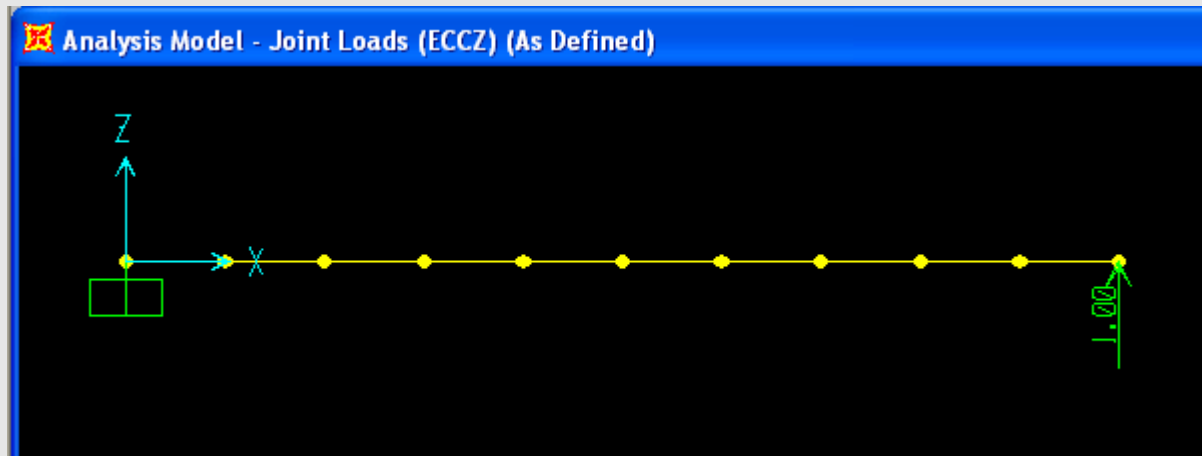


Steady State Analysis Model for the Example in CSI Analysis Reference Manual



Rotating machinery is loading the tip of cantilever structure as shown in the above screen capture.

The loading properties are as described in CSI Analysis Reference Manual, chapter "Frequency Domain Analyses", section "Steady-State Analysis >Example".

Use the *em* factor of 0.001.

Steady State Time Function

Frequency f
entered in Hz
units

SAP2000 v14.2.2 Advanced - model A V14.2.2

Steady State Function Definition

Function Name: FSQUARED

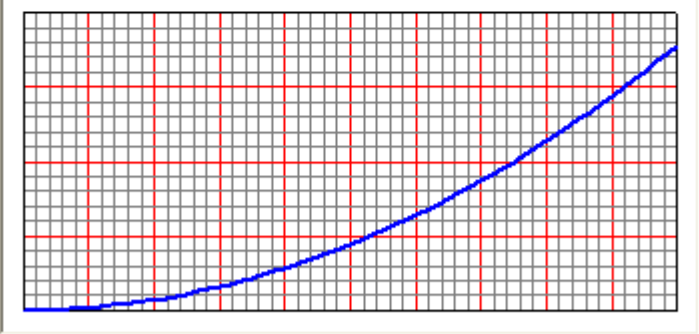
Define Function

Frequency	Value
0.	0.
0.5	9.87
1.	39.48
1.5	88.83
2.	157.91
2.5	246.74
3.	355.31
3.5	483.61
4.	631.65

Add
Modify
Delete

Frequency Units
☒ Hz ☐ RPM

Function Graph



Display Graph 0.0,0.0

OK Cancel

Steady state
function value,
calculated as $\omega^2 =$
 $(2 \pi f)^2$

Definition of the Steady State Load Case

SAP 2000 v14.2.2 Advanced - model A V14.2.2

Load Case Data - Steady-State

Load Case Name:

Notes:

Load Case Type:

Stiffness to Use:

☒ Zero Initial Conditions - Unstressed State

☐ Stiffness at End of Nonlinear Case

Important Note: Loads from the Nonlinear Case are NOT included in the current case

Solution Type:

☐ Modal ☒ Direct

Loads Applied

Load Type	Load Name	Function	Scale Factor	Phase Angle	Coord Sys	Angle
Load Pattern	ECCX	FSQUARED	1.000E-03	0.	GLOBAL	0.
Load Pattern	ECCX	FSQUARED	1.000E-03	0.	GLOBAL	0.
Load Pattern	ECCZ	FSQUARED	1.000E-03	90.	GLOBAL	0.

☒ Show Advanced Load Parameters

Frequency Step Data

First Frequency:

Last Frequency: Modal Case: MODAL

Number of Increments: Add Modal Frequencies? Yes

Num Modal Freq Deviations: 8

Num Specified Frequencies: 1

Other Parameters

Hysteretic Damping:

Hysteretic Damping

Hysteretic Damping Type

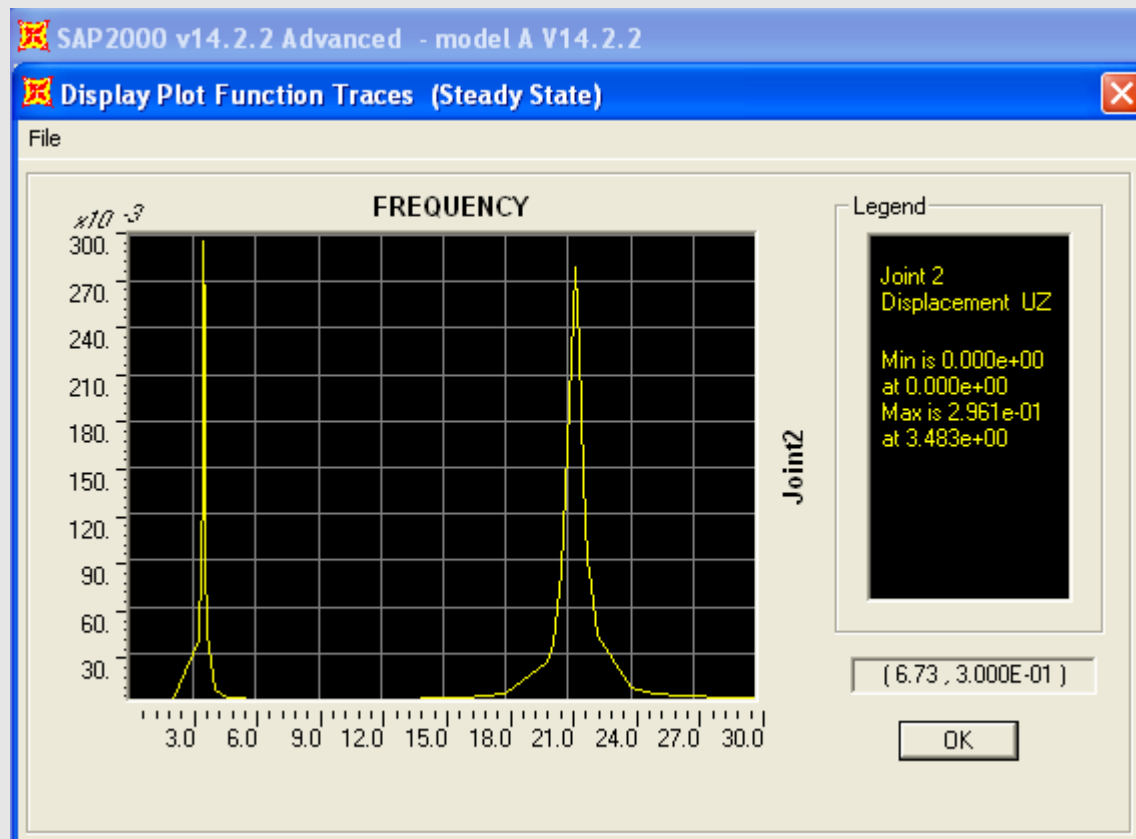
☒ Constant Hysteretic Damping for all Frequencies

☐ Interpolated Hysteretic Damping by Frequency

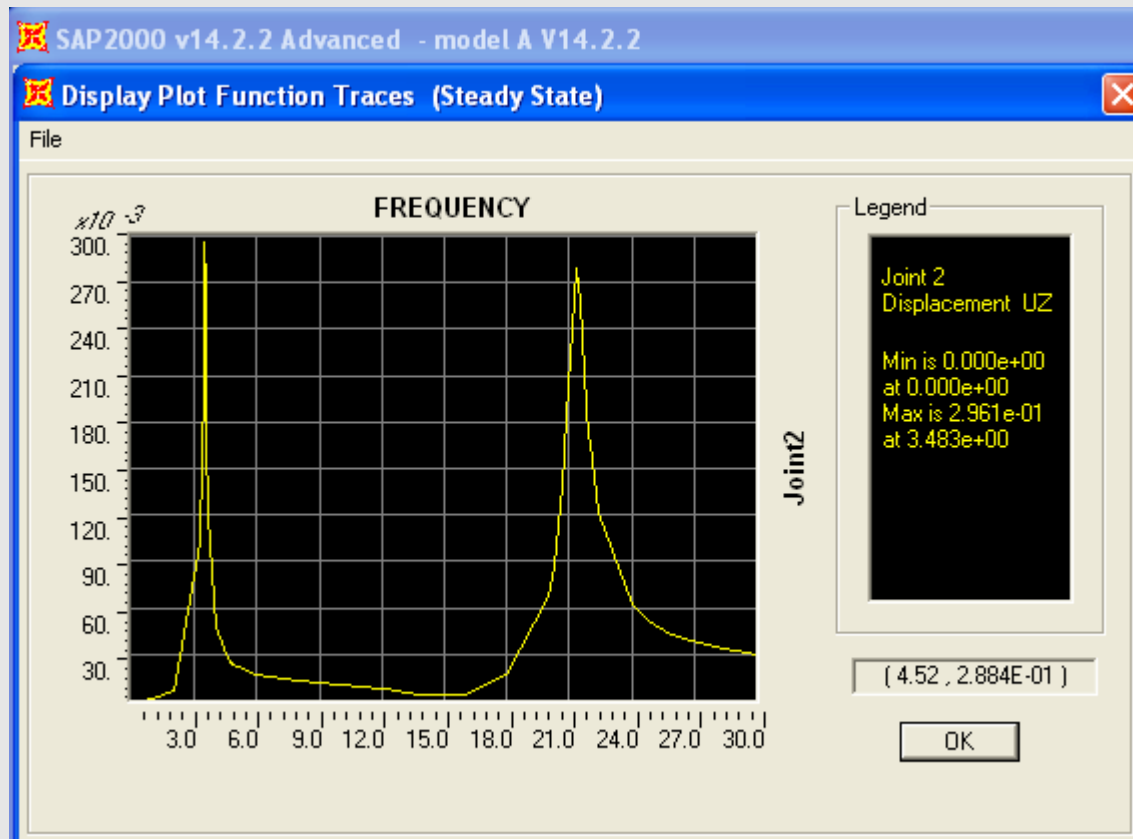
Constant Hysteretic Damping

Mass Proportional Coefficient: Stiffness Proportional Coefficient:

Vertical Displacement of Tip as a Function of Frequency for Phase Angle = 0



Magnitude of Vertical Tip Displacement as a Function of Frequency



Note that the structure resonates for frequencies of modes 2 and 5 which are vertical modes.

Modal Participating Mass Ratios

SAP2000 v14.2.2 Advanced - model A V14.2.2

Modal Participating Mass Ratios

File View Format-Filter-Sort Select Options

Units: As Noted

Modal Participating Mass Ratios

	OutputCase Text	StepType Text	StepNum Unitless	Period Sec	UX Unitless	UY Unitless	UZ Unitless	SumUX Unitless	SumUY Unitless	SumUZ Unitless
▶	MODAL	Mode	1	1.27851	0	0.64291	0	0	0.64291	0
	MODAL	Mode	2	0.287091	0	0	0.64381	0	0.64291	0.64381
	MODAL	Mode	3	0.206424	0	0.19856	0	0	0.84147	0.64381
	MODAL	Mode	4	0.074538	0	0.06816	0	0	0.90963	0.64381
	MODAL	Mode	5	0.04688	0	0	0.20045	0	0.90963	0.84426
	MODAL	Mode	6	0.038494	0	0.0348	0	0	0.94443	0.84426
	MODAL	Mode	7	0.023597	0	0.02096	0	0	0.96539	0.84426
	MODAL	Mode	8	0.017236	0	0	0.06938	0	0.96539	0.91364
	MODAL	Mode	9	0.016058	0	0.01384	0	0	0.97923	0.91364
	MODAL	Mode	10	0.011776	0	0.00952	0	0	0.98875	0.91364
	MODAL	Mode	11	0.009204	0	0.0064	0	0	0.99516	0.91364
	MODAL	Mode	12	0.009141	0	0	0.03558	0	0.99516	0.94922

Record: 1 of 12

Add Tables... Done

Modes 2 and 5 are vertical modes.

Modal Frequencies

SAP2000 v14.2.2 Advanced - model A V14.2.2

Modal Periods And Frequencies

File View Format-Filter-Sort Select Options

Units: As Noted

Modal Periods And Frequencies

	OutputCase Text	StepType Text	StepNum Unitless	Period Sec	Frequency Cyc/sec	CircFreq rad/sec	Eigenvalue rad2/sec2
▶	MODAL	Mode	1	1.27851	0.78216	4.9145	24.152
	MODAL	Mode	2	0.287091	3.4832	21.886	478.98
	MODAL	Mode	3	0.206424	4.8444	30.438	926.48
	MODAL	Mode	4	0.074538	13.416	84.295	7105.6
	MODAL	Mode	5	0.04688	21.331	134.03	17963
	MODAL	Mode	6	0.038494	25.978	163.22	26642
	MODAL	Mode	7	0.023597	42.378	266.27	70899
	MODAL	Mode	8	0.017236	58.018	364.54	132890
	MODAL	Mode	9	0.016058	62.273	391.27	153090
	MODAL	Mode	10	0.011776	84.918	533.56	284680
	MODAL	Mode	11	0.009204	108.65	682.66	466020
	MODAL	Mode	12	0.009141	109.4	687.36	472470

Record: 1 of 12

Add Tables... Done

Frequency for the first vertical mode (ie. mode 2) was used to setup time history analysis to verify the steady state results.

Equivalent Time History Load Cases

- The results of the steady state analysis were verified by time history analyses for loading frequencies of 1 Hz and 3.4832 Hz

Calculate dynamic characteristics for $f = 3.4832 \text{ Hz}$

$$f = 3.4832 \text{ Hz}$$

$$\omega = 2\pi f = 21.8856 \text{ rad/sec}$$

$$\omega^2 = 478.9791 \text{ rad}^2/\text{sec}^2$$

$$T = 1/f = 0.2871$$

Loading Characteristics of the “TH-per 1 Hz” Time History Load Case

SAP2000 v14.2.2 Advanced - model A V14.2.2

Load Case Data - Linear Modal History

Load Case Name: TH-per (1Hz) [Set Def Name] [Modify/Show...]

Load Case Type: Time History [Design...]

Initial Conditions:
☒ Zero Initial Conditions - Start from Unstressed State
☐ Continue from State at End of Modal History []
Important Note: Loads from this previous case are included in the current case

Analysis Type:
☒ Linear
☐ Nonlinear

Time History Type:
☒ Modal
☐ Direct Integration

Time History Motion Type:
☐ Transient
☒ Periodic

Modal Load Case:
Use Modes from Case: MODAL []

Loads Applied

Load Type	Load Name	Function	Scale Factor	Time Factor	Arrival Time	Coord Sys	Angle
Load Path	ECCZ	Sine 1 Cyc	0.039478	1.	0.	GLOBAL	0.
Load Pattern	ECCX	Cosine 1 Cycle	0.039478	1.	0.	GLOBAL	0.
Load Pattern	ECCZ	Sine 1 Cycle	0.039478	1.	0.	GLOBAL	0.

☒ Show Advanced Load Parameters [Add] [Modify] [Delete]

Time Step Data:
Number of Output Time Steps: 100
Output Time Step Size: 0.01

Other Parameters:
Modal Damping: Constant at 0.02 [Modify/Show...]

[OK] [Cancel]

Note:

(1) Scale factor was set to $em\omega^2 = (0.001)(6.2831)^2 = 0.039478$

(2) Time factor was set to $T = 1/f = 1$

See previous page for calculation of intermediate values.

Loading Characteristics of the “TH-per 3.4822 Hz” Time History Load Case

Note:

(1) Scale factor was set to $em\omega^2 = (0.001)(21.8856)^2 = 0.479$

(2) Time factor was set to $T = 1/f = 0.2871$

See previous page for calculation of intermediate values.

SAP2000 v14.2.2 Advanced - model A V14.2.2

Load Case Data - Linear Modal History

Load Case Name: TH-per (3.4832 Hz)

Notes:

Load Case Type: Time History

Initial Conditions:

☒ Zero Initial Conditions - Start from Unstressed State

☐ Continue from State at End of Modal History

Important Note: Loads from this previous case are included in the current case

Modal Load Case:

Use Modes from Case: MODAL

Analysis Type:

☒ Linear ☐ Nonlinear

Time History Type:

☒ Modal ☐ Direct Integration

Time History Motion Type:

☐ Transient ☒ Periodic

Loads Applied:

Load Type	Load Name	Function	Scale Factor	Time Factor	Arrival Time	Coord Sys	Angle
Load Path	ECCX	Cosine 1 C	0.479	0.2871	0.	GLOBAL	0.
Load Pattern	ECCX	Cosine 1 Cycle	0.479	0.2871	0.	GLOBAL	0.
Load Pattern	ECCZ	Sine 1 Cycle	0.479	0.2871	0.	GLOBAL	0.

☒ Show Advanced Load Parameters

Time Step Data:

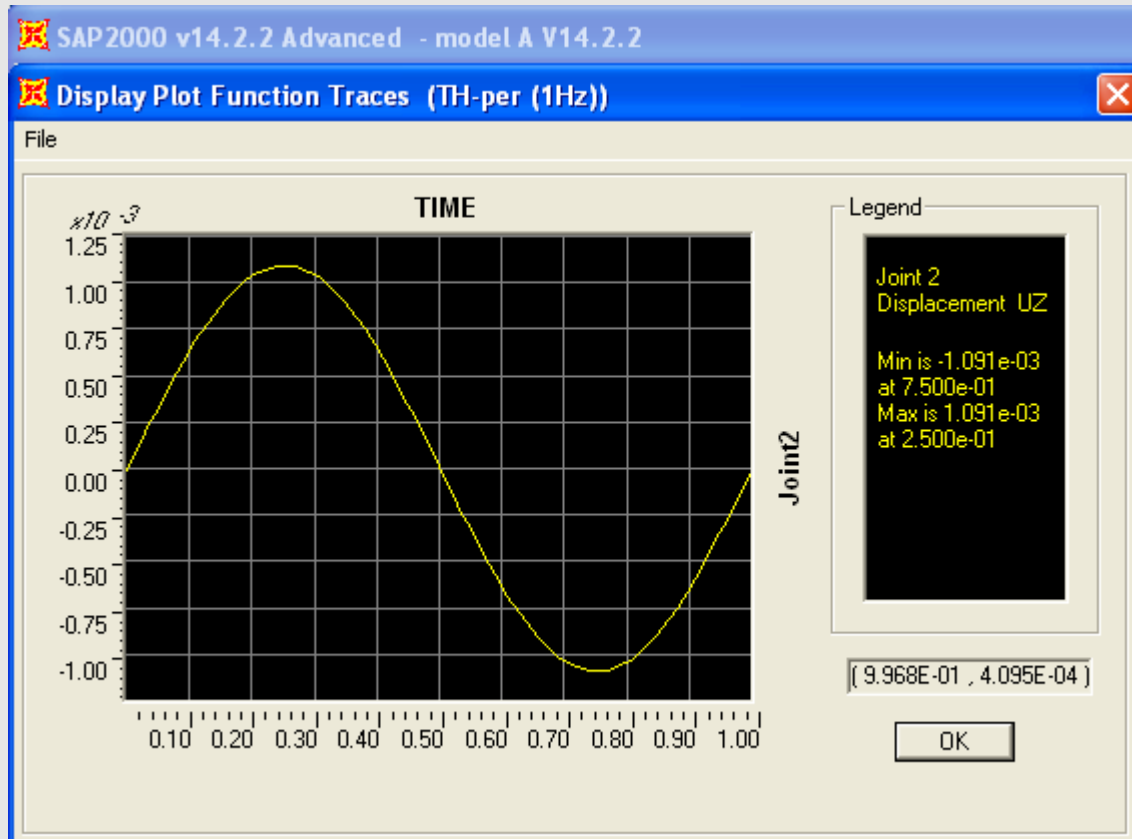
Number of Output Time Steps: 287

Output Time Step Size: 1.000E-03

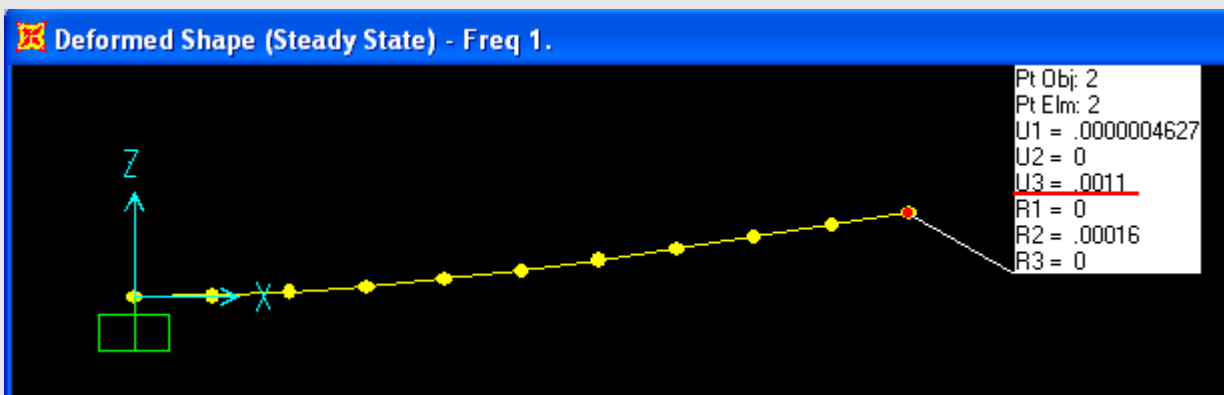
Other Parameters:

Modal Damping: Constant at 0.02

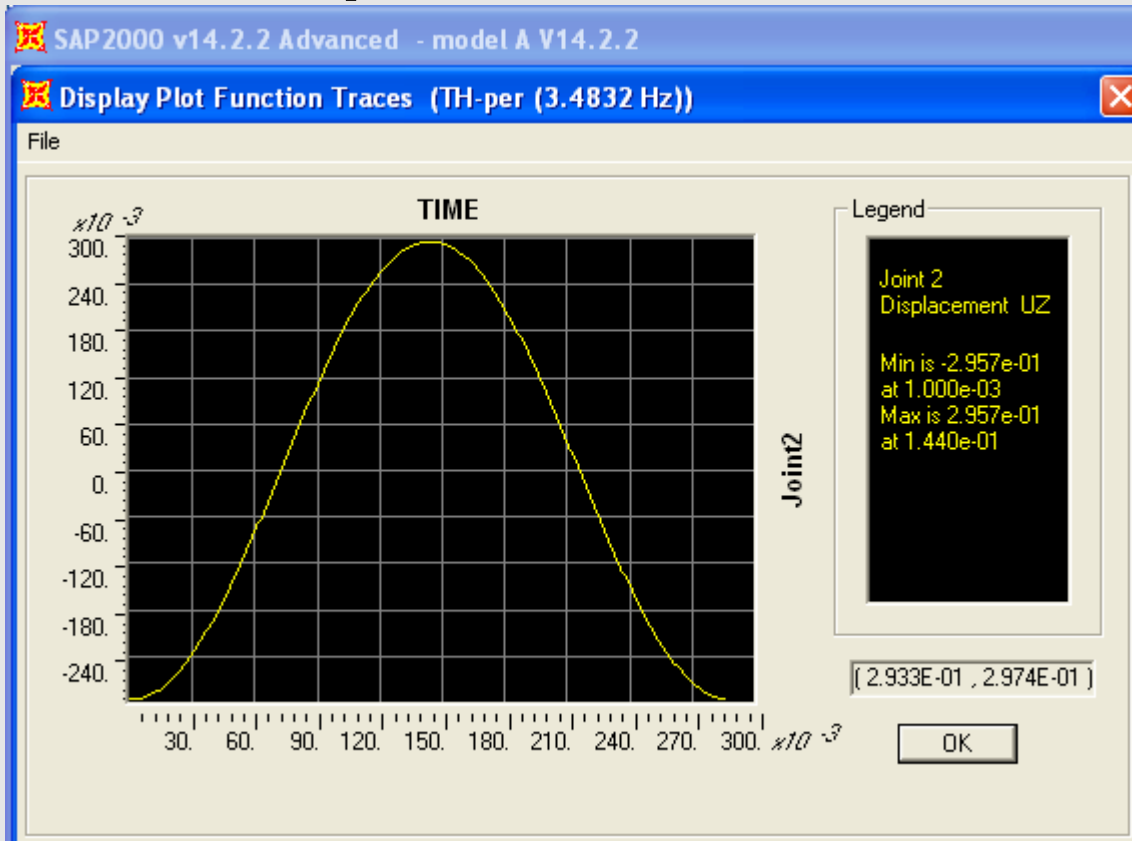
Displacement for $f = 1$ Hz



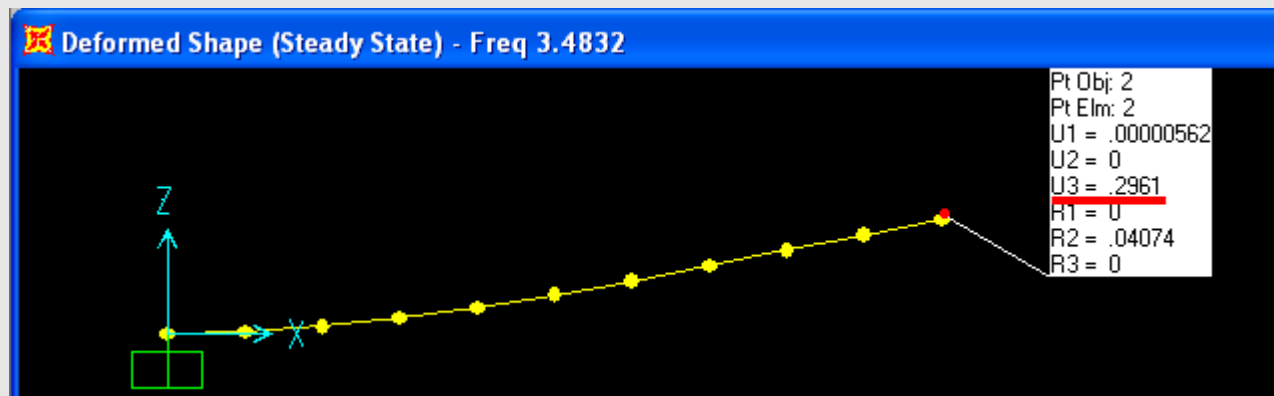
Note that the time history displacement shown in the top screen capture matches the steady-state displacement shown in the bottom screen capture.



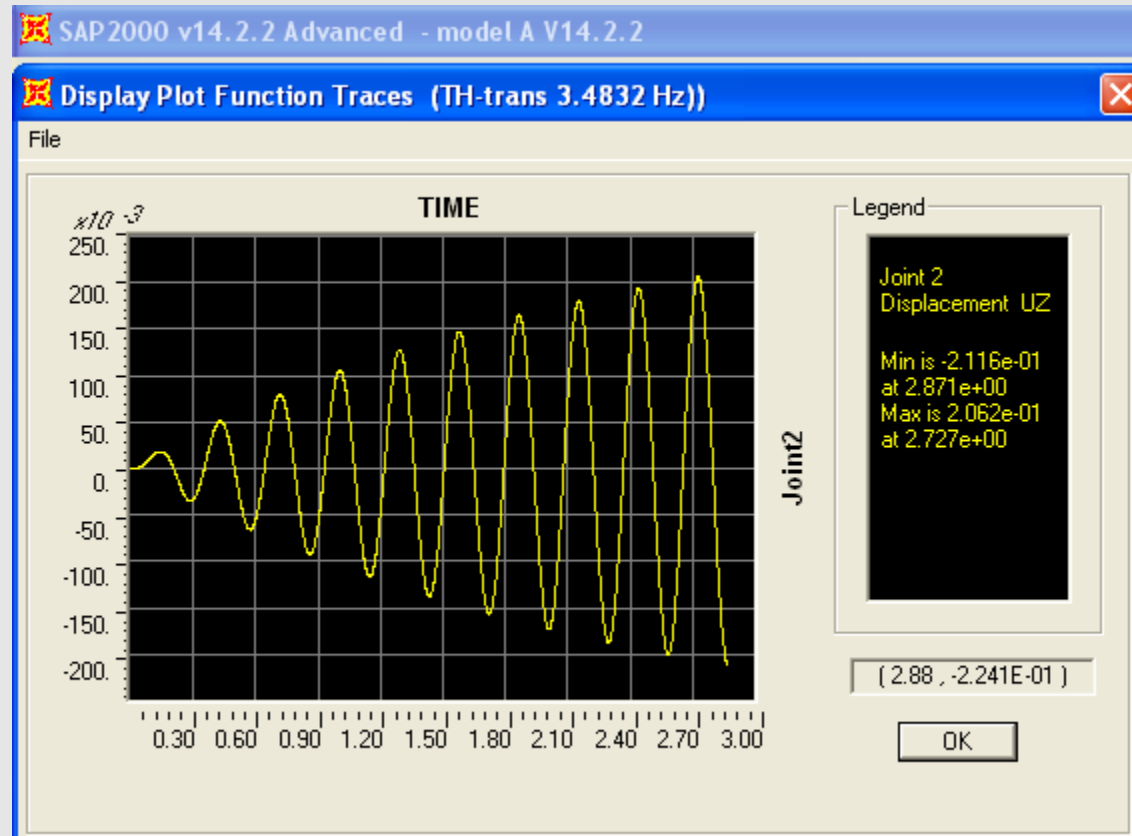
Displacements for $f = 3.4832$ Hz



Note that the time history displacement shown in the top screen capture matches the steady-state displacement shown in the bottom screen capture.



Plot of the same displacement for transient time history analysis



Note the gradual increase in amplitude due to resonance.