

# Nonlinear Vibrations of Aerospace Structures

Tutorial 01

Introduction to NI2D



# Teaching Assistant

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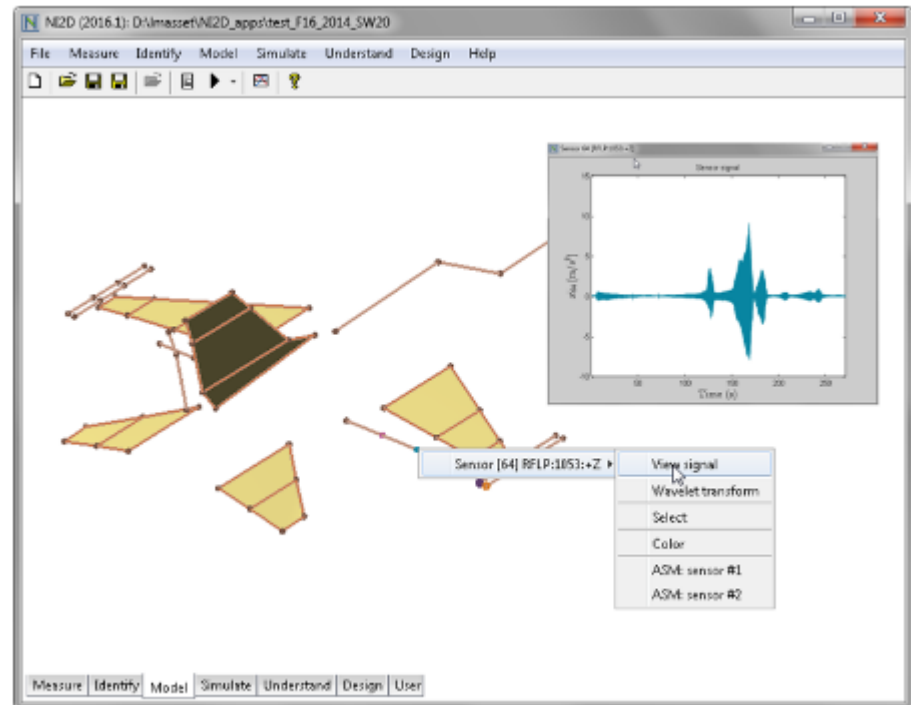
Office: +2/421 (B52)

# Tutorials and Project on the NI2D Software

Check [www.nolisys.com](http://www.nolisys.com)

You'll get free access to the NI2D software until 31/03/2022.

Matlab environment; stand alone .exe.



# NI2D Philosophy

## Nonlinear Identification to Design

- *A prototype of the structure is available:*
  - Test it, identify the nonlinearities and upgrade the linear FEM.
- *A priori knowledge about the nonlinearities is available:*
  - Load the linear FEM into NI2D and implement the nonlinearities using NI2D elements library.

# How To Read the Slides

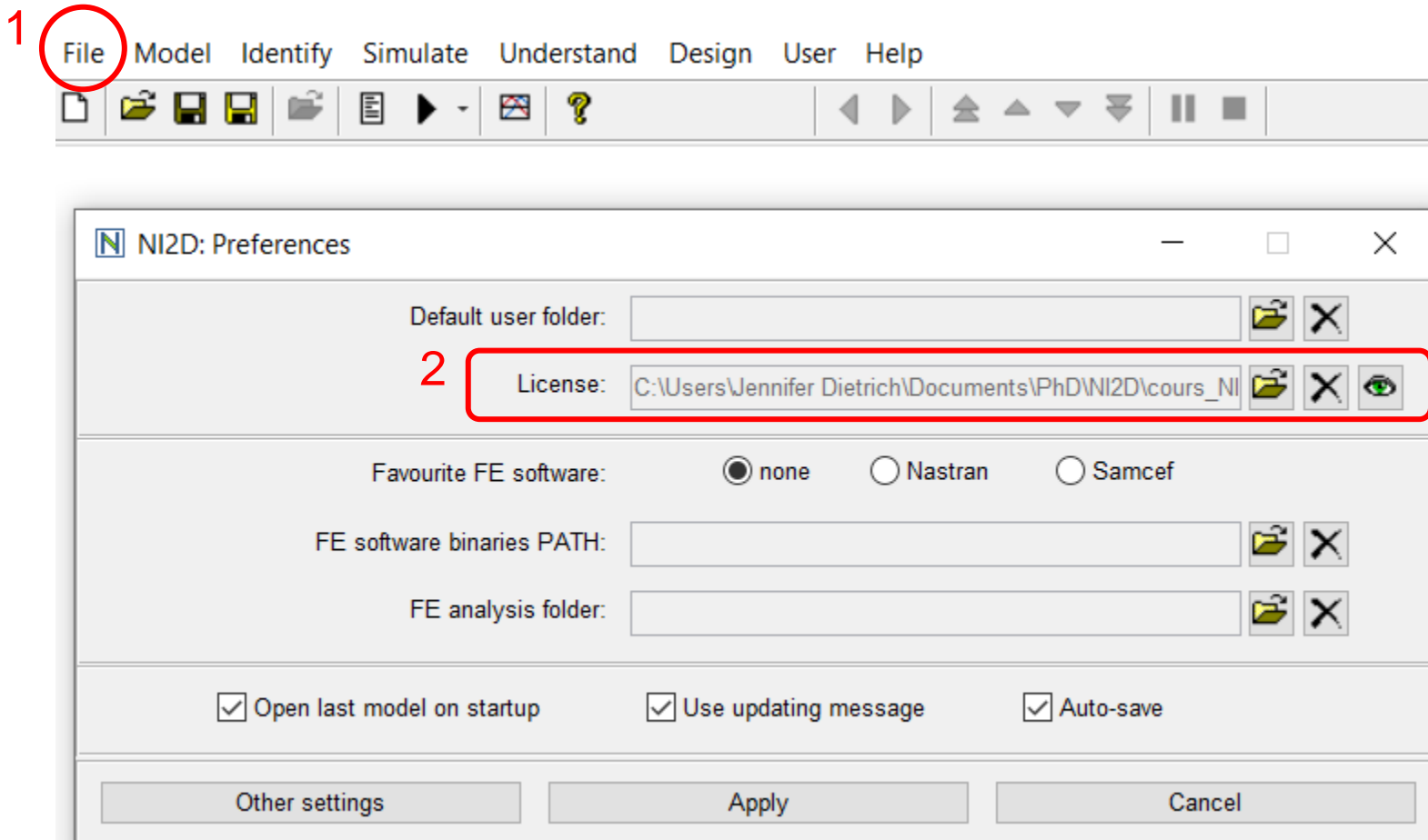
Click Here

Change  
parameters  
here

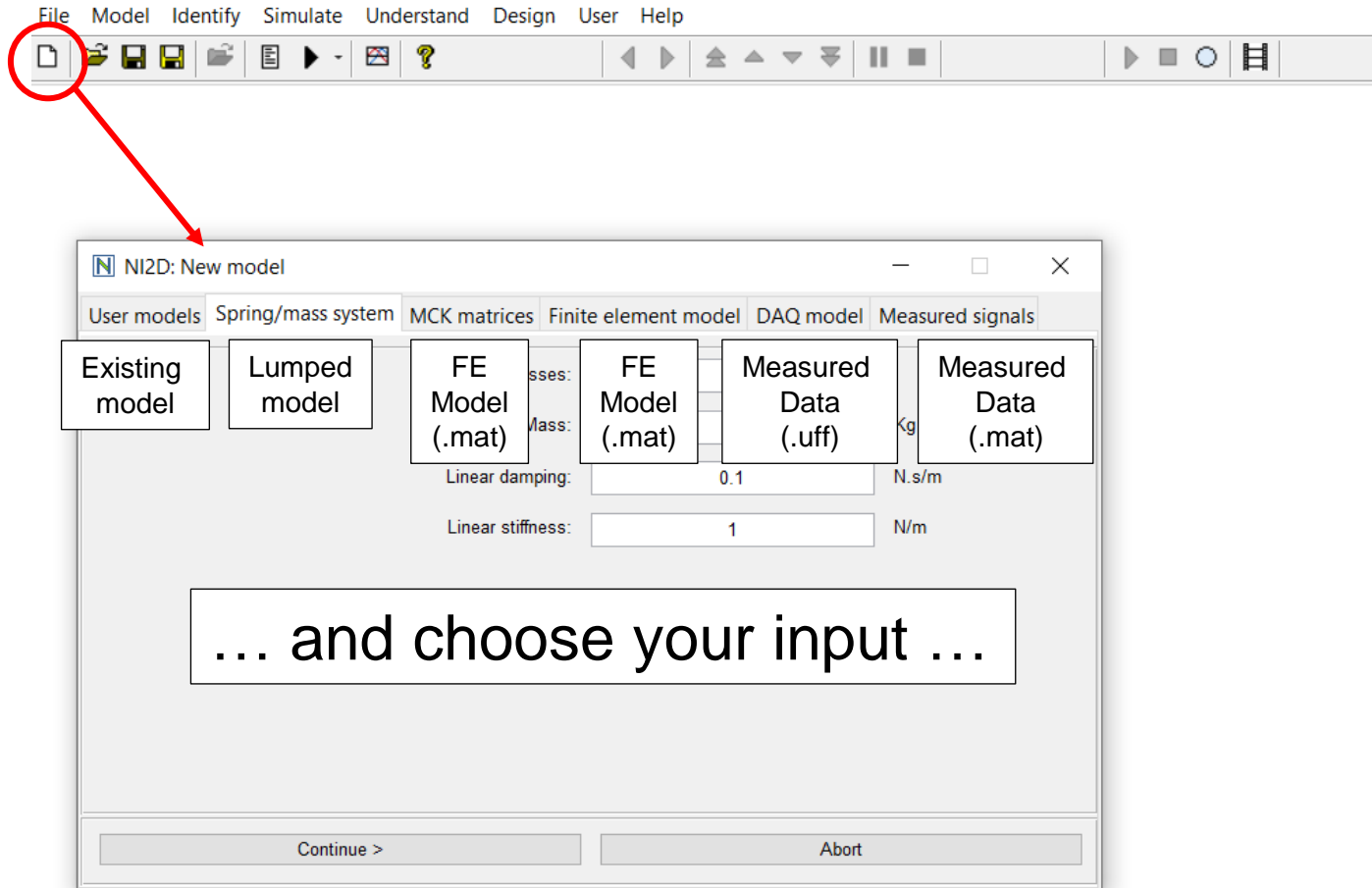
**Comments**

# Get Started with NI2D

Launch NI2D and activate your license under *Preferences* ...



# Create a New Model



# Open an existing model



Choose here

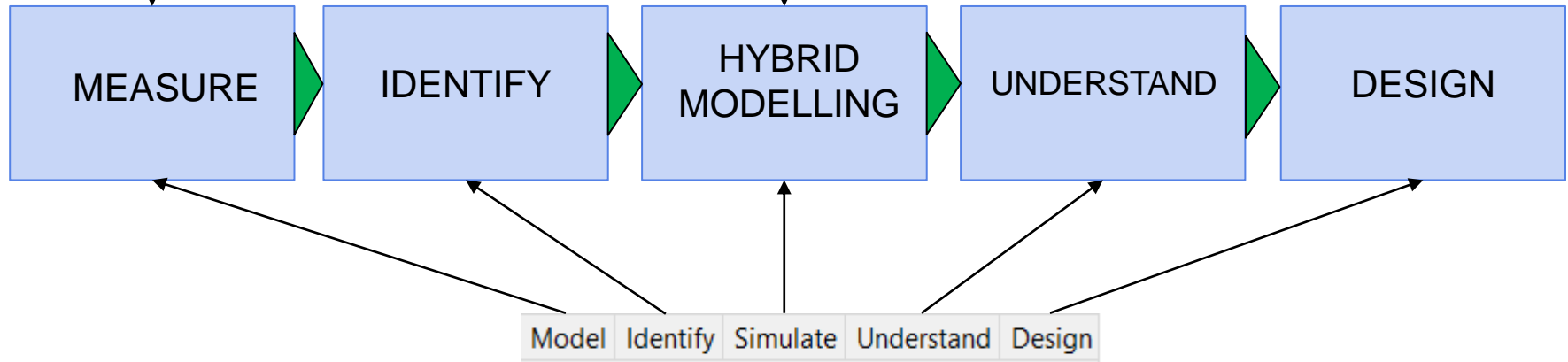
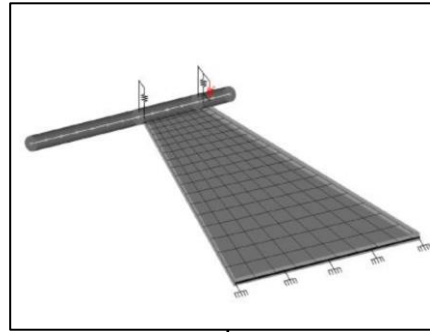


# The Different Solvers

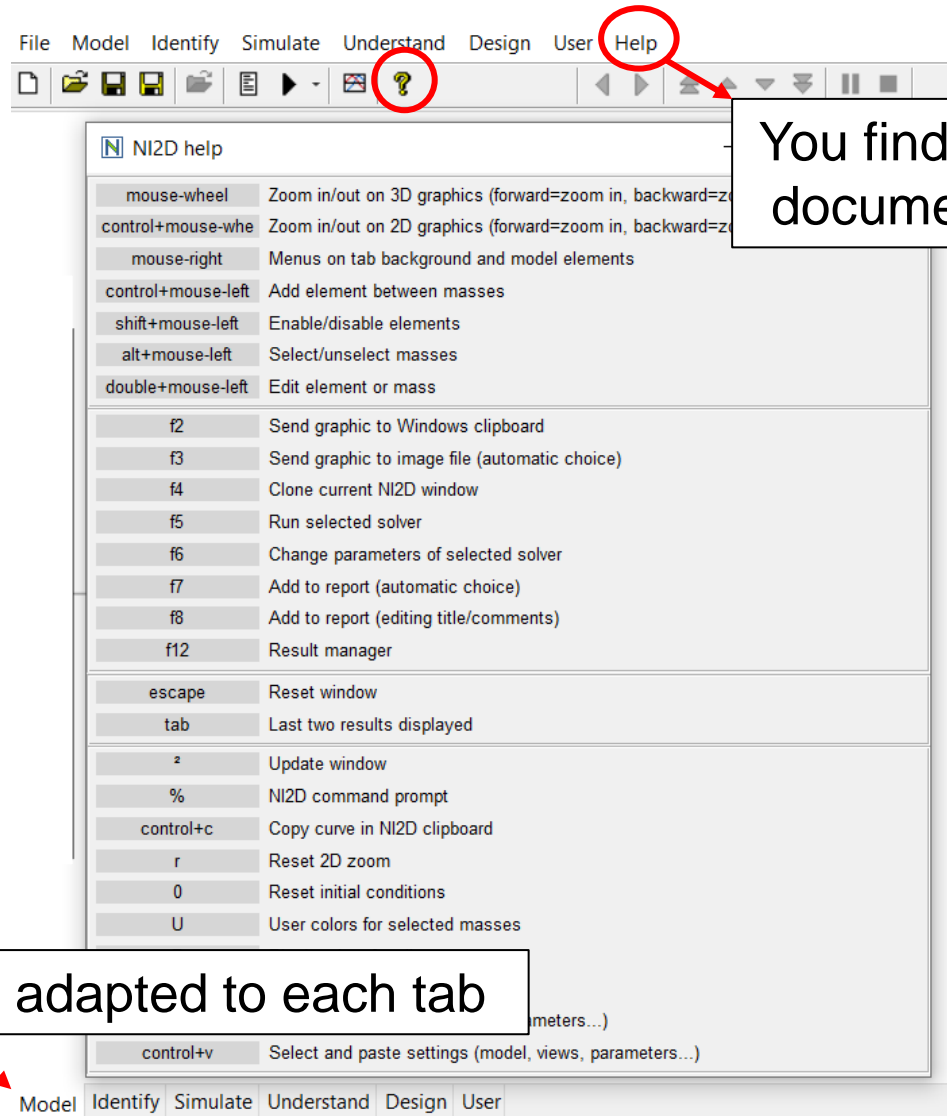
VIBRATION MEASUREMENTS



LINEAR FE-MODEL



# Need Help?



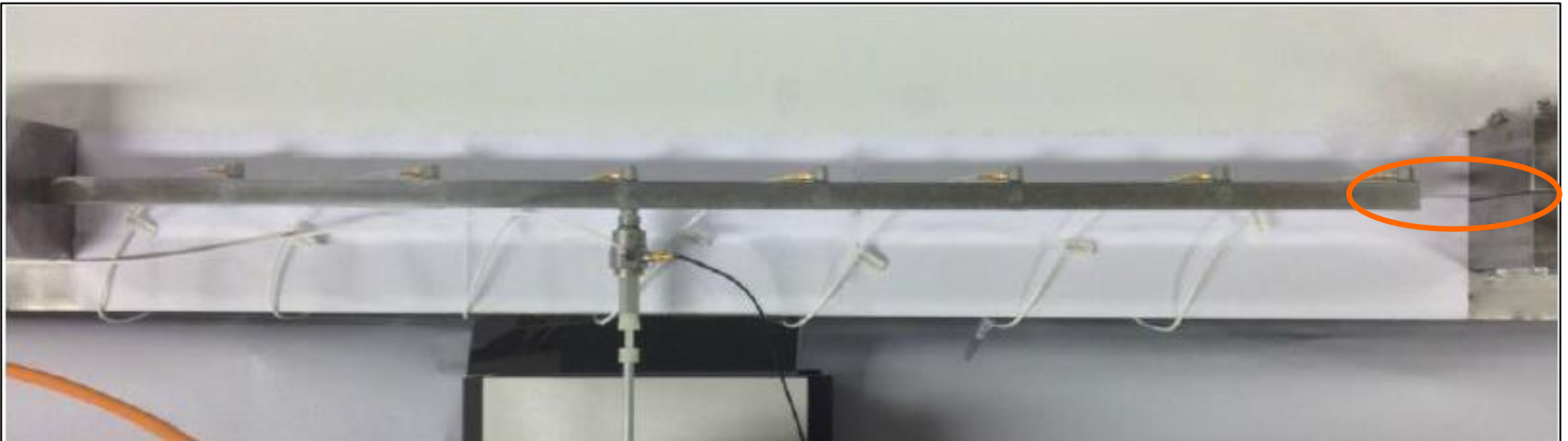
You find the software documentation here

The help menu is adapted to each tab

# Launch Your First Numerical Simulation

# Consider a Thin Short Beam ...

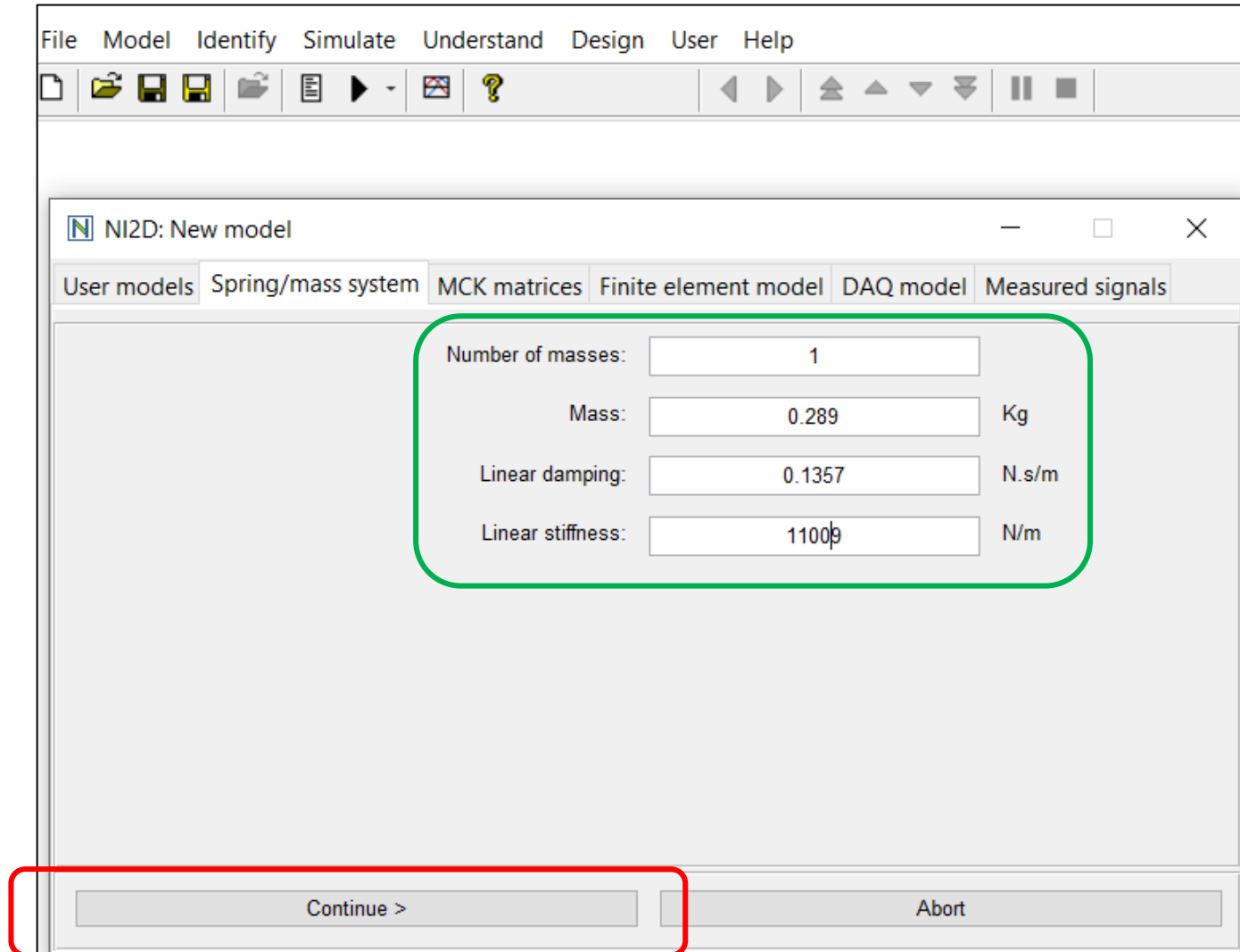
... connected to a cantilever beam (ECL benchmark)



Linear model identified at low level (31 Hz, 0.12%):

$$0.289\ddot{x} + 0.1357\dot{x} + 11009x = F \sin \omega t$$

# Create a New Model: 1 DOF Linear Oscillator



# You Can Change the Coefficients Anytime ...

File Model Identify Simulate Understand Design User Help

Double click

0.1357·x

11009·x

0.289

mode 1: 31.0631 Hz / 0.12 %

Linear modal properties

Model Identify Simulate Understand Design User

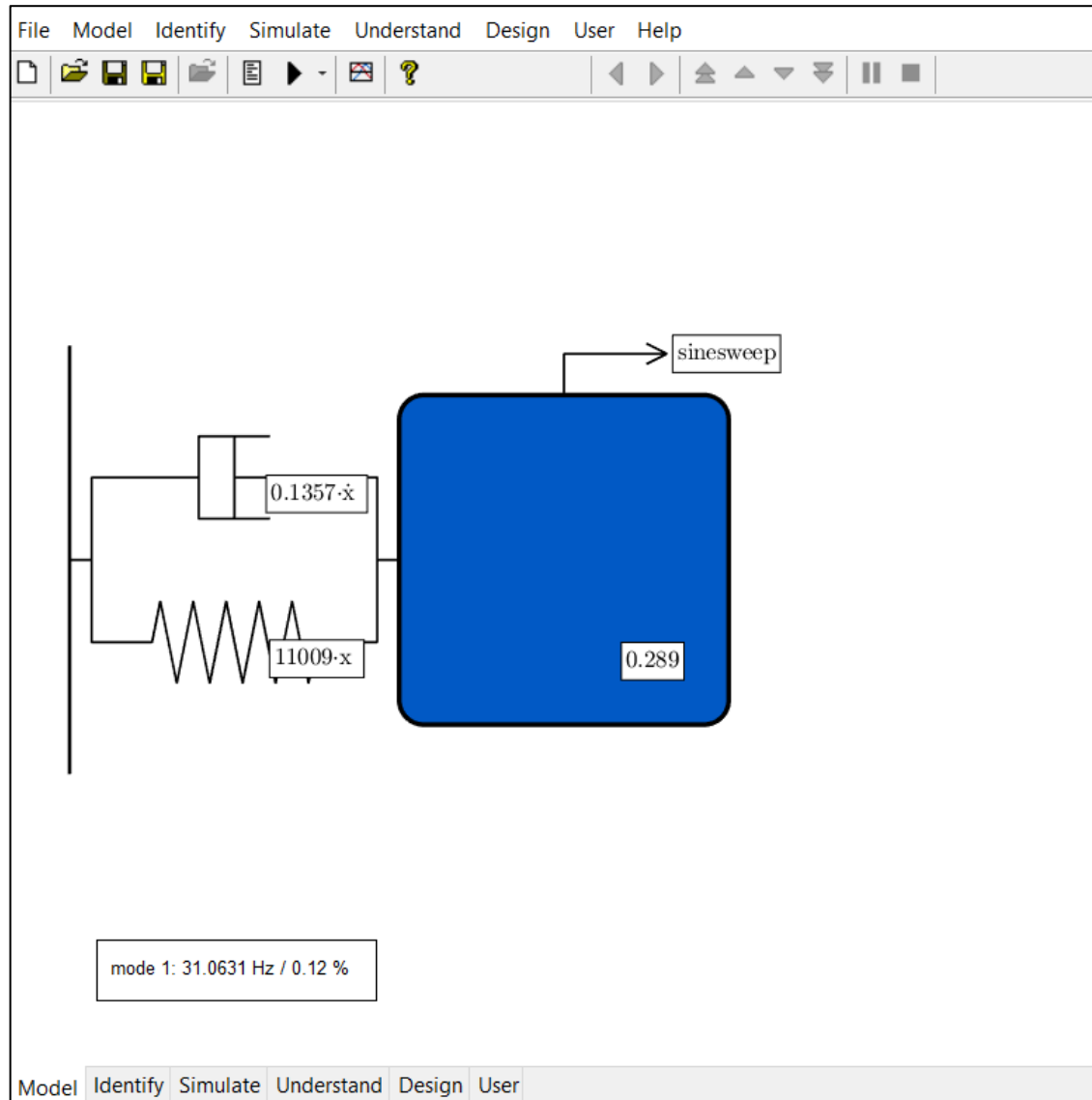
# Add an External Force

The screenshot shows a software interface with a menu bar (File, Model, Identify, Simulate, Understand, Design, User, Help) and a toolbar. The main workspace displays a mechanical model consisting of a vertical bar, a spring, and a mass. A blue block labeled "Double click" is positioned over the mass, with an arrow pointing to a text box containing the mathematical expression  $\sin(2 \cdot \pi \cdot t)$ . A dialog box titled "External force on dof n°1" is open, showing tabs for "Sine", "Sine Sweep", "Random", "User", and "Measure". The "Sine Sweep" tab is selected and circled in red. The dialog box contains the following settings:

- Amplitude: 0.06 N
- Starting frequency: 30 Hz
- Ending frequency: 40 Hz
- Sweep rate: 0.5 Hz/min
- Sweep style:  linear  log

At the bottom of the dialog box, the "Apply" button is circled in red. Other buttons include "Newmark (F5)" and "Cancel". The status bar at the bottom of the window shows "mode 1: 31.0631 Hz /".

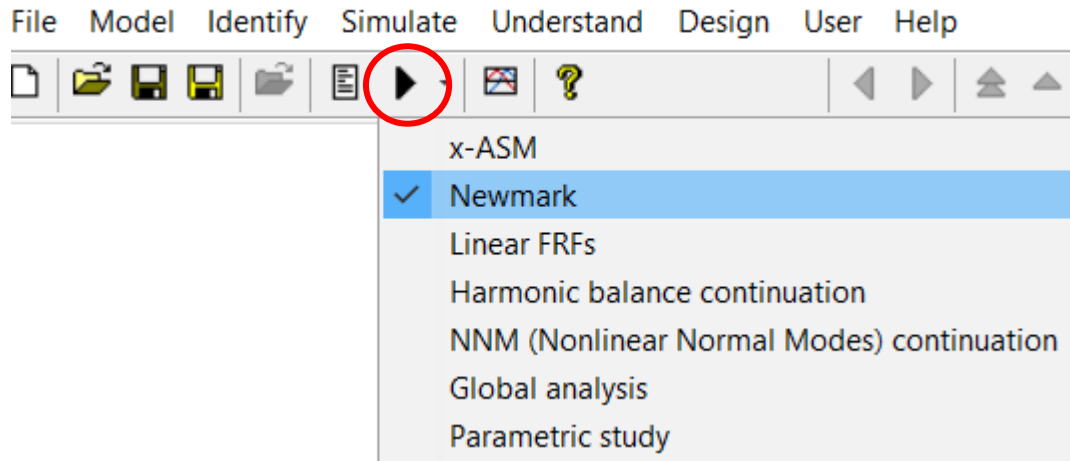
# The Final Linear Model



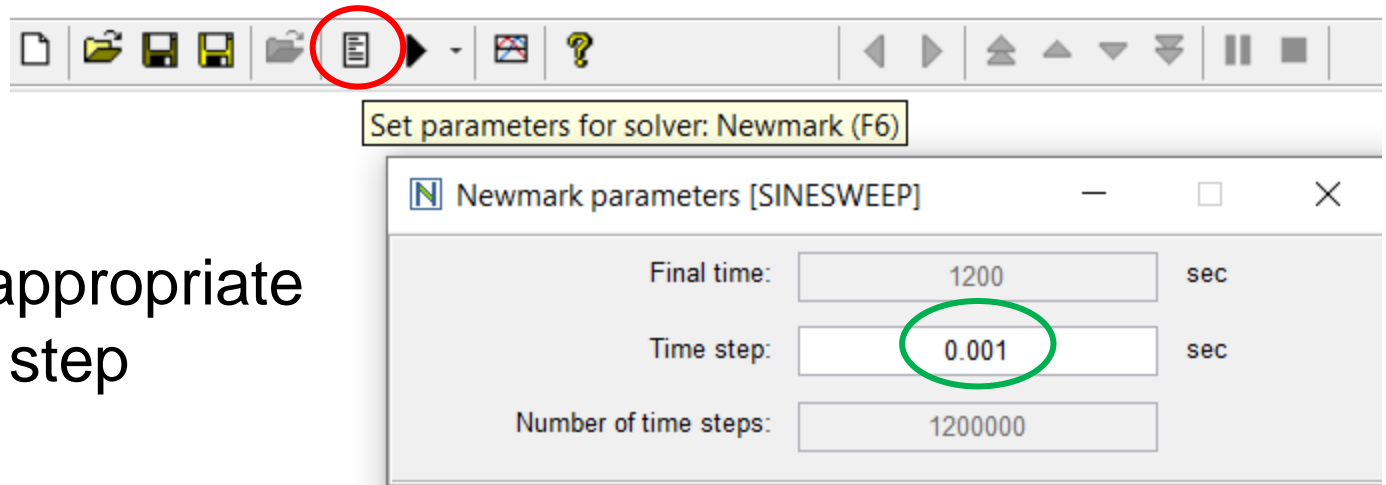


# Calculate the Time Response with Newmark

1.



2.

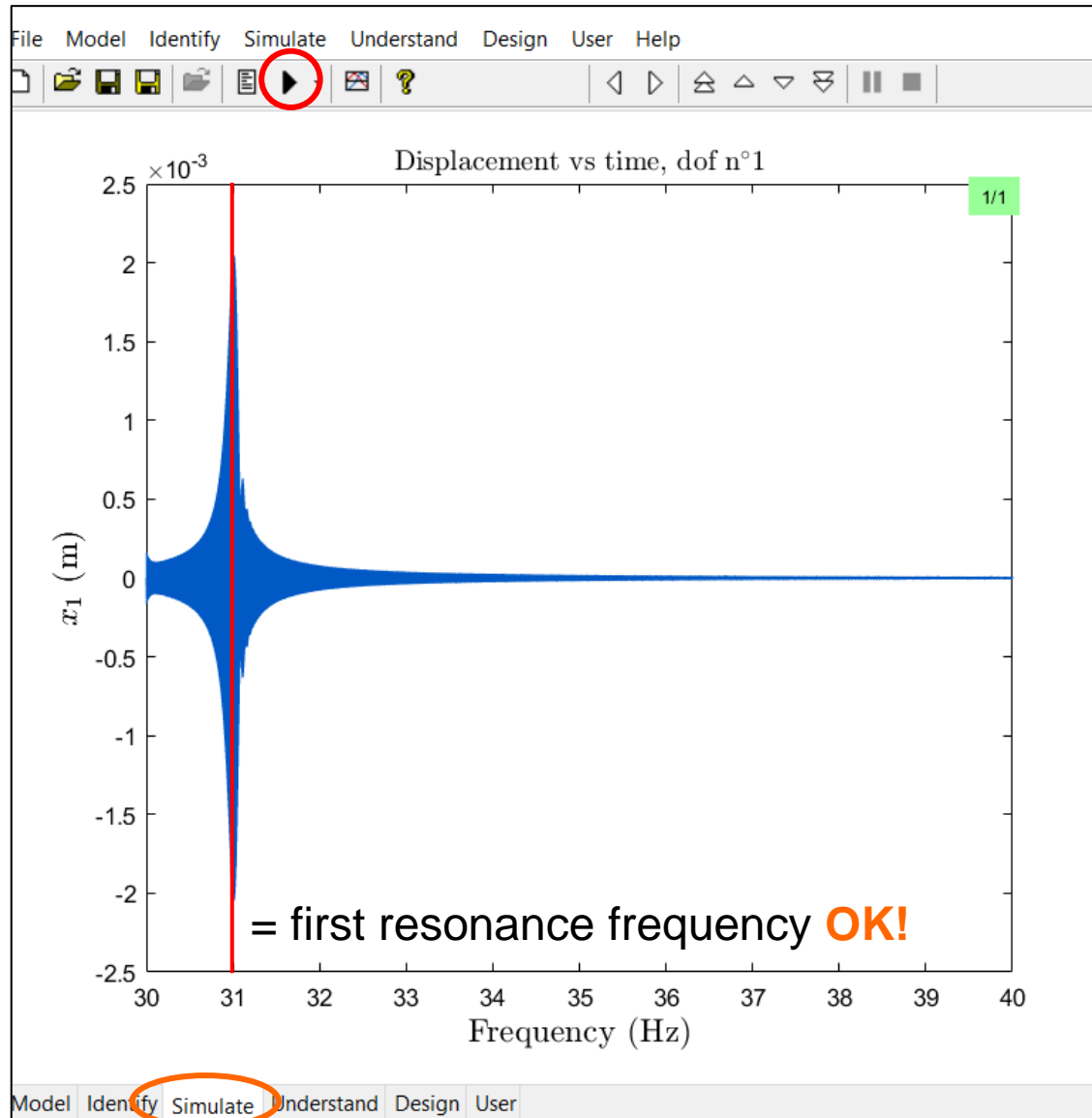


Select an appropriate time step

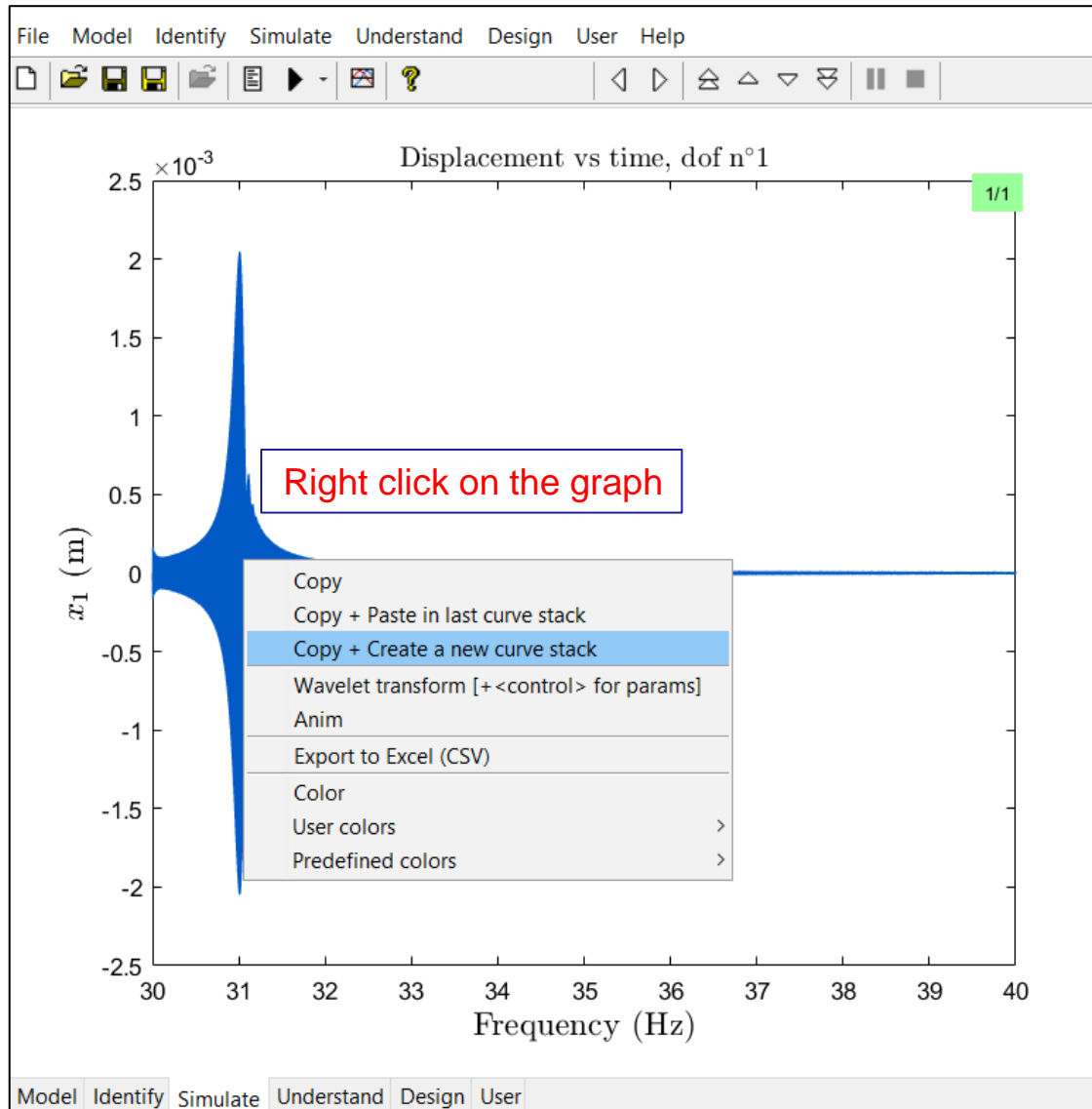
# How to Choose the Right Sampling Frequency?

Algorithm	$\gamma$	$\beta$	Stability limit $\omega h$	Accuracy	
				Amplitude error $\rho - 1$	Periodicity error $\frac{\Delta T}{T}$
Purely explicit	0	0	0	$\frac{\omega^2 h^2}{4}$	—
Central difference	$\frac{1}{2}$	0	2	0	$-\frac{\omega^2 h^2}{24}$
Fox & Goodwin	$\frac{1}{2}$	$\frac{1}{12}$	2.45	0	$O(h^3)$
Linear acceleration	$\frac{1}{2}$	$\frac{1}{6}$	3.46	0	$\frac{\omega^2 h^2}{24}$
Average constant acceleration	$\frac{1}{2}$	$\frac{1}{4}$	$\infty$	0	$\frac{\omega^2 h^2}{12}$
Average constant acceleration (modified)	$\frac{1}{2} + \alpha$	$\frac{(1 + \alpha)^2}{4}$	$\infty$	$\alpha - \frac{\omega^2 h^2}{2}$	$\frac{\omega^2 h^2}{12}$

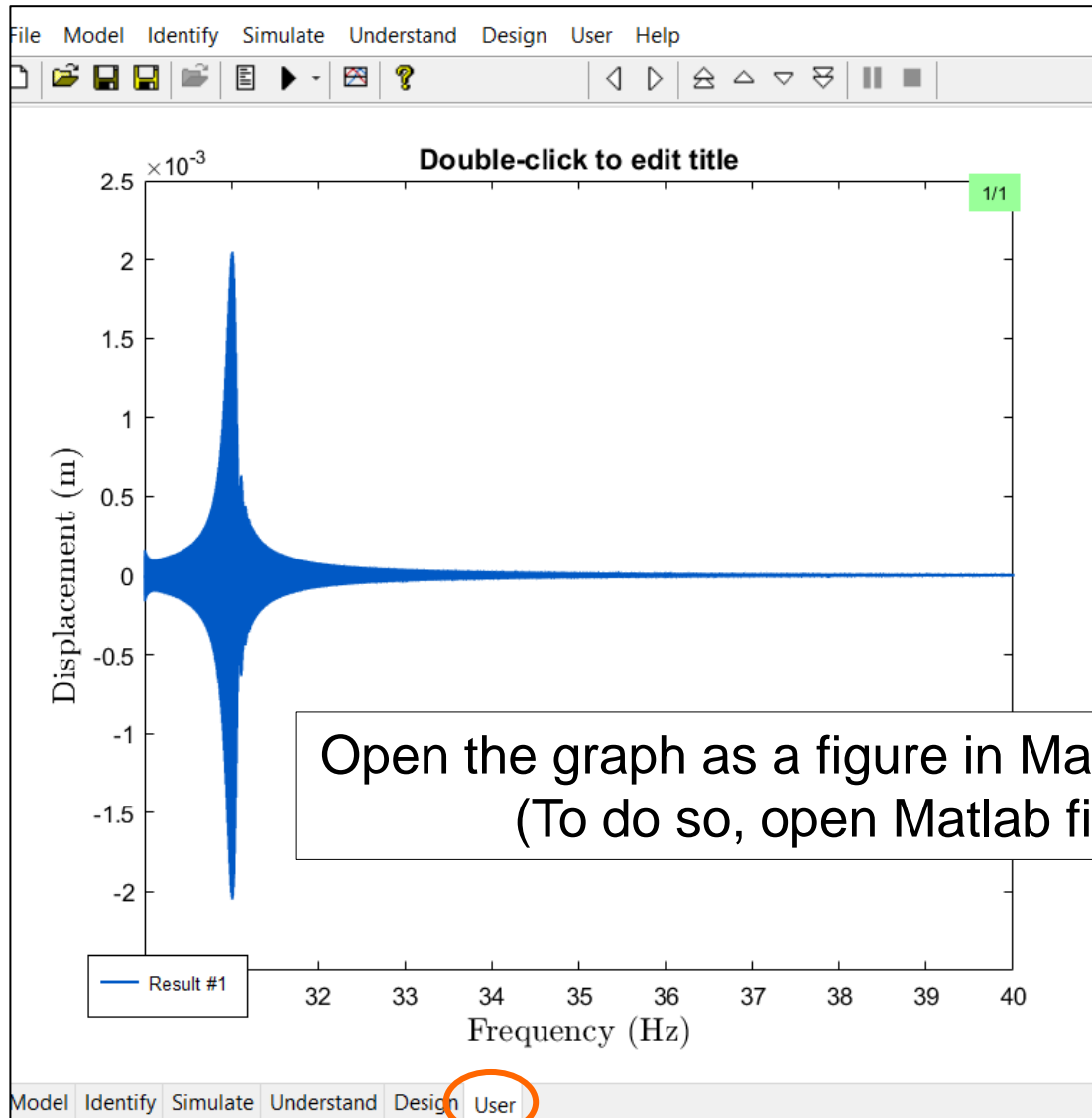
# Now: Run



# Save Your Results in a Curve Stack

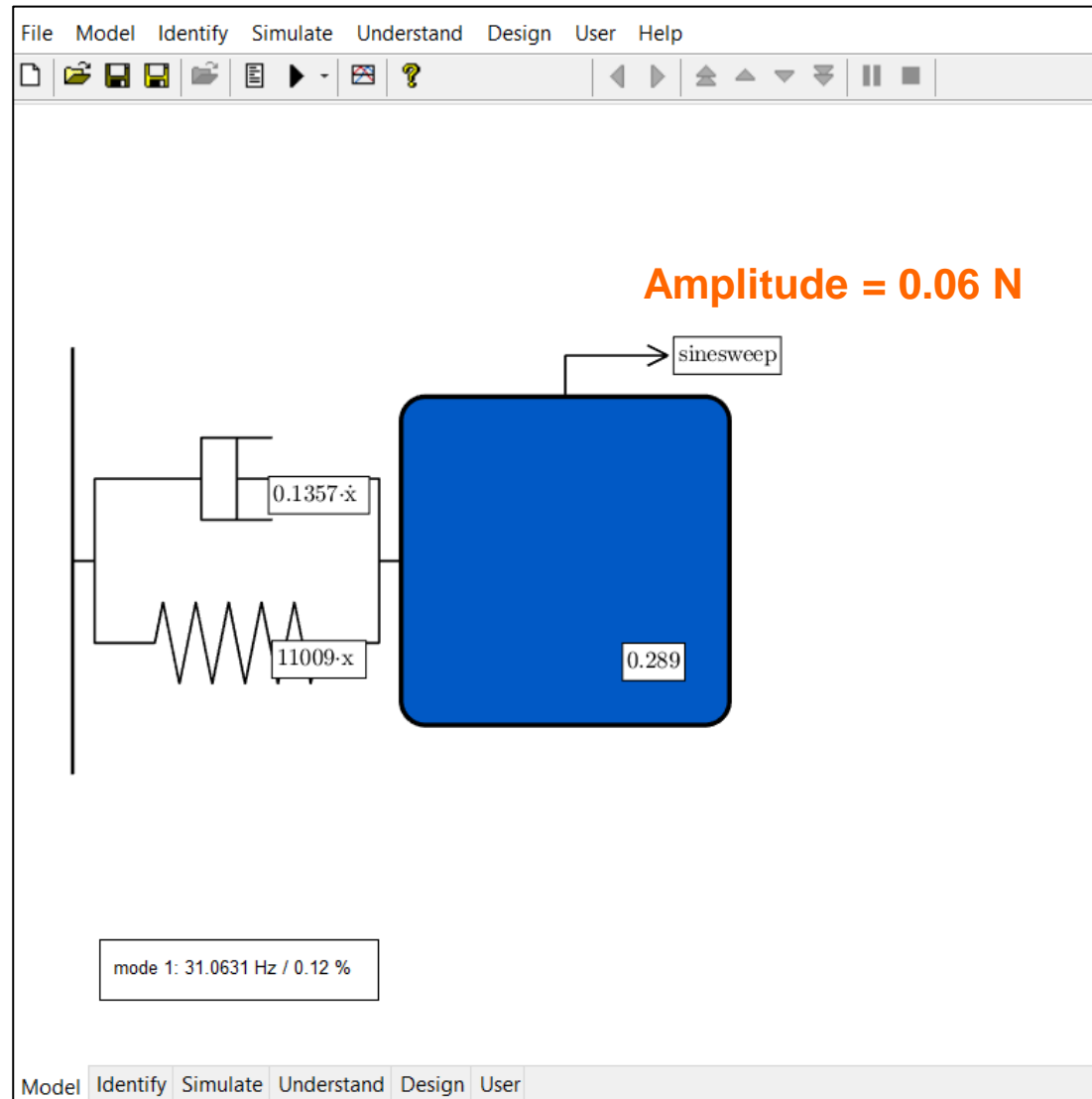


# Check Your Results Anytime

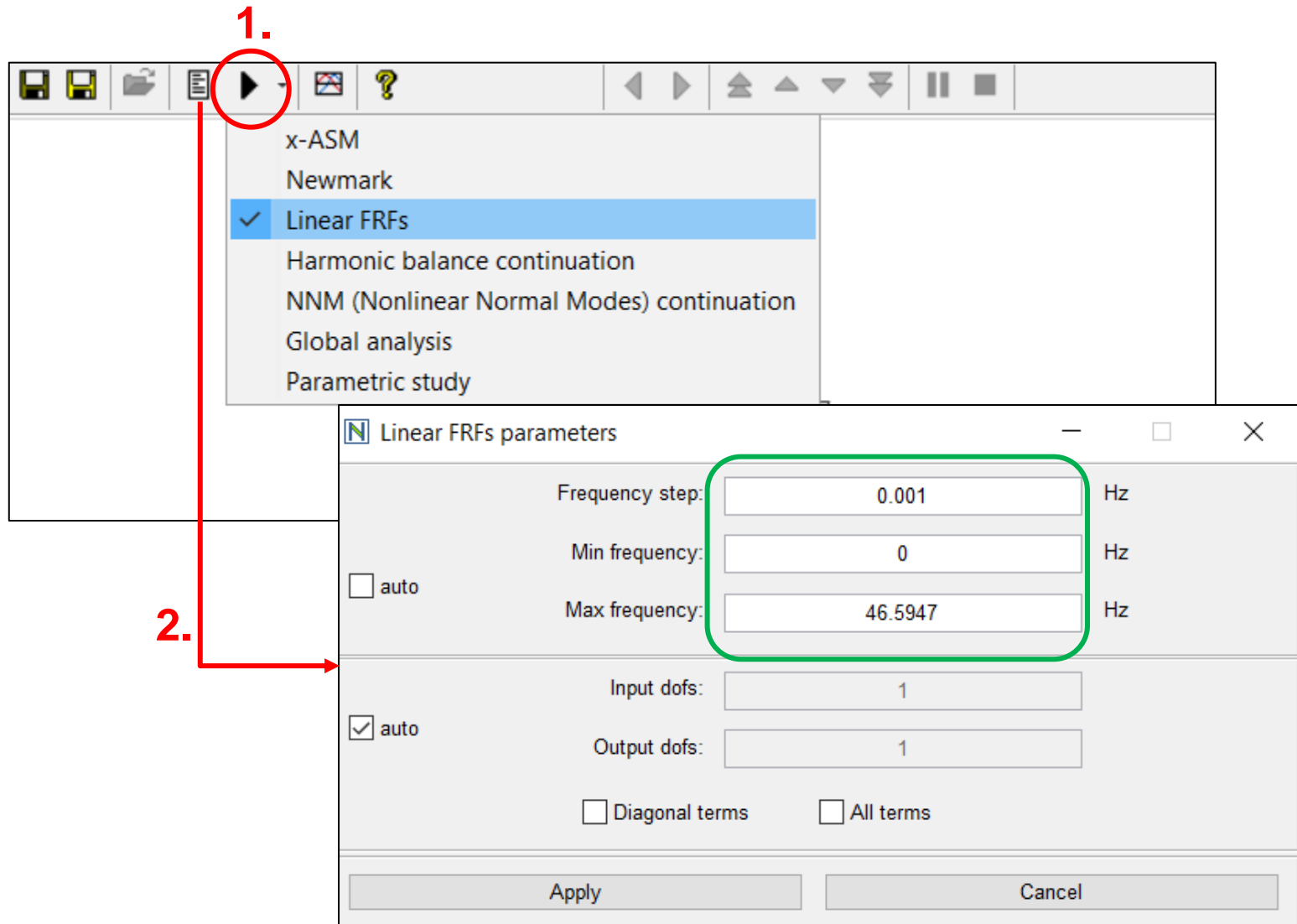


# Frequency Response Functions

# The Linear Model

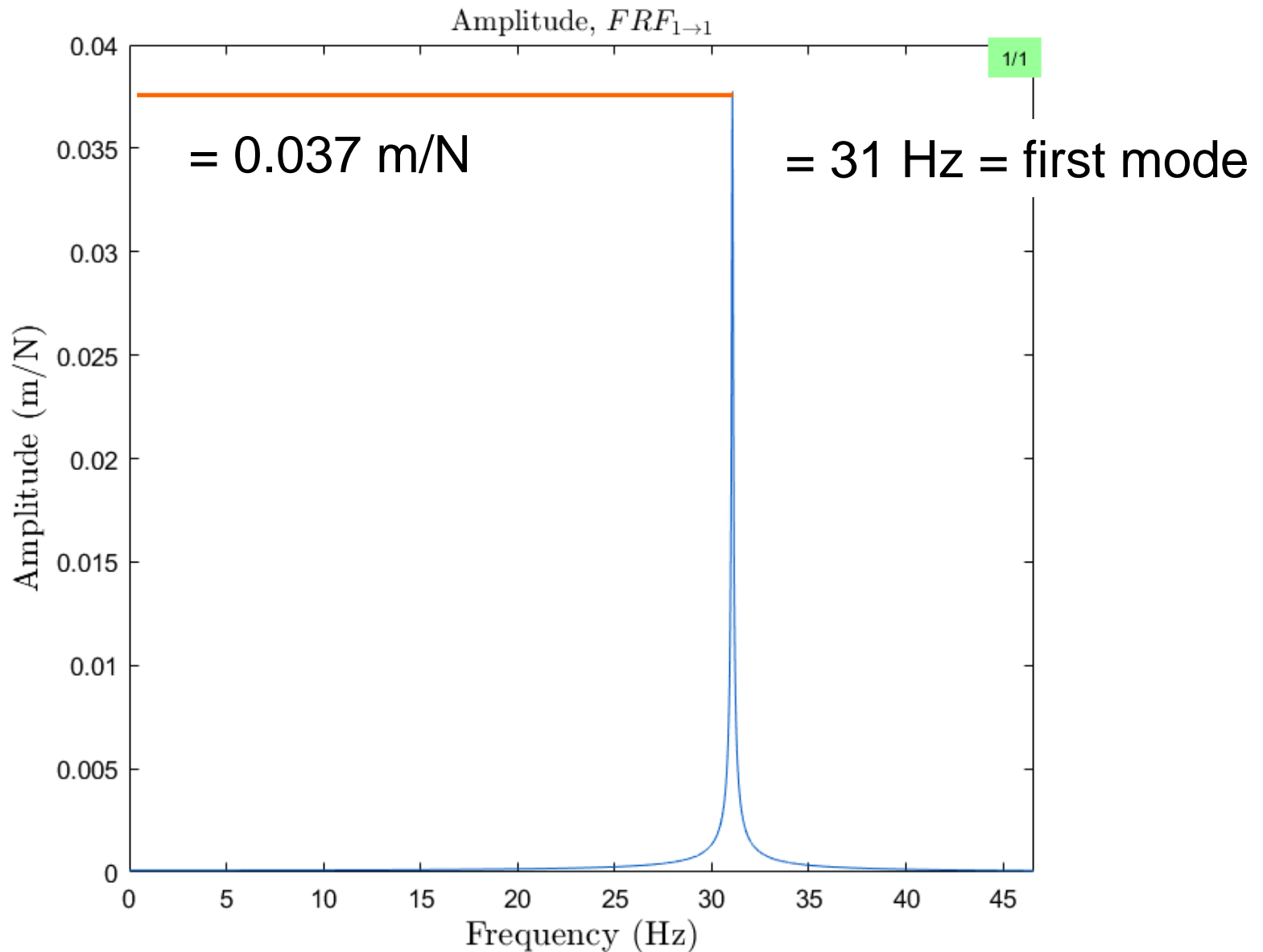


# Calculate the Linear FRF ...

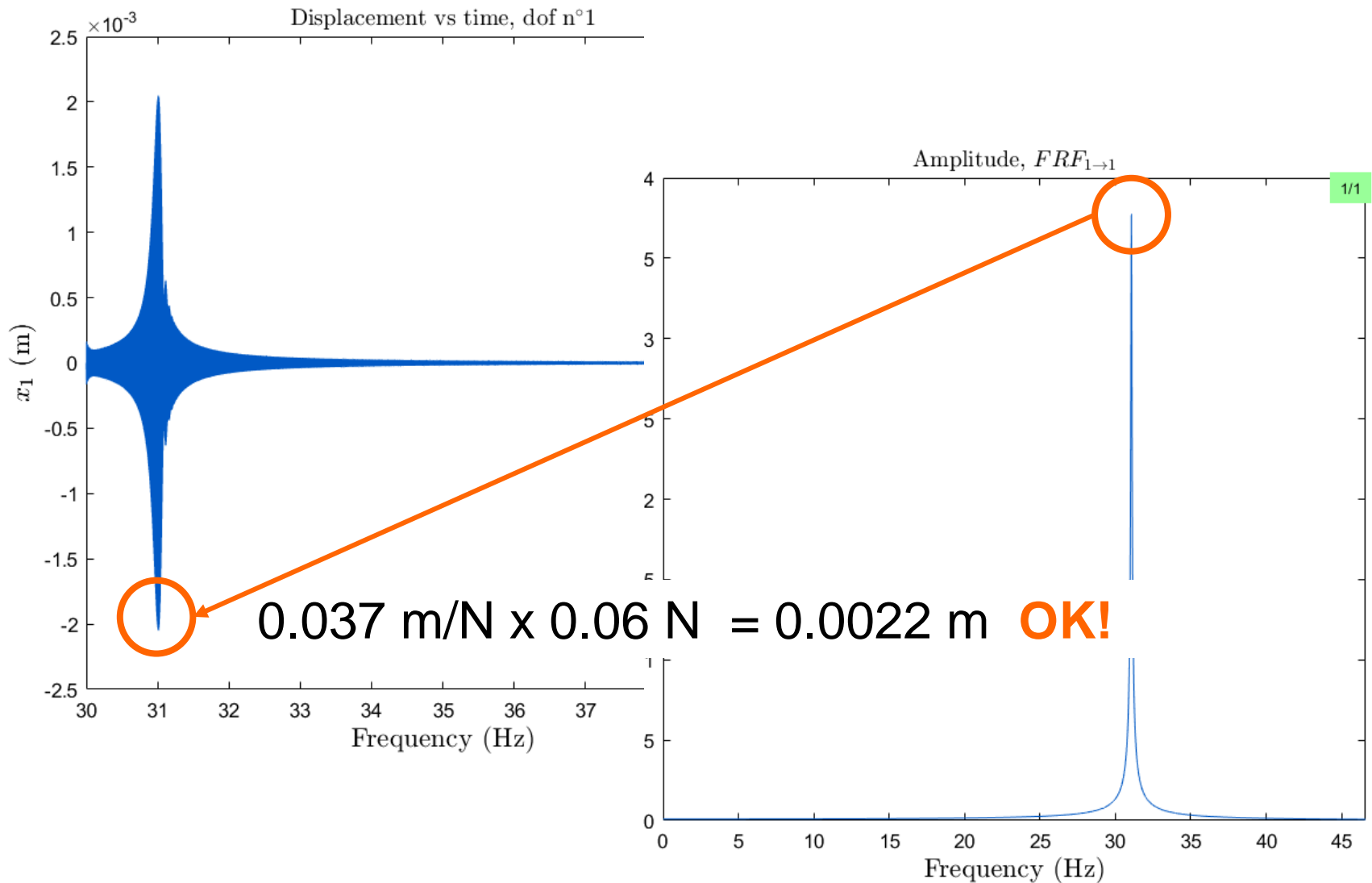




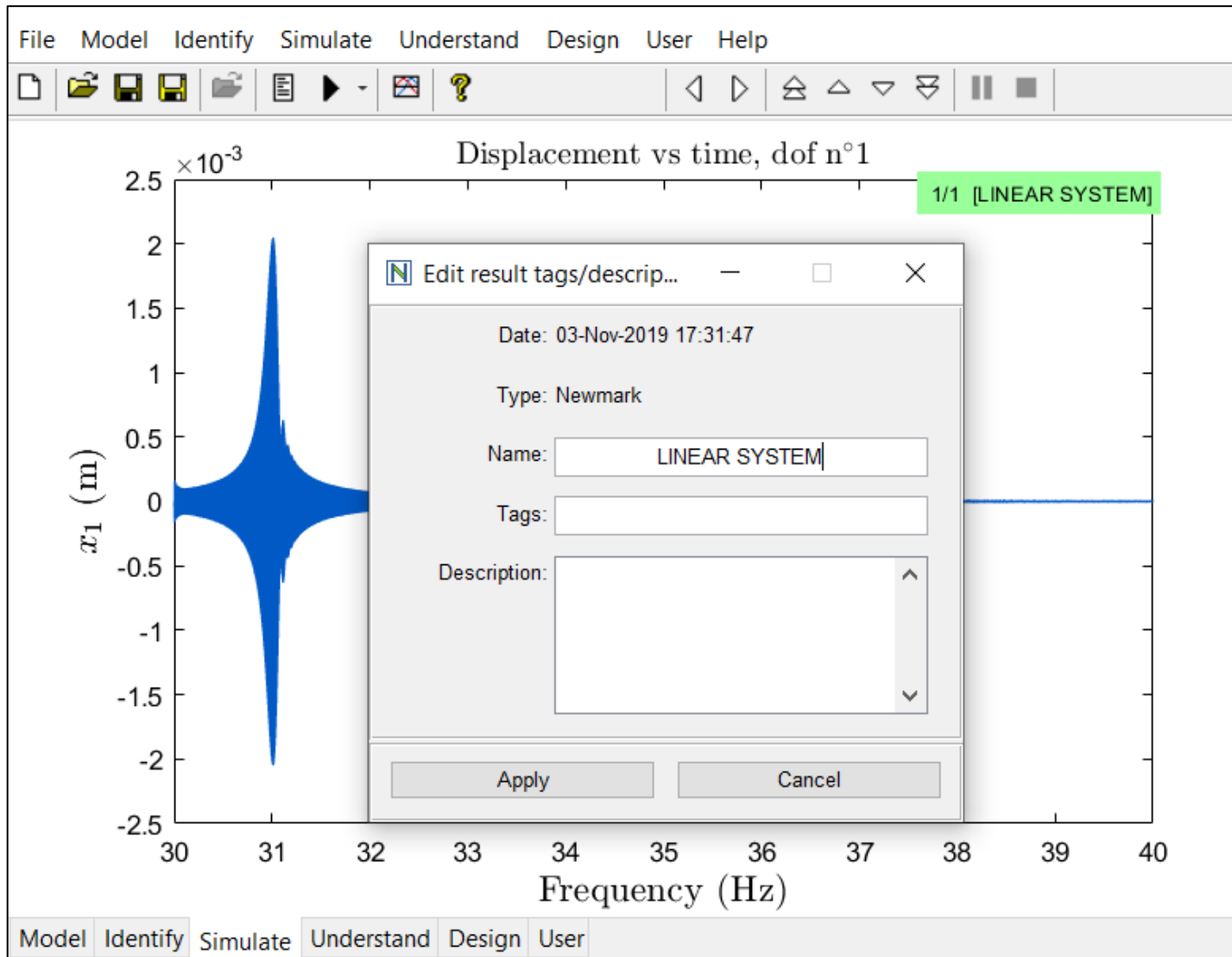
# And Check the Result



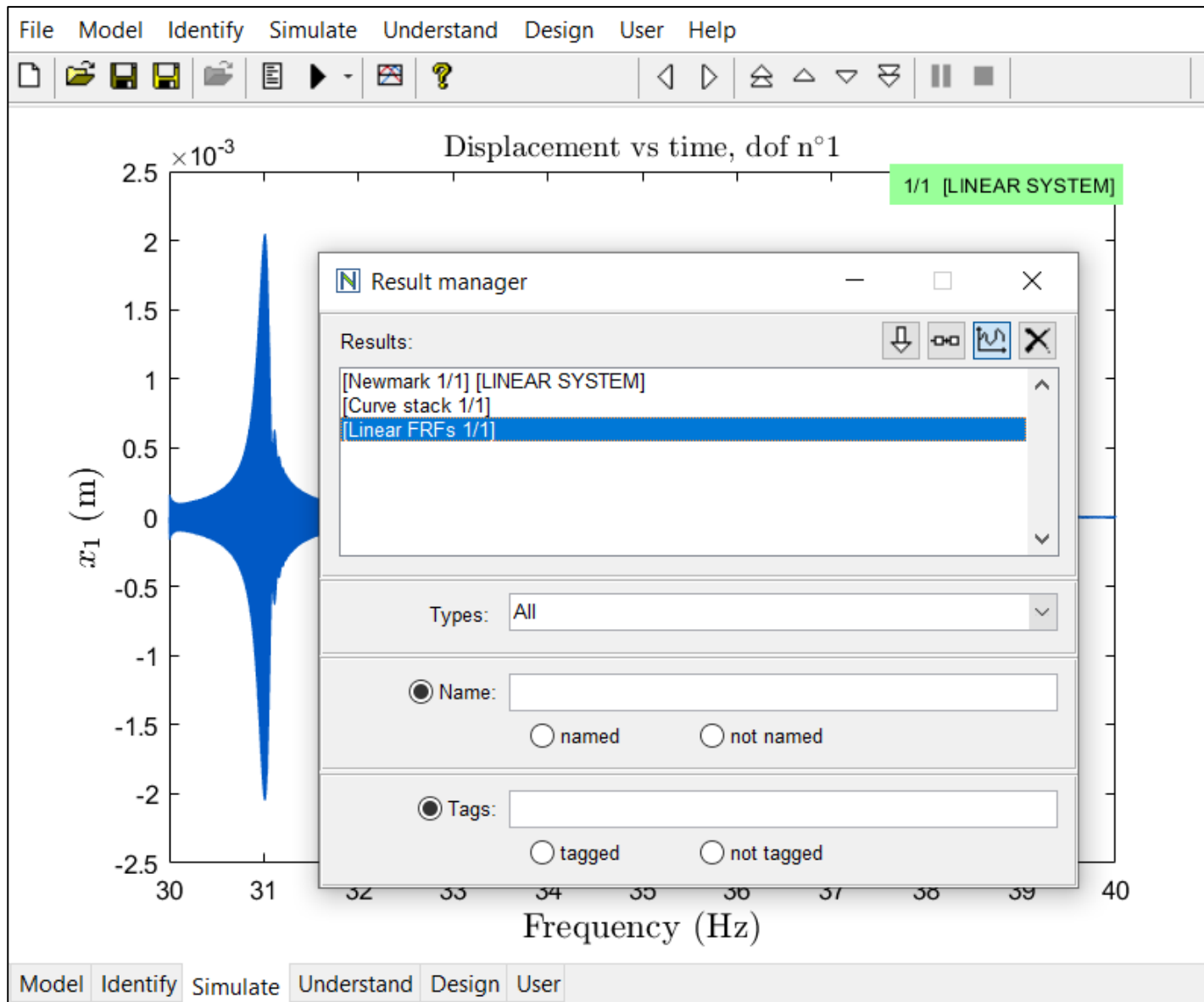
# Compare the Time and the Frequency Response



# You Can Tag Your Results (F11) ...

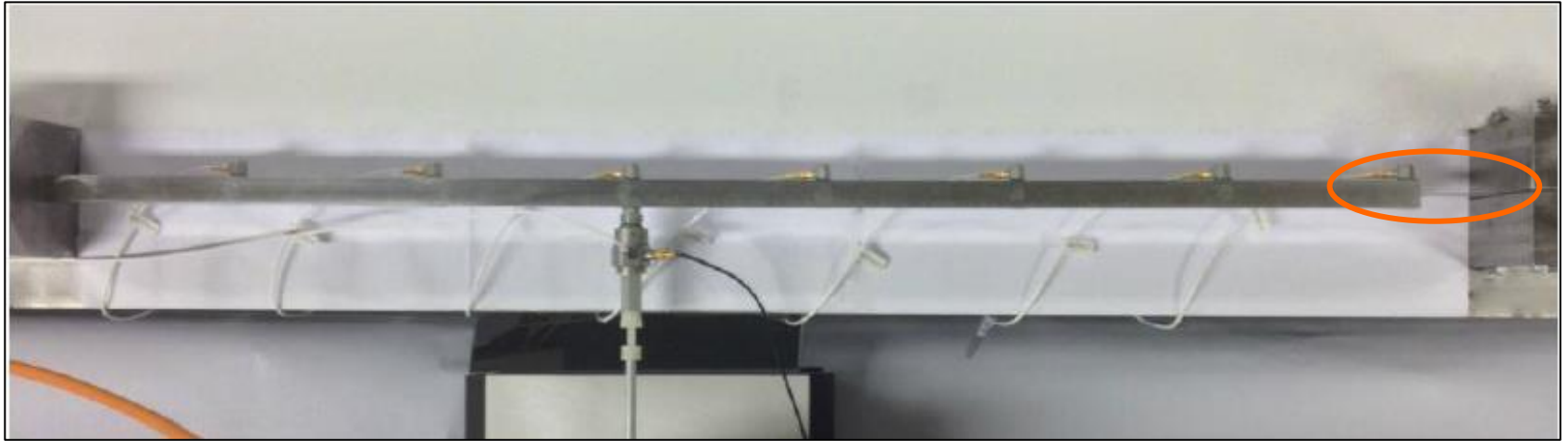


# And Manage All Your Results (F12)



# Launch Your First Nonlinear Simulation

# Nonlinear Model of the 1<sup>st</sup> Beam Mode



Linear model identified at low level (31 Hz, 0.12%):

$$0.289\ddot{x} + 0.1357\dot{x} + 11009x = F \sin \omega t$$

Nonlinearity identified at high level:  $2.37 \cdot 10^9 x^3$

# Upgrade the Linear Model from T02 ...

The screenshot shows a software application window with a menu bar (File, Model, Identify, Simulate, Understand, Design, User, Help) and a toolbar. The main workspace contains a block diagram with a blue rectangular block. A red arrow points from a text box labeled "Ctrl + left click" to the blue block. A dialog box titled "Add element at position 1" is open, displaying a list of elements: Nonlinear polynomial stiffness (highlighted), Nonlinear cubic spline stiffness, Nonlinear piecewise linear stiffness, Nonlinear contact, Nonlinear polynomial damping, Coulomb friction, Trilinear damping, Point-by-point damping, and Hysteretic damping (Bouc-Wen). The dialog has "OK" and "Cancel" buttons. The background diagram includes a block with the expression  $0.1357 \cdot \dot{x}$  and another with  $11009 \cdot x$ . A status bar at the bottom shows "mode 1: 31.0631 Hz / 0.12 %".

# With a Cubic Spring

The screenshot displays a software interface with a menu bar (File, Model, Identify, Simulate, Understand, Design, User, Help) and a toolbar. The main workspace shows a mechanical model of a mass-spring-damper system. A blue mass is connected to a fixed wall on the left by three parallel elements: a spring with a coefficient of  $2.37e+09 \cdot x^3$ , a damper with a coefficient of  $0.1357 \cdot \dot{x}$ , and a linear spring with a coefficient of  $11009 \cdot x$ . A sine sweep input labeled "sinesweep" is applied to the mass. A modal analysis result box indicates "mode 1: 31.0631 Hz / 0.12 %".

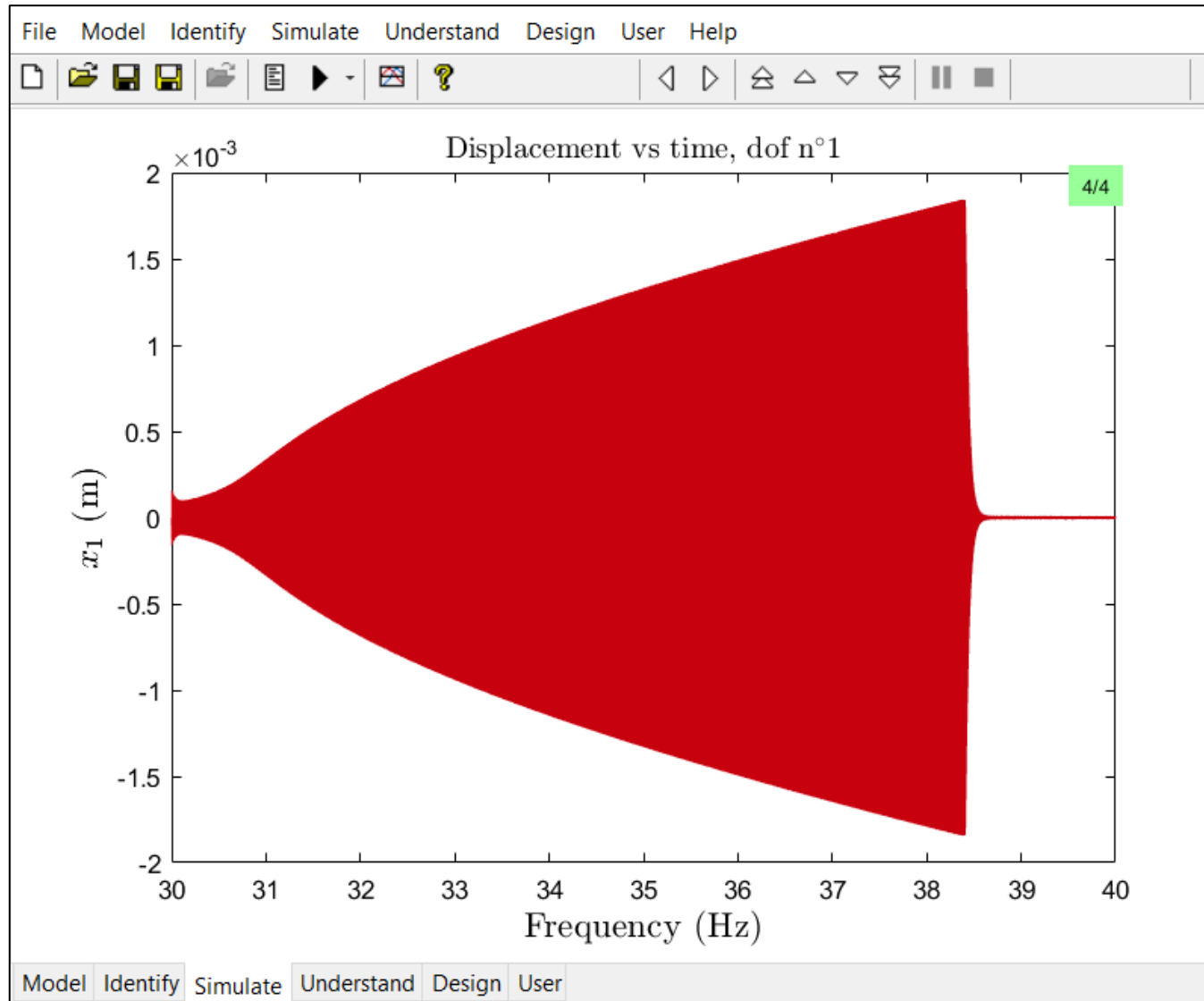
A dialog box titled "Polynomial NL spring n..." is open, showing the configuration for the cubic spring. The dialog includes the following fields and options:

- Coefficient:  N/m^x
- Exponent:
- Radio buttons:  odd,  even,  unilateral
- Buttons: Apply, Cancel

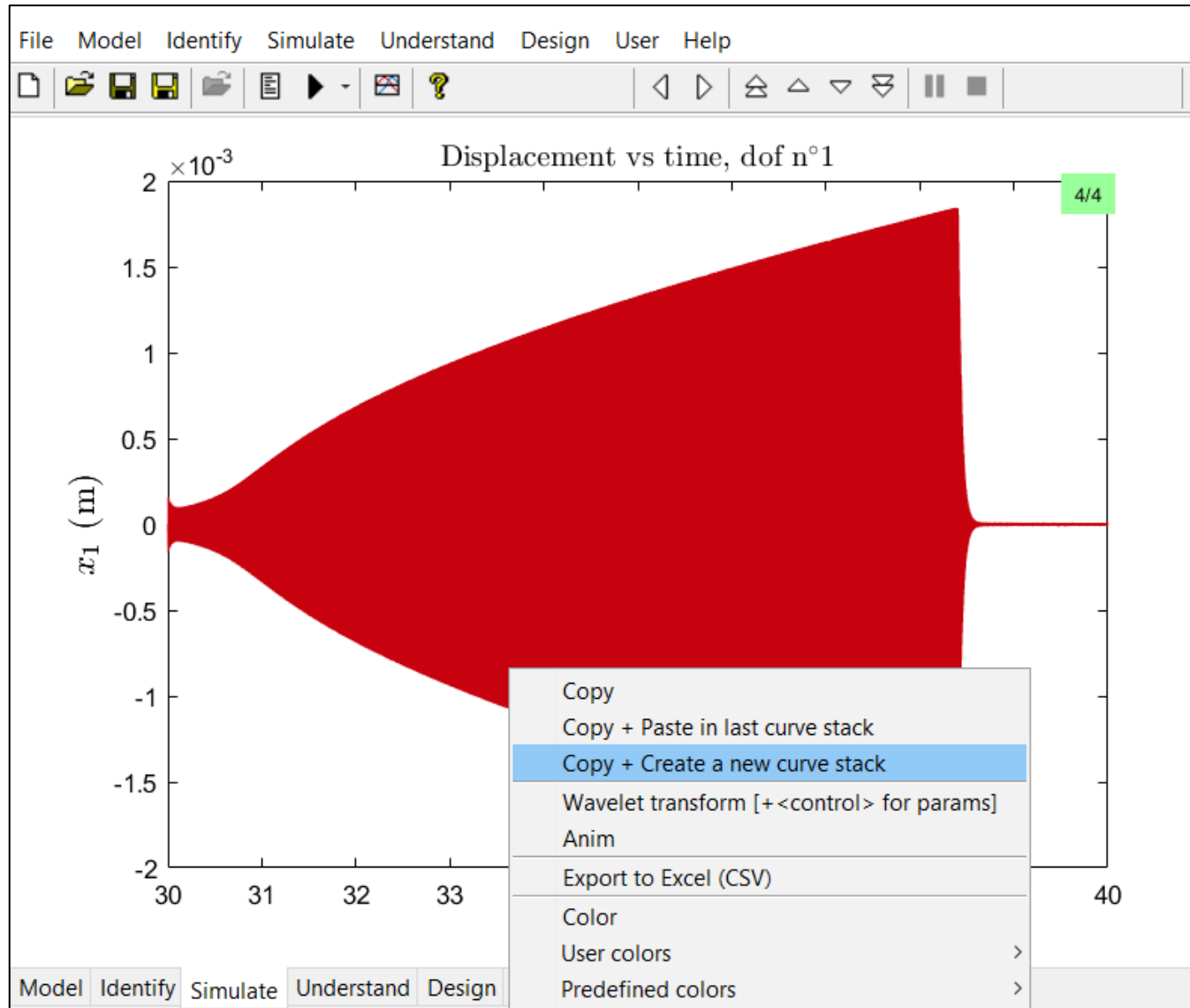
At the bottom of the interface, a secondary menu bar shows "Model Identify Simulate Understand Design User".



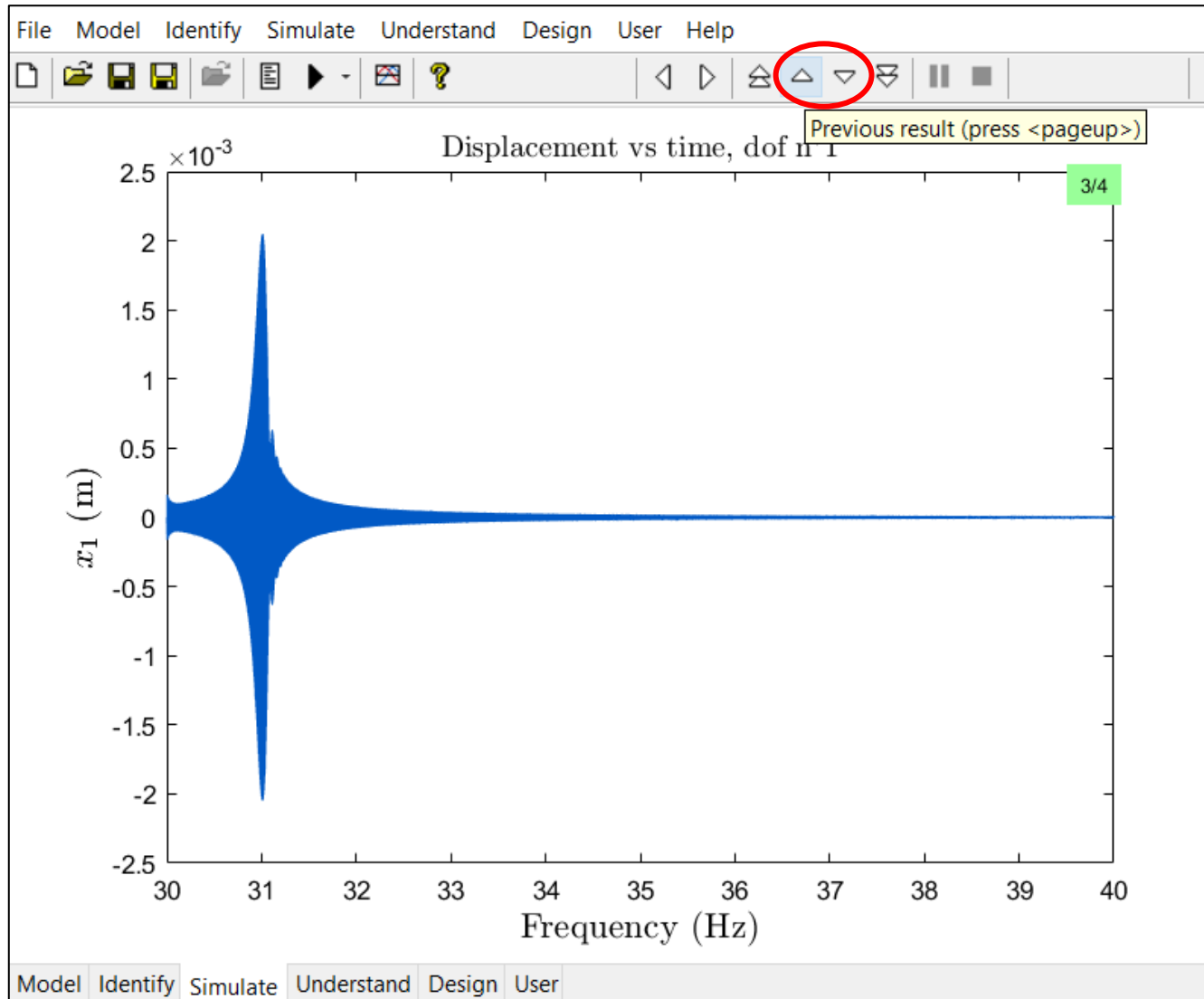
# Run the Newmark Time Integration Again ...



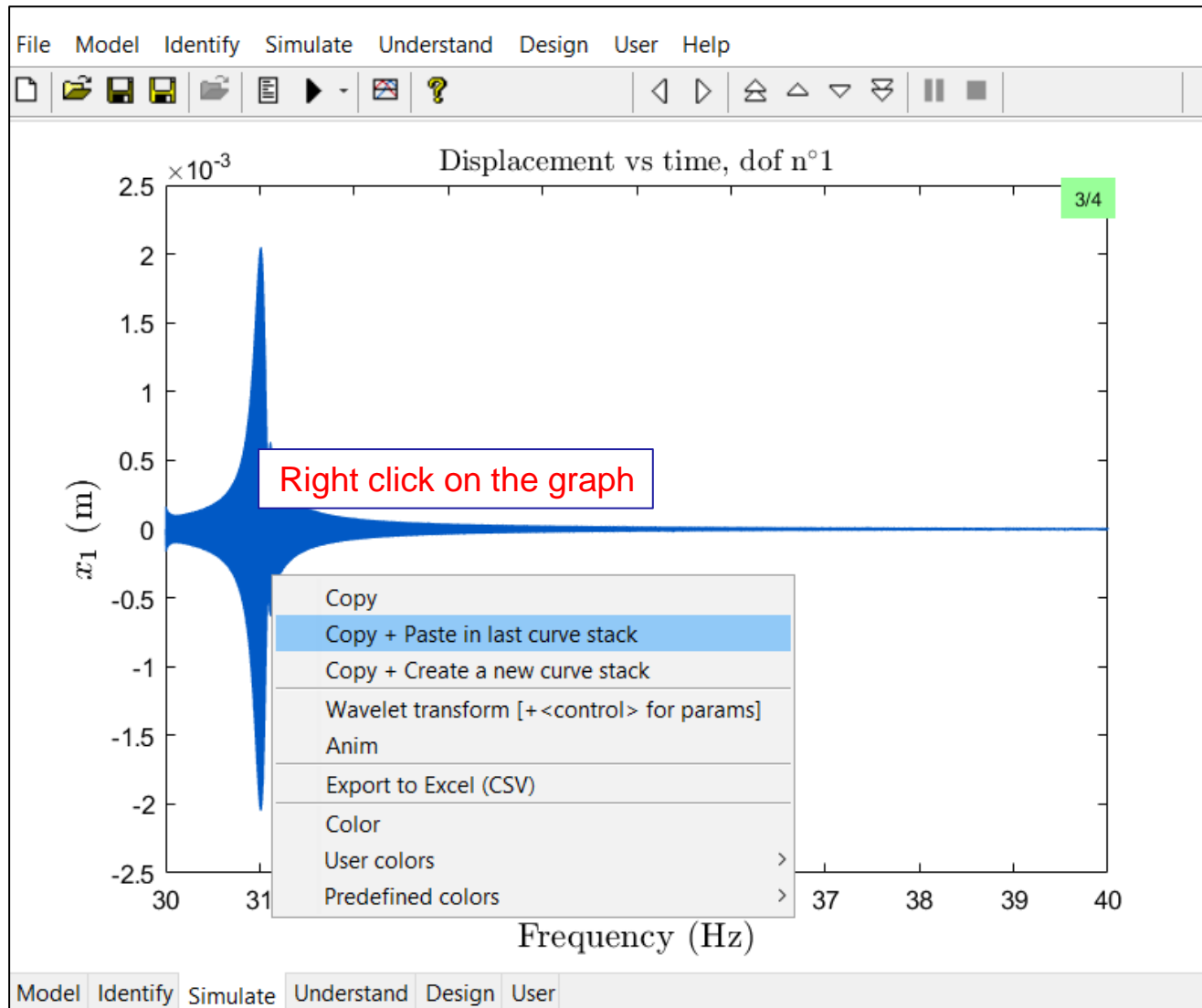
# And Save Your Results For Comparison



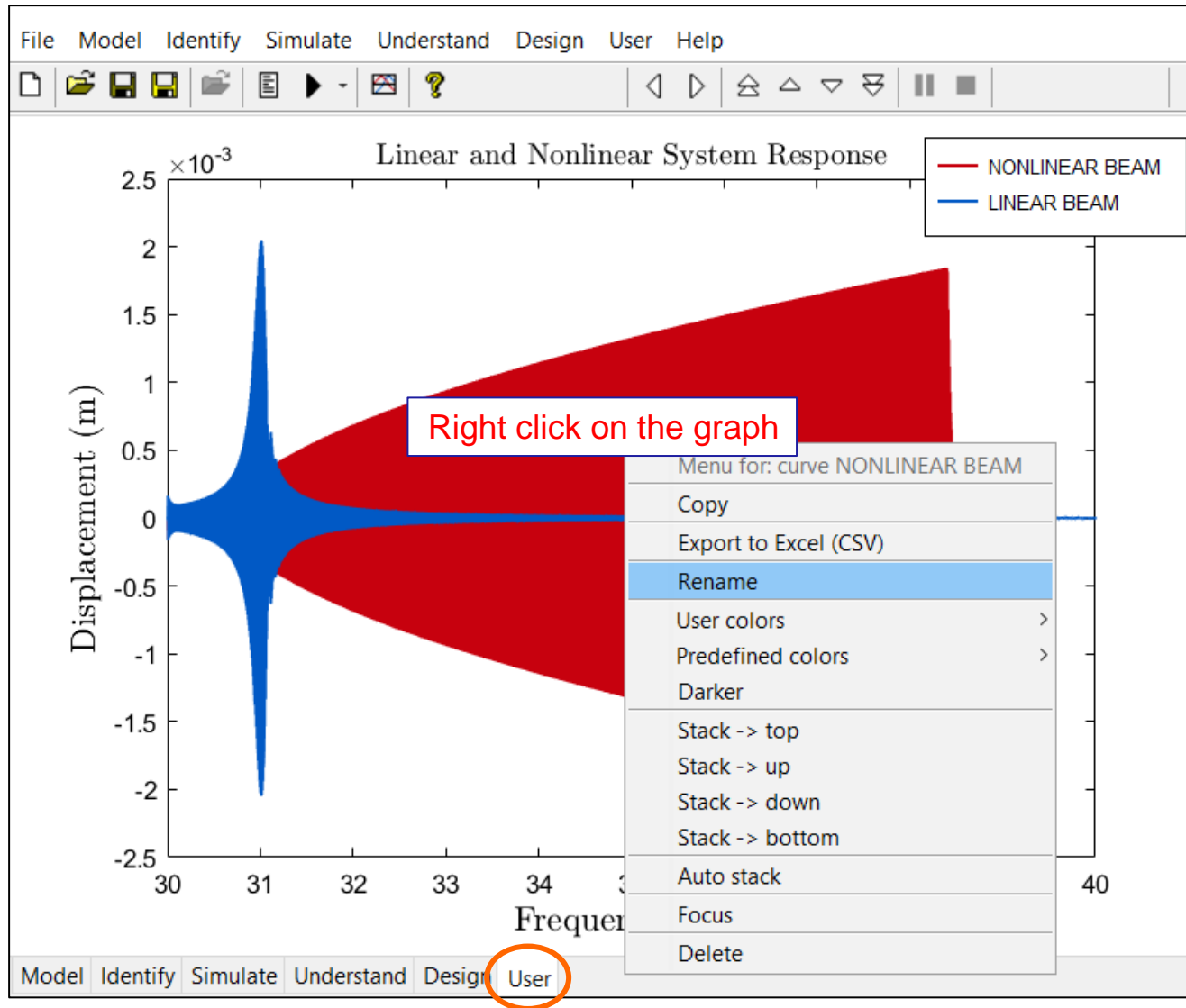
# You Can Scroll through Previous Results



# And Save Different Results in the Same Curve Stack

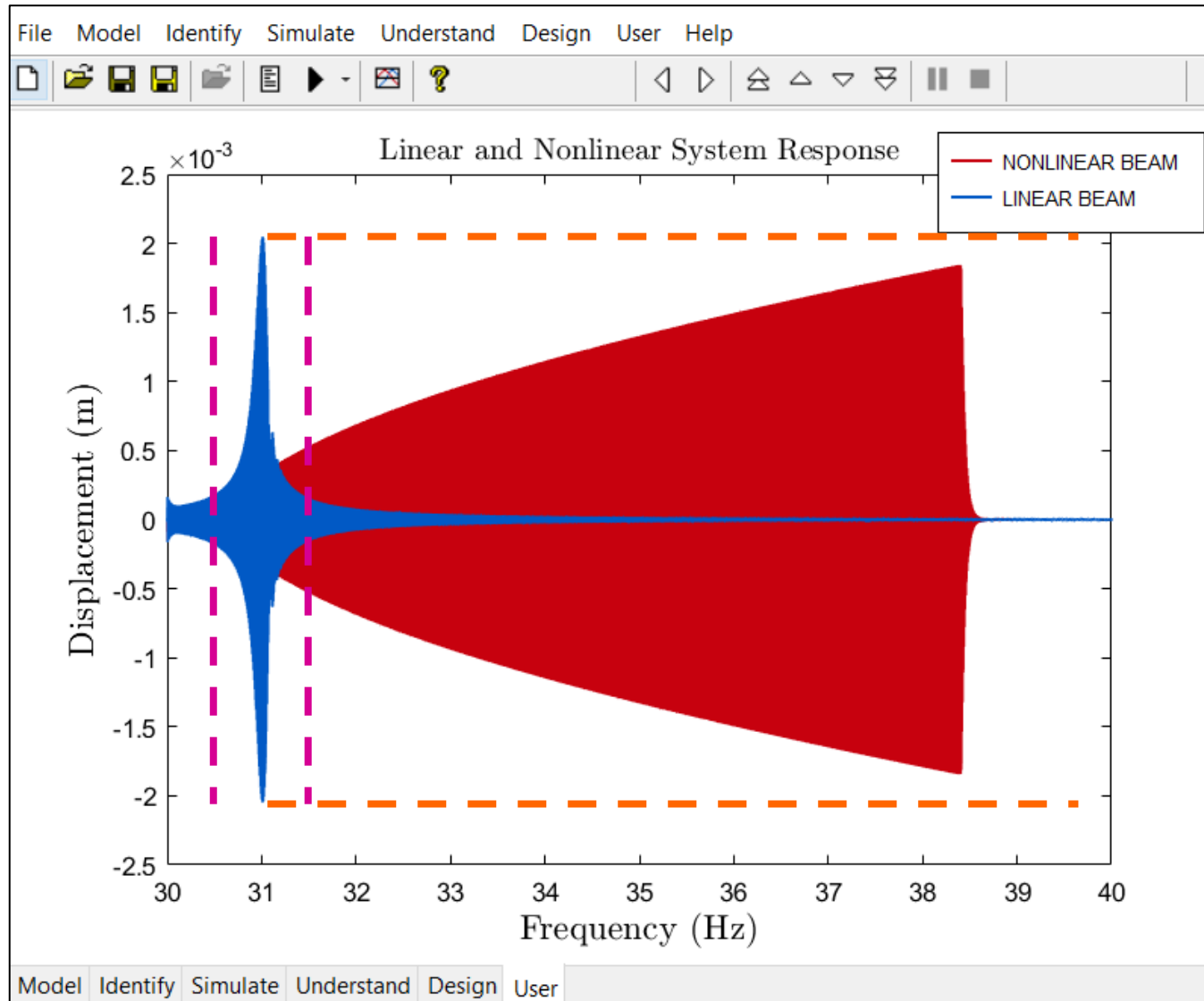


# Rename and Arrange Everything in Your Graph ...

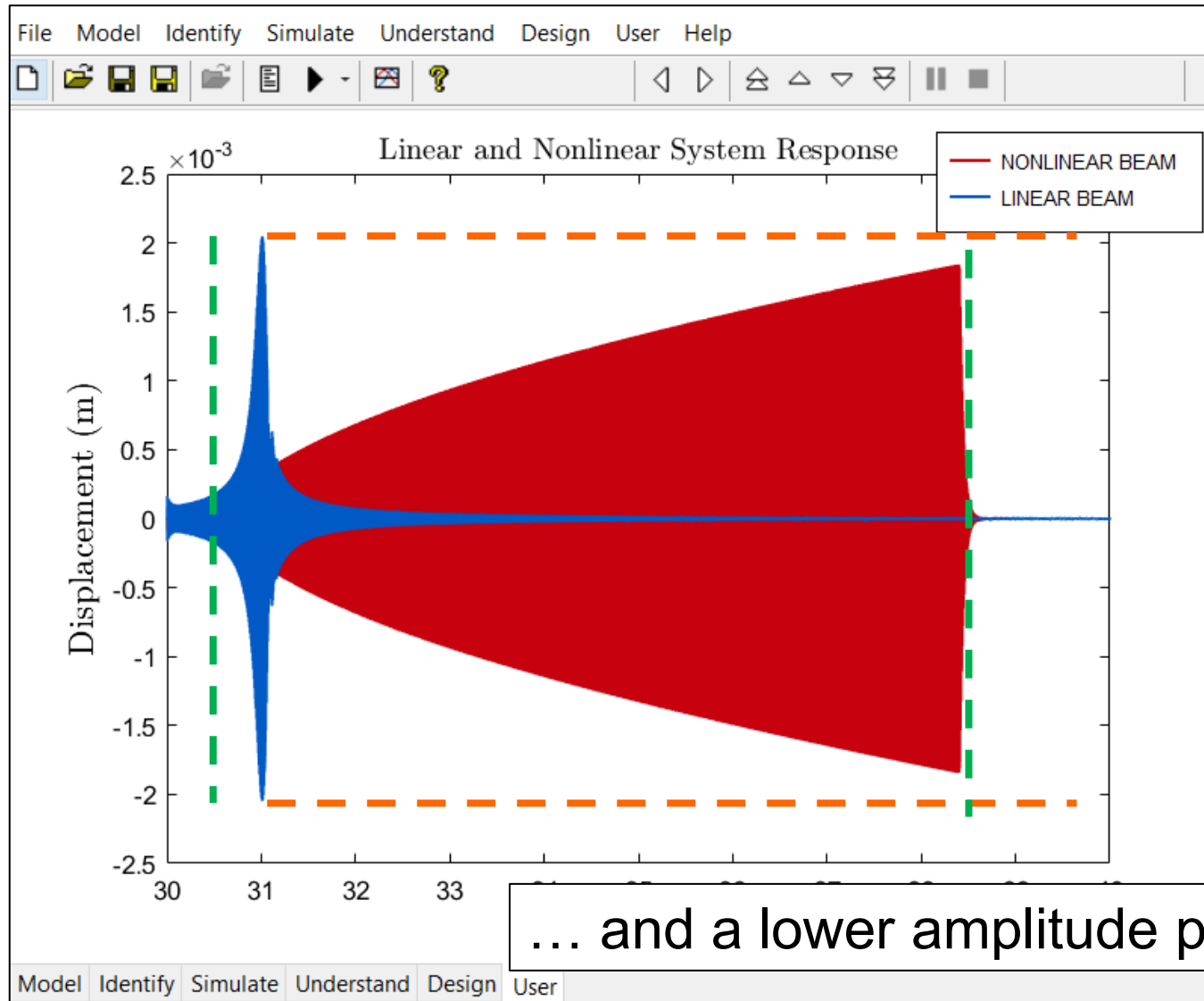


What can we observe?

# Nonlinearity Introduces a Fundamental Change

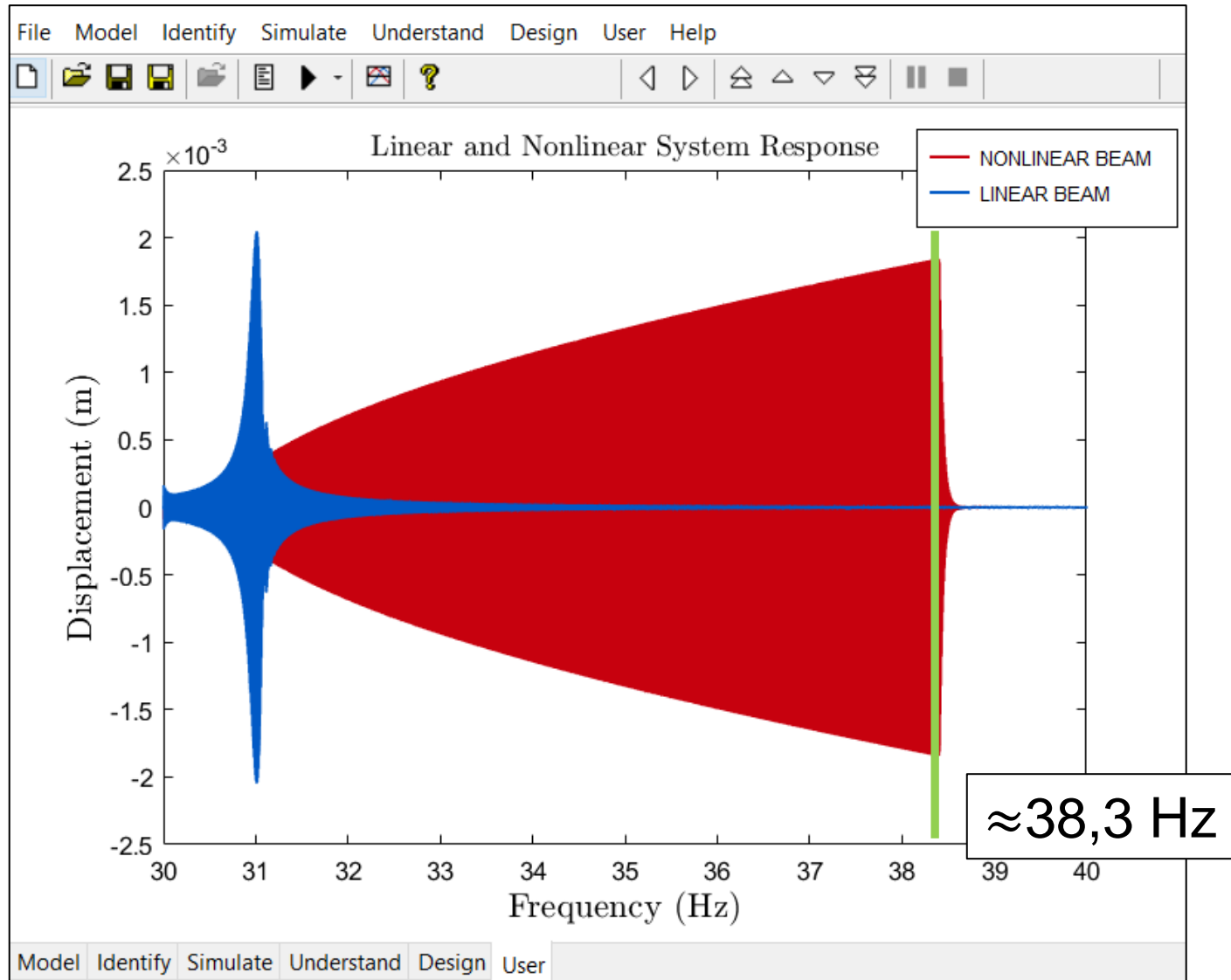


# The Nonlinear System Response Has a Greater Bandwidth ...





# The Resonance Frequency Shifts



# A Jump Downwards Can Be Observed

