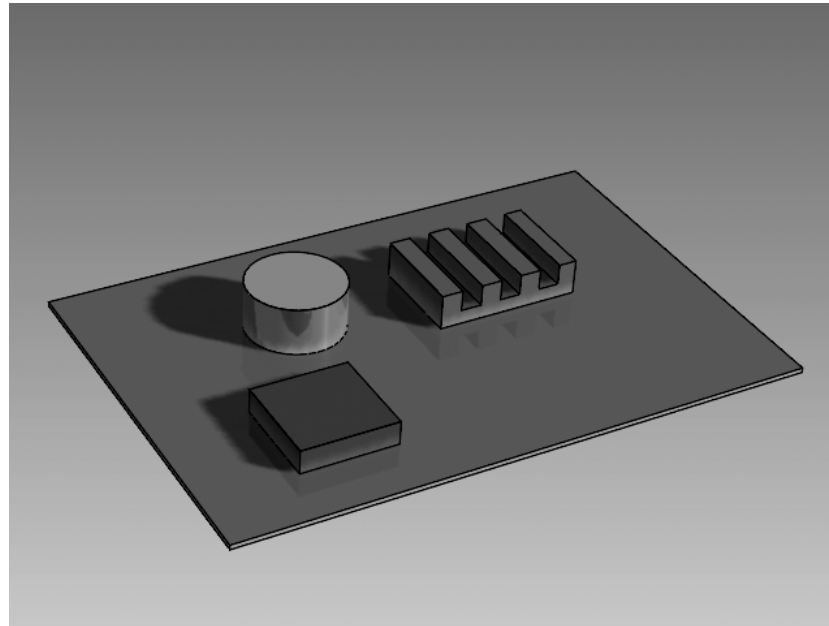


Random Vibration Analysis of a Circuit Board



Sean Harvey

August 2000

CSI Tip of the Week

Random Vibrations

- Outline
 - Introduction
 - Sample Problem
 - Description
 - Pre Processing Steps Omitted
 - Interactive steps
 - Specify Modal Analysis
 - Specify Modal Analysis Options
 - Constrain Board
 - Solve Modal
 - Specify Spectrum Analysis
 - Specify Analysis Options
 - Specify PSD Settings
 - Specify PSD vs. Frequency
- (Continued)
 - Plot Input PSD
 - Specify Damping
 - Flag Nodes to get PSD Input
 - Solve for Participation Factors
 - Set PSD Calculation Controls
 - Solve Random Vibration Solution
 - Set Mode Combination
 - Calculate mode combinations and 1 sigma response
 - Post Processing Results Summary
 - 1 sigma Results
 - Post Processing 1 sigma Displacements
 - Post Processing 1 sigma Stresses
 - Plotting Response PSD in Post 26

CSI ANSYS Tip of the Week

Introduction

What is a Random Vibration Analysis?

- A Random Vibration Analysis is a form of Spectrum Analysis.
- The *spectrum* is a graph of spectral value versus frequency that captures the intensity and frequency content of time-history loads.
- Random vibration analysis is *probabilistic* in nature, because both input and output quantities represent only the *probability* that they take on certain values.

Introduction

What is a Random Vibration Analysis (continued)?

- Random Vibration Analysis uses Power spectral density to quantify the loading.
- (PSD) is a statistical measure defined as the limiting mean-square value of a random variable. It is used in *random vibration analyses* in which the instantaneous magnitudes of the response can be specified only by probability distribution functions that show the probability of the magnitude taking a particular value.

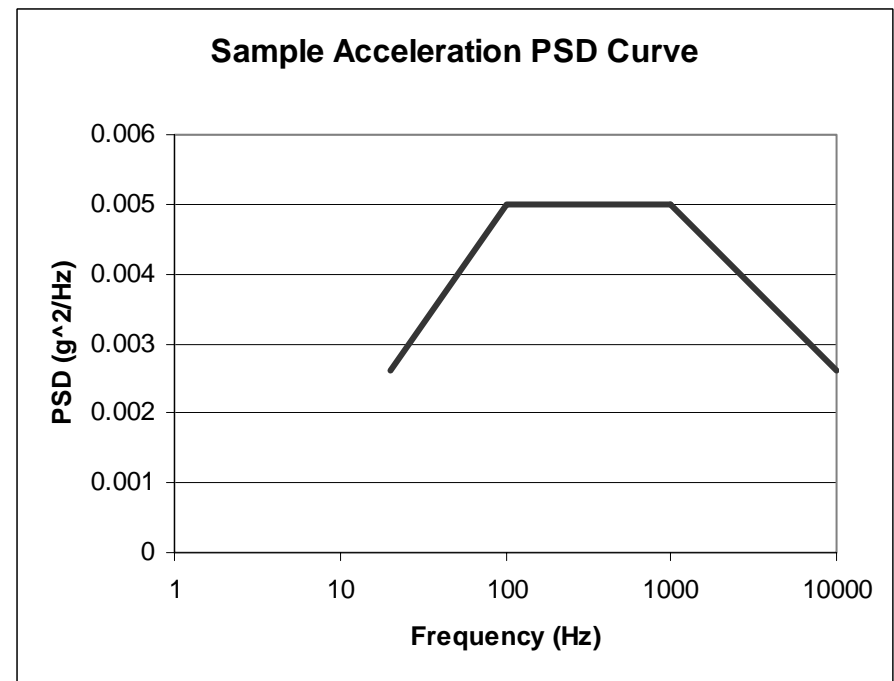
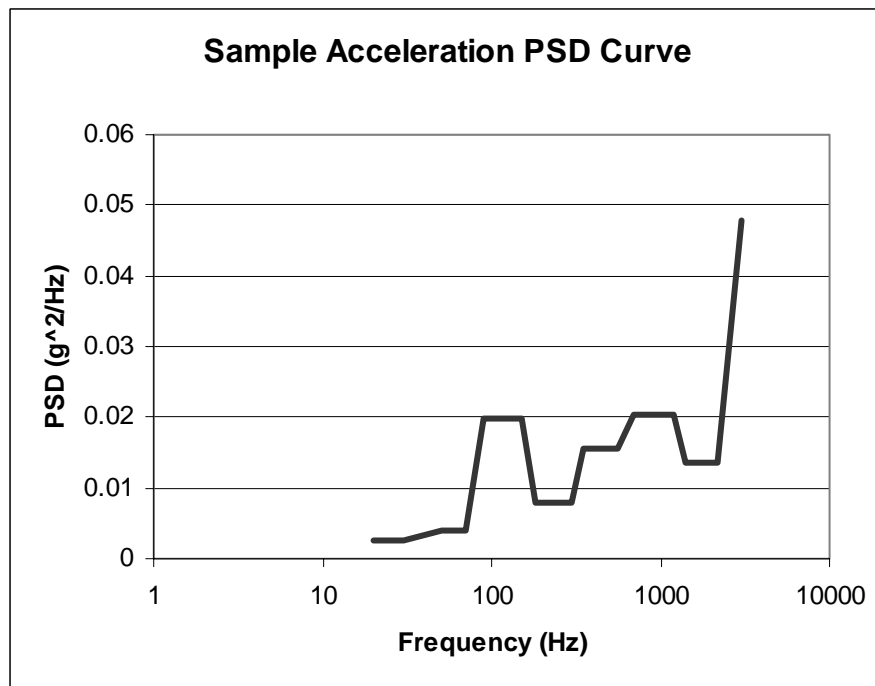
Introduction

What is a PSD Spectrum?

- A *PSD spectrum* is a statistical measure of the response of a structure to random dynamic loading conditions. It is a graph of the PSD value versus frequency, where the PSD may be a displacement PSD, velocity PSD, acceleration PSD, or force PSD. Mathematically, the area under a PSD-versus-frequency curve is equal to the variance (square of the standard deviation of the response).

Introduction

Sample PSD Curves



CSI ANSYS Tip of the Week

Introduction

How does one obtain a PSD Spectrum?

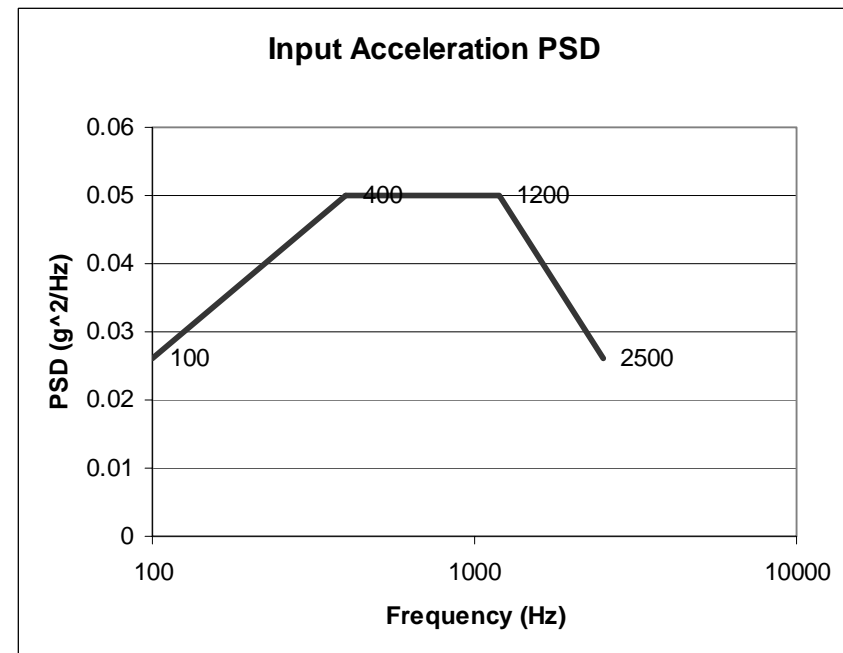
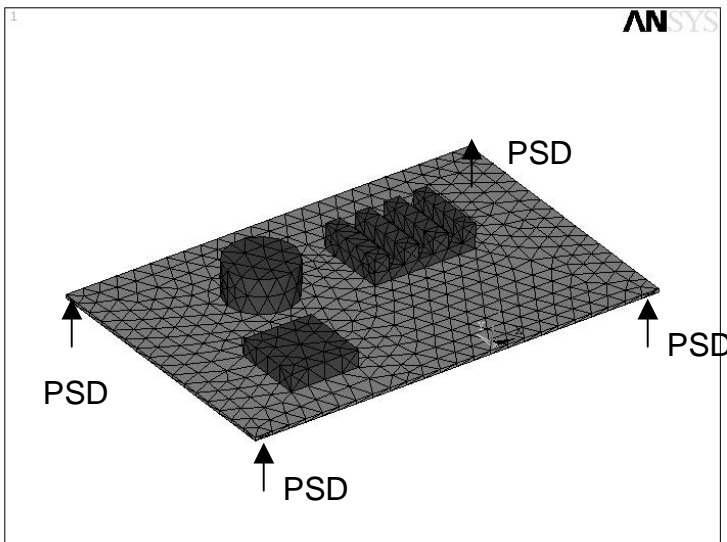
- *PSD spectrum* curves are generally supplied as a spec., or are measured and calculated using vibration analysis equipment.

Sample Problem

The following steps will detail running through a simple PSD analysis using the GUI. An input file with every command is included at the end of this document...

Sample Problem Description

- Circuit Board exposed to a Base Acceleration Power Spectral Density (g^2/Hz) input in the global Z direction (normal to board) on 4 corners as show below;



CSI ANSYS Tip of the Week

Sample Problem Description

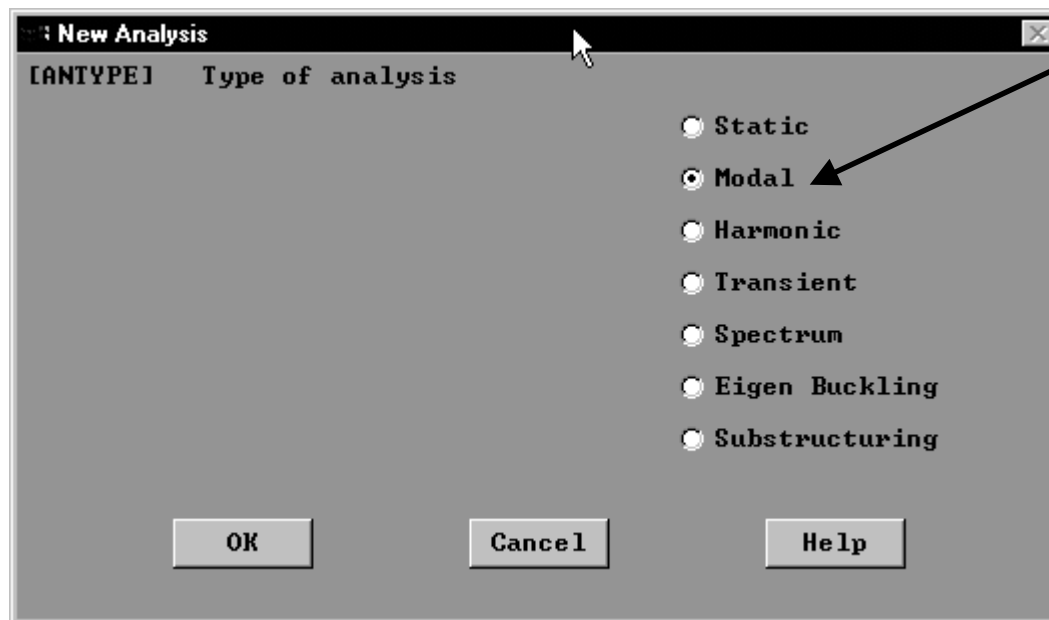
- Circuit Board with 3 components
- Board Constrained at 4 corners in all DOF
- Damping Ratio = 2%
- Model meshed with Solid92 10 noded tetrahedrons

Sample Problem Description

- Preprocessing steps - Details omitted
 - Import Geometry, Glue Volumes, Define Material Properties, Assign Material Attributes, Set Element Type, Mesh Model.
- Solution steps - Step by Step starting on next slide...

Specify Modal Analysis

ANSYS Main Menu > Solution > New Analysis

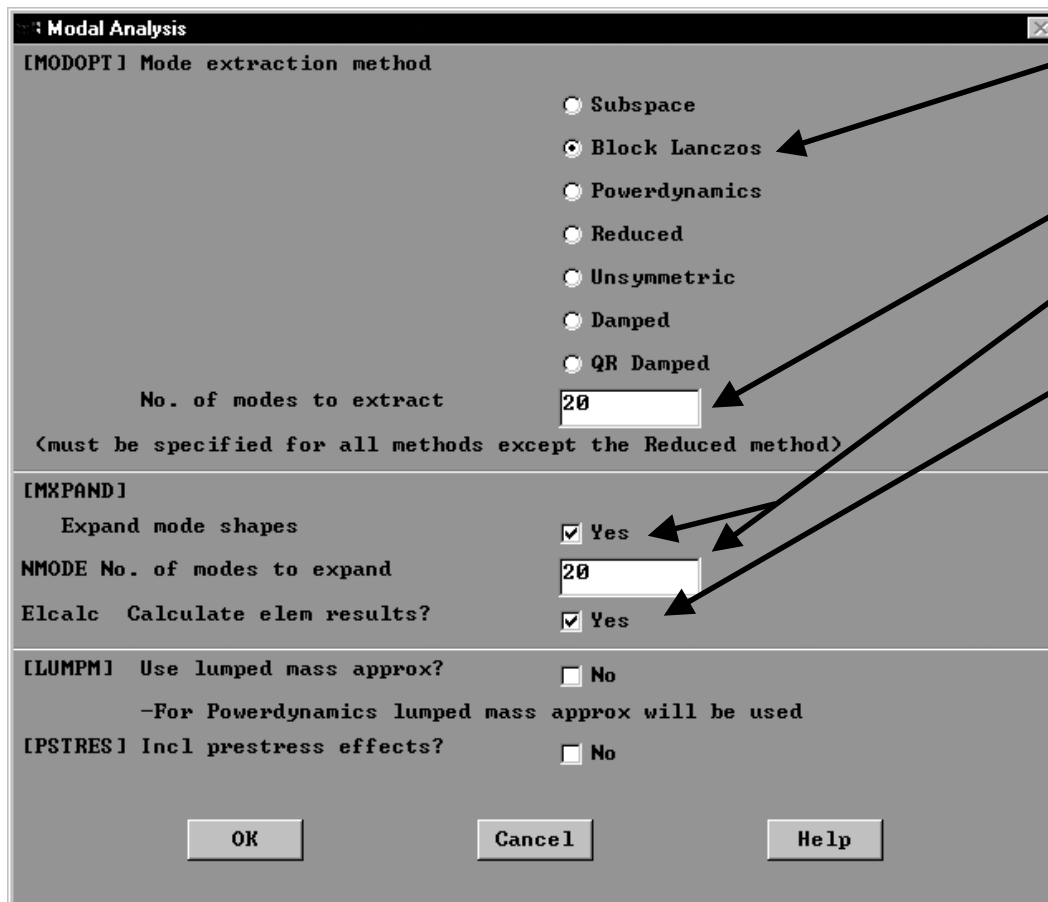


•Pick Modal

CSI ANSYS Tip of the Week

Specify Modal Analysis Options

ANSYS Main Menu > Solution > Analysis Options



The image shows the 'Modal Analysis' dialog box in ANSYS. It is divided into several sections. The top section, '[MODEPT] Mode extraction method', contains radio buttons for Subspace, Block Lanczos (selected), Powerdynamics, Reduced, Unsymmetric, Damped, and QR Damped. Below this is a text input field for 'No. of modes to extract' with the value '20'. A note below the field states '<must be specified for all methods except the Reduced method>'. The middle section, '[MXPAND]', contains a checkbox for 'Expand mode shapes' (checked), a text input field for 'NMODE No. of modes to expand' with the value '20', and a checkbox for 'Elcalc Calculate elem results?' (checked). The bottom section, '[LUMPM]', contains a checkbox for 'Use lumped mass approx?' (unchecked) with a note '-For Powerdynamics lumped mass approx will be used'. The bottom-most section, '[PSTRES]', contains a checkbox for 'Incl prestress effects?' (unchecked). At the bottom of the dialog are three buttons: 'OK', 'Cancel', and 'Help'.

Modal Analysis

[MODEPT] Mode extraction method

☐ Subspace
☒ Block Lanczos
☐ Powerdynamics
☐ Reduced
☐ Unsymmetric
☐ Damped
☐ QR Damped

No. of modes to extract: 20
<must be specified for all methods except the Reduced method>

[MXPAND]

Expand mode shapes: ☒ Yes
NMODE No. of modes to expand: 20
Elcalc Calculate elem results?: ☒ Yes

[LUMPM] Use lumped mass approx?: ☐ No
-For Powerdynamics lumped mass approx will be used

[PSTRES] Incl prestress effects?: ☐ No

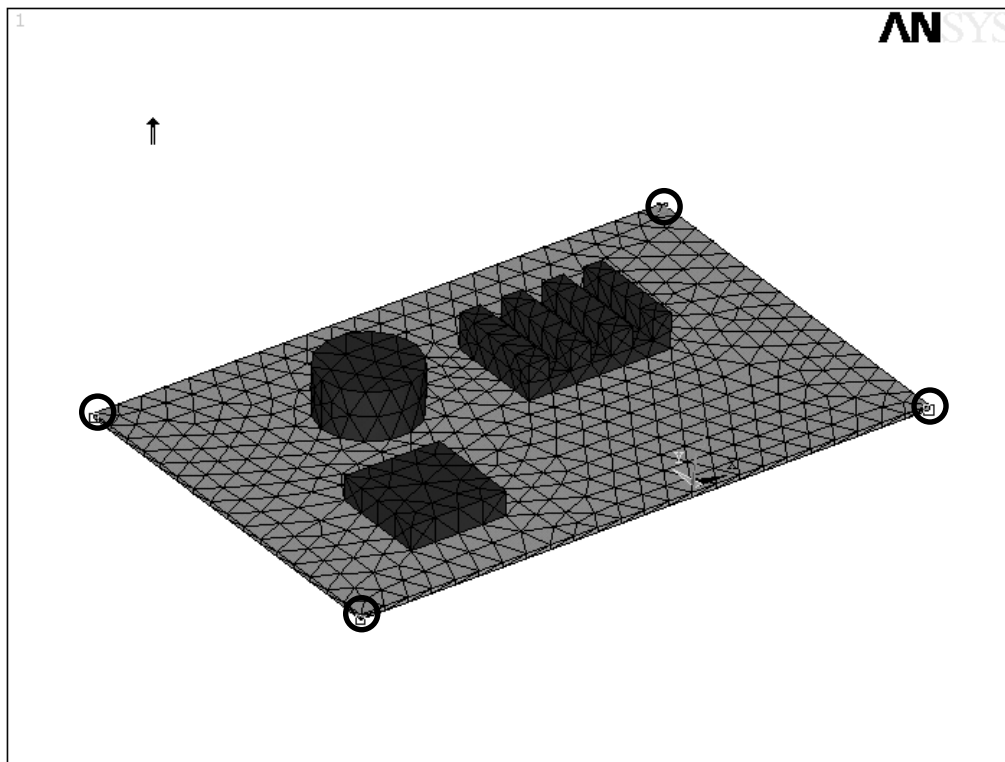
OK Cancel Help

- Pick Modal Extraction Method (Block Lanczos a good choice)
- Specify 20 modes to extract
- Expand all modes
- Calculate Element results

CSI ANSYS Tip of the Week

Constrain Board

ANSYS Main Menu > Solution > Apply > Displacement > On Nodes

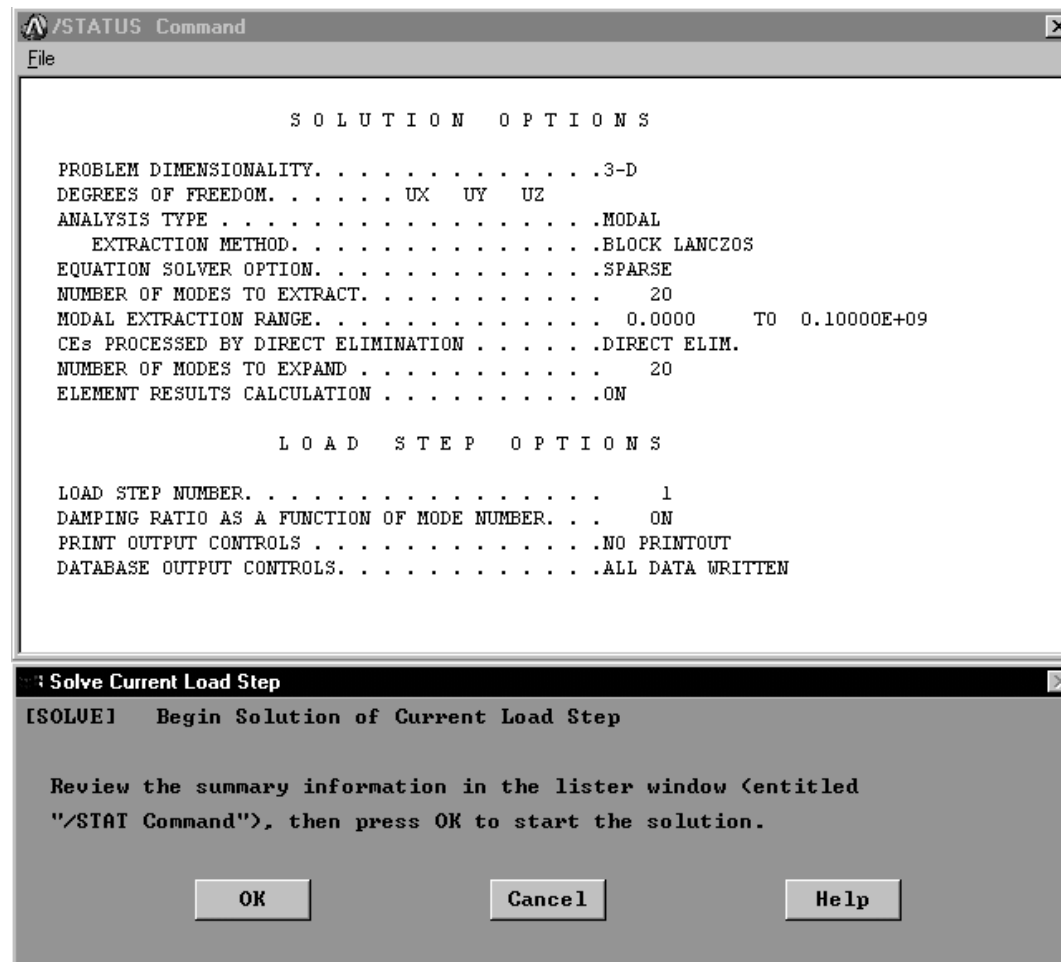


- Pick the 4 corner nodes on the bottom side of the board
 - 1748
 - 1782
 - 1902
 - 2038
- Constrain All DOF (UX,UY,UZ)

CSI ANSYS Tip of the Week

Solve Modal

ANSYS Main Menu > Solution > Solve

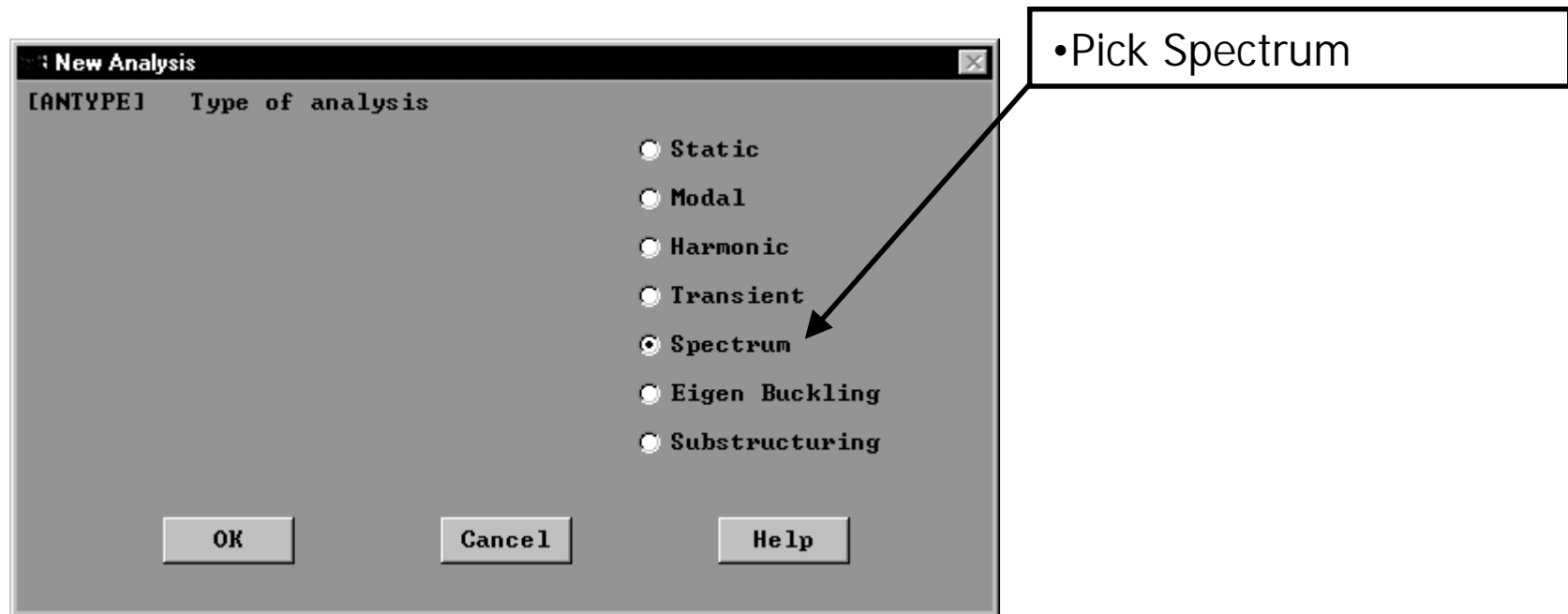


CSI ANSYS Tip of the Week

Specify Spectrum Analysis

ANSYS Main Menu> Finish

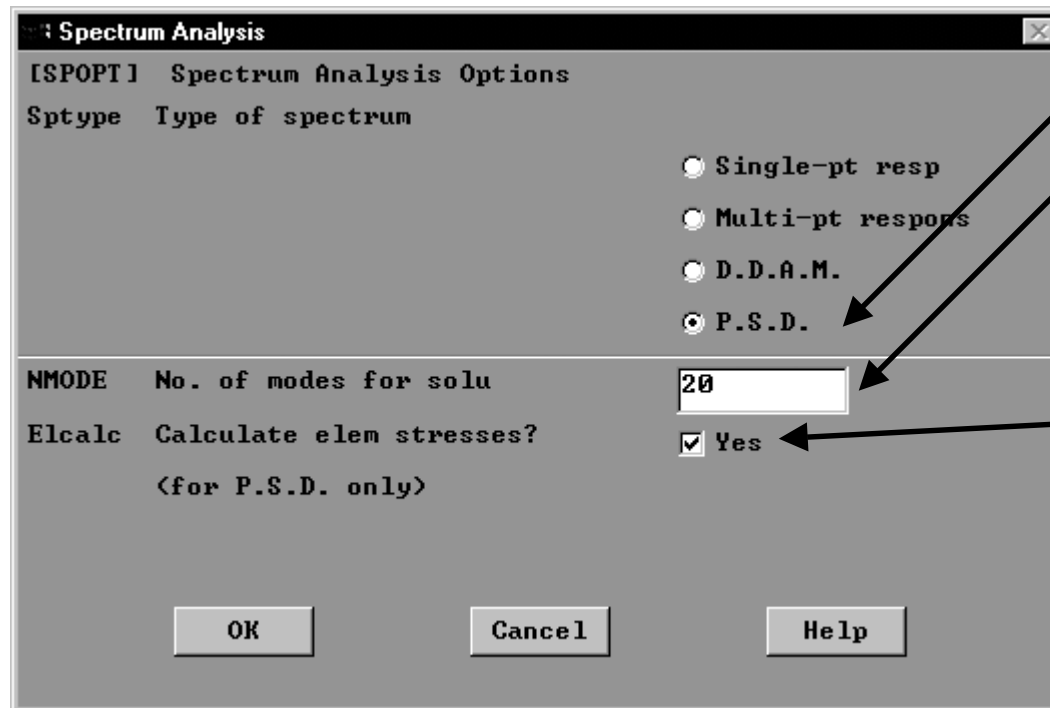
ANSYS Main Menu> Solution > New Analysis



CSI ANSYS Tip of the Week

Specify Analysis Options

ANSYS Main Menu > Solution > Analysis Options

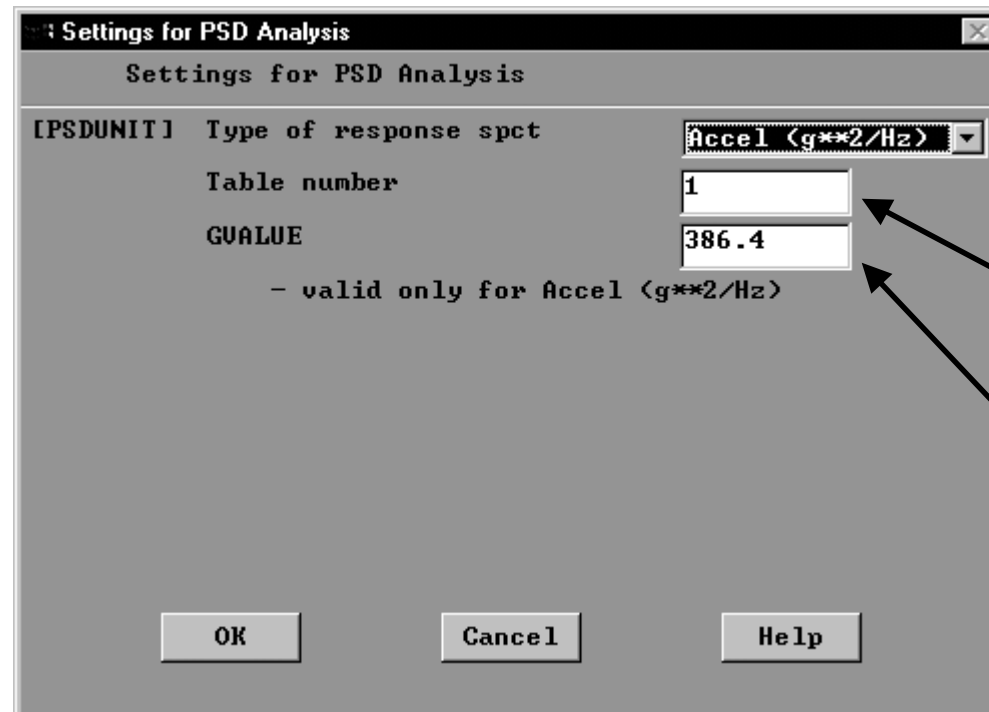


- Specify P.S.D
- Specify the number of modes from the modal to include in the PSD analysis.
- Specify to Calculate Element Results (stresses, strains, etc.)

CSI ANSYS Tip of the Week

Specify PSD Settings

ANSYS Main Menu > Solution > Spectrum > PSD > Settings



- Input data will be in terms of g^2/Hz , therefore specify this setting
- Analysis has one PSD table, therefore leave table number to 1
- Specify Value of acceleration due to gravity (g)

CSI ANSYS Tip of the Week

Specify PSD vs. Frequency

ANSYS Main Menu > Solution > Spectrum > PSD > PSD vs. Freq

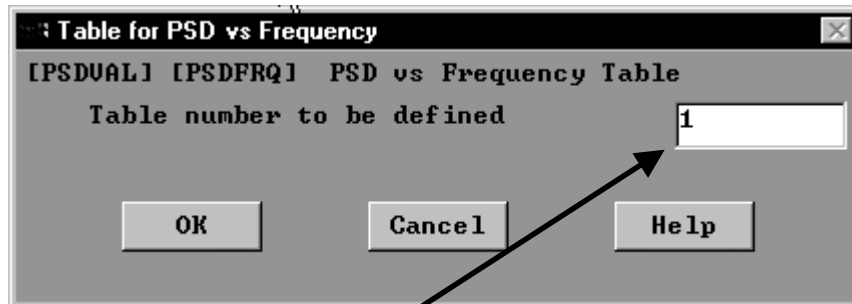


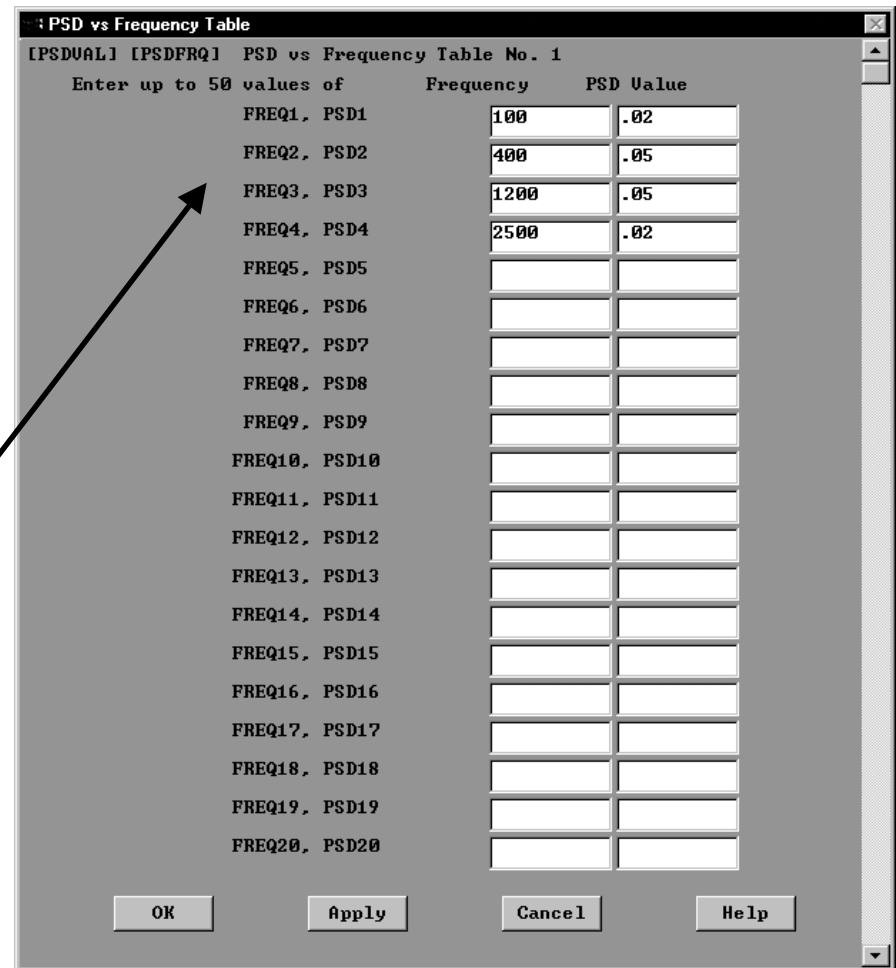
Table for PSD vs Frequency

[PSDUAL] [PSDFRQ] PSD vs Frequency Table

Table number to be defined:

OK Cancel Help

- Specify 1 for the PSD Table (only one table in this analysis)
- Enter Frequency and Value data



PSD vs Frequency Table

[PSDUAL] [PSDFRQ] PSD vs Frequency Table No. 1

Enter up to 50 values of

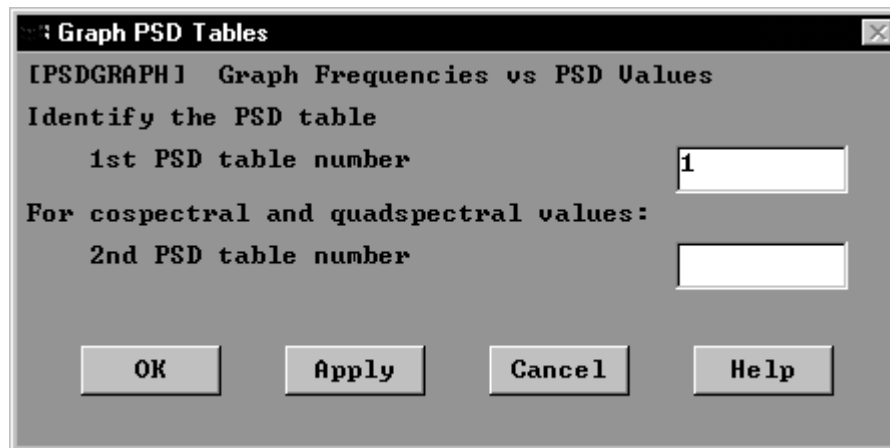
	Frequency	PSD Value
FREQ1, PSD1	100	.02
FREQ2, PSD2	400	.05
FREQ3, PSD3	1200	.05
FREQ4, PSD4	2500	.02
FREQ5, PSD5		
FREQ6, PSD6		
FREQ7, PSD7		
FREQ8, PSD8		
FREQ9, PSD9		
FREQ10, PSD10		
FREQ11, PSD11		
FREQ12, PSD12		
FREQ13, PSD13		
FREQ14, PSD14		
FREQ15, PSD15		
FREQ16, PSD16		
FREQ17, PSD17		
FREQ18, PSD18		
FREQ19, PSD19		
FREQ20, PSD20		

OK Apply Cancel Help

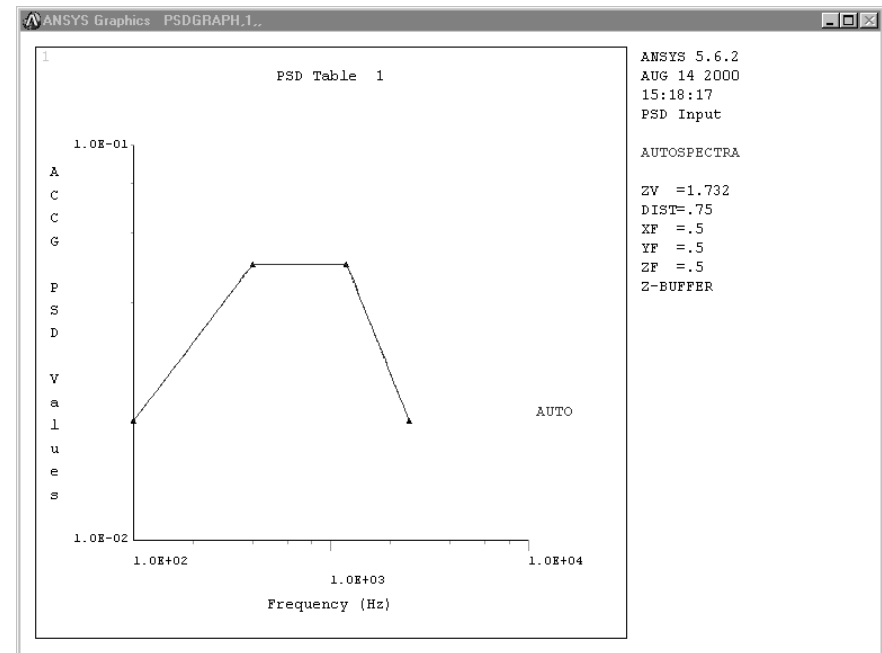
CSI ANSYS Tip of the Week

Plot Input PSD

ANSYS Main Menu > Solution > Spectrum > PSD > Plot



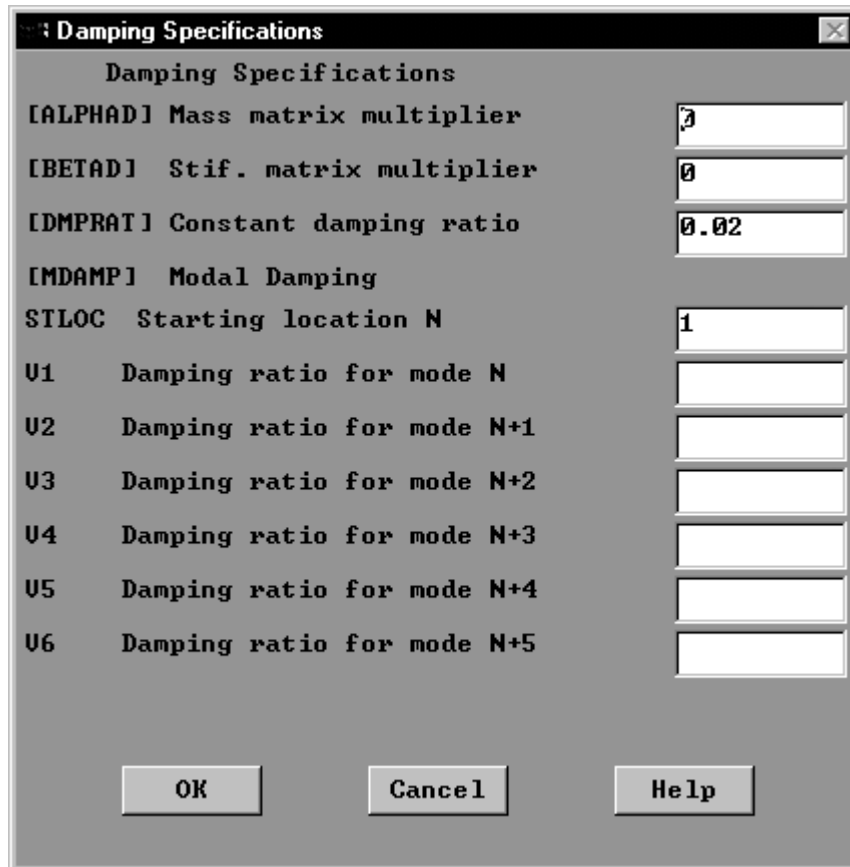
•Set table to 1



CSI ANSYS Tip of the Week

Specify Damping

ANSYS Main Menu > Solution > Time/Frequency > Damping



The image shows the 'Damping Specifications' dialog box in ANSYS. It contains the following fields and options:

Field/Option	Value
[ALPHAD] Mass matrix multiplier	3
[BETAD] Stif. matrix multiplier	0
[DMPRAT] Constant damping ratio	0.02
[MDAMP] Modal Damping	
STLOC Starting location N	1
U1 Damping ratio for mode N	
U2 Damping ratio for mode N+1	
U3 Damping ratio for mode N+2	
U4 Damping ratio for mode N+3	
U5 Damping ratio for mode N+4	
U6 Damping ratio for mode N+5	

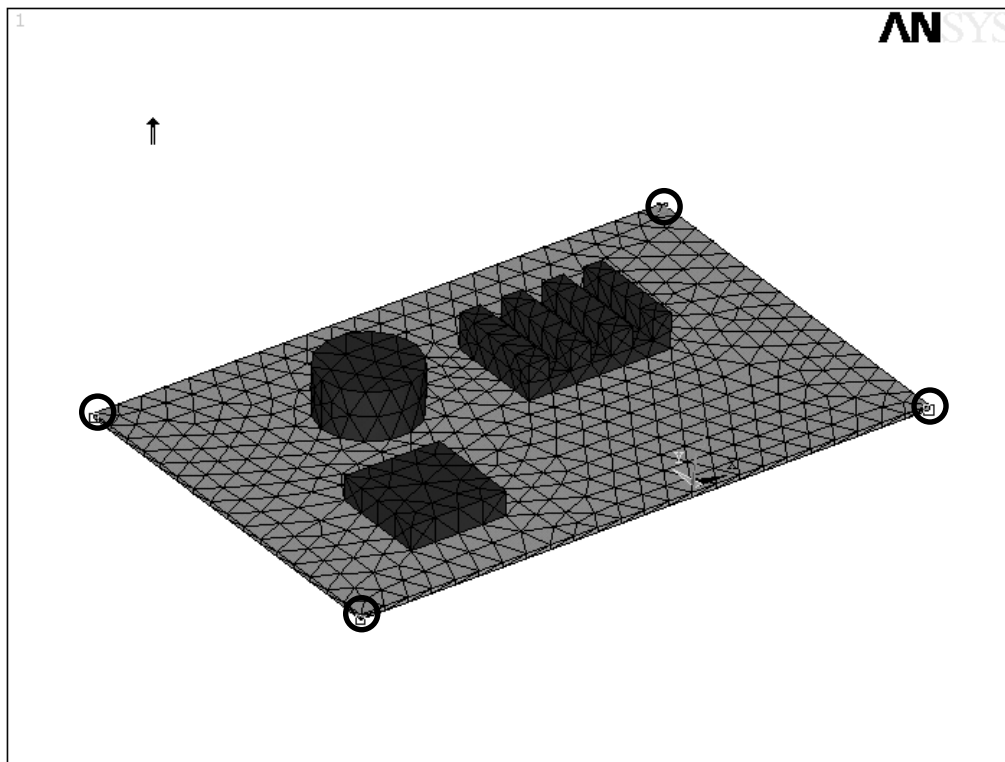
Buttons: OK, Cancel, Help

•Specify 2% Constant Damping Ratio

CSI ANSYS Tip of the Week

Flag Nodes to get PSD Input

ANSYS Main Menu > Solution > Apply > Spectrum > Base PSD Excit > On Nodes



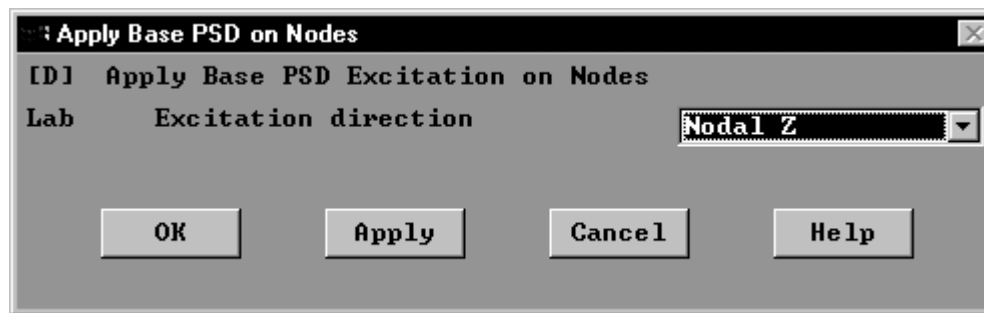
• Pick the 4 corner nodes on the bottom side of the board

- 1748
- 1782
- 1902
- 2038

CSI ANSYS Tip of the Week

Flag Nodes to get PSD Input

ANSYS Main Menu > Solution > Apply > Spectrum > Base PSD Excit > On Nodes



- Specify Excitation direction to Z

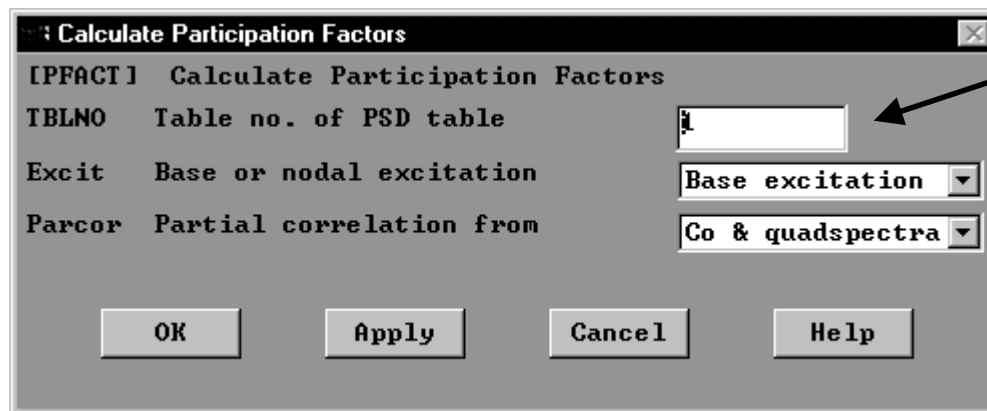
Note: This will flag a 1 displacement on the node telling ANSYS the previously defined PSD table is to be applied. You can apply base excitations only at nodes that were constrained in the modal analysis.

- UX,UY =0 Constraints on these 4 nodes are left over from Modal Analysis, and remain through PSD Analysis. No need to re-specify them.

CSI ANSYS Tip of the Week

Solve for Participation Factors

ANSYS Main Menu > Solution > Apply > Spectrum > Calculate PF ...



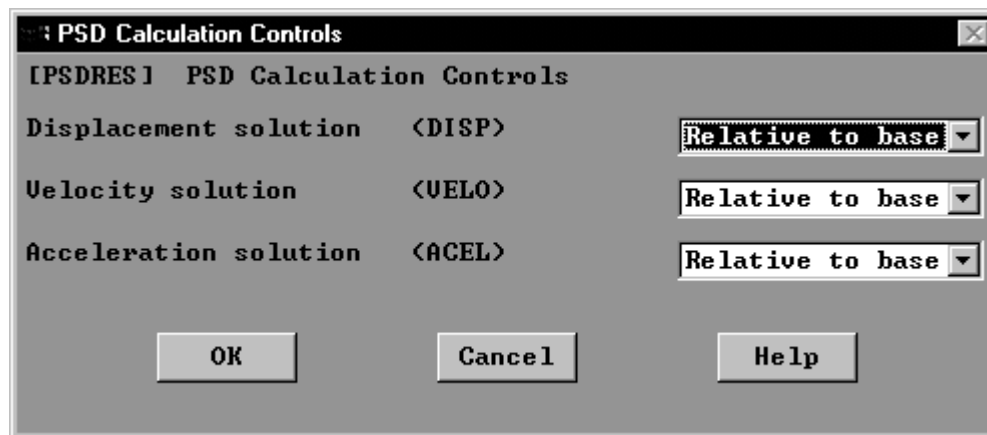
- Specify 1 for table
- Specify Base excitation Problem
- Leave parcor to default. Not required for single PSD excitation

Note: This step Calculates the participation factors for the specified PSD table

CSI ANSYS Tip of the Week

Set PSD Calculation Controls

ANSYS Main Menu > Solution > Spectrum > PSD > Calc Controls



• Specify all Solution items are to be calculated Relative to Base. This means the input excitation is subtracted out. Input nodes have their results reported as zero.

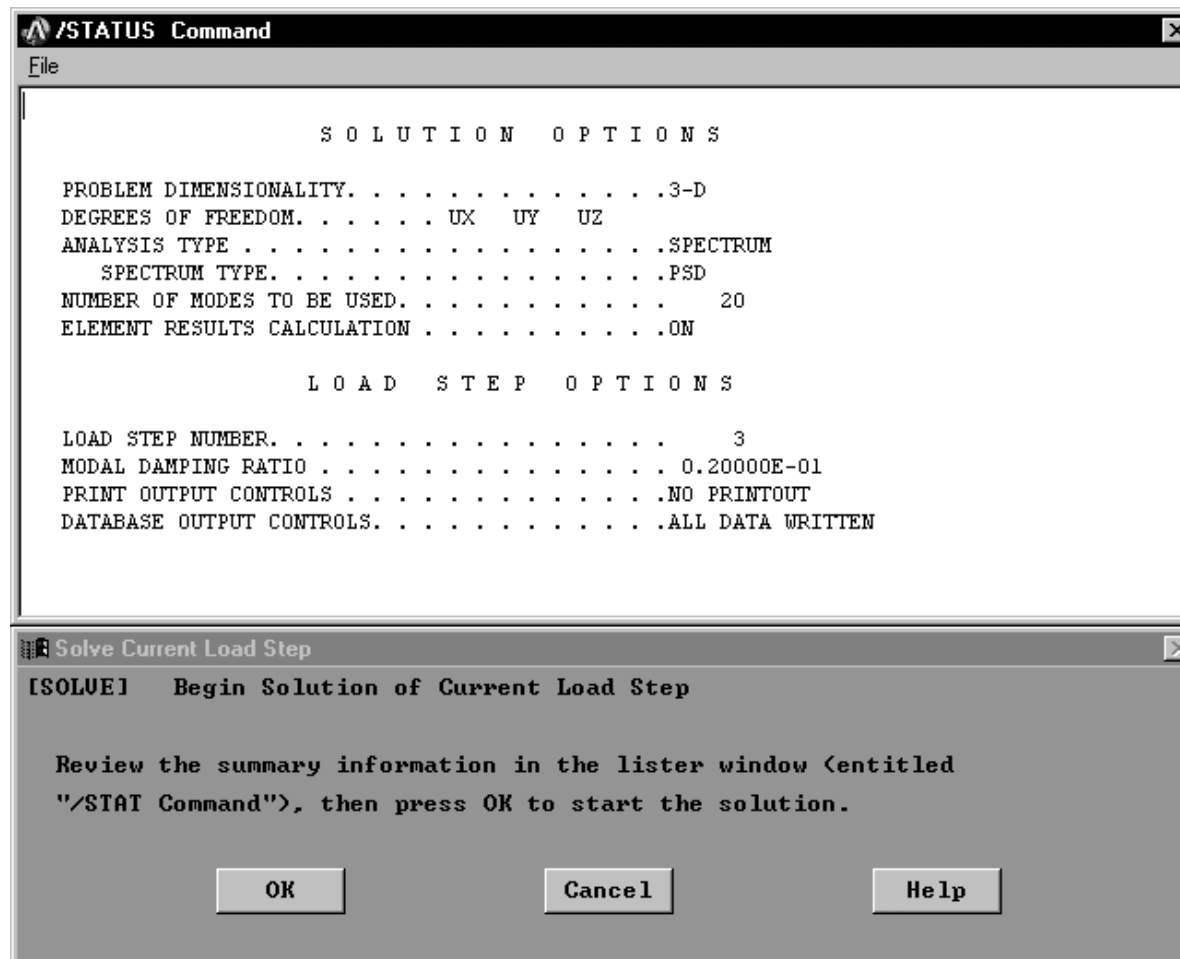
Note:

These specifications are for the general postprocessor results, not the time history postprocessor.

CSI ANSYS Tip of the Week

Solve Random Vibration Solution

ANSYS Main Menu > Solution > Solve > Current LS

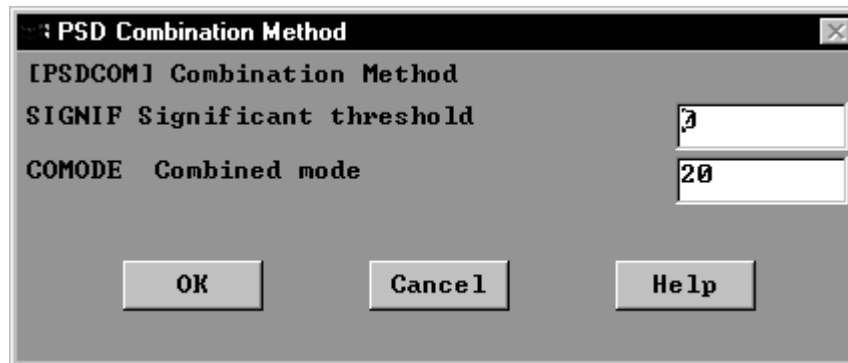


CSI ANSYS Tip of the Week

Set Mode Combination

ANSYS Main Menu> Finish

ANSYS Main Menu> Solution > Spectrum > PSD > Mode Combine ...

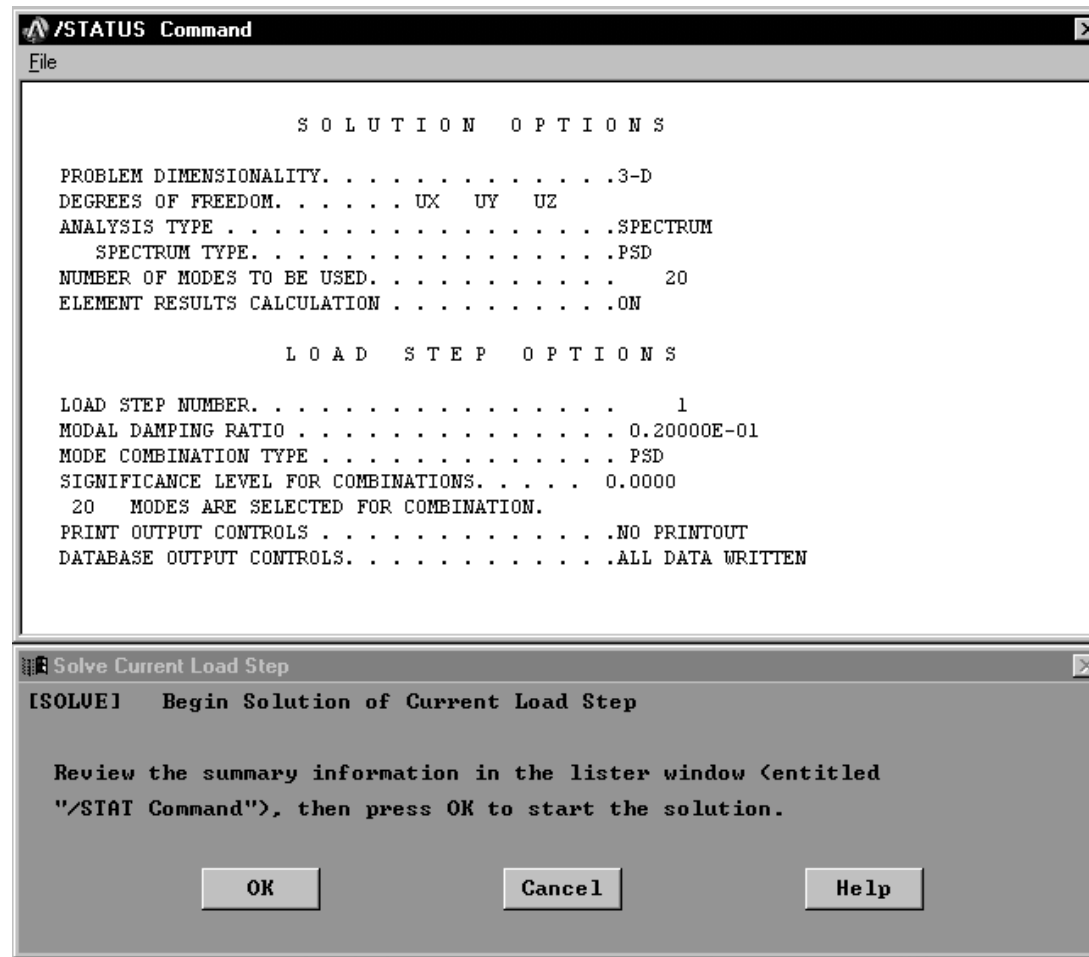


- Leave significance at 0.
- All 20 modes will be used in mode combination

CSI ANSYS Tip of the Week

Calculate mode combinations and 1 sigma response

ANSYS Main Menu > Solution > Solve > Current LS



CSI ANSYS Tip of the Week

Post Processing Results Summary

ANSYS Main Menu > General Post Processor > Results Summary

- Load step 1 - modal results
- Load step 2 - unit static solutions
- Load step 3 - 1 sigma displacements, strains, stresses
- Load step 4 - 1 sigma velocities
- Load step 5 - 1 sigma accelerations

Results File: junk.rst

Available Data Sets:

Set	Frequency	Load Step	Substep	Cumulative
12	1533.6	1	12	12
13	1689.9	1	13	13
14	1782.6	1	14	14
15	1925.8	1	15	15
16	2028.7	1	16	16
17	2081.6	1	17	17
18	2190.3	1	18	18
19	2496.0	1	19	19
20	2518.7	1	20	20
21	0.0000	2	1	21
22	0.0000	3	1	22
23	0.0000	4	1	23
24	0.0000	5	1	24

Read Next Previous

Close Help

CSI ANSYS Tip of the Week

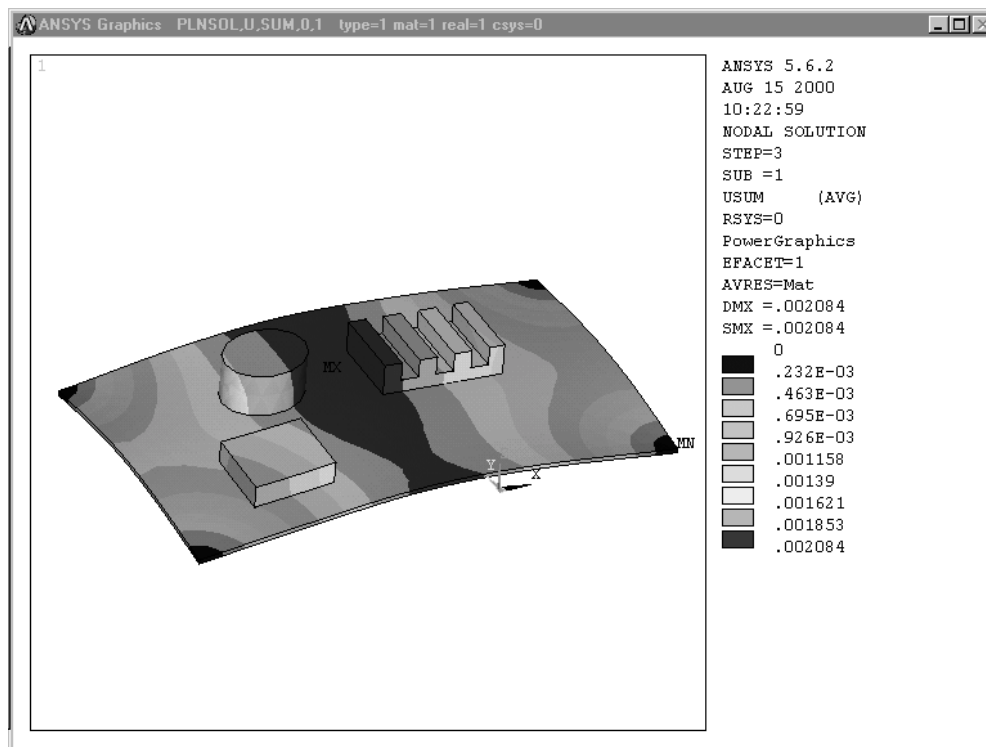
1 sigma Results

1 σ results are typically used for:

- First passage failure calculations
 - What is the probability that the displacement at a DOF will exceed a displacement limit in a given time period?
- Fatigue calculations
 - Based on the premise that the stress level is at or below 1 σ 68.2% of the time, between 1 σ and 2 σ 27.2% of the time (95.4-68.2), and between 2 σ and 3 σ 4.3% of the time (99.7-95.4), and above 3 σ less than .3% of the time.

Post Processing 1 sigma Displacements

ANSYS Main Menu > General Post Processor > Plot Results > Nodal Solution
>DOF Solution > USUM

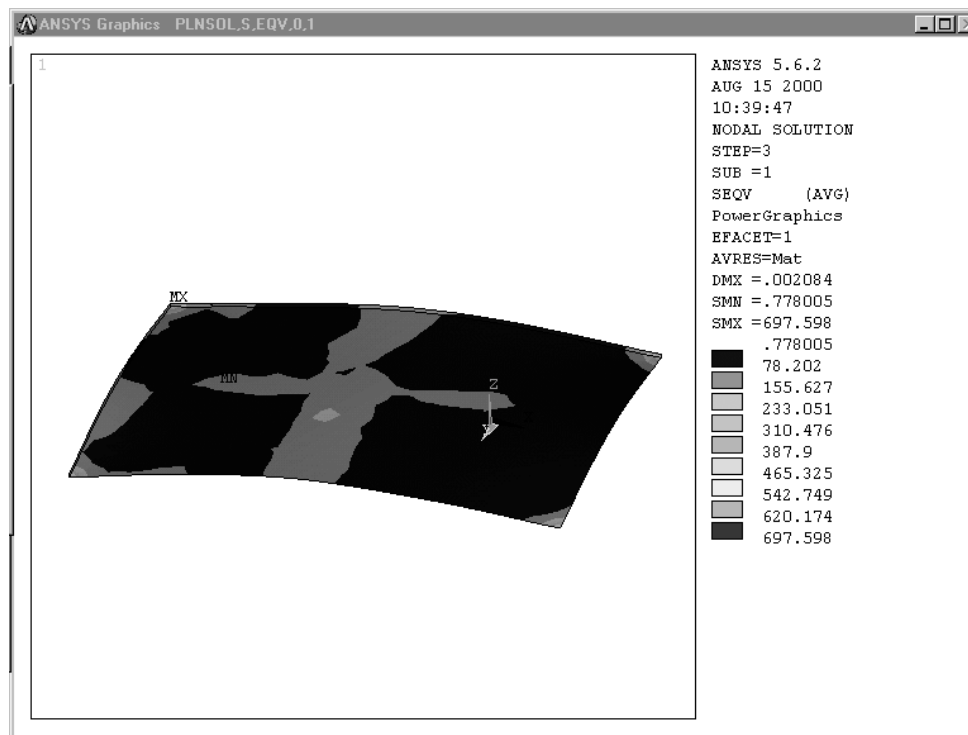


- 1 sigma board deflection = .002"
- 3 sigma board deflection = $3 * .002"$
= .006"
- Therefore, only .3% of the time,
board deflection will exceed .006"

CSI ANSYS Tip of the Week

Post Processing 1 sigma Stresses

ANSYS Main Menu > General Post Processor > Plot Results > Nodal Solution
> Stress > SEQV

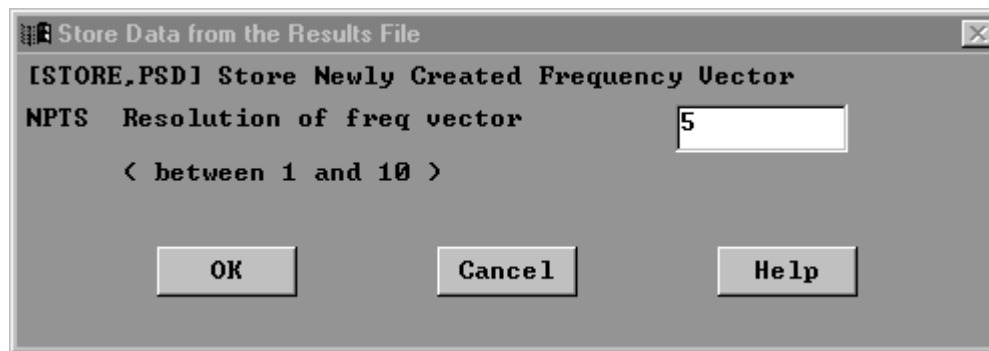


- 1 sigma corner stress = 698 psi
- 3 sigma corner stress = $3 \times 698 \text{ psi} = 2094 \text{ psi}$
- Therefore, only .3% of the time, board corner stress will exceed 2094 psi
- Note: For simplicity in this model, the corner nodes are constrained. This creates singular stress results. In reality, modeling and holding the actual mounting hold would provide more accurate results.

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Store Data

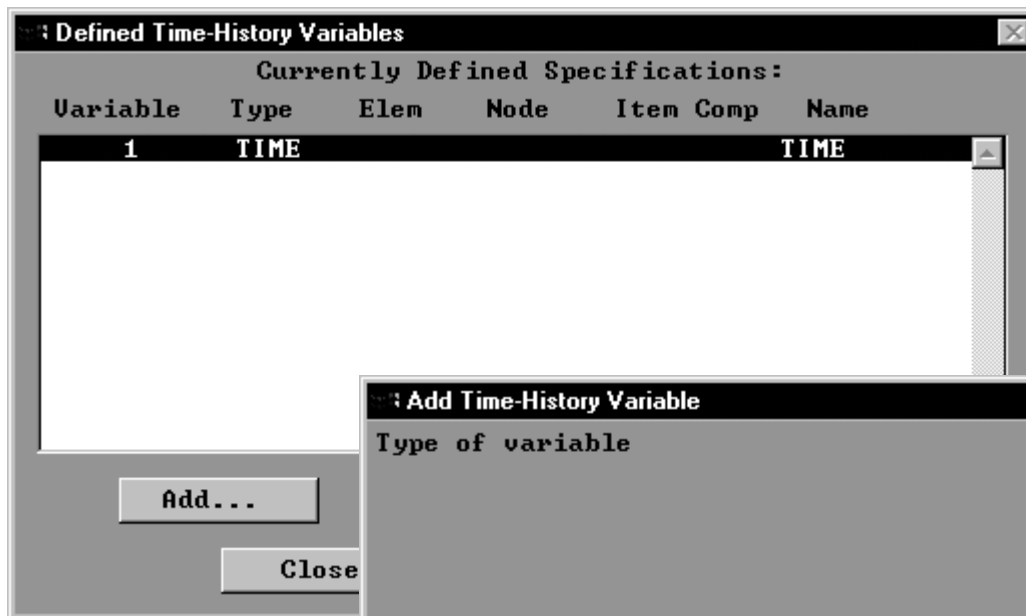


- This command sets the resolution of the frequency vector for the PSD curve. 10 gives finer results 1 gives coarser results. 5 is the default.

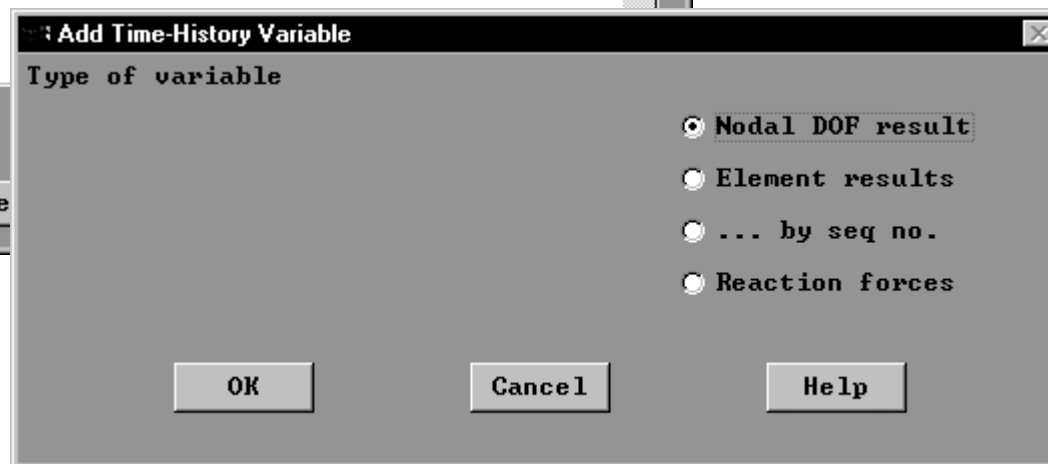
CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Define Variables



- This command defines the variables that we want to see as a function of time or frequency

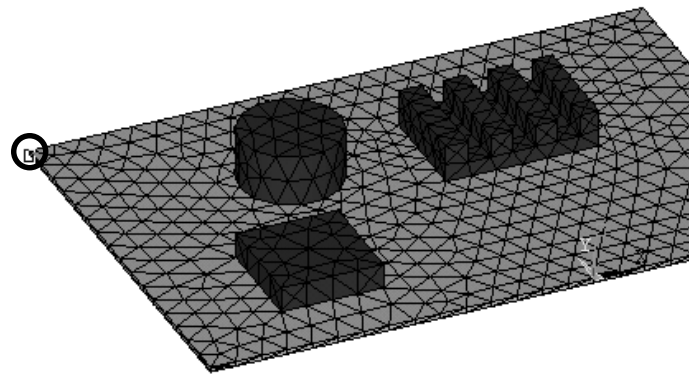


CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Define Variables

Pick one corner node that was constrained. 1748 is picked in this case.

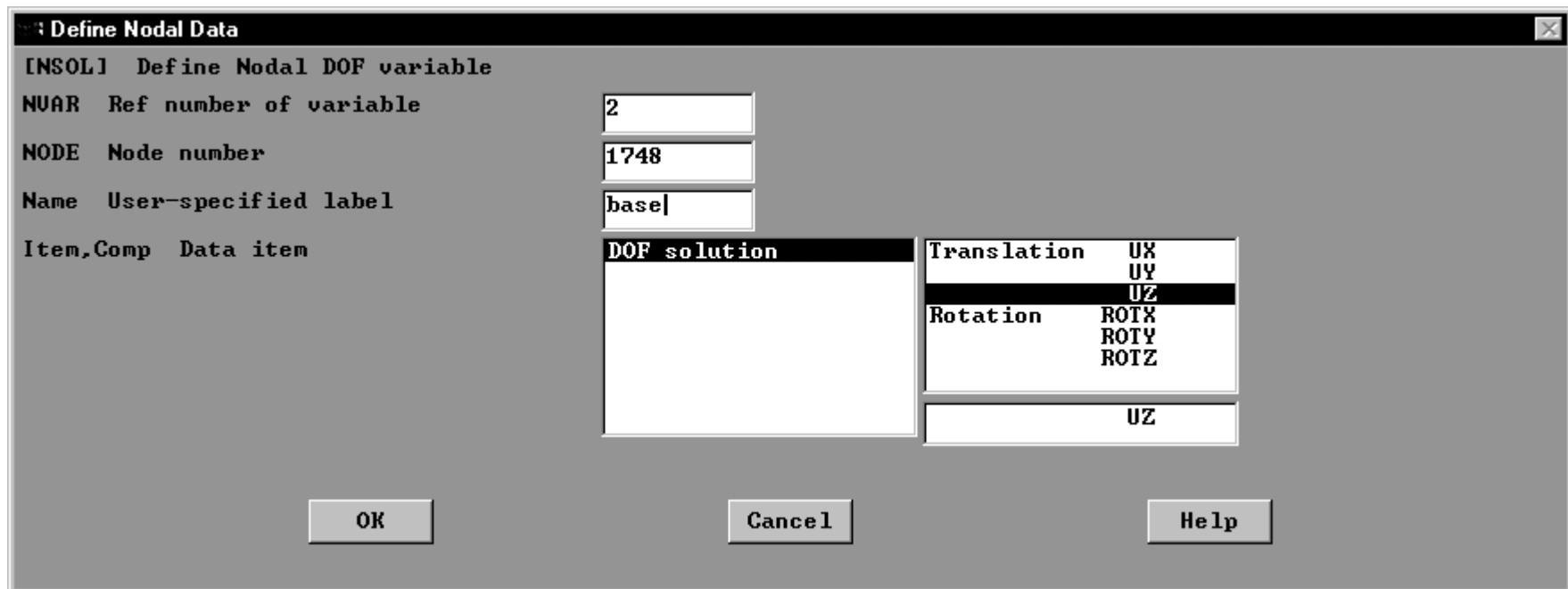


Define Nodal Data	
<input checked="" type="radio"/> Pick	<input type="radio"/> Unpick
<input type="radio"/> Single	<input type="radio"/> Box
<input type="radio"/> Polygon	<input type="radio"/> Circle
<input type="radio"/> Loop	
Count = 1	
Maximum = 1	
Minimum = 1	
Node No. = 1748	
For Keyboard Entry:	
<input checked="" type="radio"/> List of Items	
<input type="radio"/> Min, Max, Inc	
OK	Apply
Reset	Cancel
Pick All	Help

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu> Time History Post Processor > Define Variables



Define Nodal Data

[INSOL] Define Nodal DOF variable

NVAR Ref number of variable: 2

NODE Node number: 1748

Name User-specified label: base

Item,Comp	Data item												
DOF solution	<table border="1"> <tr> <td>Translation</td> <td>UX</td> </tr> <tr> <td></td> <td>UY</td> </tr> <tr> <td></td> <td>UZ</td> </tr> <tr> <td>Rotation</td> <td>ROTX</td> </tr> <tr> <td></td> <td>ROTY</td> </tr> <tr> <td></td> <td>ROTZ</td> </tr> </table>	Translation	UX		UY		UZ	Rotation	ROTX		ROTY		ROTZ
Translation	UX												
	UY												
	UZ												
Rotation	ROTX												
	ROTY												
	ROTZ												

UZ

OK Cancel Help

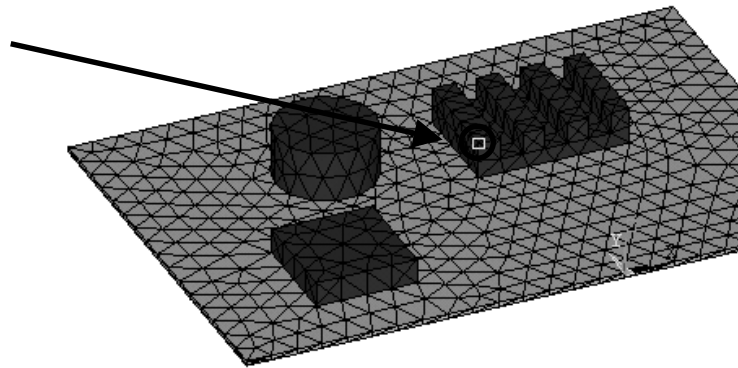
Specify UZ DOF and specify a label, in this case label is called base.

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Define Variables

Pick node 350 on top of component

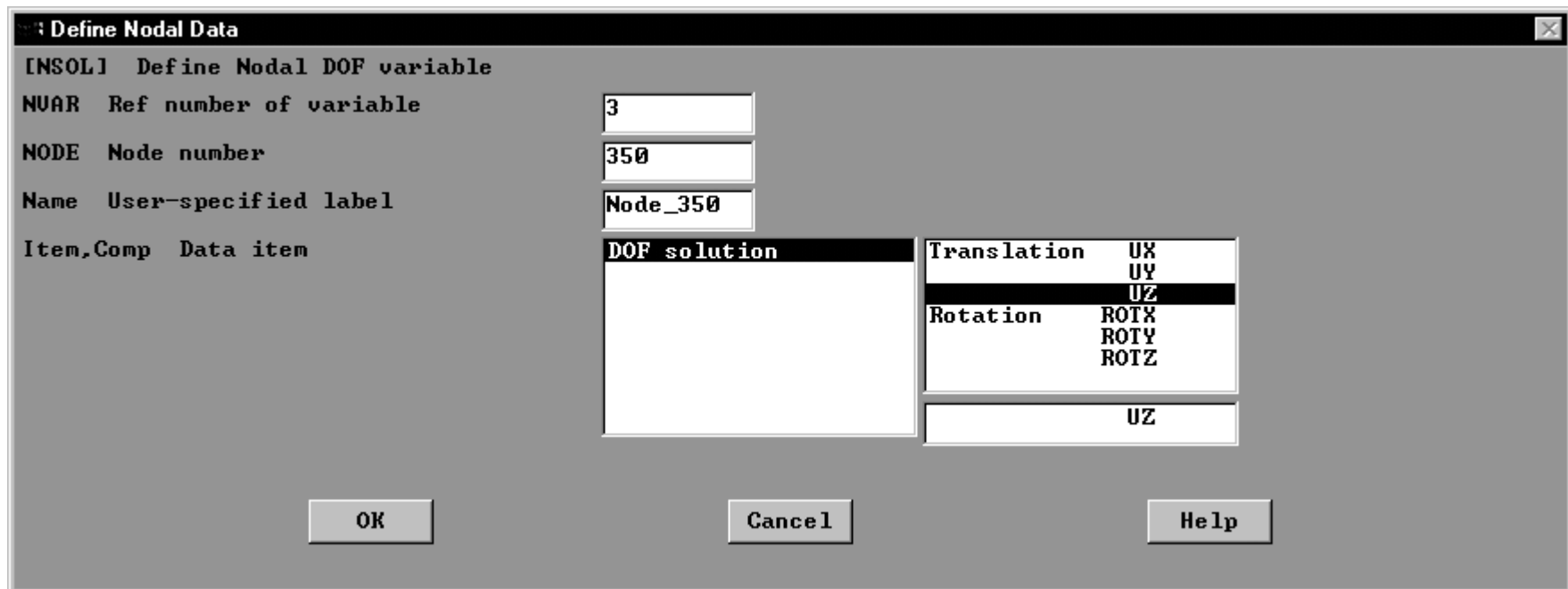


Define Nodal Data	
<input checked="" type="radio"/> Pick	<input type="radio"/> Unpick
<hr/>	
<input type="radio"/> Single	<input type="radio"/> Box
<input type="radio"/> Polygon	<input type="radio"/> Circle
<input type="radio"/> Loop	
<hr/>	
Count	= 1
Maximum	= 1
Minimum	= 1
Node No.	= 350
<hr/>	
For Keyboard Entry:	
<input checked="" type="radio"/> List of Items	
<input type="radio"/> Min, Max, Inc	
<hr/>	
OK	Apply
Reset	Cancel
Pick All	Help

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu> Time History Post Processor > Define Variables



Define Nodal Data

[INSOL] Define Nodal DOF variable

NVAR Ref number of variable: 3

NODE Node number: 350

Name User-specified label: Node_350

Item,Comp	Data item												
DOF solution	<table border="1"> <tr> <td>Translation</td> <td>UX</td> </tr> <tr> <td></td> <td>UY</td> </tr> <tr> <td></td> <td>UZ</td> </tr> <tr> <td>Rotation</td> <td>ROTX</td> </tr> <tr> <td></td> <td>ROTY</td> </tr> <tr> <td></td> <td>ROTZ</td> </tr> </table>	Translation	UX		UY		UZ	Rotation	ROTX		ROTY		ROTZ
Translation	UX												
	UY												
	UZ												
Rotation	ROTX												
	ROTY												
	ROTZ												

UZ

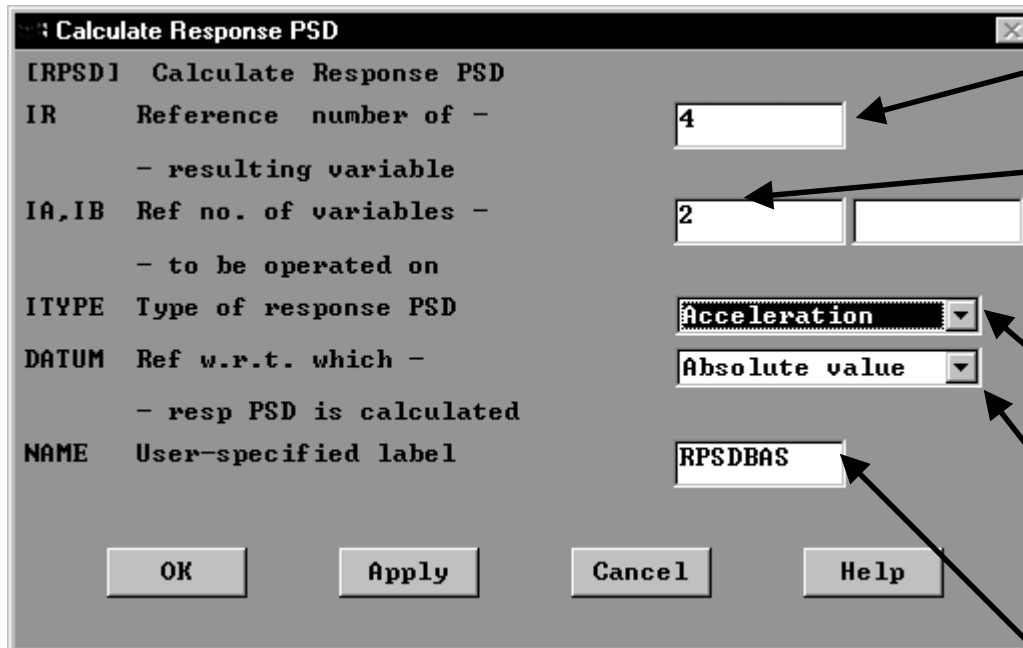
OK Cancel Help

Specify UZ DOF and specify a label, in this case label is called Node_350.

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Calculate Resp PSD



Calculate Response PSD

[RPSD] Calculate Response PSD

IR Reference number of - 4

- resulting variable

IA,IB Ref no. of variables - 2

- to be operated on

ITYPE Type of response PSD Acceleration

DATUM Ref w.r.t. which - Absolute value

- resp PSD is calculated

NAME User-specified label RPSDBAS

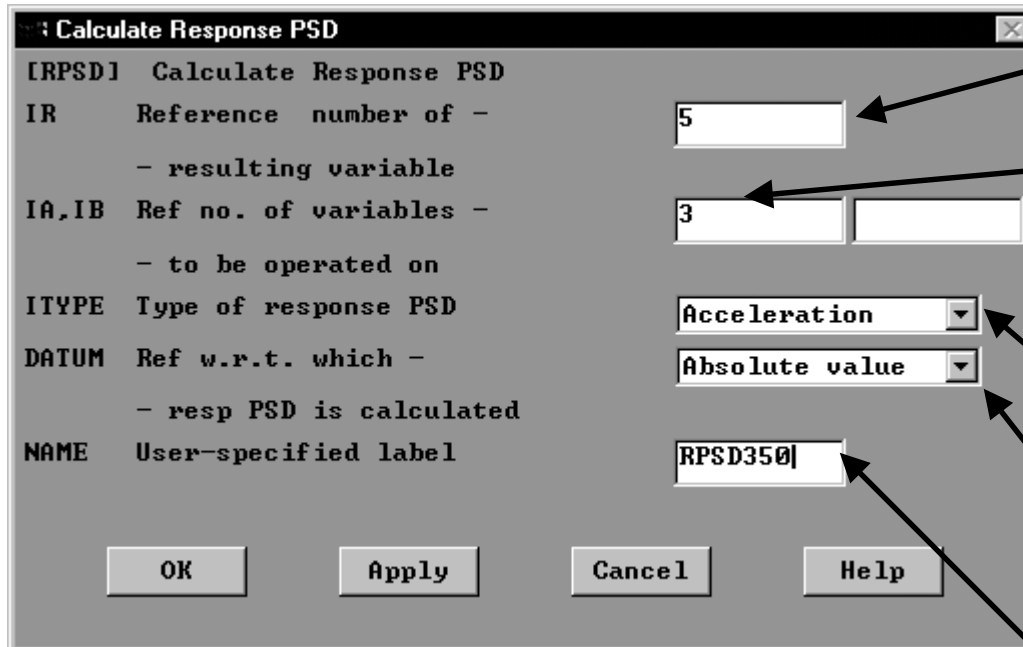
OK Apply Cancel Help

- Specify new variable number to store PSD in
- Specify existing variable number that has DOF solution. In this case 2 is the corner node base excitation.
- Specify the response to be acceleration.
- Specify absolute in order to plot input PSD and response PSD together
- Give new variable a label

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Calculate Resp PSD



Calculate Response PSD

[RPSD] Calculate Response PSD

IR Reference number of - 5

- resulting variable

IA,IB Ref no. of variables - 3

- to be operated on

ITYPE Type of response PSD Acceleration

DATUM Ref w.r.t. which - Absolute value

- resp PSD is calculated

NAME User-specified label RPSD350

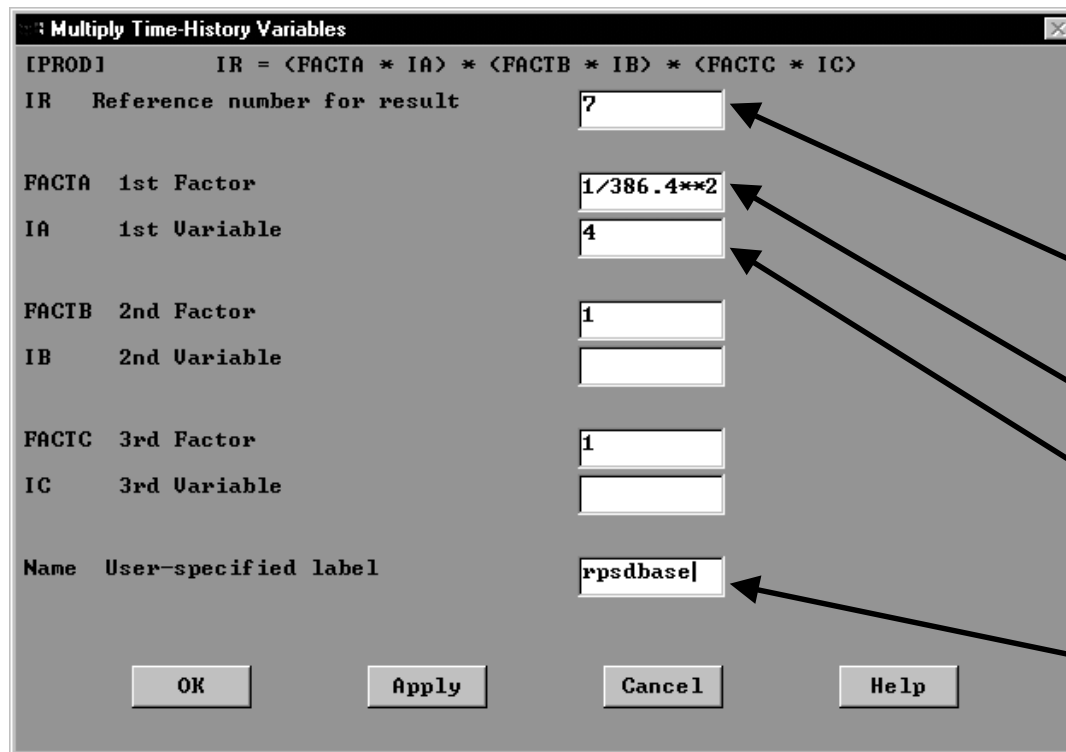
OK Apply Cancel Help

- Specify new variable number to store PSD in
- Specify existing variable number that has DOF solution. In this case 3 is the node on top of a component
- Specify the response to be acceleration.
- Specify absolute in order to plot input PSD and response PSD together
- Give new variable a label

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Math Operations



Multiply Time-History Variables

[PROD] IR = <FACTA * IA> * <FACTB * IB> * <FACTC * IC>

IR Reference number for result

FACTA 1st Factor

IA 1st Variable

FACTB 2nd Factor

IB 2nd Variable

FACTC 3rd Factor

IC 3rd Variable

Name User-specified label

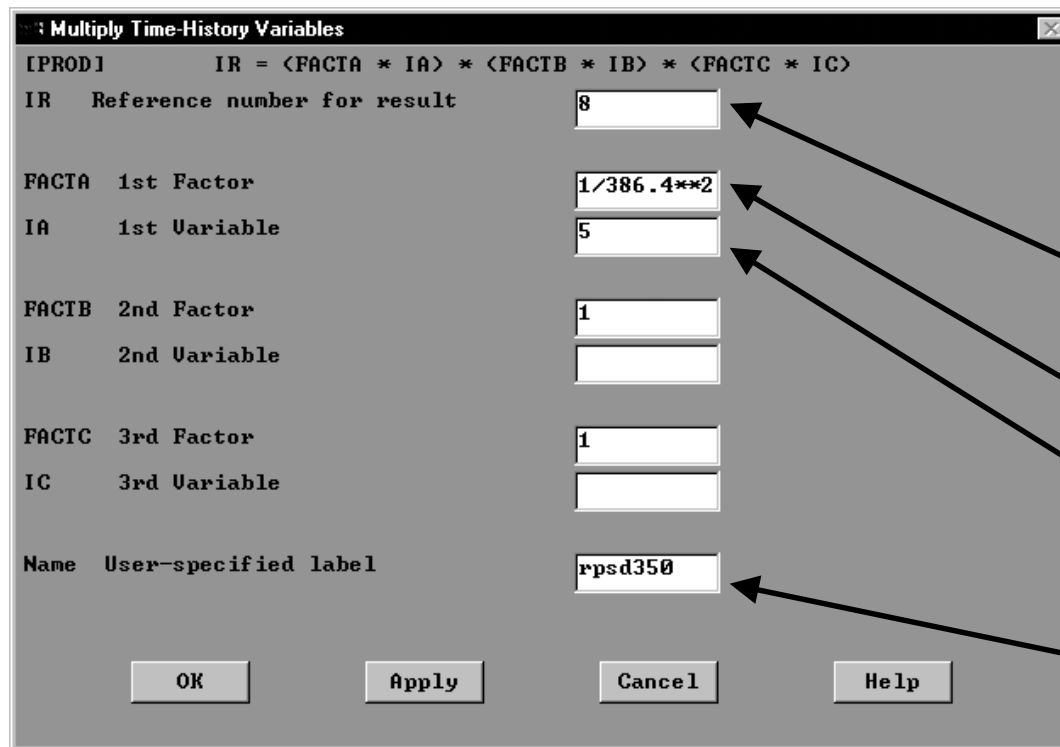
OK Apply Cancel Help

- Convert results from $\text{in}^2/\text{sec}^4/\text{Hz}$ into g^2/Hz by dividing results by $1/\text{g}^2 = 1/386.4^{**2}$
- Specify variable 7 gets the results of this operation
- Specify $1/\text{g}^2$ factor
- Specify variable 4 to operate on. This has the input PSD in $\text{in}^2/\text{sec}^4/\text{Hz}$
- Give new variable a label

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Math Operations



Multiply Time-History Variables

[PROD1] IR = <FACTA * IA> * <FACTB * IB> * <FACTC * IC>

IR Reference number for result

FACTA 1st Factor

IA 1st Variable

FACTB 2nd Factor

IB 2nd Variable

FACTC 3rd Factor

IC 3rd Variable

Name User-specified label

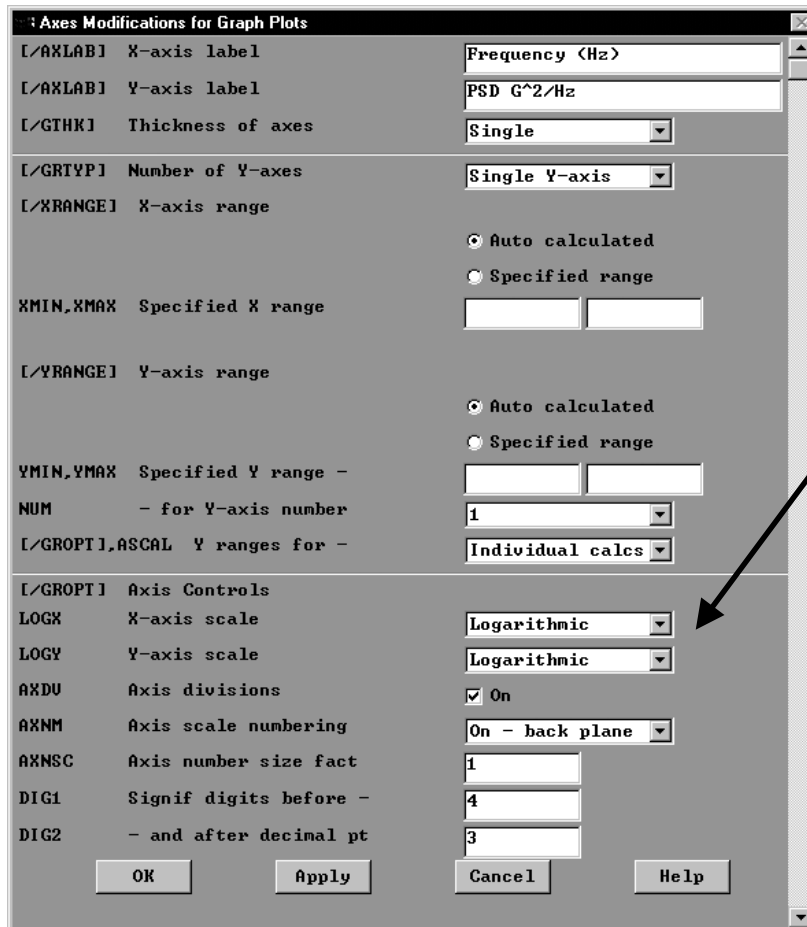
OK Apply Cancel Help

- Convert results from $\text{in}^2/\text{sec}^4/\text{Hz}$ into g^2/Hz by dividing results by $1/\text{g}^2 = 1/386.4^{**2}$
- Specify variable 8 gets the results of this operation
- Specify $1/\text{g}^2$ factor
- Specify variable 5 to operate on. This has the **component node PSD** in $\text{in}^2/\text{sec}^4/\text{Hz}$
- Give new variable a label

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

Plot Controls > Style > Graphs > Modify Axes



Axes Modifications for Graph Plots

[/AXLAB] X-axis label: Frequency <Hz>

[/AYLAB] Y-axis label: PSD G²/Hz

[/GTHK] Thickness of axes: Single

[/GRTYP] Number of Y-axes: Single Y-axis

[/XRANGE] X-axis range: ☐ Auto calculated ☐ Specified range

XMIN,XMAX Specified X range:

[/YRANGE] Y-axis range: ☐ Auto calculated ☐ Specified range

YMIN,YMAX Specified Y range -

NUM - for Y-axis number: 1

[/GROPT],ASCAL Y ranges for - Individual calcs

[/GROPT] Axis Controls

LOGX X-axis scale: Logarithmic

LOGY Y-axis scale: Logarithmic

AXDU Axis divisions: ☒ On

AXNM Axis scale numbering: On - back plane

AXNSC Axis number size fact: 1

DIG1 Signif digits before - 4

DIG2 - and after decimal pt: 3

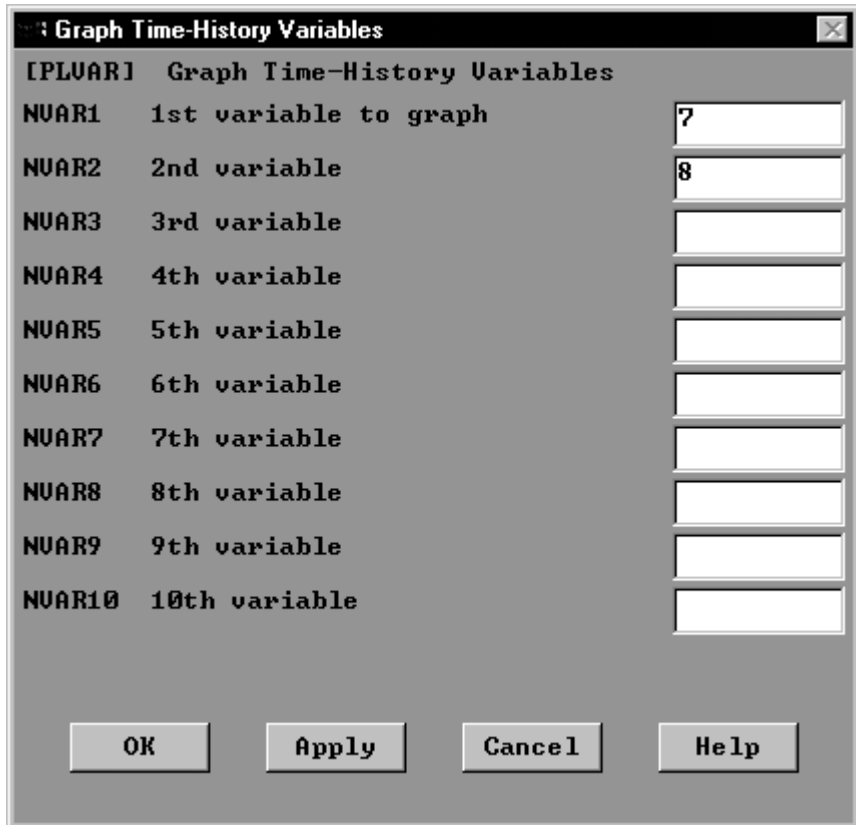
OK Apply Cancel Help

- Define labels for graph
- Set axes to Logarithmic

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Graph Variables



The dialog box titled "Graph Time-History Variables" contains a list of variables to be graphed. The first variable, NVAR1, is labeled "1st variable to graph" and has the value "7" entered in its corresponding input field. The second variable, NVAR2, is labeled "2nd variable" and has the value "8" entered in its input field. The remaining variables, NVAR3 through NVAR10, are labeled "3rd variable" through "10th variable" and have empty input fields. At the bottom of the dialog box are four buttons: OK, Apply, Cancel, and Help.

Variable	Description	Value
NVAR1	1st variable to graph	7
NVAR2	2nd variable	8
NVAR3	3rd variable	
NVAR4	4th variable	
NVAR5	5th variable	
NVAR6	6th variable	
NVAR7	7th variable	
NVAR8	8th variable	
NVAR9	9th variable	
NVAR10	10th variable	

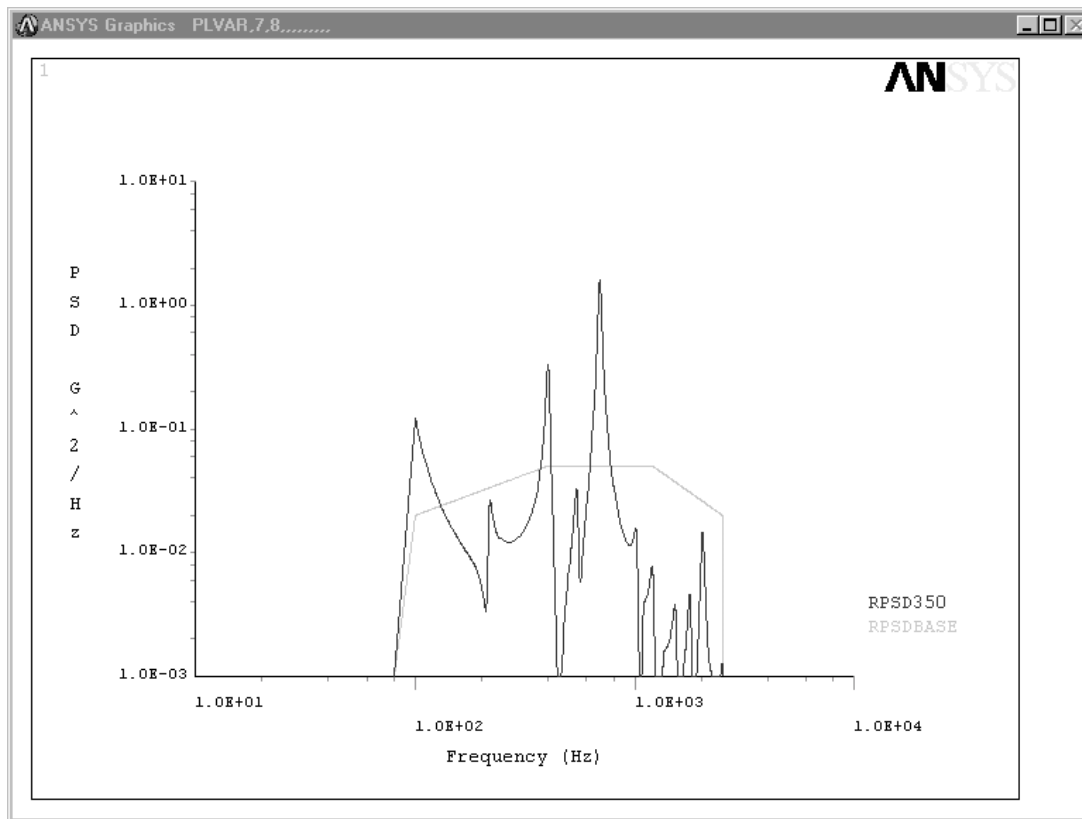
•Plot input PSD (g^2/Hz)
variable 7

•Plot response PSD (g^2/Hz)
variable 8

CSI ANSYS Tip of the Week

Plotting Response PSD in Post 26

ANSYS Main Menu > Time History Post Processor > Graph Variables



- Plot shows the response PSD of the component on the board versus the input PSD at one of the corner nodes.
- From this plot we see the dynamic amplification the circuit board provides from the input PSD.

CSI ANSYS Tip of the Week