Ansys Mechanical Linear and Nonlinear Dynamics

Module 02: Damping

Release 2022 R2

Please note:
- These training materials were developed and tested in Ansys Release 2022 R2. Although they are expected to behave similarly in later releases, this has not been tested and is not guaranteed.
- The screen images included with these training materials may vary from the visual appearance of a local software session.

Module 02 Learning Outcomes

- After completing this module, you will:
  - Be able to identify the various types of damping available in Ansys Mechanical.
  - Know what forms of damping are supported and available for a given analysis type.
  - Gain experience calculating damping values for some of the more common applications of damping.

Module 02 Topics

A. Damping Definition
B. Types of Damping
C. Damping Matrices and Support for Analysis Types
D. Viscous Damping
E. Example Viscous Damping Calculations
F. Numerical Damping
G. Damping Summary
H. Damping Resources in the Help Documentation

A. Damping Definition

- Damping is an energy-dissipation mechanism that causes vibrations to diminish over time and eventually stop.
  - e.g. vibrational energy that is converted to heat or sound

- In damping, the energy of the vibrating system is dissipated by various mechanisms, and often more than one mechanism may be present at the same time.

- The amount of damping may depend on the material, the velocity of motion, and/or the frequency of vibration.

B. Types of Damping

- Damping is generally classified as:
  - Viscous damping (e.g. dashpot, shock absorber)
    - Damping forces are proportional to the velocity (or frequency) of the body
  - Material / Solid / Hysteretic damping (e.g. internal friction)
    - Damping forces are proportional to displacements (strains)
  - Coulomb or dry-friction damping (e.g. sliding friction)
    - Damping force opposes velocity and is equal to μN; independent of velocity once sliding initiates
  - Numerical damping (artificial damping)
    - Not true damping

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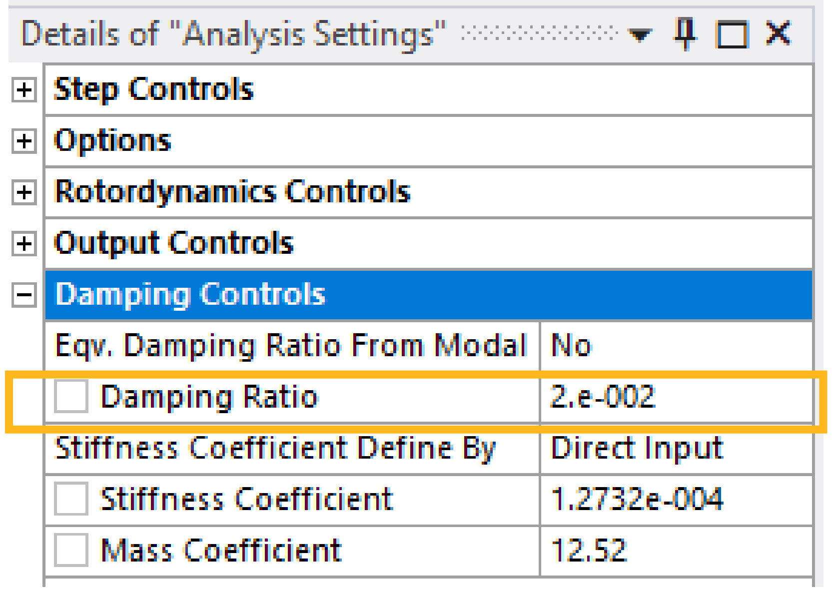
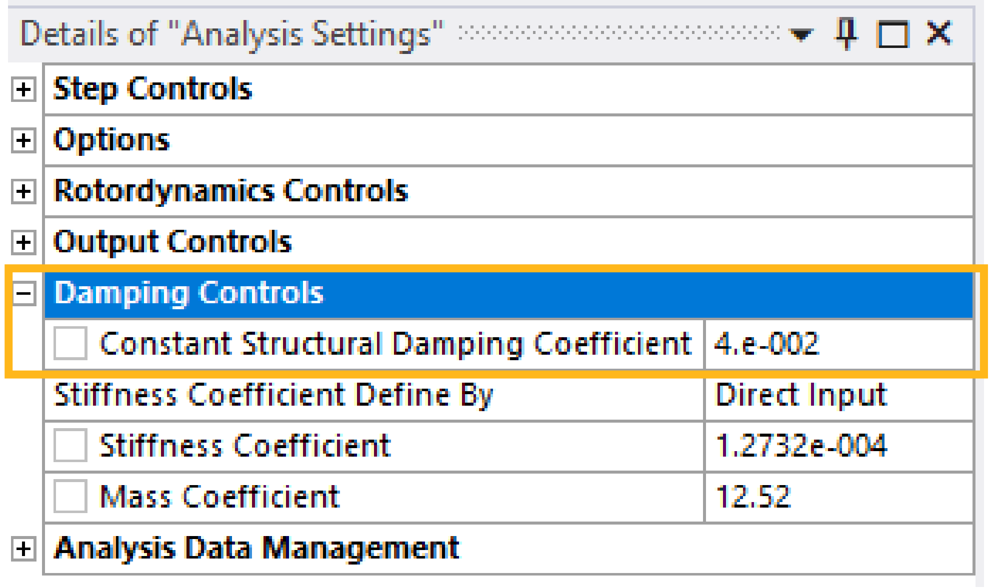
… Types of Damping

- The damping available for dynamic analyses within Ansys generally falls within one of the two forms:
  - Viscous damping (e.g. dashpot, shock absorber)
    - Found on Spring, Joint, and Bearing Connections
    - Mass and Stiffness (Rayleigh) damping, found within Analysis Settings (Global) and/or Engineering Data (for material dependency)
  - Hysteretic damping (e.g. internal friction)
    - Damping Ratio and/or Constant Structural Damping Coefficient, found within Analysis Settings (Global) and/or Engineering Data (for material dependency)

… Types of Damping

- The types of damping mentioned previously are implemented on a Global basis by one or more of the following Analysis Settings … :
  - Damping Ratio (DMPRAT)
    - Defined as the ratio of damping to critical damping
  - Constant Structural Damping Coefficient (DMPSTR)
  - Mass Coefficient (Alpha Damping) and Stiffness Coefficient (Beta Damping), (ALPHAD, BETAD)

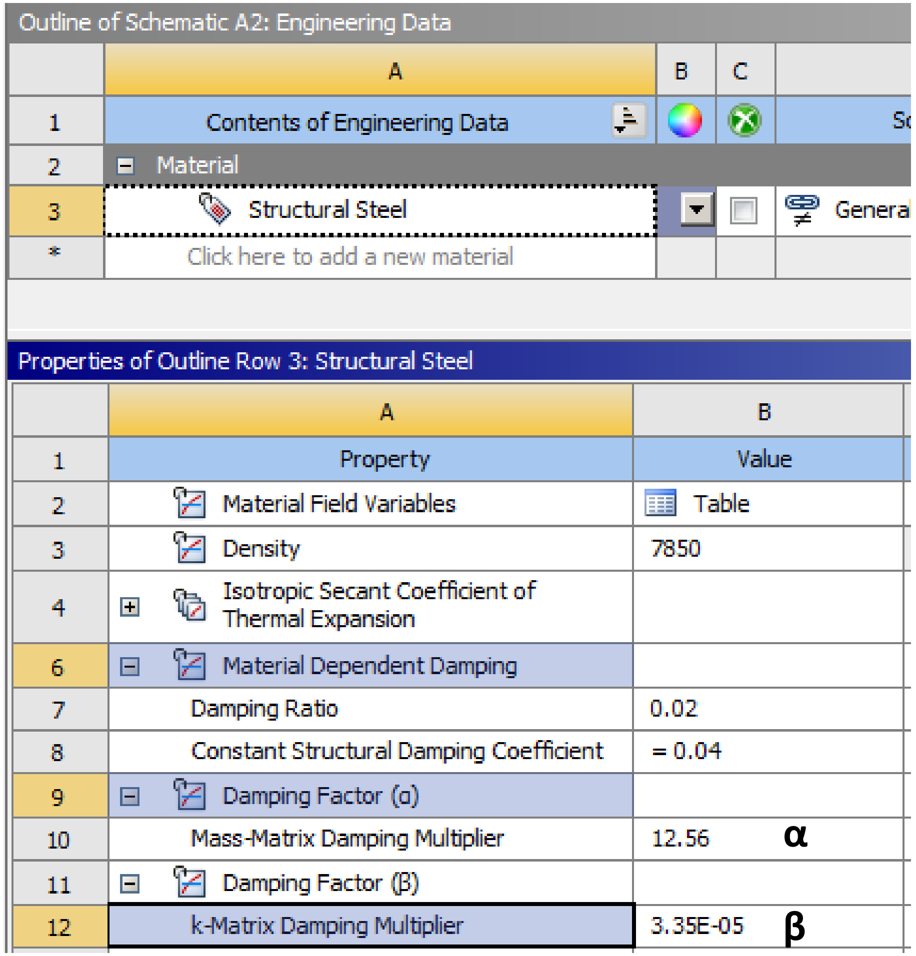




Note: Underlined text throughout this document links to the Ansys Help Documentation

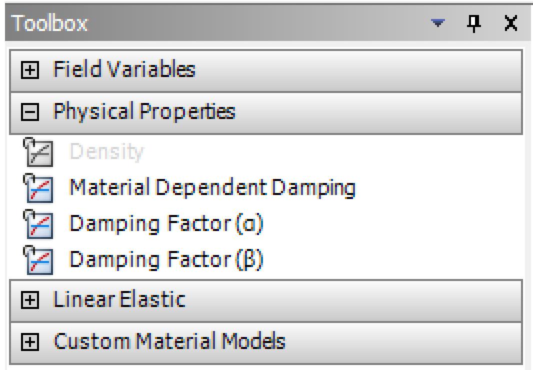
… Types of Damping

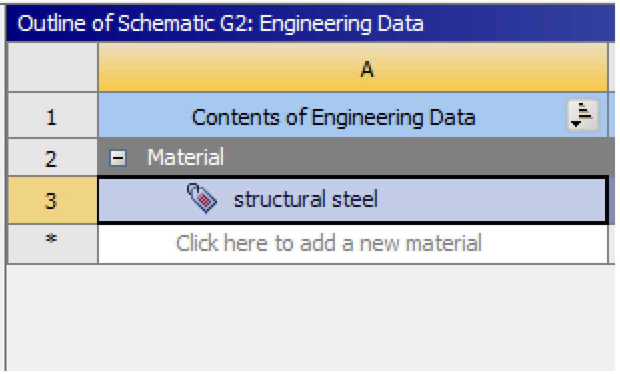
- … and on a Material basis within Engineering Data by one or more of the following … :
  - Material Dependent Damping
    - Damping Ratio (MP,DMPR)
    - Constant Structural Damping Coefficient (MP,DMPS)
  - Damping Factor (α)
    - Mass-Matrix Damping Multiplier (MP,ALPD)
  - Damping Factor (β)
    - k-Matrix Damping Multiplier (MP,BETD)



	A	B	C	
1	Contents of Engineering Data			S
2	Material			
3	Structural Steel			Genera
*	Click here to add a new material			

	A	B	
1	Property	Value	
2	Material Field Variables	Table	
3	Density	7850	
4	Isotropic Secant Coefficient of Thermal Expansion		
6	Material Dependent Damping		
7	Damping Ratio	0.02	
8	Constant Structural Damping Coefficient	= 0.04	
9	Damping Factor (α)		
10	Mass-Matrix Damping Multiplier	12.56	α
11	Damping Factor (β)		
12	k-Matrix Damping Multiplier	3.35E-05	β

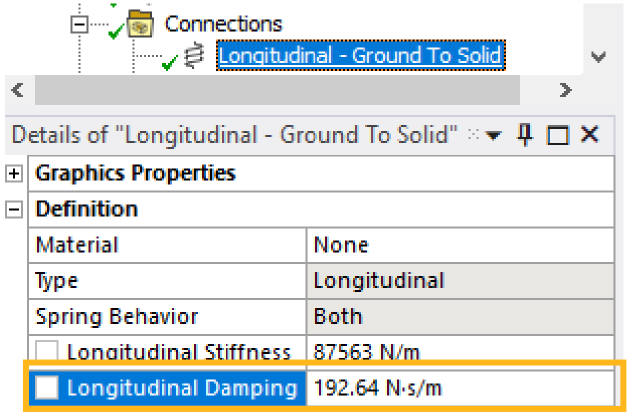


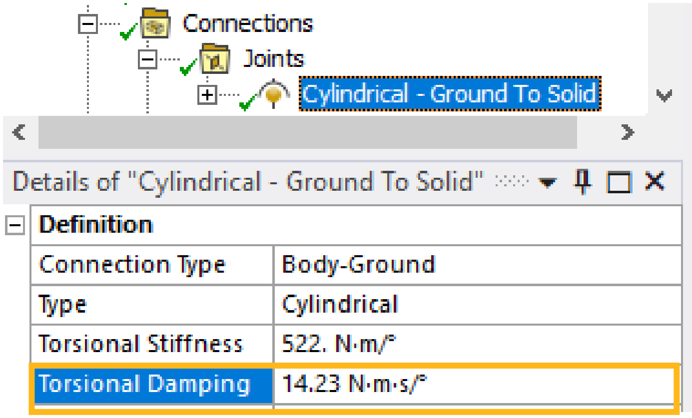


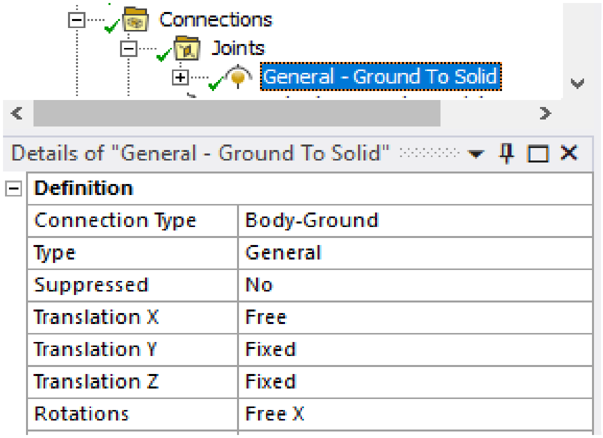
	A
1	Contents of Engineering Data
2	Material
3	structural steel
*	Click here to add a new material

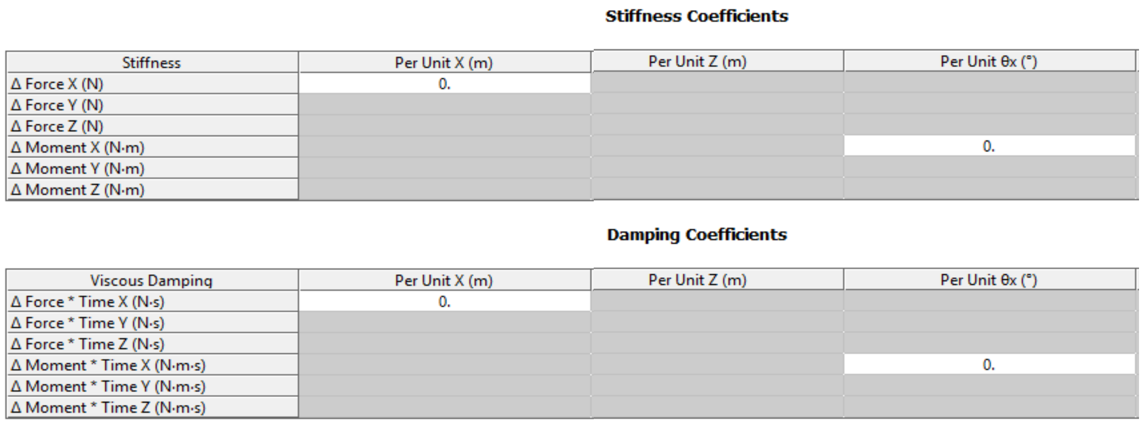
… Types of Damping

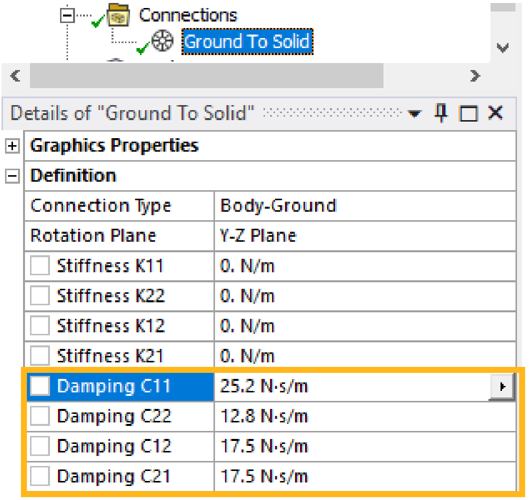
- … and on an Element basis by one or more of the following Connections … :
  - Longitudinal Damping
    - Springs (COMBIN14)
  - Torsional Damping
    - Revolute and Cylindrical Joints (MPC184)
  - Viscous Damping
    - Bushing and General Joints (MPC184, COMBI250)
  - Damping C11, C22, C12, C21
    - Bearings (COMBI214)











C. Damping Matrices and Support for Analysis Types

- It’s possible to define more than one type of damping within a given analysis type.
  - Each analysis type has its own form of the Damping Matrix [C]
    - Damped Modal
    - Full Harmonic and Full Transient
    - Mode Superposition
      - Harmonic
      - Transient
      - Response Spectrum
      - Random Vibration
  - All damping inputs are summed together within the Damping Matrix for a given analysis type

… Damping Matrices and Support for Analysis Types

- For example, the non-linear governing equation for Transient Dynamic analysis is … :

$$\overbrace{[M]\{\ddot{u}\}}^{F_{\text{inertia}}}+\overbrace{[C]\{\dot{u}\}}^{F_{\text{damping}}}+\overbrace{[K(u)]\{u\}}^{F_{\text{stiffness}}}=\overbrace{\{F(t)\}}^{F_{\text{applied}}}$$

[M]: is structural mass matrix

[C]: is structural damping matrix

[K]: is structural stiffness matrix

{F}: is the load vector

$\{\ddot{u}\}$: is nodal acceleration vector

$\{\dot{u}\}$: is nodal velocity vector

{u}: is nodal displacement vector

(t): is time

… Damping Matrices and Support for Analysis Types

- … for which the complete damping matrix [C], is given by:

$$[C]=\alpha[M]+\beta[K]+\sum_{i=1}^{N_{ma}}\alpha_i^m[M_i]+\sum_{i=1}^{N_{ma}^{MD}}\sum_{k=1}^{N_{sa}}\alpha_p[M_k]_i$$

$$+\sum_{j=1}^{N_{mb}}\beta_j^m[K_j]+\sum_{j=1}^{N_{mb}^{MD}}\sum_{n=1}^{N_{sb}}\beta_q[K_n]_j+\sum_{k=1}^{N_e}[C_k]+\sum_{l=1}^{N_g}[G_l]+\frac{g}{2\pi\Omega}[K]+\sum_{j=1}^{N_m}\frac{m_j}{2\pi\Omega}[K_j]$$

α: Global Mass-Matrix Multiplier (alpha damping, ALPHAD)

β: Global k-Matrix Multiplier (beta damping, BETAD)

g: constant structural damping coefficient (DMPSTR)

α_i^m : Mass matrix multiplier for material i (alpha damping, MP,ALPD)

β_j^m : Stiffness matrix multiplier for material j (beta damping, MP,BETD)

m_j: constant structural damping coefficient for material j (MP,DMPS)

C_k: Element damping (via the various Connection elements, COMBIN14, MPC184, etc.)

Other terms not mentioned include mass and stiffness damping based upon elements with mass and stiffness proportional damping and defined sections (not native to Mechanical) and gyroscopic damping (Rotordynamics analysis)

… Damping Matrices and Support for Analysis Types

- The damping matrices relative to each analysis type are covered throughout the remainder of this course within their respective module.
- Following are tabular summaries of the types of damping natively exposed in Mechanical for each analysis type.
  - Those entries with an “*” require Commands objects to enable damping in Mechanical

Damping Support for Modal Analysis					
	Rayleigh Damping		Element Damping	Constant Structural Damping Coefficient	
	Global	Material-Dependent		Global	Material-Dependent
	ALPHAD BETAD	MP,ALPD MP,BETD	COMBIN14, MPC184,COMBI214, ETC.	DMPSTR	MP,DMPS
Undamped Modal	✗	✗	✗	✗	✗
Damped Modal	✓	✓	✓	✓	✓

Damping Support for Solutions Using Full System Matrices (Full Method)					
	Rayleigh Damping		Element Damping	Constant Structural Damping Coefficient	
	Global	Material-Dependent		Global	Material-Dependent
	ALPHAD BETAD	MP,ALPD MP,BETD	COMBIN14, MPC184,COMBI214, ETC.	DMPSTR	MP,DMPS
Full Harmonic	✓	✓	✓	✓	✓
Full Transient	✓	✓	✓	✓ *	✓ *

* Requires use of command object with appropriate *DMPSFreq* on TRNOPT ; discussed in Module 09.

Damping Support for Solutions Using Reduced System Matrices (MSUP Method)					
	Rayleigh Damping	**Damping Ratio**		**Element Damping**	**Constant Structural Damping Coefficient**
	Global	**Global**	**Material Dependent**		**Global**
	ALPHAD BETAD	**DMPRAT**	**MP,DMPR**	**COMBIN14, MPC184, COMBI214, ETC.**	**DMPSTR**
MSUP Harmonic	✓	✓	✓	✓ †	✓
MSUP Transient	✓	✓	✓	✓ †	✗
Response Spectrum	✓	✓	✓	✗	✗
Random	✓	✓	✓	✗	✗

† Requires use of Reduced Damped Solver in Modal analysis; discussed in Modules 06 and 09.

D. Viscous Damping

- As depicted in the previous summary tables, Rayleigh damping inputs ALPHAD and BETAD may be used throughout a wide variety of dynamic analyses to define the mass and stiffness matrix multipliers α and β within the damping matrix [C]:

$$[C] = \alpha[M] + \beta[K]$$

- A useful relationship allows us to calculate values of α and β from a known or assumed value of the damping ratio ξ and a natural frequency ω:

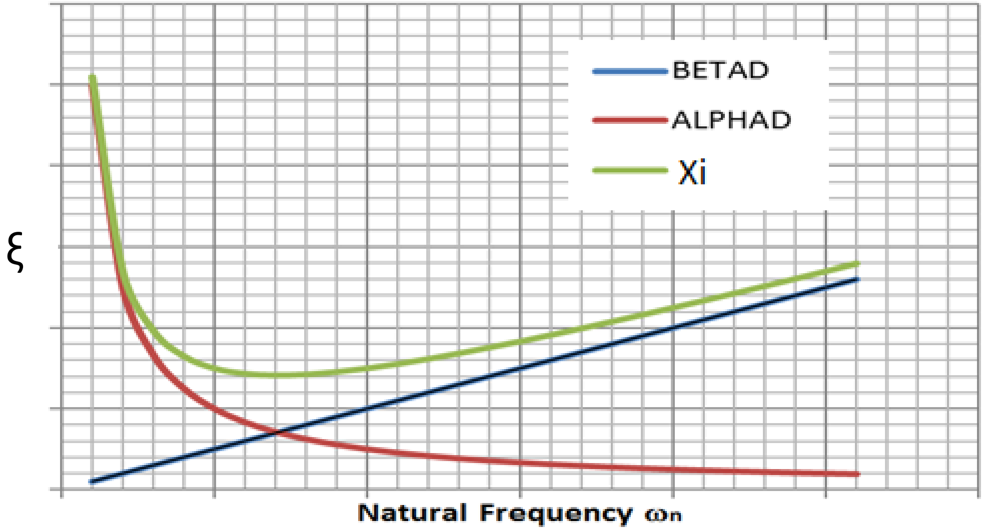
$$\xi_i = \frac{\alpha}{2\omega_i} + \frac{\beta\omega_i}{2}$$

… Viscous Damping

In many practical structural problems, alpha damping (or mass damping) may be ignored ($\alpha = 0$). In such cases, you can evaluate β from known values of ξ and ω, as

$$\xi = \frac{\beta\omega}{2} \quad \text{or} \quad \beta = \frac{2\xi}{\omega}$$

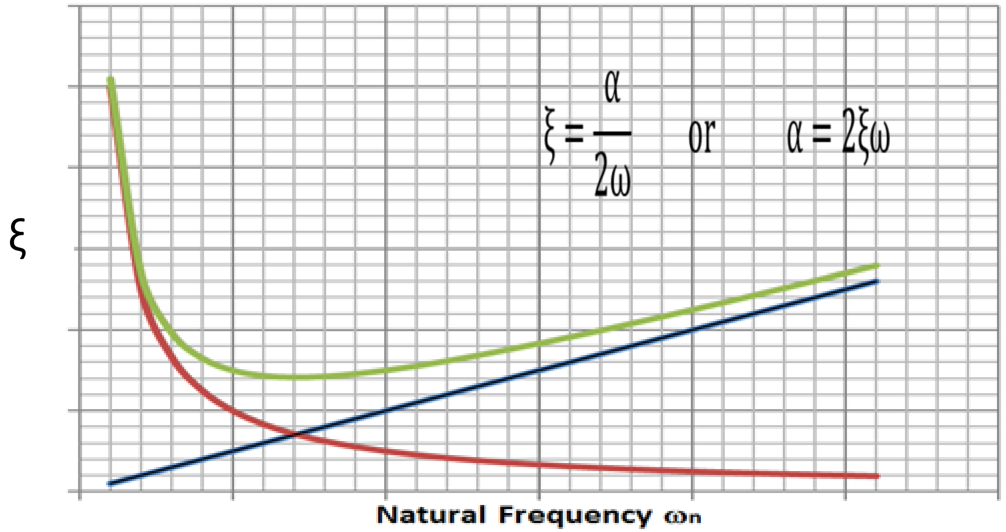
With a given value of β damping, the damping ratio ξ is directly proportional to frequency, i.e., lower frequencies will be damped less, and higher frequencies will be damped more (rigid body damping is ignored).



… Viscous Damping

With a given value of α damping, the damping ratio ξ is inversely proportional to frequency, i.e., lower frequencies will be damped more, and higher frequencies will be damped less.

$$\xi = \frac{\alpha}{2\omega} \qquad \text{or} \qquad \alpha = 2\xi\omega$$



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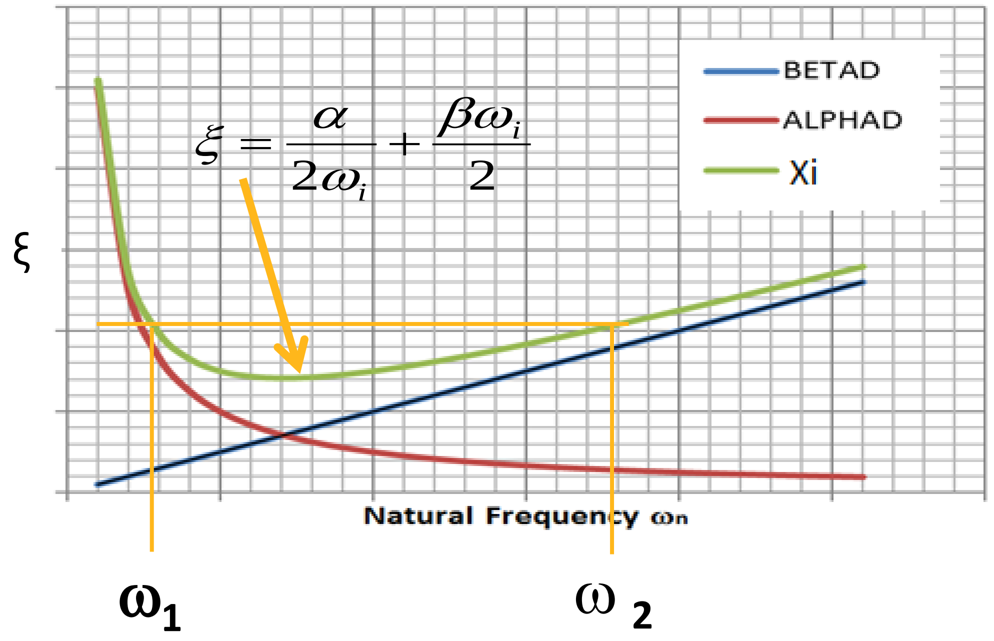
… Viscous Damping

To specify both α and β for a given damping ratio ξ, it is commonly assumed that the sum of the α and β terms is nearly constant over a range of frequencies. Therefore, given ξ and a frequency range ω_1 to ω_2, two simultaneous equations can be solved for α and β:

$$\frac{\alpha}{2\omega_1} + \beta\frac{\omega_1}{2} = \xi$$
$$\frac{\alpha}{2\omega_2} + \beta\frac{\omega_2}{2} = \xi$$

$$\alpha = 2\xi\frac{\omega_1\omega_2}{\omega_1 + \omega_2}$$
$$\beta = \frac{2\xi}{\omega_1 + \omega_2}$$



E. Example Viscous Damping Calculations

- In most cases, the desired damping values can be calculated with a knowledge of:
  - The Damping Ratio (ξ) or Constant Structural Damping Coefficient (g)
  - The expected response frequency, ω (obtained from a modal analysis or hand calculation)
  - Critical Damping, C_c (damping at which no oscillations occurs)
- Recall the following relationships:
  - The Damping Ratio is $\xi = c/C_c$
  - Critical Damping is $C_c = 2\sqrt{(km)}$ or $C_c = 2m\omega$
  - $\omega = \sqrt{(k/m)}$

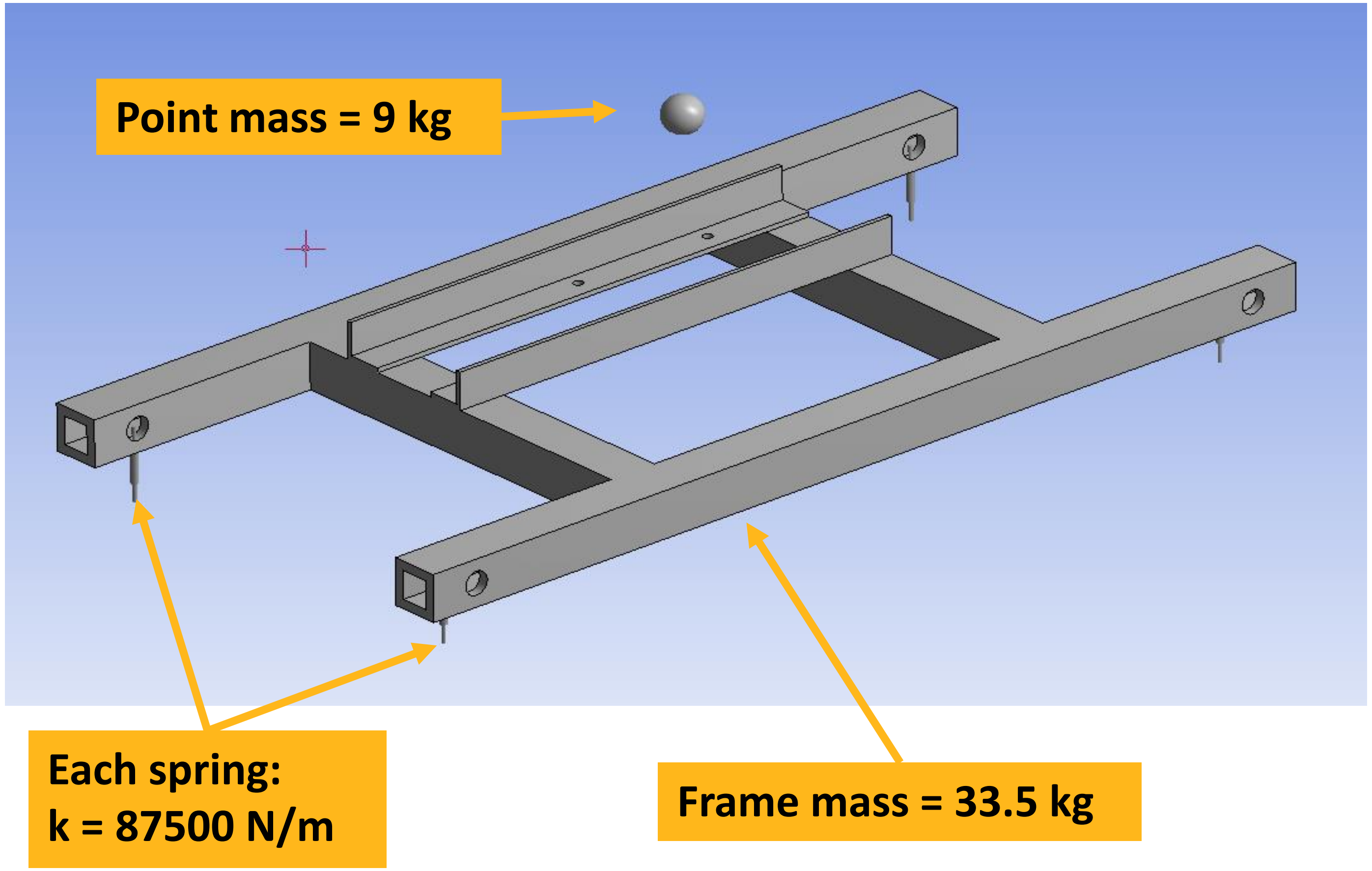
Properties of Outline Row 3: Structural Steel

	A	B
1	Property	Value
2	Material Field Variables	Table
3	Density	7850
4	⊞ Isotropic Secant Coefficient of Thermal Expansion	
6	⊟ Material Dependent Damping	
7	Damping Ratio	0.02
8	Constant Structural Damping Coefficient	= 0.04

- Lastly, the Constant Structural Damping Coefficient (g), as shown in Engineering Data, is automatically calculated as $g = 2\xi$ when the Damping Ratio (ξ) is defined.

… Example Viscous Damping Calculations

- Given the information on the previous slide and the example model below, the required damping input, c, for the body-to-ground springs can be calculated with the following known and assumed quantities:



$$\omega = \sqrt{\frac{k}{m}}$$

Four springs in parallel, k = 350,000 N/m
Total mass = 42.5 kg

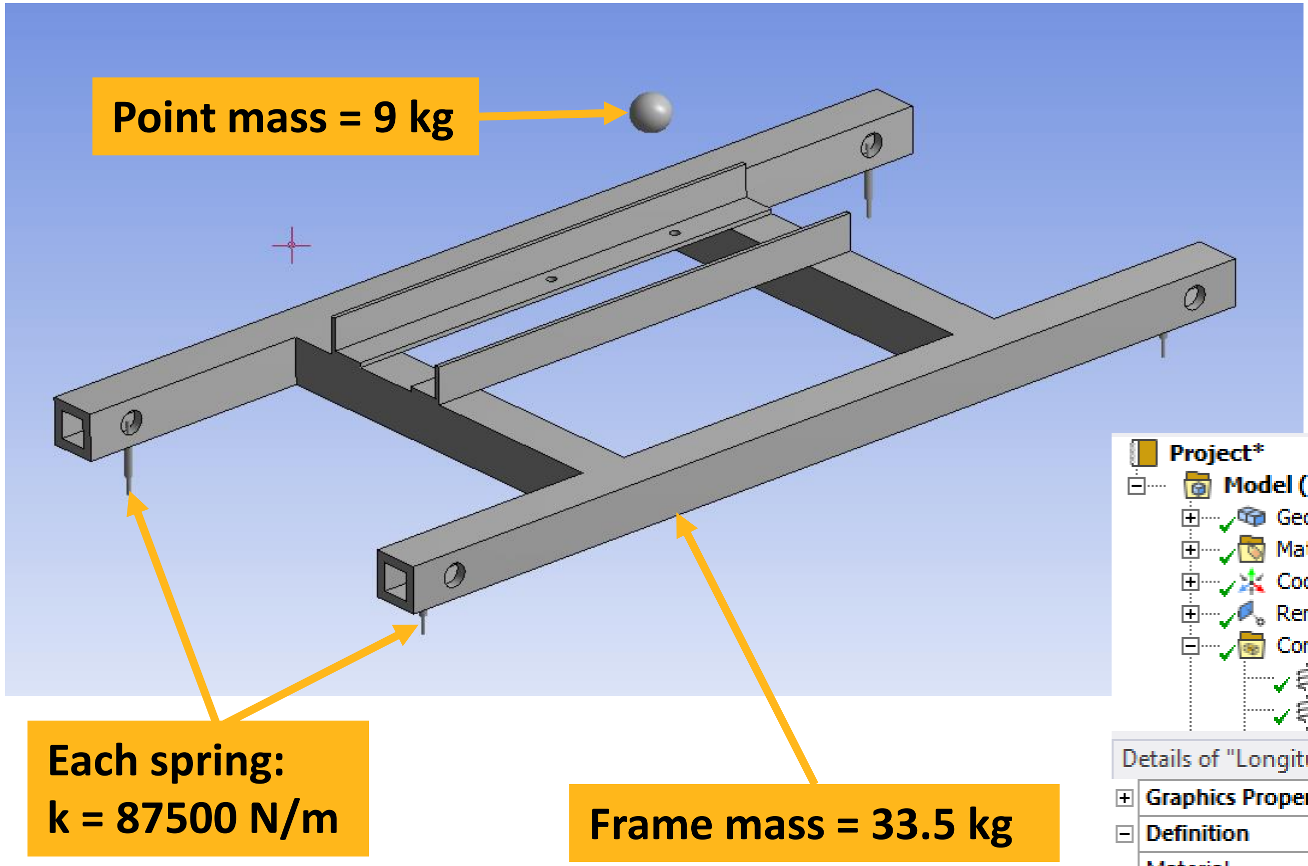
$$\omega = \sqrt{\frac{350000}{42.5}} = 90.7 \text{ rad/sec}$$

Recalling that $\omega = 2\pi f$:

Therefore, f = 14.4 hz (this should match a modal analysis)

… Example Viscous Damping Calculations

- … assuming the springs offer a damping ratio of 10%:



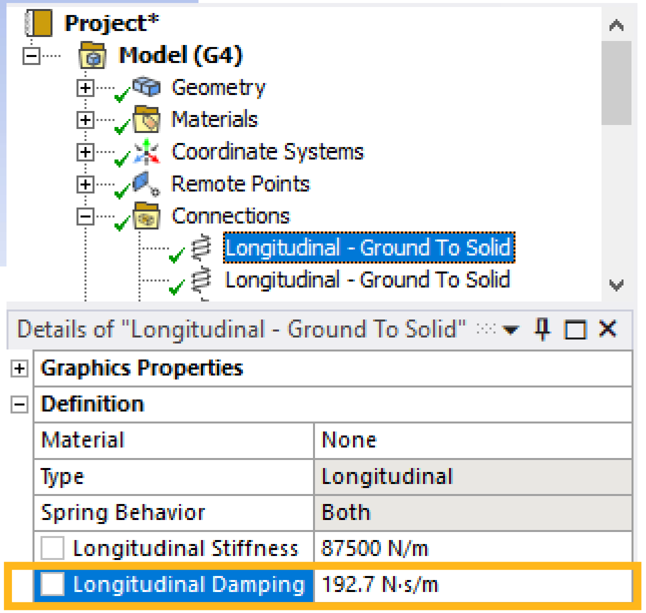
$\xi = c/C_c = 0.10$ and $C_c = 2m\omega$

Therefore, $c = 0.1C_c = 0.2m\omega$

$$c = (.2)(42.5\ \text{kg})(90.7\ \text{rad/s}) = 770.95\ \text{kg/s}$$

Dividing evenly among 4 springs,

$$c = 192.7\ \text{kg/s or } 192.7\ \text{N-s/m}$$

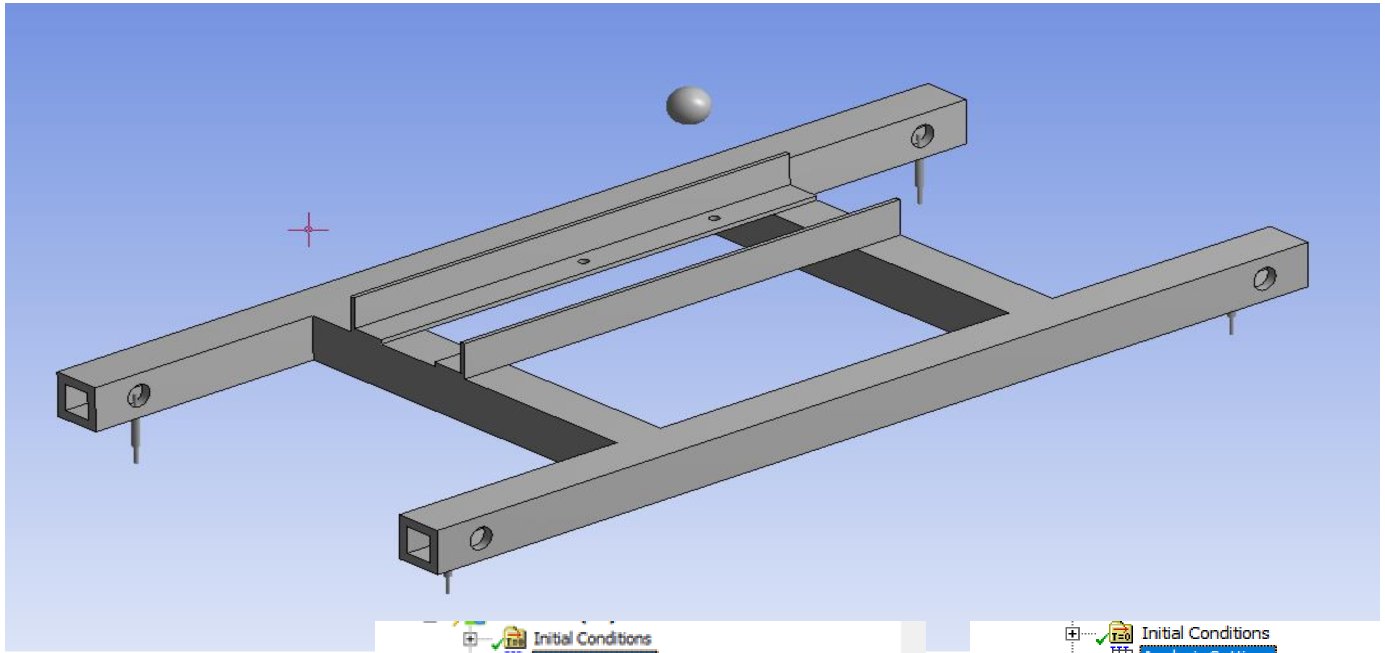


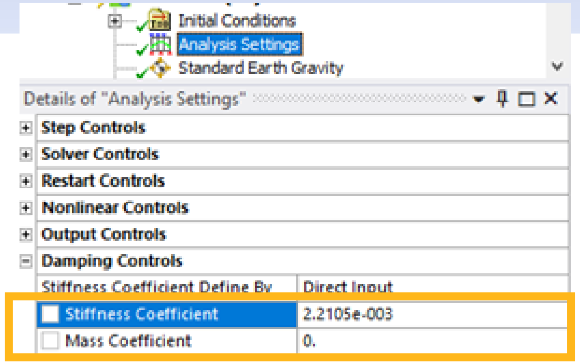
… Example Viscous Damping Calculations

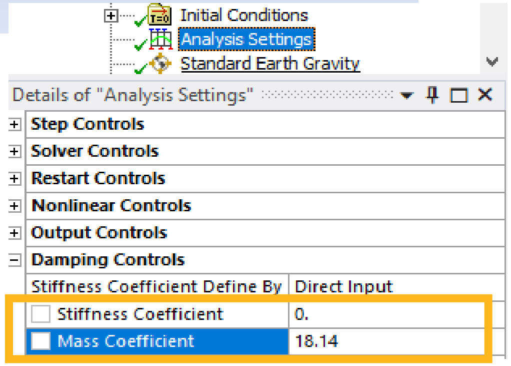
- For the same model, if we want to apply either mass or stiffness damping via the Rayleigh constants α or β,:

$$[C] = \alpha[M] + \beta[K]$$

$$\xi_i = \frac{\alpha}{2\omega_i} + \frac{\beta\omega_i}{2}$$







With α assumed = 0,

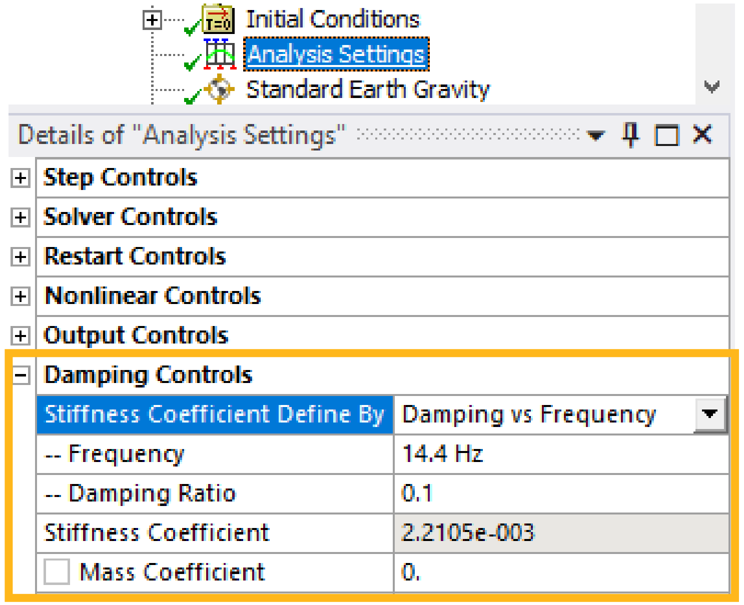
$$\beta = 2\xi/\omega$$
$$= 2(0.1)/90.7 \text{ rad/s}$$
$$\beta = 2.21\text{e-}3$$

Or, With β assumed = 0,

$$\alpha = 2\xi\omega$$
$$= 2(0.1)(90.7 \text{ rad/s})$$
$$\alpha = 18.14$$

… Example Viscous Damping Calculations

- For the stiffness coefficient, Mechanical offers an automatic calculation of β based upon a user-input Frequency and Damping Ratio:
  - Set the “Stiffness Coefficient Defined By” = Damping vs Frequency
  - Here the frequency is entered in Hz, so f = ω/2π
  - Common practice is to use the dominant response frequency expected; either calculated by hand or from a preliminary modal analysis



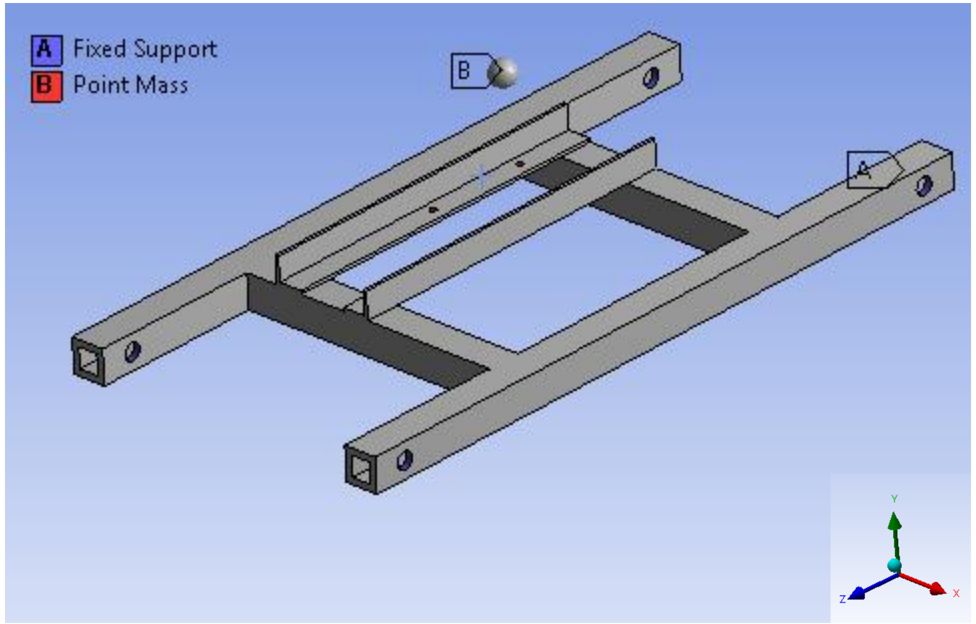
$$f = \omega/2\pi$$

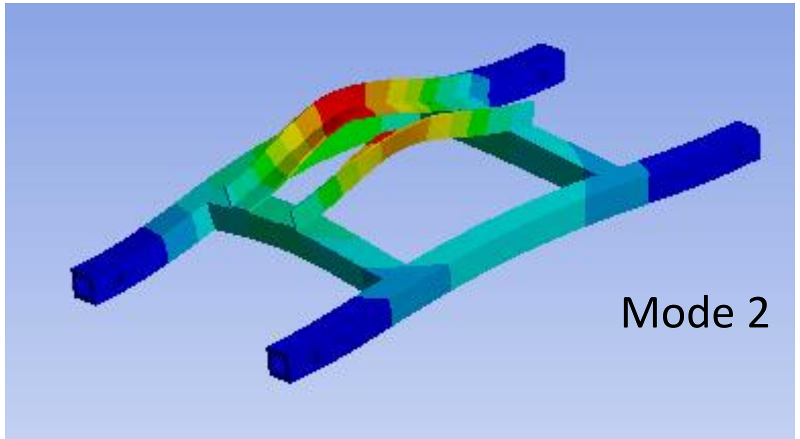
$$= \left(90.7\,\frac{\text{rad}}{\text{s}}\right)/2\pi\left(\frac{rad}{cyc}\right)$$

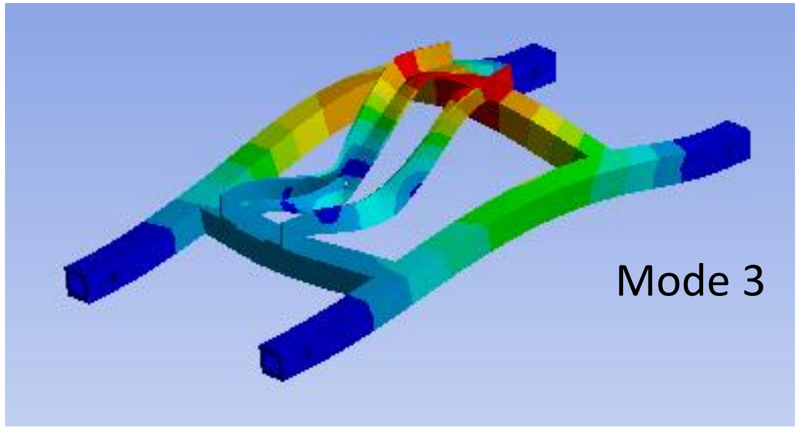
$$\text{f} = 14.4\ \text{Hz}$$

… Example Viscous Damping Calculations

- As a final example, take the same frame with fixed supports in place of the body-ground springs:
  - A modal analysis shows Mode 2 = 208.4 Hz and Mode 3 = 295.8 Hz







Tabular Data

	Mode	Frequency [Hz]
1	1.	180.09
2	2.	208.39
3	3.	295.82
4	4.	390.9

… Example Viscous Damping Calculations

- … Modes 2 and 3 could be used along with the assumption that the sum of the Rayleigh damping terms is constant over that frequency range:
  - Here, since there are no compliant spring members in the system, it's likely the damping ratio is much smaller, perhaps 2%

Converting the second and third mode shape frequencies into circular frequencies, ω

$$\omega 1 = 2\pi(208.4) = 1309.4$$

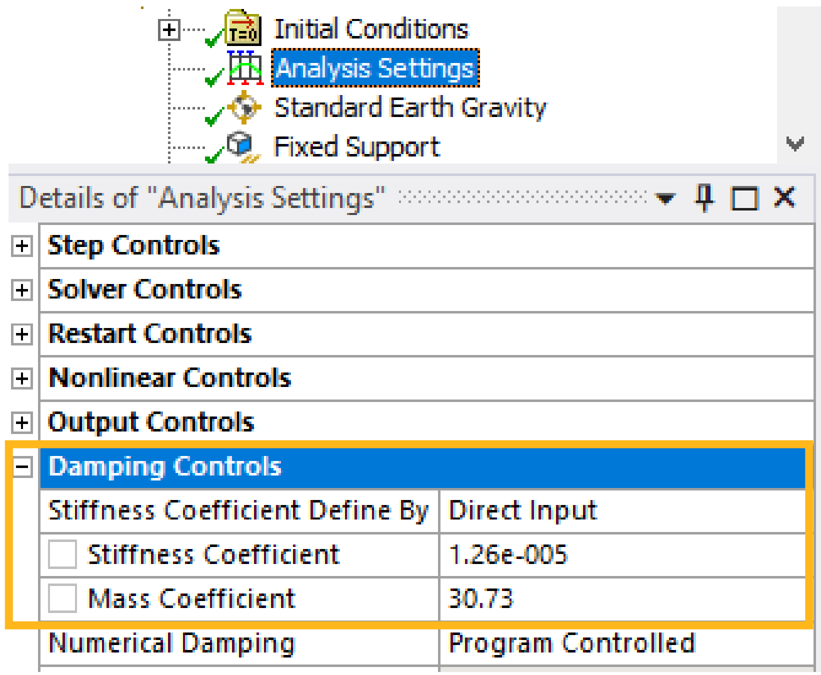
$$\omega 2 = 2\pi(295.8) = 1858.6$$

$$\alpha = 2\xi\frac{\omega_1\omega_2}{\omega_1+\omega_2}$$

$$= 2(.02)\frac{(1309.4)(1858.6)}{(1309.4+1858.6)} = 30.73$$

$$\beta = \frac{2\xi}{\omega_1 + \omega_2}$$

$$= \frac{2(.02)}{1309.4+1858.6} = 1.26\text{e-}5$$



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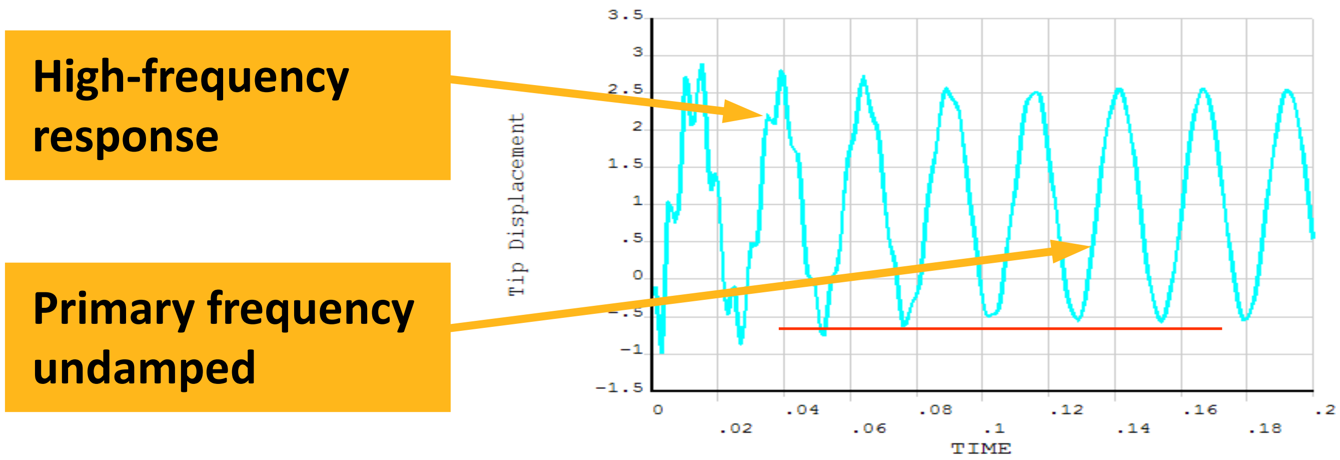
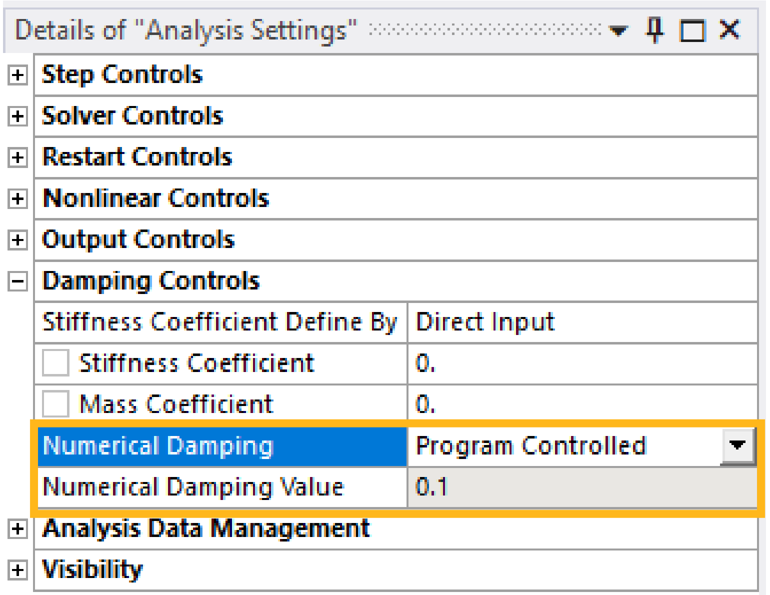
F. Numerical Damping

- Not true damping.
- Artificially controls numerical noise produced by the higher frequencies of a structure.
- Stabilizes the numerical integration scheme by damping out the unwanted high frequency modes.
- The default value of 10% will damp-out spurious high frequencies and is a sensible value to try initially.
- Use the lowest possible value that damps out nonphysical response without significantly affecting the final solution.
- Available only for transient structural analyses. Certain limitations apply for MSUP transient analyses (discussed in Module 09).





G. Damping Summary

- In summary, Engineering Data and Mechanical allow the following four inputs for damping:
  - Alpha α and Beta β damping (viscous)
    - Global or material-dependent.
    - Defines the mass matrix multiplier α and stiffness matrix multiplier β for damping.
  - Element damping (viscous)
    - Defines the damping coefficients (c) directly.
  - Constant structural damping coefficient, g or damping ratio, ξ (hysteretic)
    - Global or material-dependent.
    - Damping Ratio defines the ratio of actual damping to critical damping.
    - Constant Structural Damping Coefficient = 2ξ when ξ is defined in Engineering Data.
  - Numerical damping (artificial)
    - Defines the amplitude decay factor obtained through a modification of the time-integration scheme.
    - Available only in transient analysis.
- As a general "rule", damping ratio (ξ) applies to MSUP analyses, damping coefficient (g) applies to Full analyses
- NOTE: The effects are cumulative if set in conjunction.

H. Damping Resources in the Help Documentation

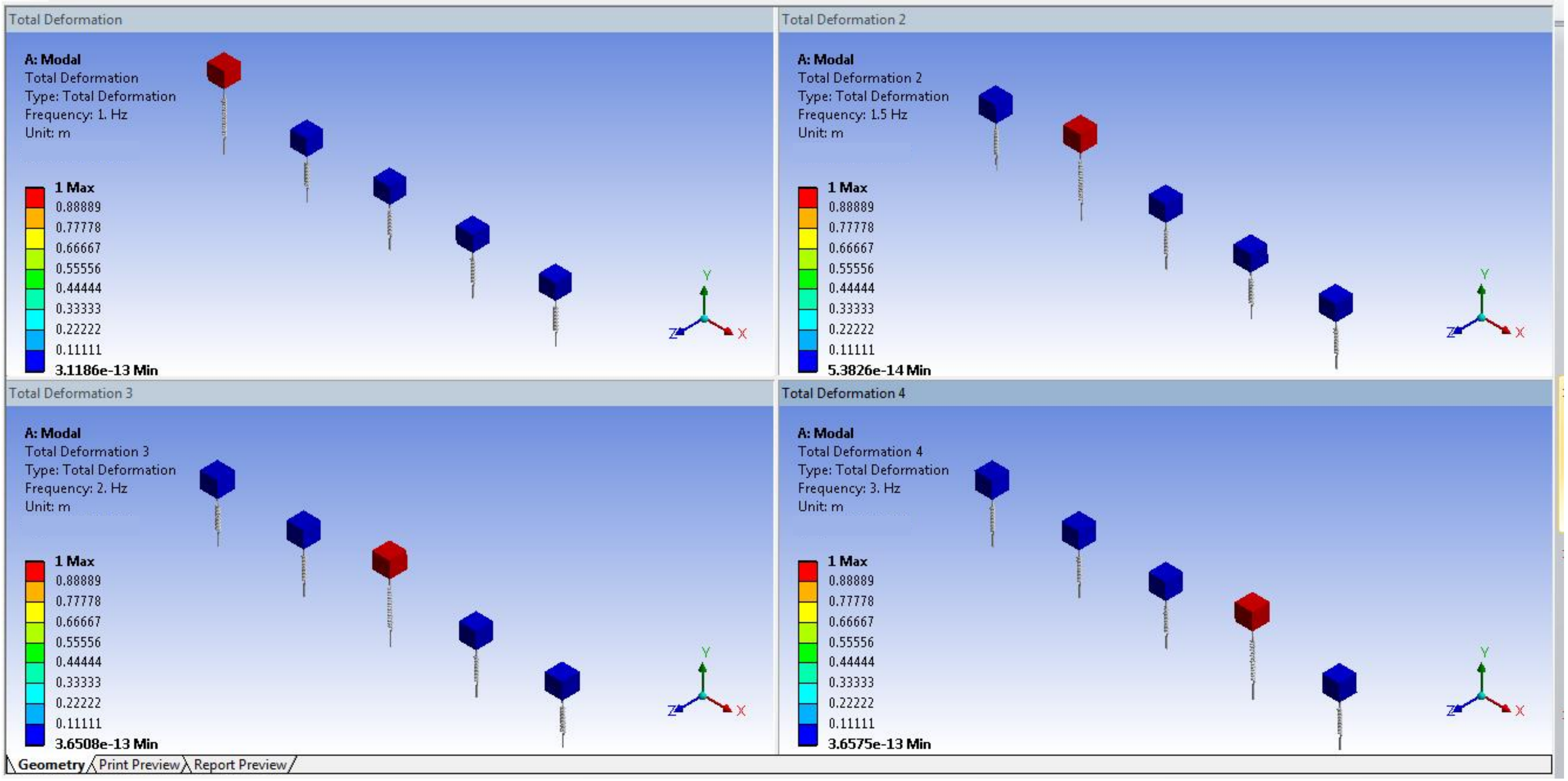
Damping controls within Mechanical
https://ansyshelp.ansys.com/account/secured?returnurl=/Views/Secured/corp/v222/wb_sim/ds_damping_controls.html?q=Damping

Damping within Engineering Data
https://ansyshelp.ansys.com/account/secured?returnurl=/Views/Secured/corp/v222/wb_sim/ds_Define_Resources_step.html%23ds_Material_Dependent_Definition

Damping Matrices within APDL Theory Manual
https://ansyshelp.ansys.com/account/secured?returnurl=/Views/Secured/corp/v222/ans_thry/thy_tool3.html

Damping Specific to each analysis type:
https://ansyshelp.ansys.com/account/secured?returnurl=/Views/Secured/corp/v222/ans_str/Hlp_G_STR1D.html

Workshop 02.1: SDOF Oscillators



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