *pressed***, **ODS-FRFs** are calculated, and three Data Blocks are displayed together, as shown below.

Each Measurement Set of Auto & Cross spectra is displayed ***on the upper-left side*** as is added into the Data Block **BLK: All M#s**

All nine **Measurement Sets** of Auto & Cross spectra are saving into **BLK: All M#s**, which is displayed ***on the lower-left side***

The **ODS-FRF**s and the **Auto spectra** for each Measurement Set are adding to **BLK: Unscaled ODS-FRFs**, and are displayed ***on the right side***



*Auto & Cross spectra (left side) & Unscaled **ODS-FRF**s (right side)*

STEP 2 - OVERLAYING THE REFERENCE AUTO SPECTRA

- ***Press* Hotkey 2 Overlay Reference Auto Spectra**

When **Hotkey 1 was *pressed***, **297 ODS-FRFs** for the Bridge were calculated using ***9 independently acquired* Measurement Sets** of Auto & Cross spectra.

Each Measurement Set was acquired while the Bridge was impacted, but ***the impact force level was not controlled.*** Therefore, the ***bridge response levels were probably different*** when each Measurement Set of data was acquired.

Different Bridge response levels can be determined by ***overlaying the Reference Auto spectra*** from all 9 Measurement Sets.

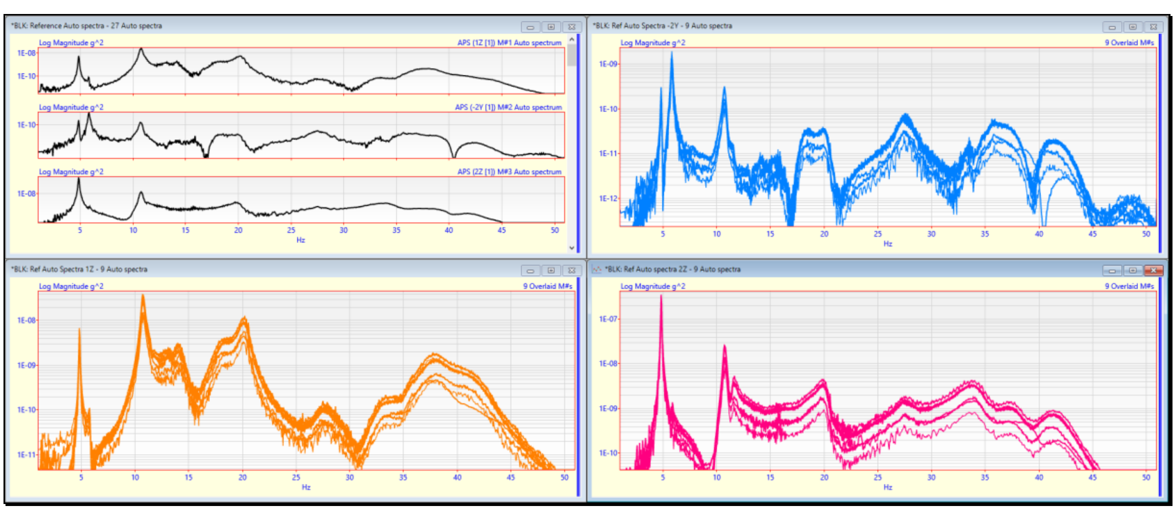
When **Hotkey 2 is *pressed***, the Auto spectra for each of the references (**1Z, -2Y** & **2Z)** are overlaid. Nine Auto spectra are overlaid for each reference, as shown below.

The Data Block containing ***all* 27 Reference Auto spectra** is ***on the upper-left***

The Auto spectra for **reference 1Z** are ***on the lower-left***

The Auto spectra for **reference -2Y** are ***on the upper-right***

The Auto spectra for **reference 2Z** are ***on the lower-right***



Reference Auto spectra overlaid for each Measurement Set/

All three sets of overlaid **reference Auto spectra** show that the ***Bridge response level was different*** during the acquisition of each Measurement Set.

STEP 3 - SCALING THE ODS-FRFs

- ***Press* Hotkey 3 Scale the ODS-FRFs**

In **Step 2**, the overlaid Auto spectra for Reference **DOFs** (**1Z, -2Y** & **2Z)** showed that each Measurement Set of data was acquired when the bridge was ***impacted using different impact levels.***

To display **ODS**'s in animation, the **ODS-FRF**s must be scaled to account for the difference in force levels (and hence response levels), between all Measurement Sets.

The **ODS-FRFs** for each reference **(1Z, -2Y**, **2Z)** must be scaled separately using the reference Auto spectra for each reference.

SCALING METHOD

Each **ODS-FRF** is scaled by first calculating an ***average*** **Reference Auto spectrum** for all Measurement Sets. Then, each **ODS-FRF** is rescaled by ***multiplying it by the average*** **Reference Auto spectrum** and ***divided it by the*** **Reference Auto spectrum** for its Measurement Set.

If the **Line** cursor is displayed, rescaling is done using the **Auto spectrum** data at the Line cursor position

If a **Peak** or **Band** cursor is displayed, rescaling is done using the **Auto spectrum** data in the cursor band

If now cursor is displayed, ***all* of the Auto spectrum data** is used for re-scaling

When **Hotkey 3 is *pressed***, four Data Blocks are displayed together, as shown below.

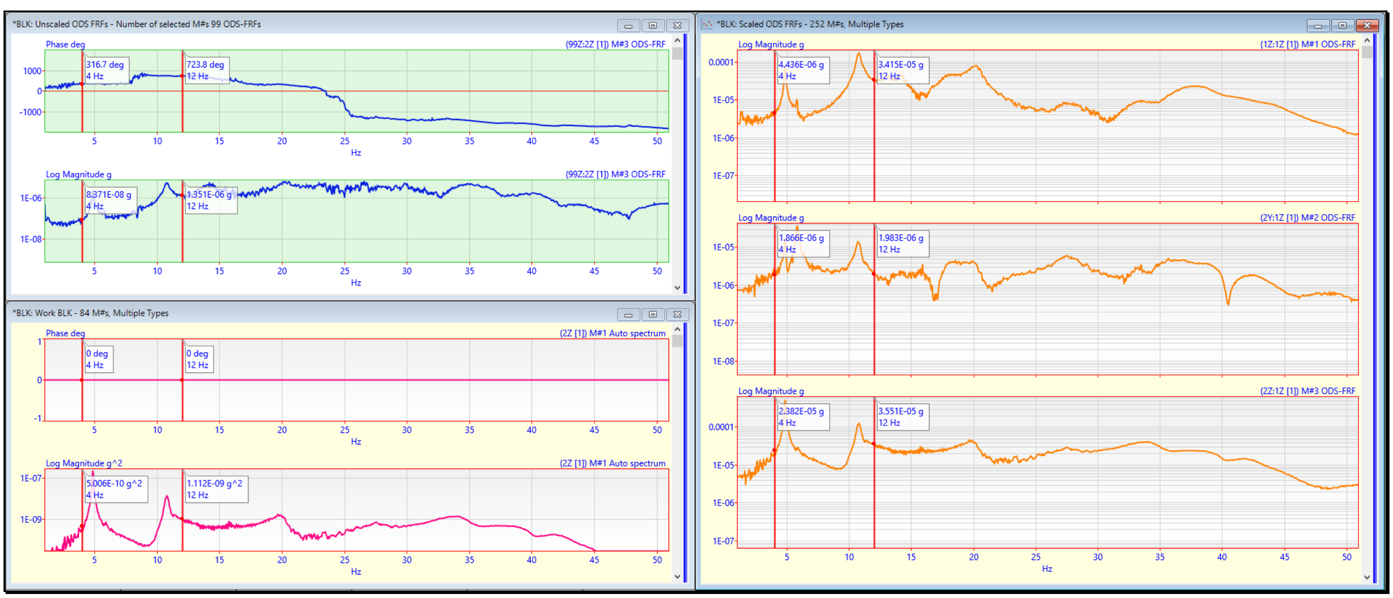
The Data Block **BLK: Unscaled ODS-FRFs** containing ***all of the un-scaled* ODS-FRFs** is ***on the upper-left***

The **Auto spectra** for **reference 2Z** are ***on the lower-left***

Scaling was done using the ***averaged*** **reference Auto Spectrum data** in the cursor band shown in the Data Blocks below.

The scaled **ODS-FRF**s are saved in a new Data Block **BLK: Scaled ODS-FRFs** displayed ***on the right side***

BLK: Scaled ODS-FRFs contains **75 *unique* ODS-FRFs** for each reference, for a total of **225 ODS-FRFs**



*Unscaled **ODS-FRF**s (upper-left) Reference Auto spectra (lower-left) & Scaled **ODS-FRF**s (right side)*

STEP 4 - COMPARING ODS's FROM DIFFERENT REFERENCES

- ***Press* Hotkey 4 Compare ODS's from Different References**

Ideally, the same frequency-based **ODS** should be obtained at the same frequency from any set of **ODS-FRF**s calculated for any Reference DOF.

Each **ODS** is a ***summation of mode shapes***, and mode shapes are independent of the Reference DOF.

Law of Modal Analysis: ***All vibration is a summation of mode shapes***

By choosing different Reference **DOFs** from which to display an **ODS**, you will see that the **Law of Modal Analysis** is valid except when an **ODS** is not well defined for a particular reference DOF.

When a reference DOF is chosen ***at or near a nodal point*** of a mode shape, that mode ***will not participate*** in the **ODS** from that reference

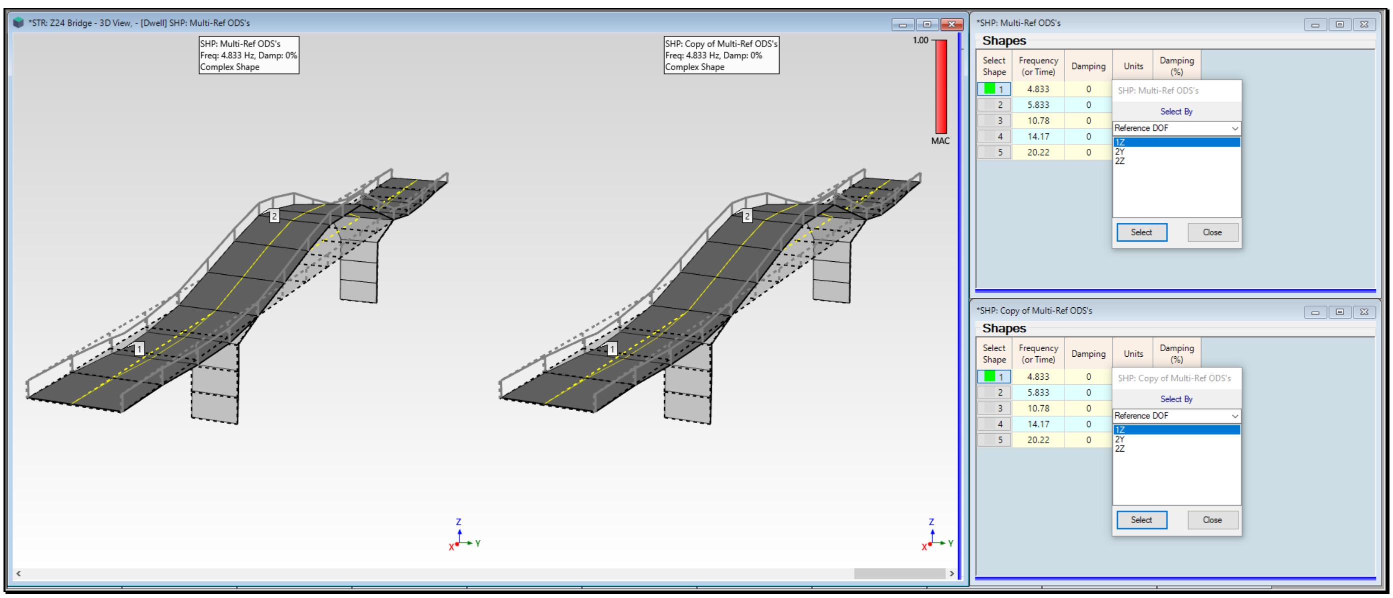
When **Hotkey 4 is *pressed***, the **Real part** of the **ODS-FRF**s is displayed and the **ODS** at several of its resonance peaks is saved into a Shape Table **SHP: Multi-Ref ODS's**.

The **Real part** of the **ODS-FRF**s contains the ***magnitude & phase*** of the frequency-based **ODS** at the Line cursor

After the **ODS**'s at several resonances are saved into **SHP: Multi-Ref ODS's,** animation of two **ODS**'s is begun. Each **ODS** in **SHP: Multi-Ref ODS's** is compared side-by-side with its ***closest matching* ODS *from a copy*** of **SHP: Multi-Ref ODS's**.

Because **BLK: Scaled ODS-FRFs** contains ***multi-reference* ODS-FRFs**, the **ODS**'s saved in **SHP: Multi-Ref ODS's** are also multi-reference **ODS**'s

When animation from **SHP: Multi-Ref ODS's** & **Copy of SHP: Multi-Ref ODS's** begins, a **select reference DOF** dialog box will appear in front of each Shape Table



*Side-by-Side Display of the **ODS** from Reference 1Z with the **ODS** from Reference 2Z.*

If an **ODS** is displayed ***at or near a resonance peak***, the mode shape of that resonance will ***dominate the* ODS**.

- Select a ***different shape*** in Shape Table **SHP: Multi-Ref ODS's**
- Select a ***different reference DOF*** in either Shape Table

The **4.833 Hz *first bending mode shape*** of the bridge ***dominates the* ODS** in all three references of **ODS-FRF** data.

MAC BAR

The **MAC** bar ***in the upper-right corner*** of the **ODS** display indicates ***how similar*** two **ODS**'s are to each other.

MAC has values ***between*** **0 & 1**

MAC ***greater than*** **0.9** ➔ two **ODS**'s ***are similar***

STEP 5 - REVIEW STEPS

To review the steps of this App Note,

- ***Press*** **Hotkey 5 Review Steps**