Nonlinear Vibrations of Aerospace Structures

Tutorial 01

Introduction to NI2D

Nonlinear Identification to Design
Software

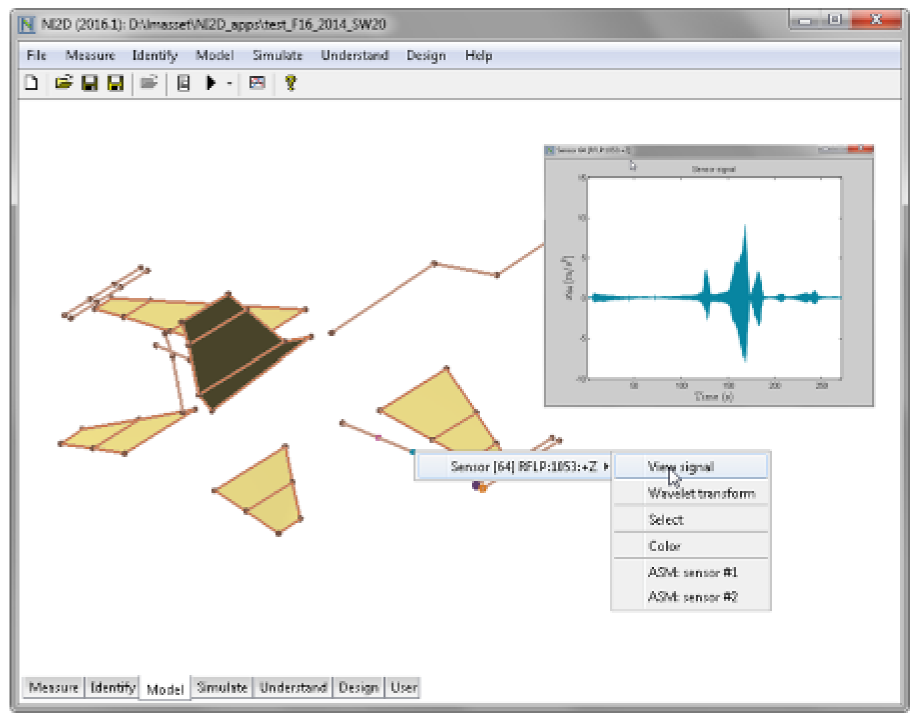
Tutorials and Project on the NI2D Software

Check www.nolisys.com

You'll get free access to the NI2D software.

Matlab environment; stand alone .exe.

Nonlinear Identification to Design
Software



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

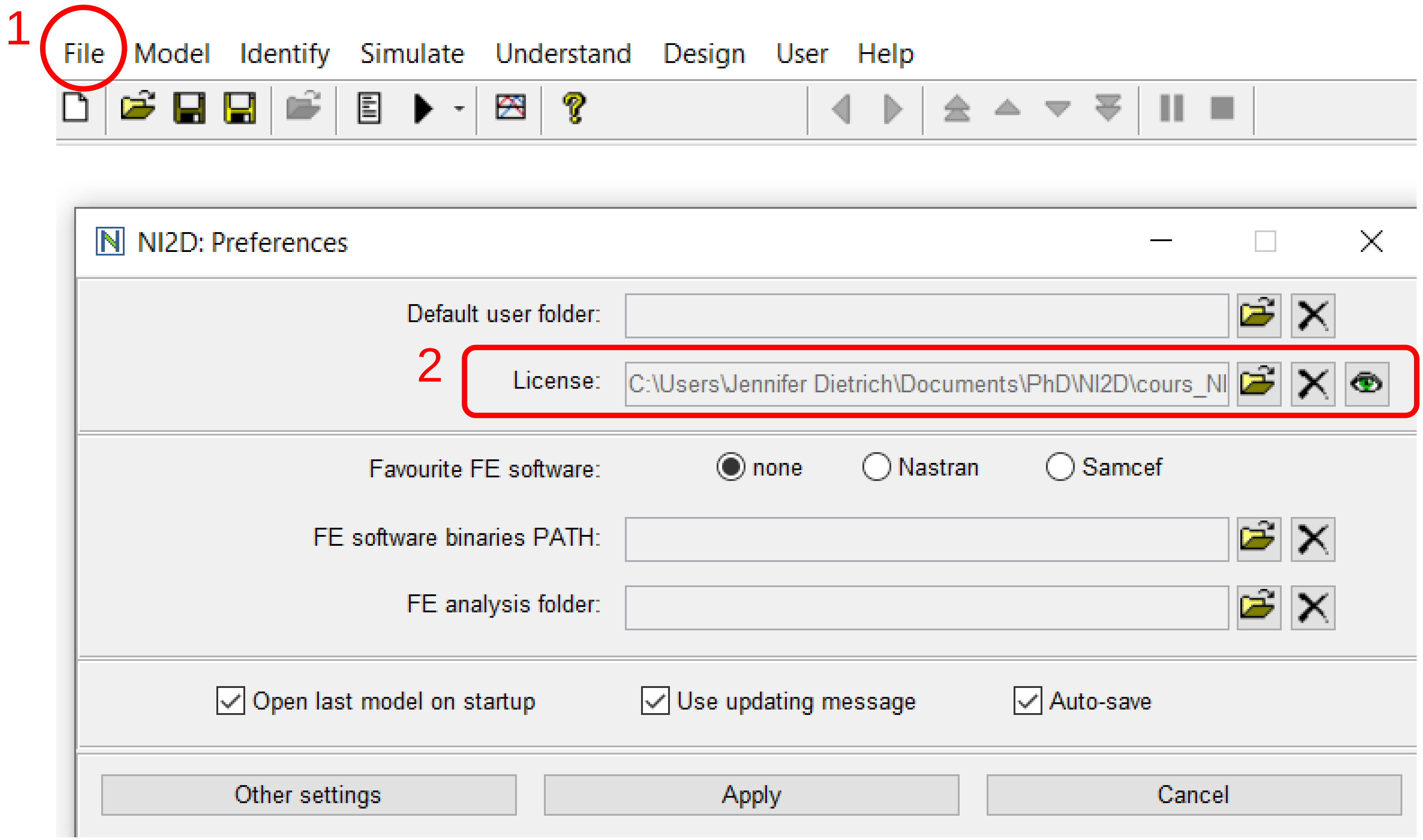
Click Here

Change parameters here

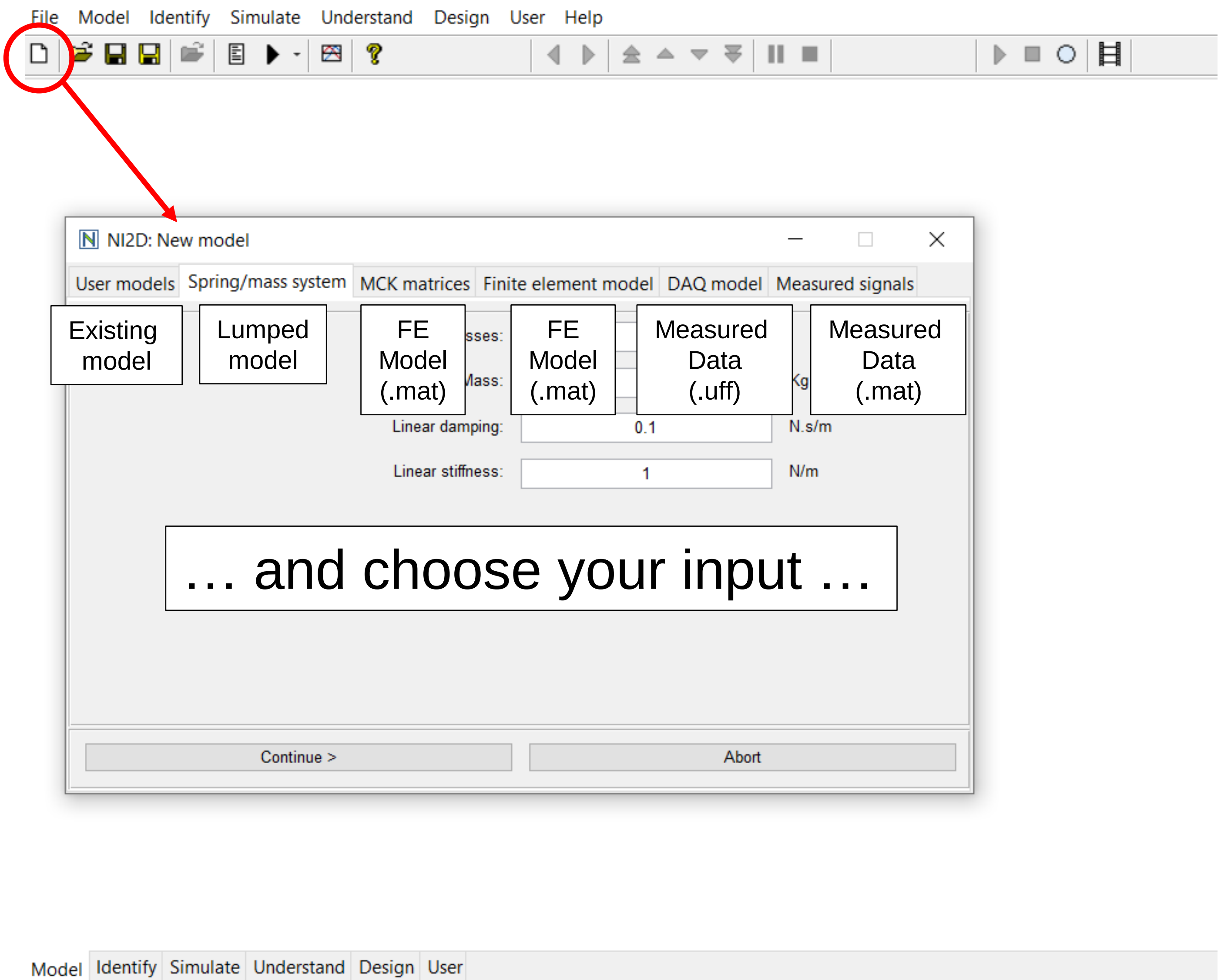
Comments

Get Started with NI2D

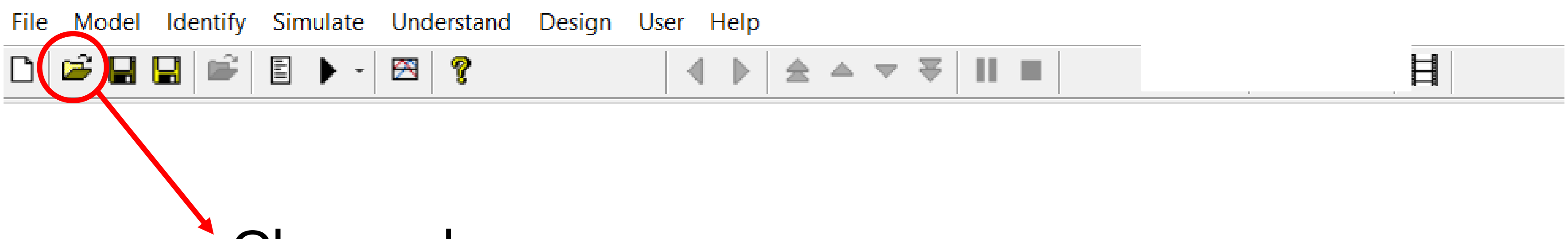
Launch NI2D and activate your license under *Preferences* …



Create a New Model

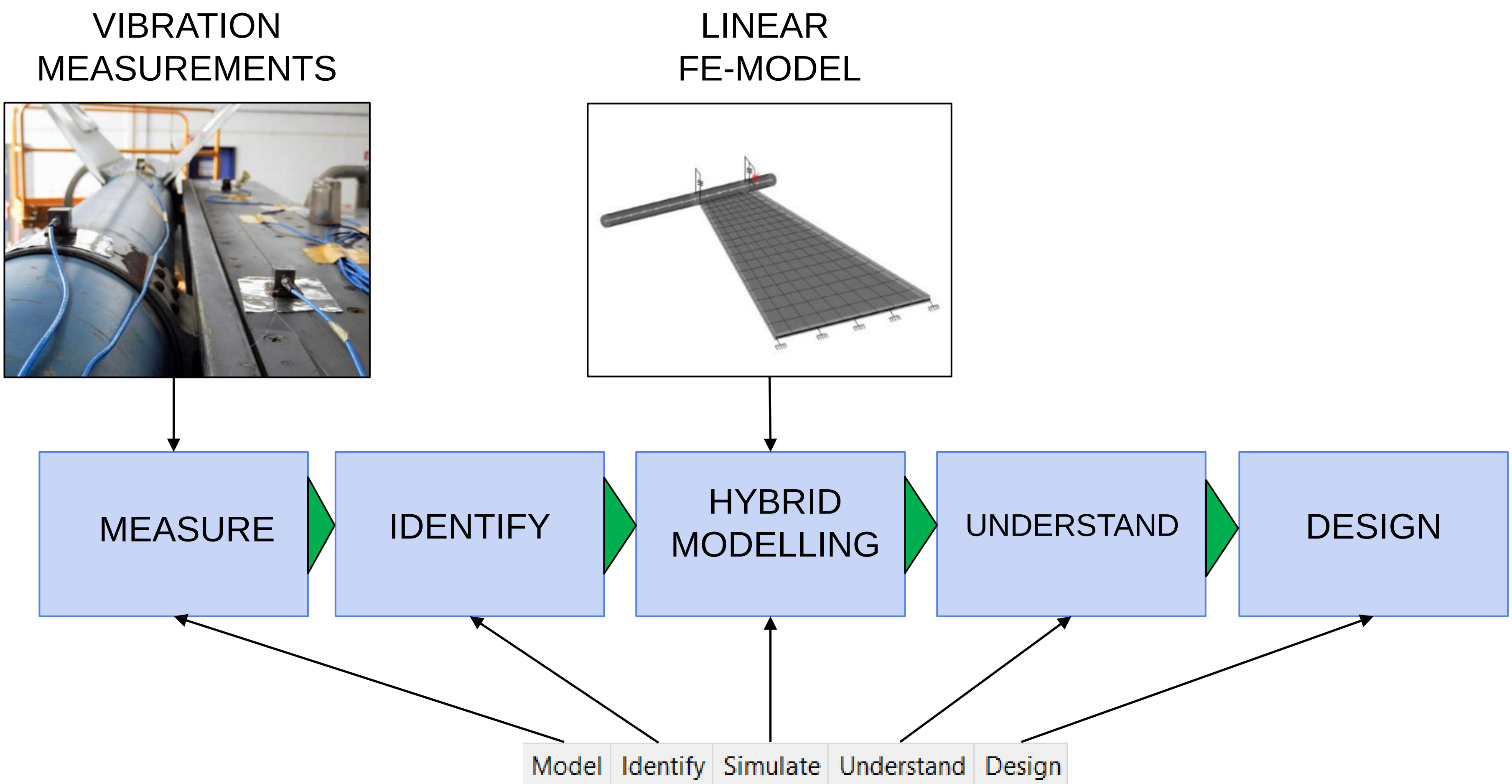


Open an existing model

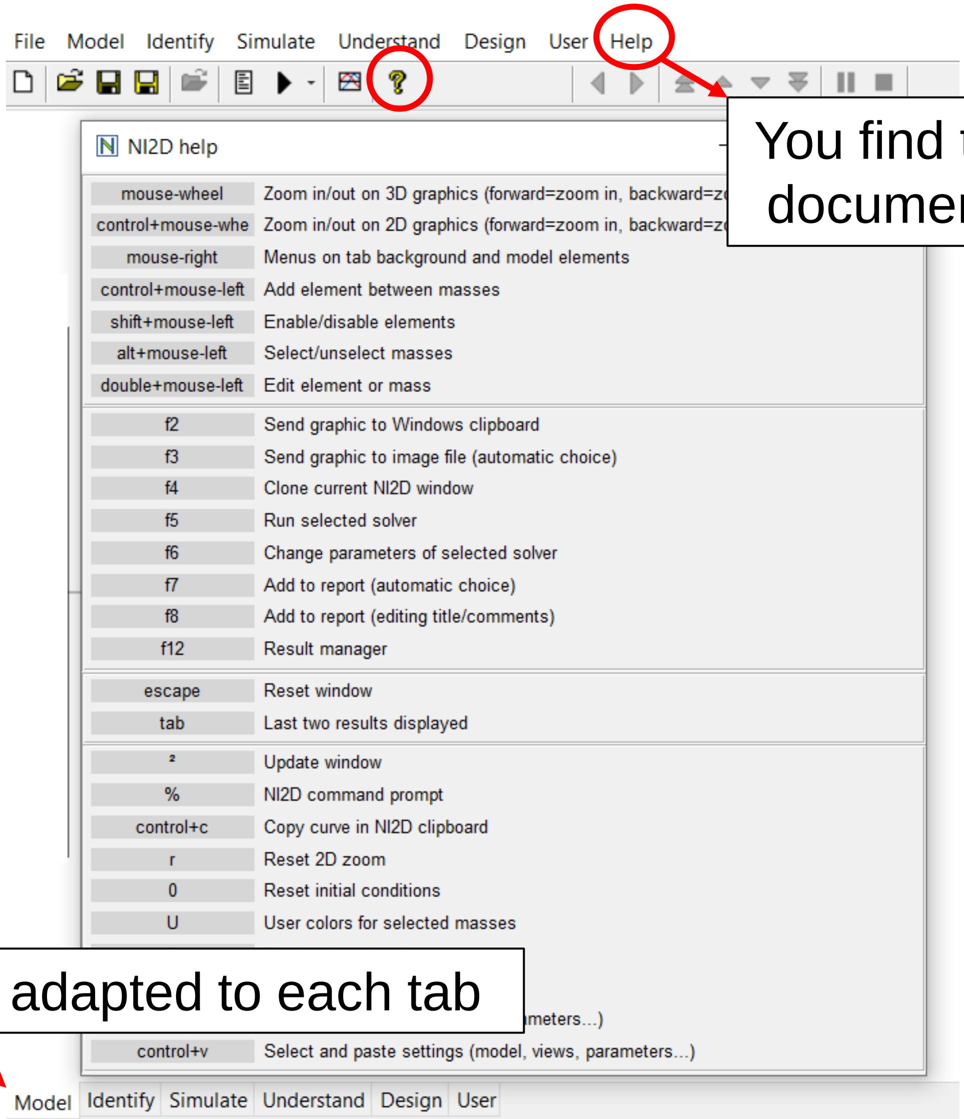


Choose here

The Different Solvers



Need Help?



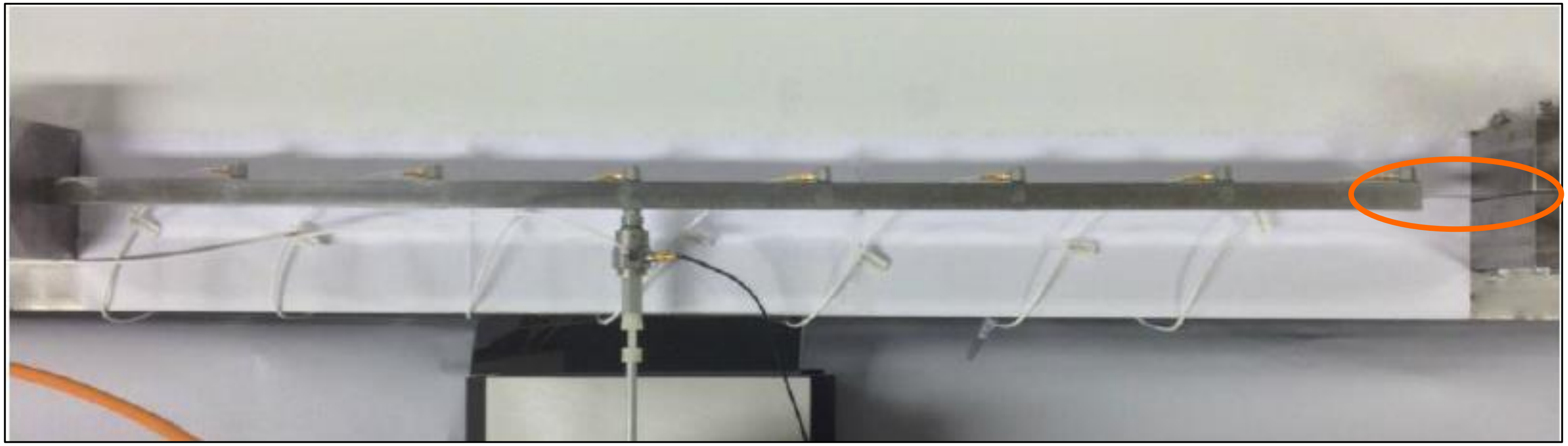
You find the software documentation here

The help menu is adapted to each tab

Launch Your First Numerical Simulation

Consider a Thin Short Beam …

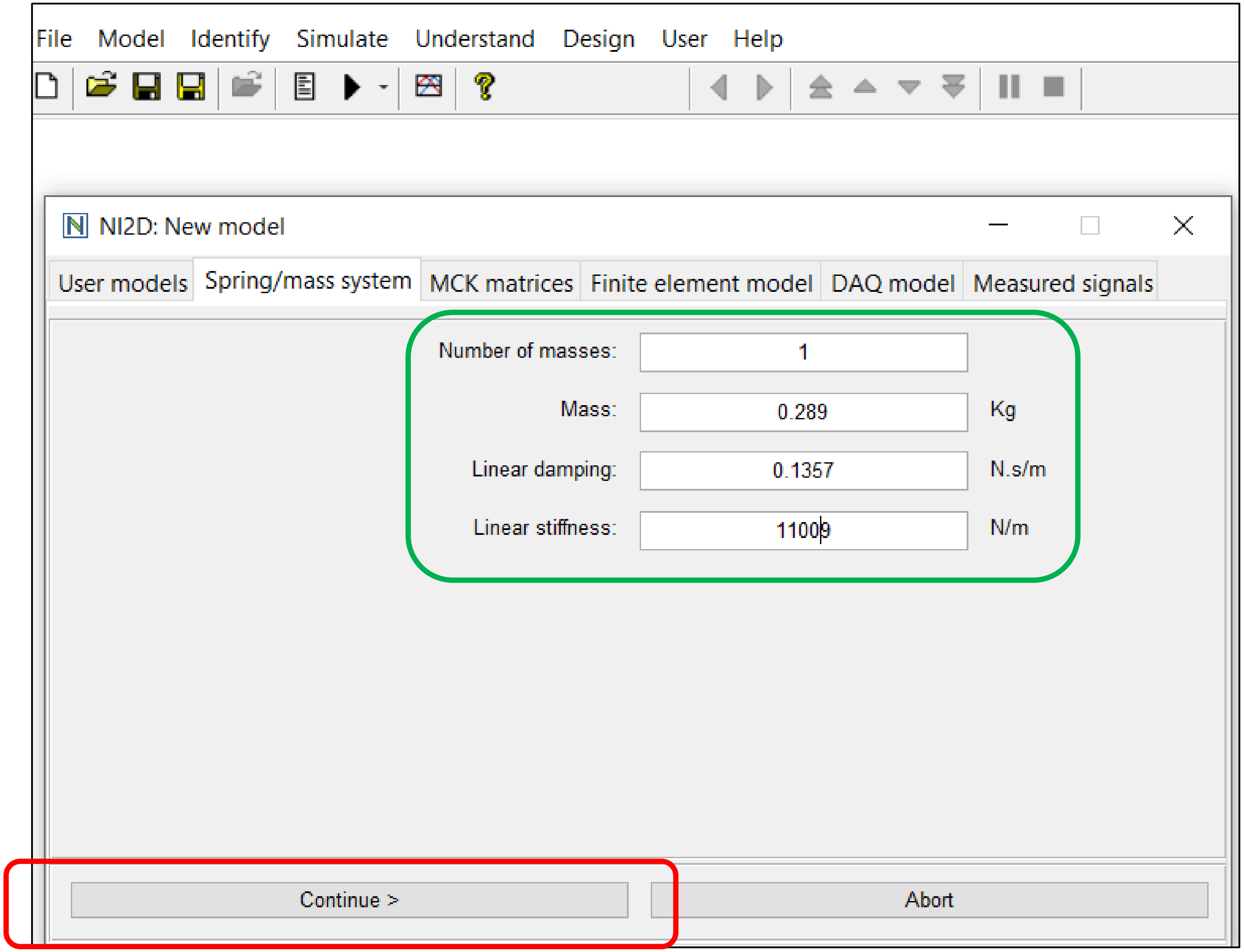
… connected to a cantilever beam (ECL benchmark)



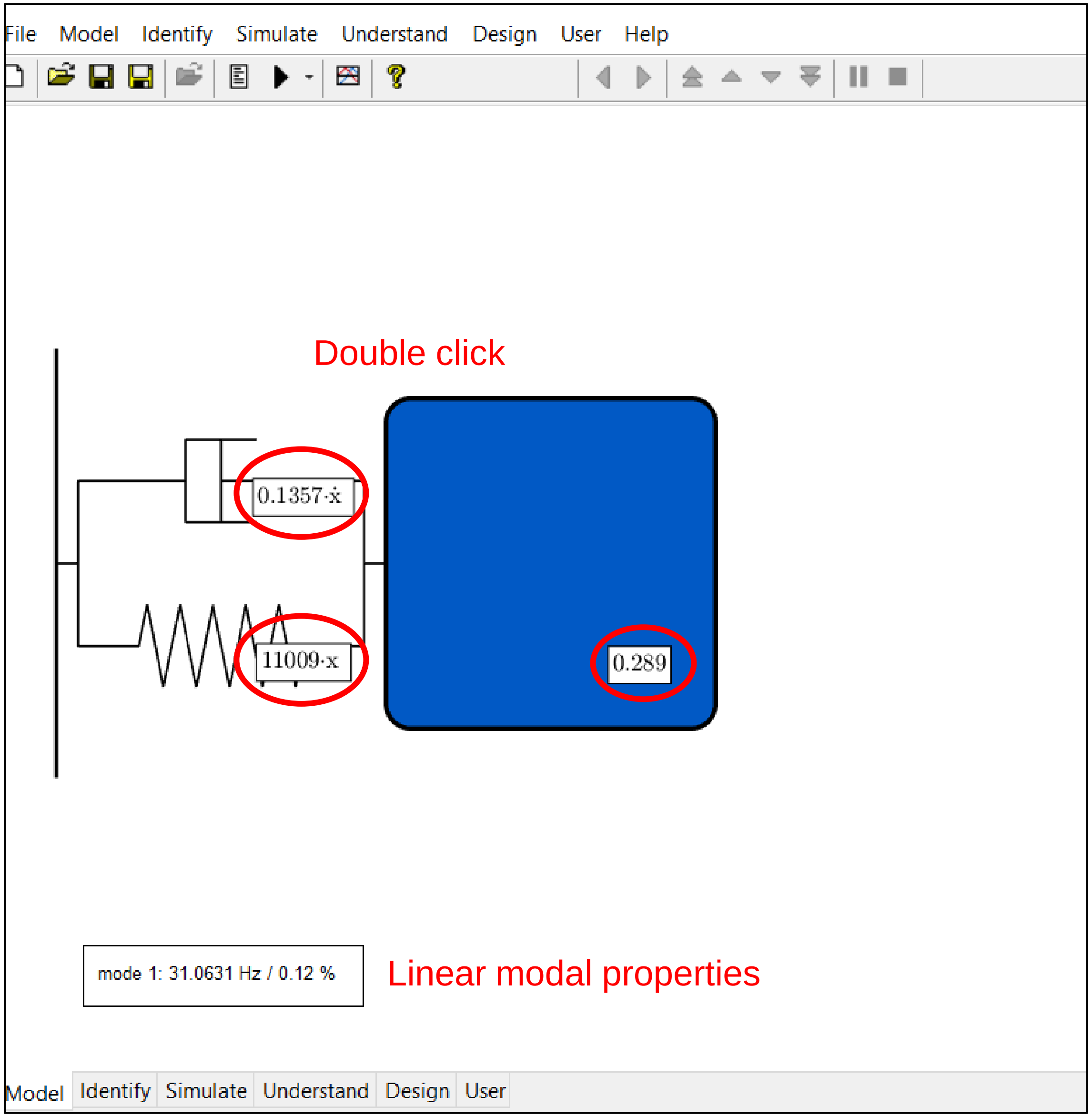
Linear model identified at low level (31 Hz, 0.12%):

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

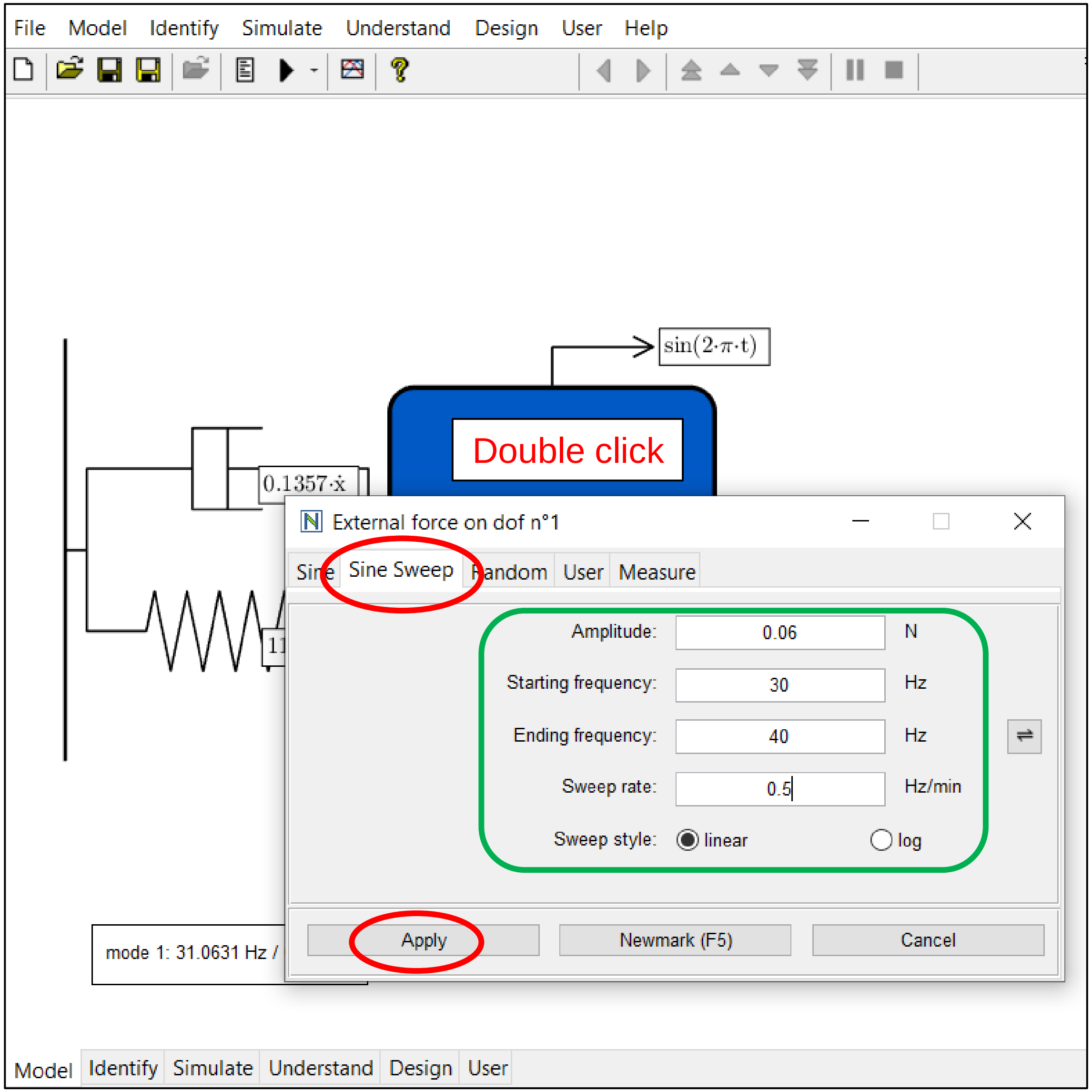
Create a New Model: 1 DOF Linear Oscillator



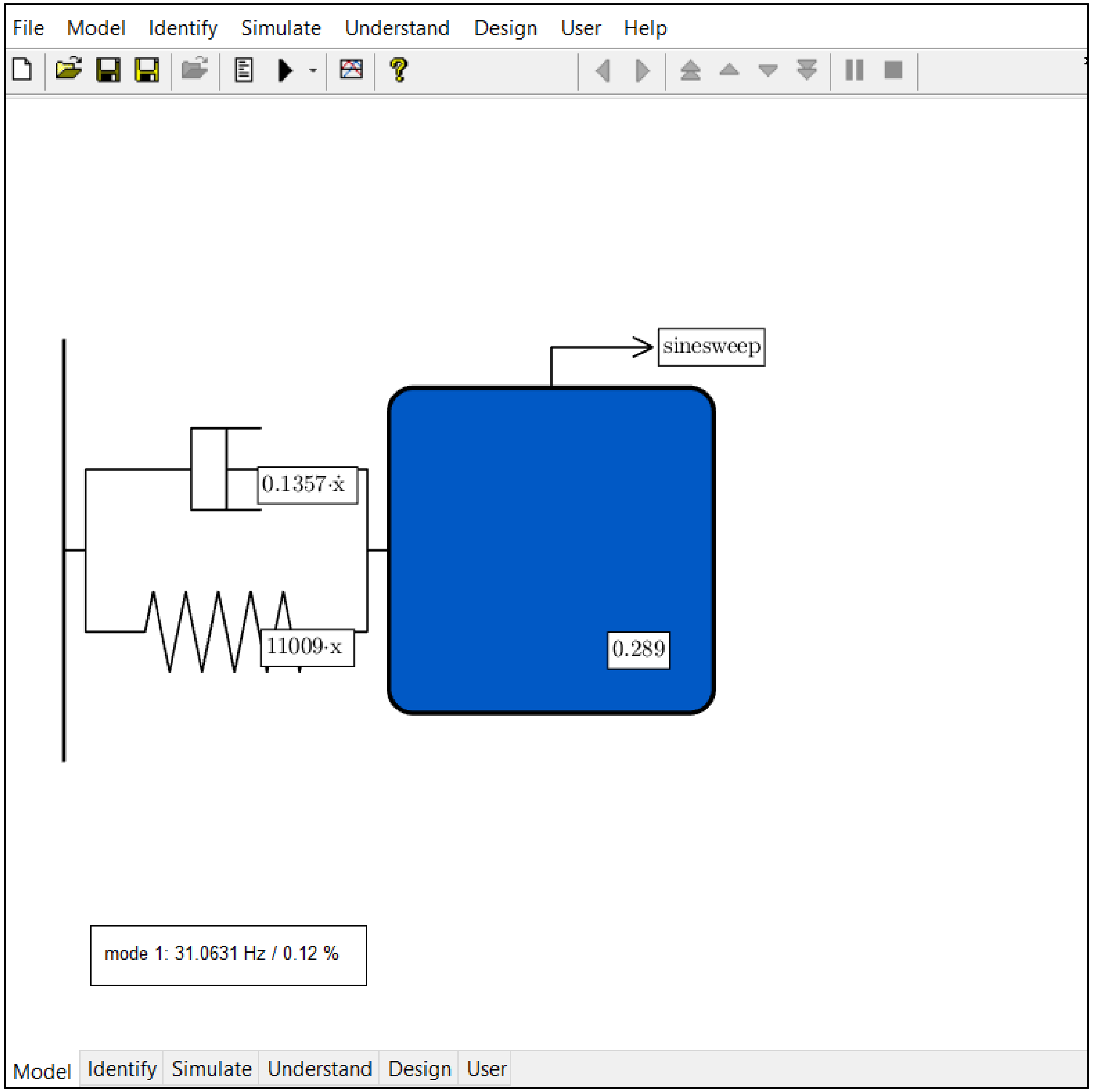
You Can Change the Coefficients Anytime …



Add an External Force

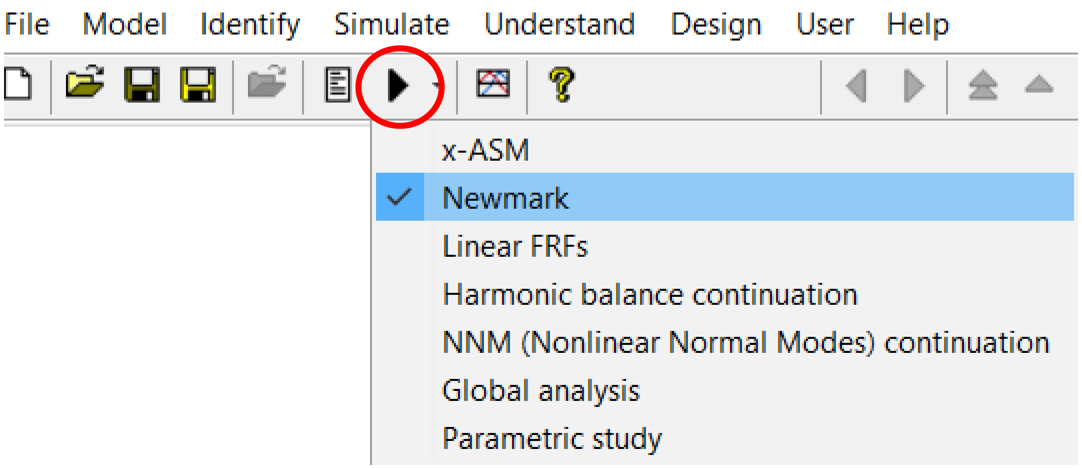


The Final Linear Model

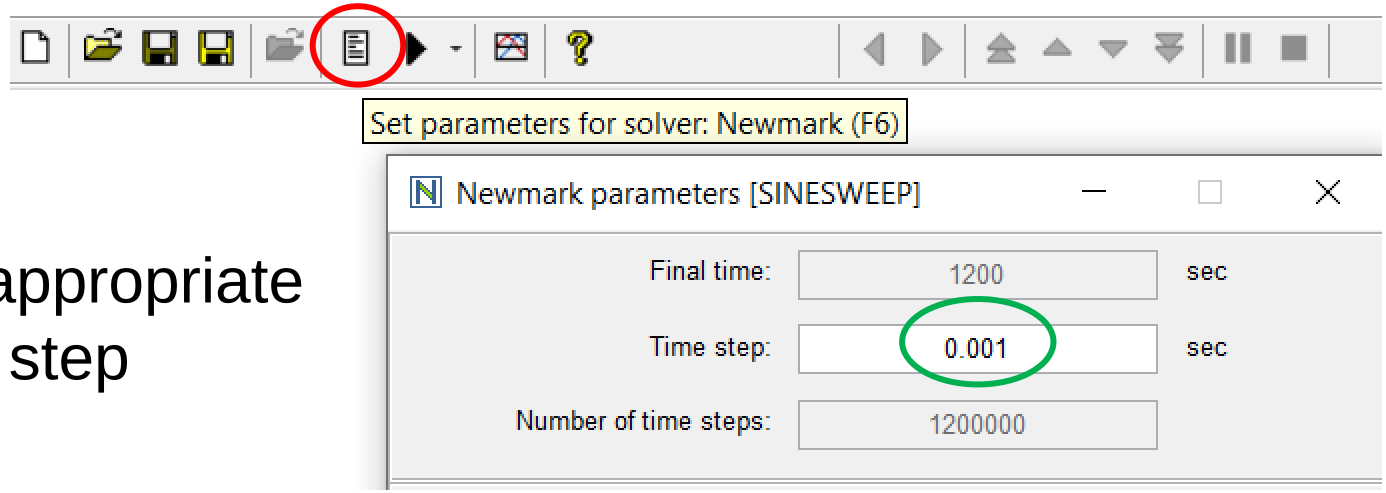


Calculate the Time Response with Newmark

1.



2.

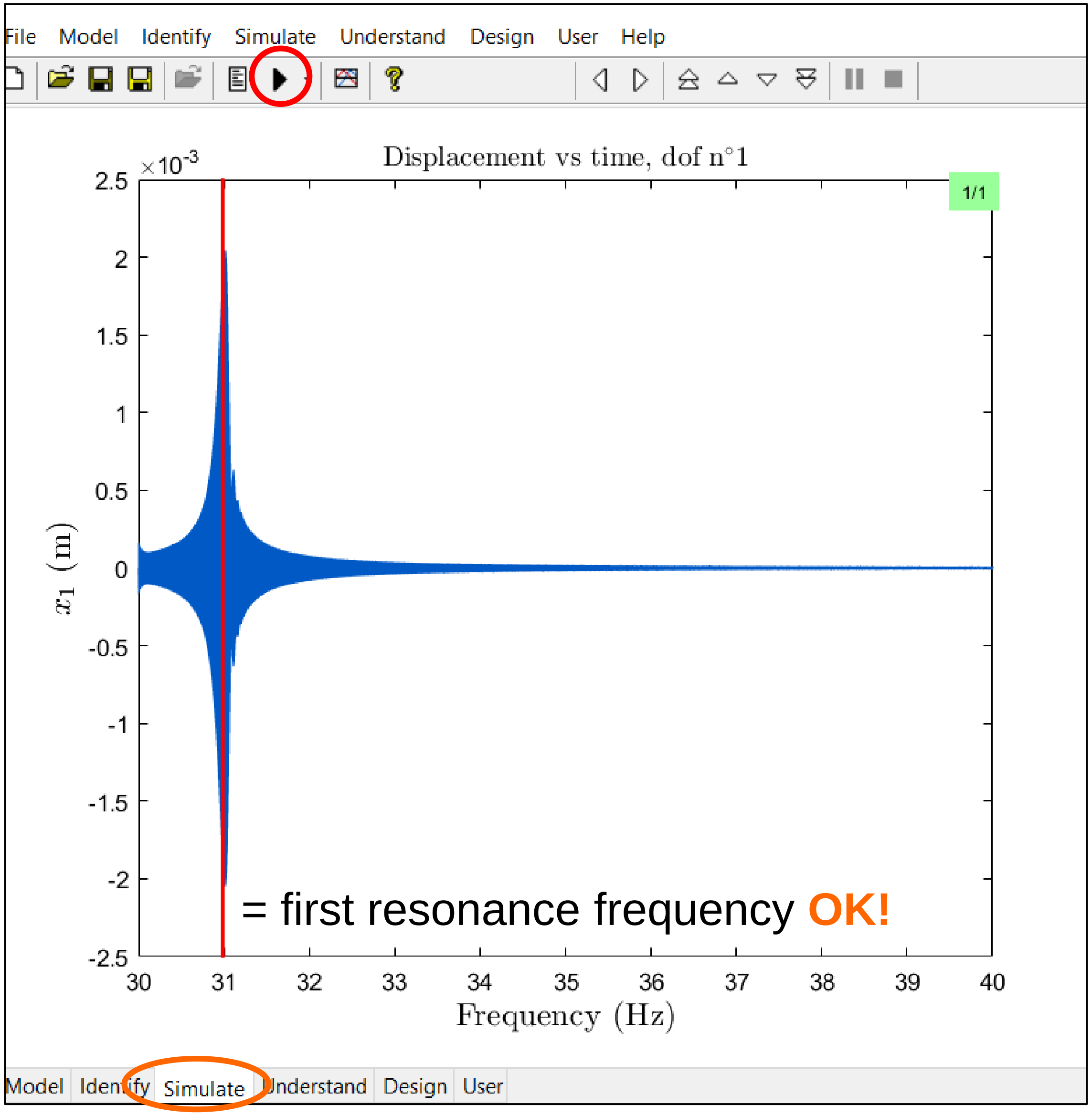


Select an appropriate time step

How to Choose the Right Sampling Frequency?

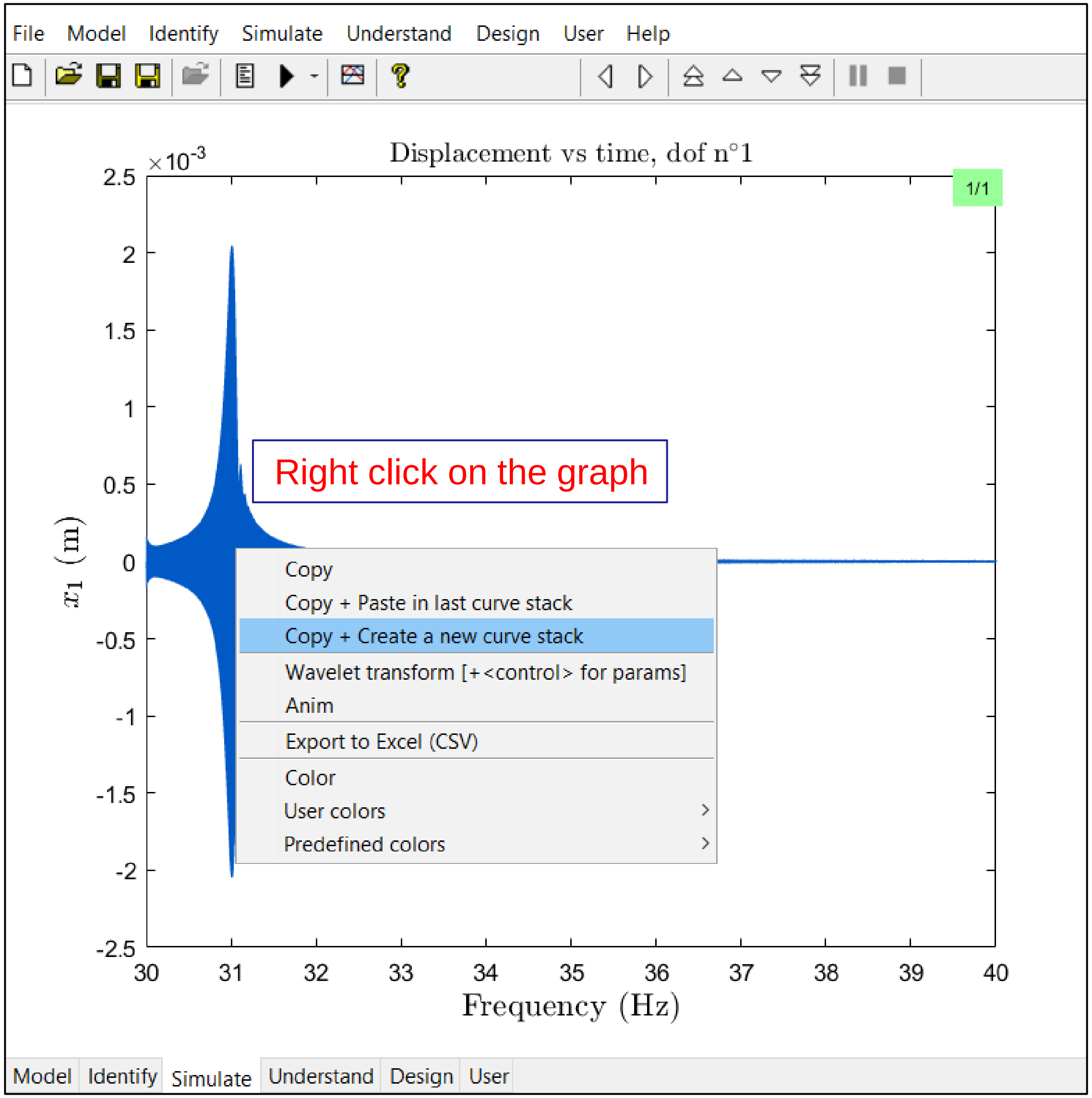
			Stability limit	Accuracy: Amplitude error	Accuracy: Periodicity error
Algorithm	γ	β	ωh	$\rho - 1$	$\frac{\Delta T}{T}$
Purely explicit	0	0	0	$\frac{\omega^2 h^2}{4}$	$-$
Central difference	$\frac{1}{2}$	0	2	0	$-\frac{\omega^2 h^2}{24}$
Fox & Goodwin	$\frac{1}{2}$	$\frac{1}{12}$	2.45	0	$O(h^3)$
Linear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

Now: Run

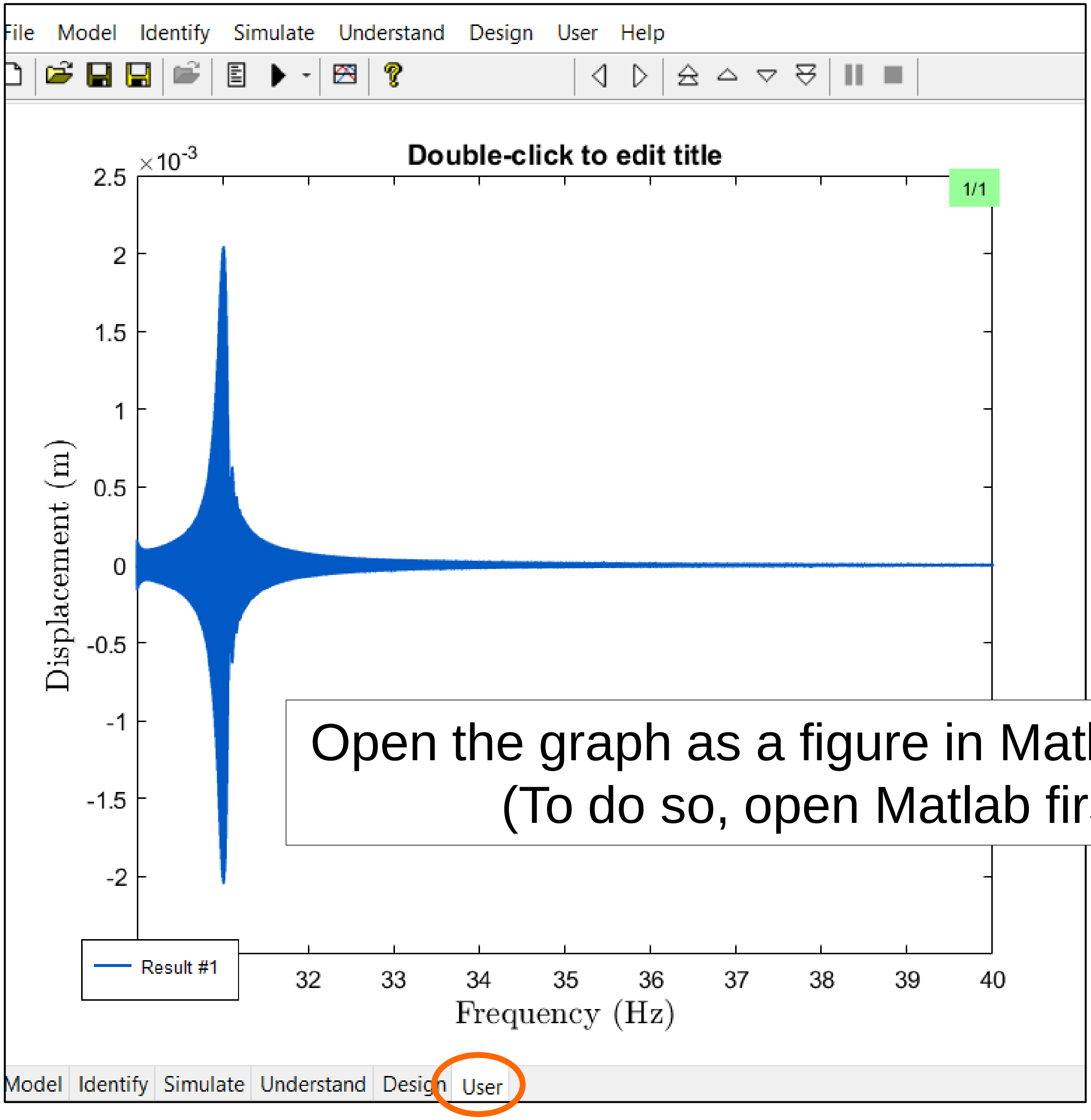


File
Model
Identify
Simulate
Understand
Design
User
Help
Displacement vs time, dof n°1
×10^-3
1/1
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
x_1 (m)
30
31
32
33
34
35
36
37
38
39
40
Frequency (Hz)
= first resonance frequency OK!
Model
Identify
Simulate
Understand
Design
User

Save Your Results in a Curve Stack



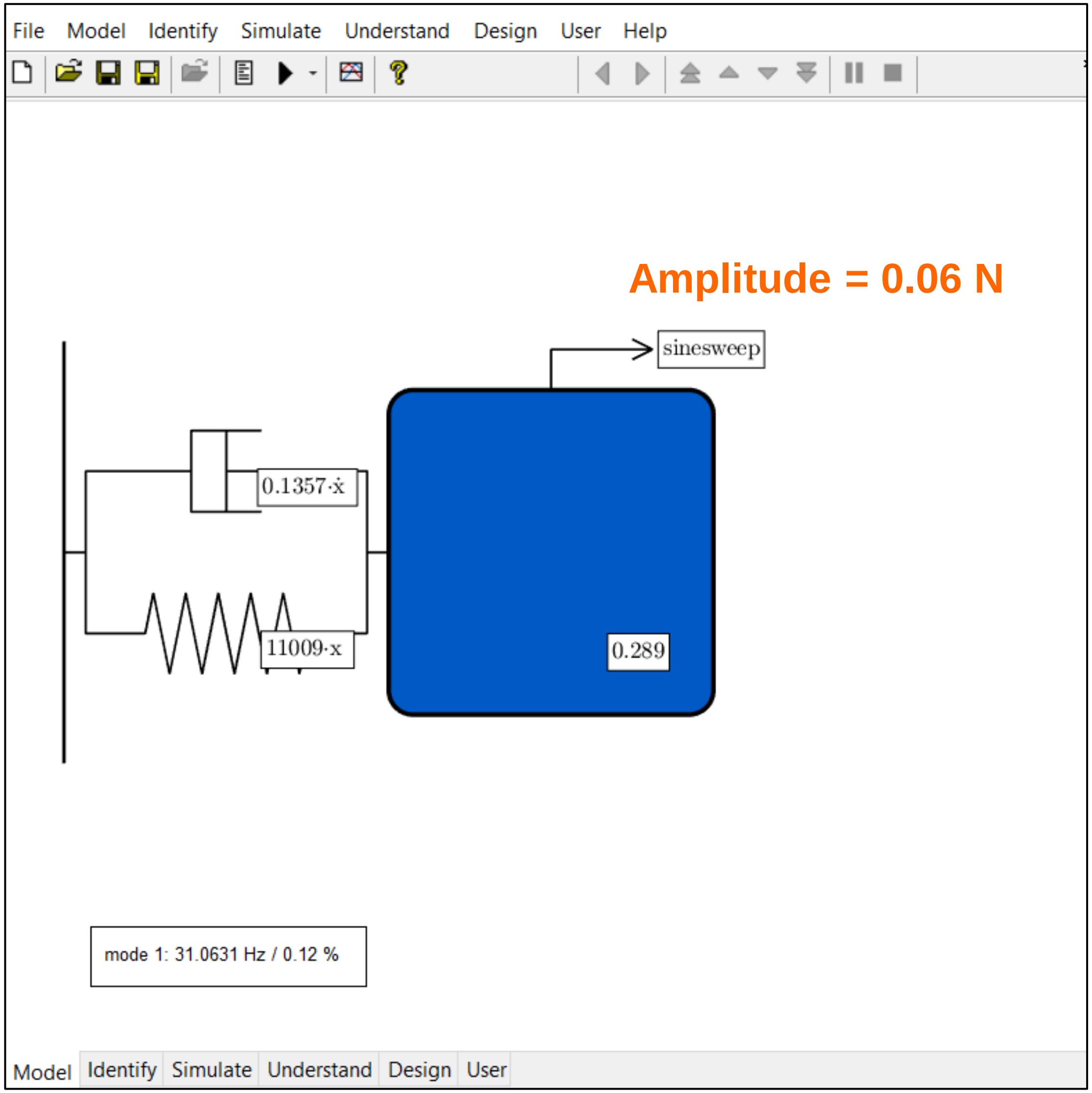
Check Your Results Anytime



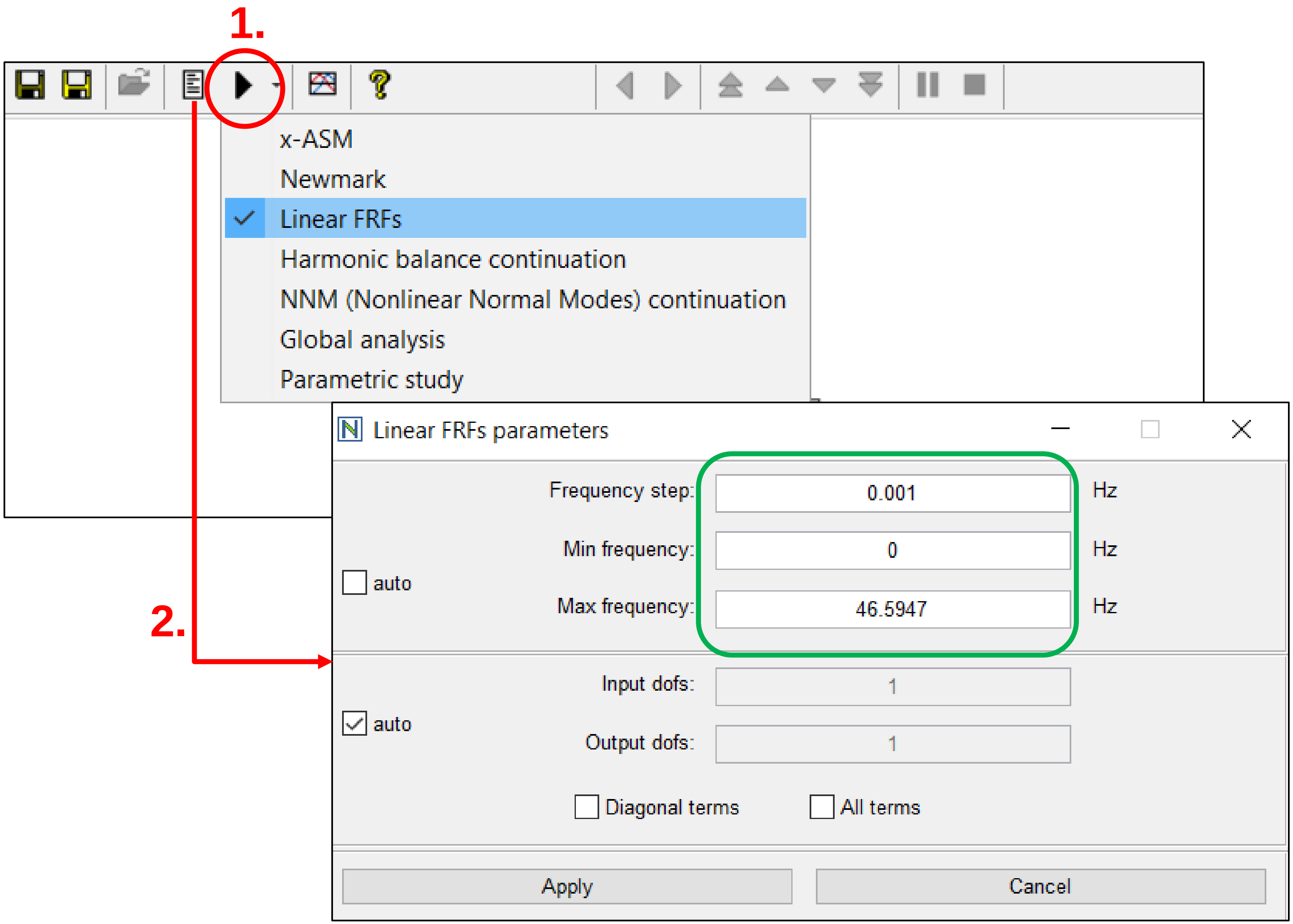
Open the graph as a figure in Matlab with *F4*
(To do so, open Matlab first)

Frequency Response Functions

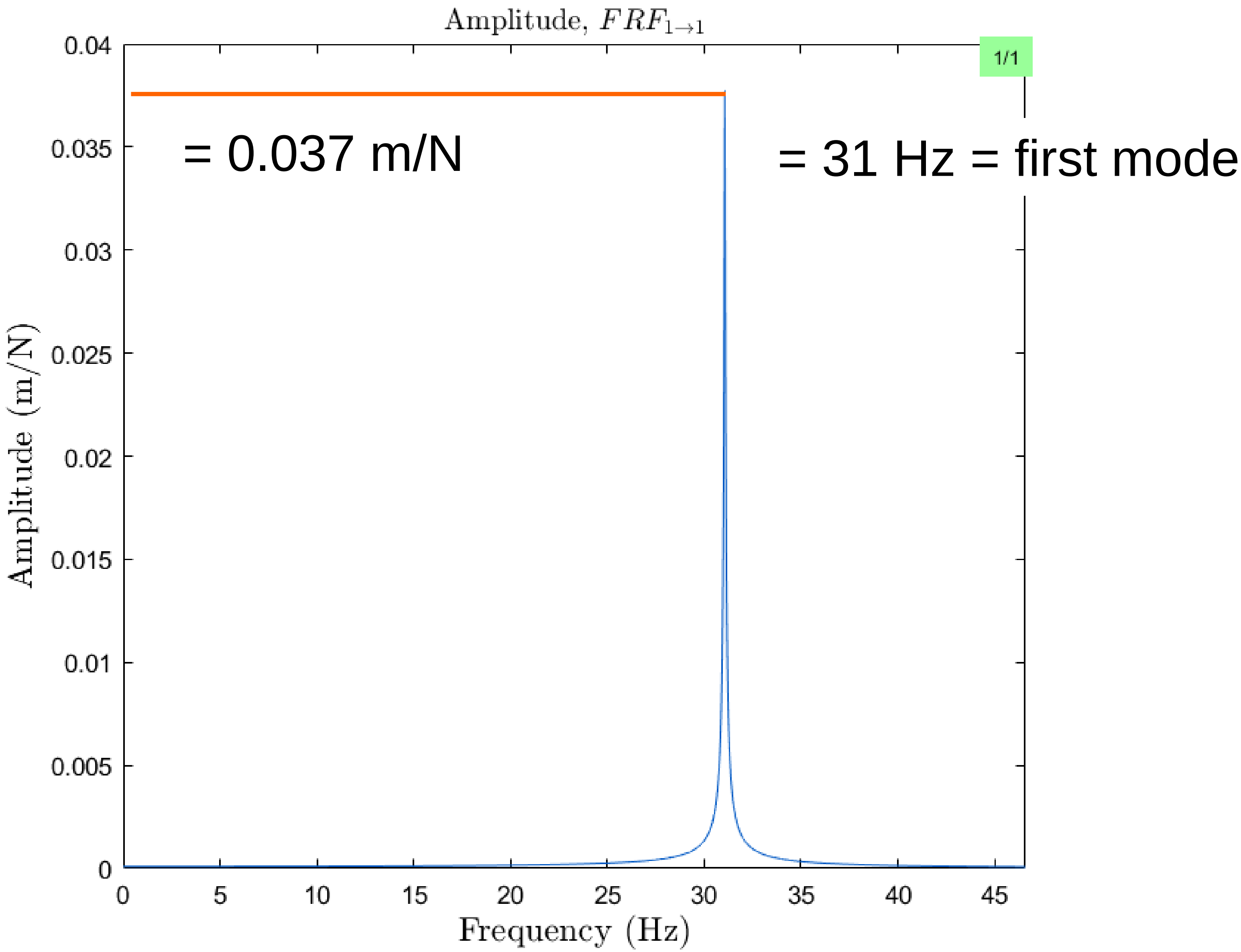
The Linear Model



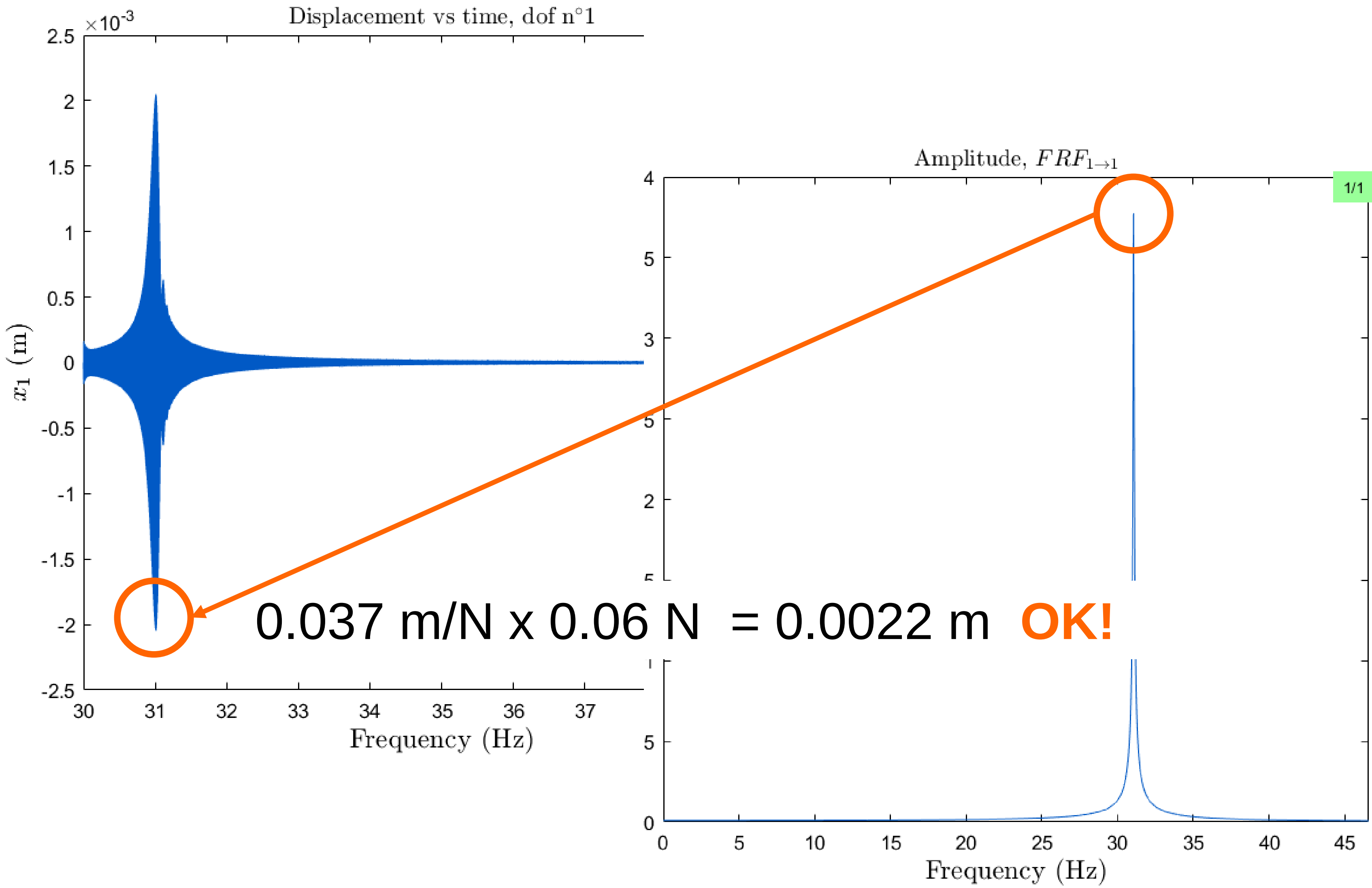
Calculate the Linear FRF …



And Check the Result

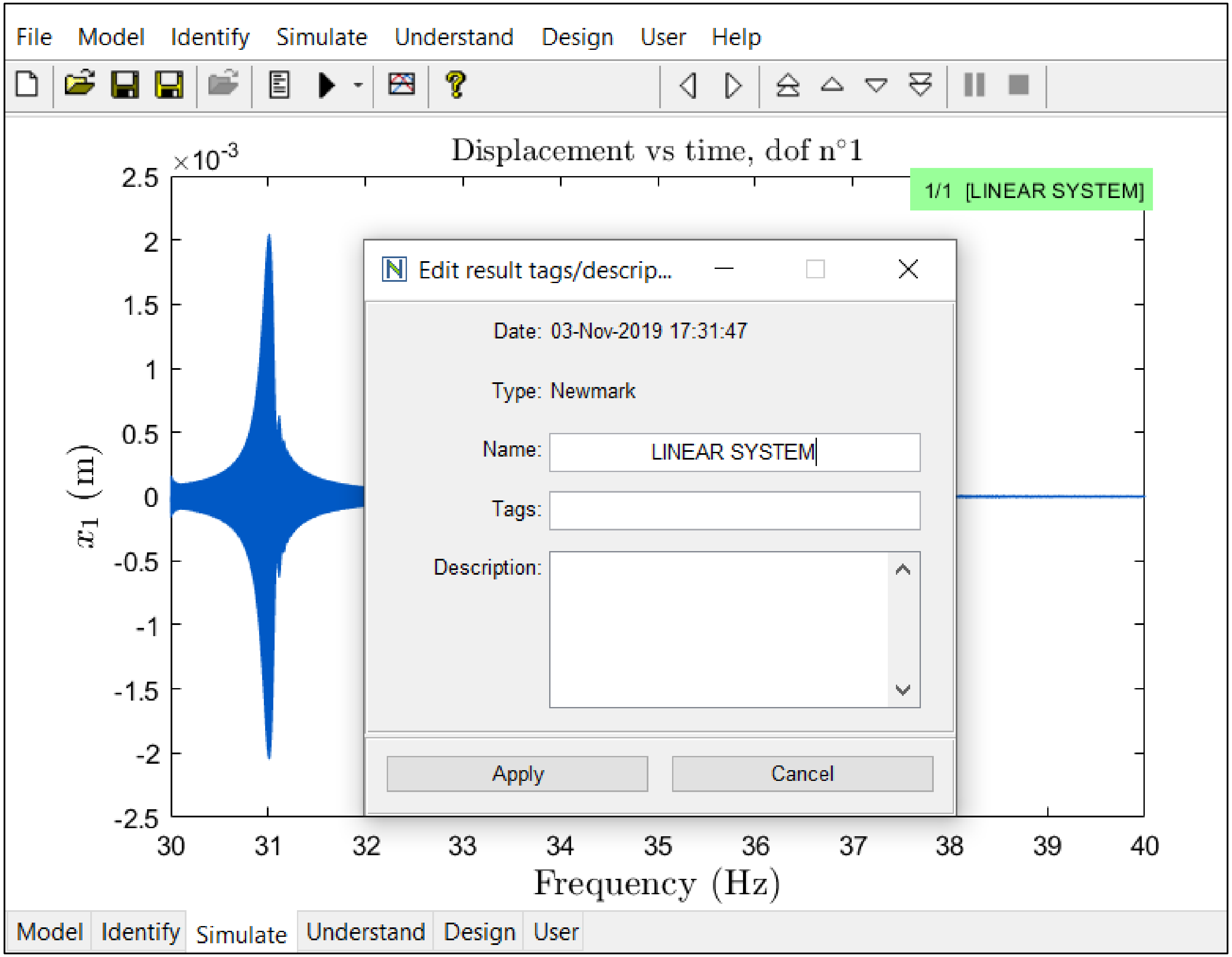


Compare the Time and the Frequency Response

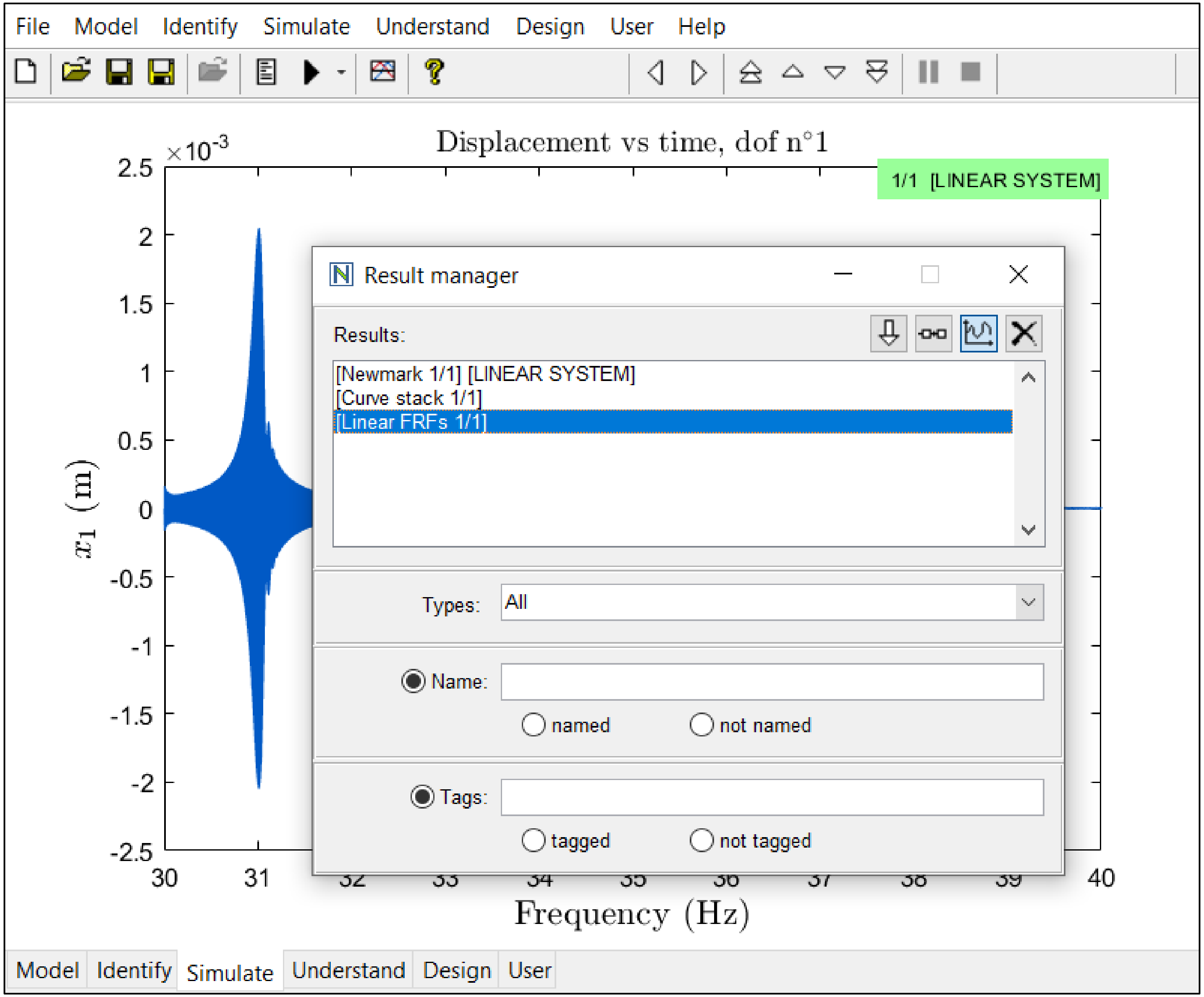


0.037 m/N x 0.06 N = 0.0022 m **OK!**

You Can Tag Your Results (F11) …

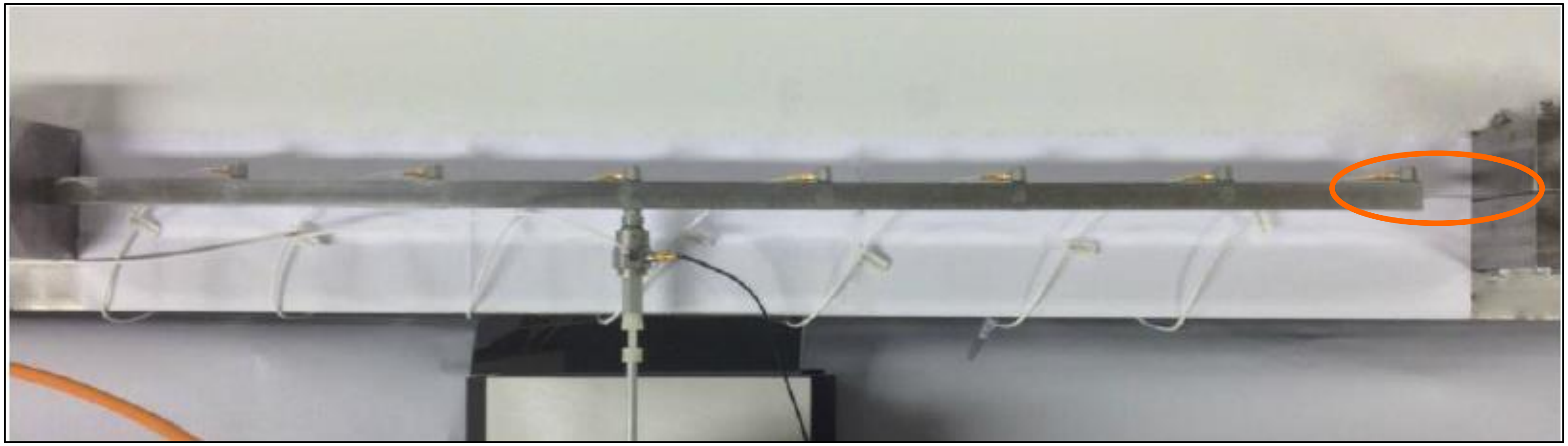


And Manage All Your Results (F12)



Launch Your First Nonlinear Simulation

Nonlinear Model of the 1st Beam Mode

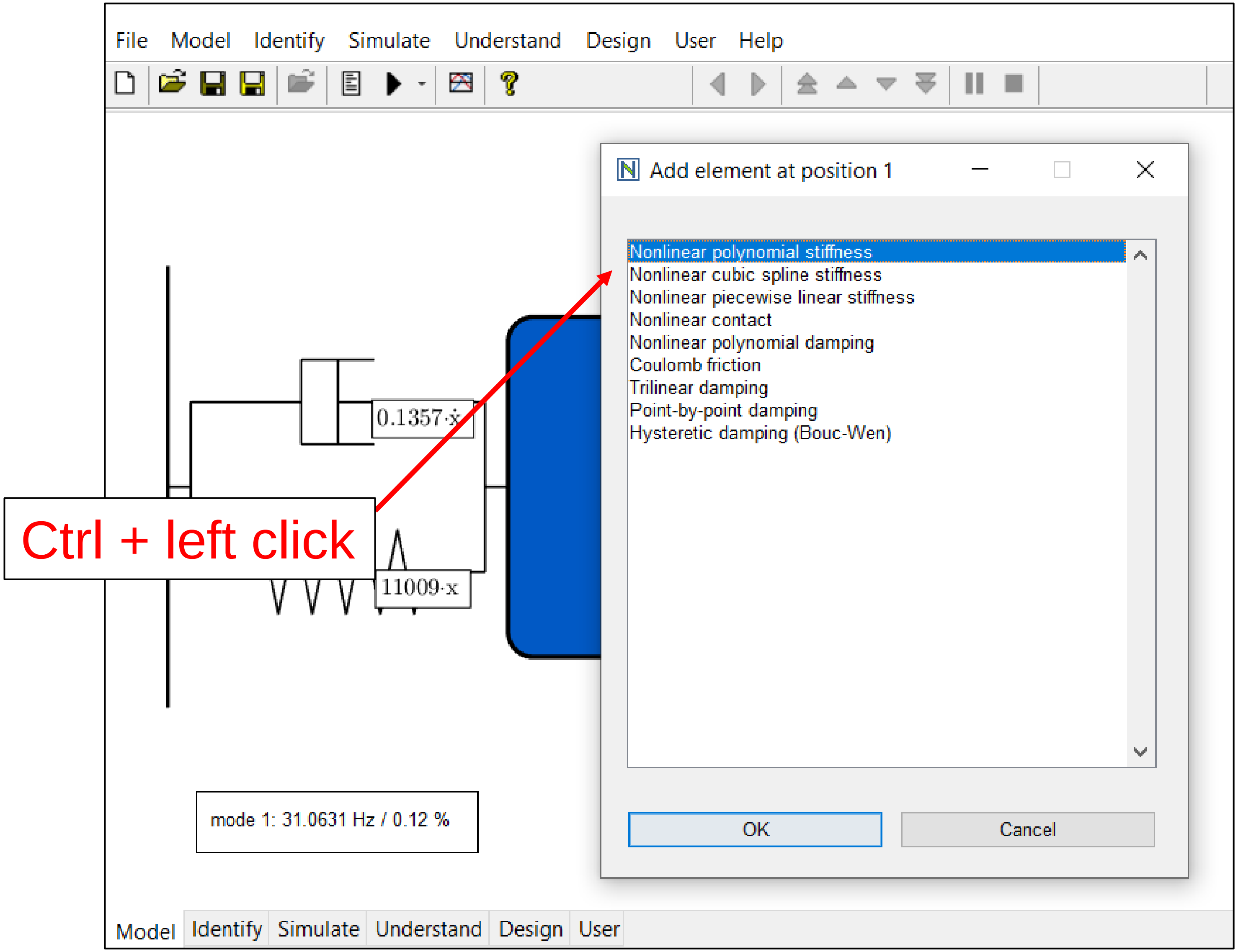


Linear model identified at low level (31 Hz, 0.12%):

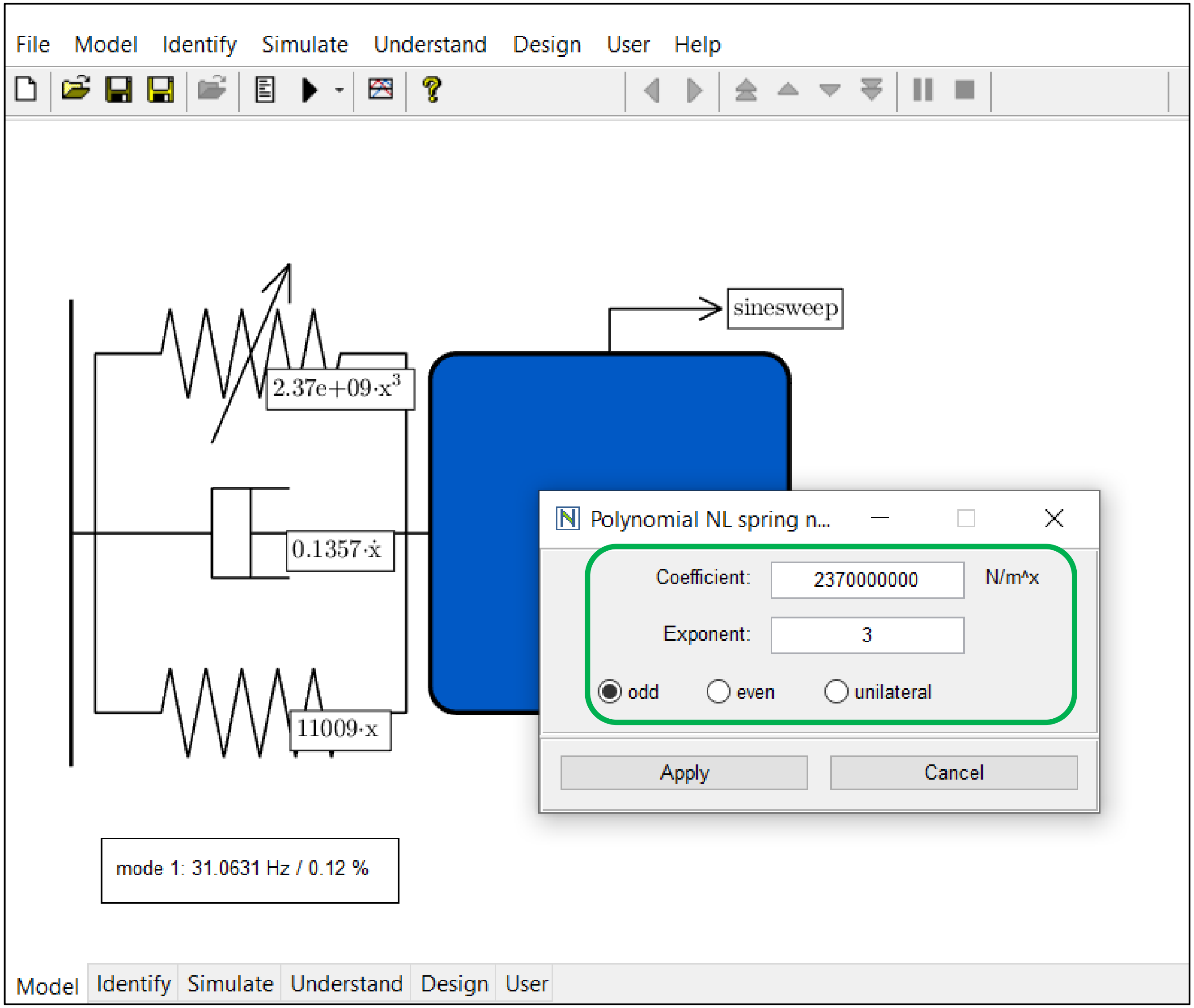
$$0.289\ddot{x} + 0.1357\dot{x} + 11009x = F\sin\omega t$$

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

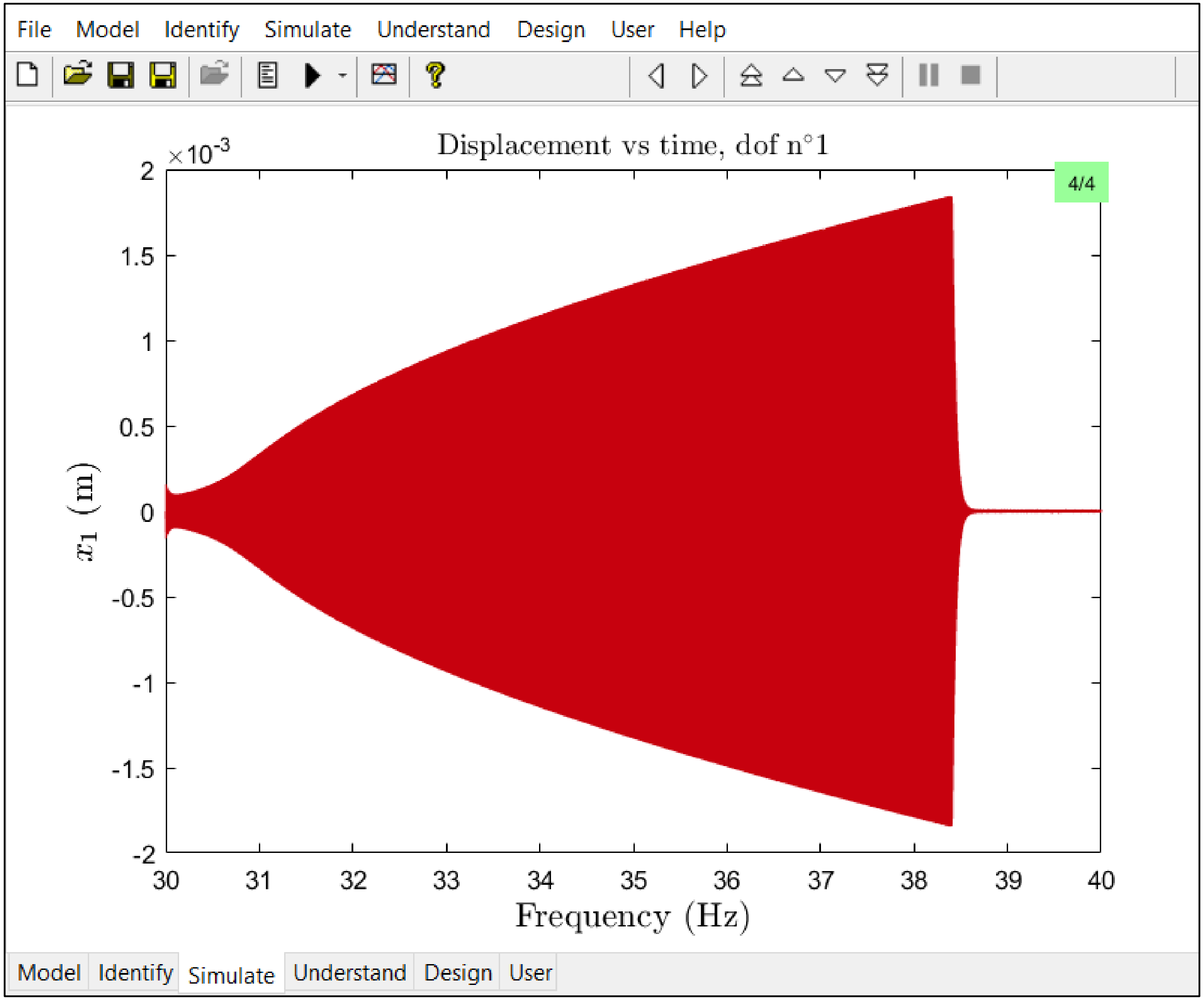
Upgrade the Linear Model from T02 …



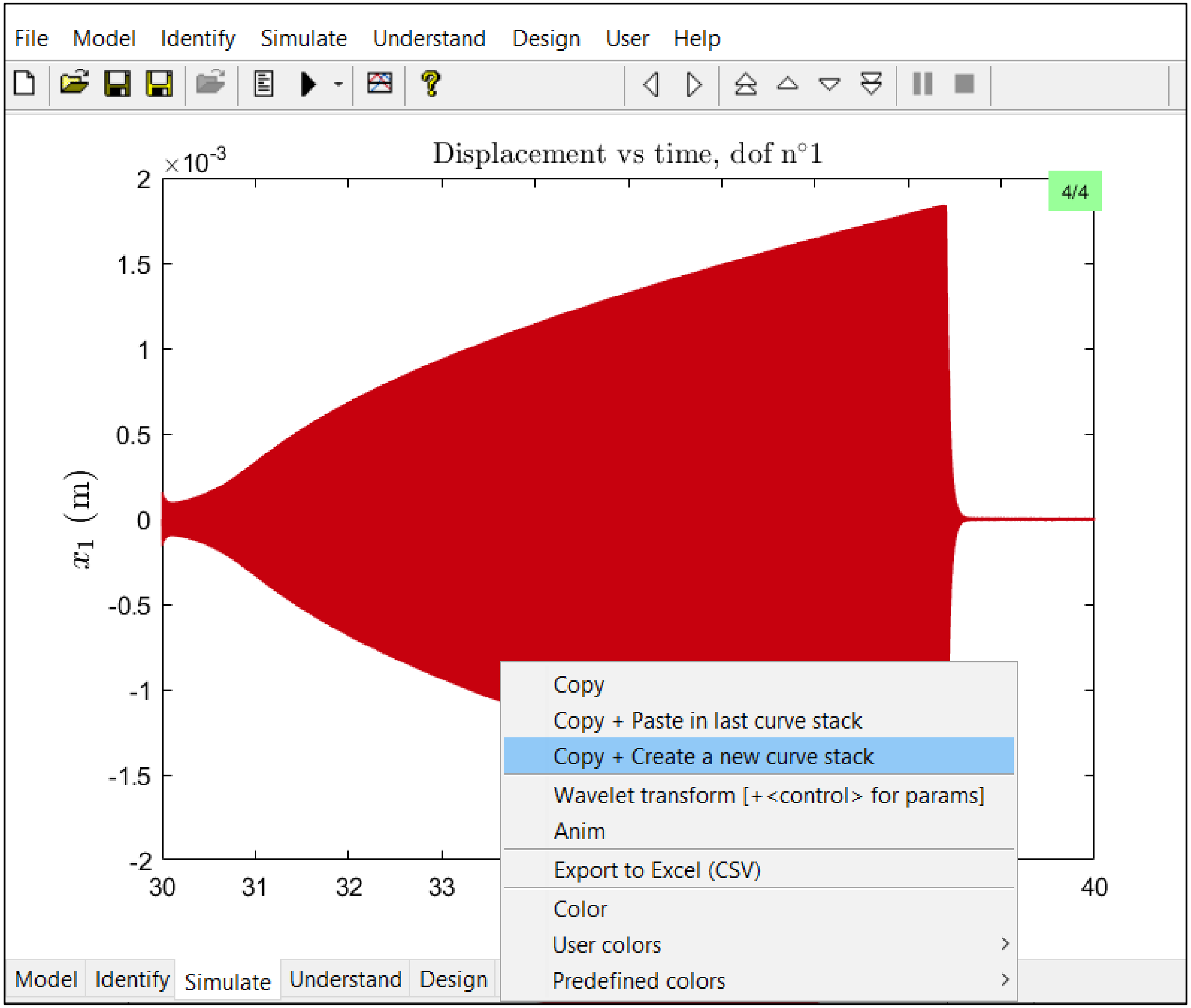
With a Cubic Spring



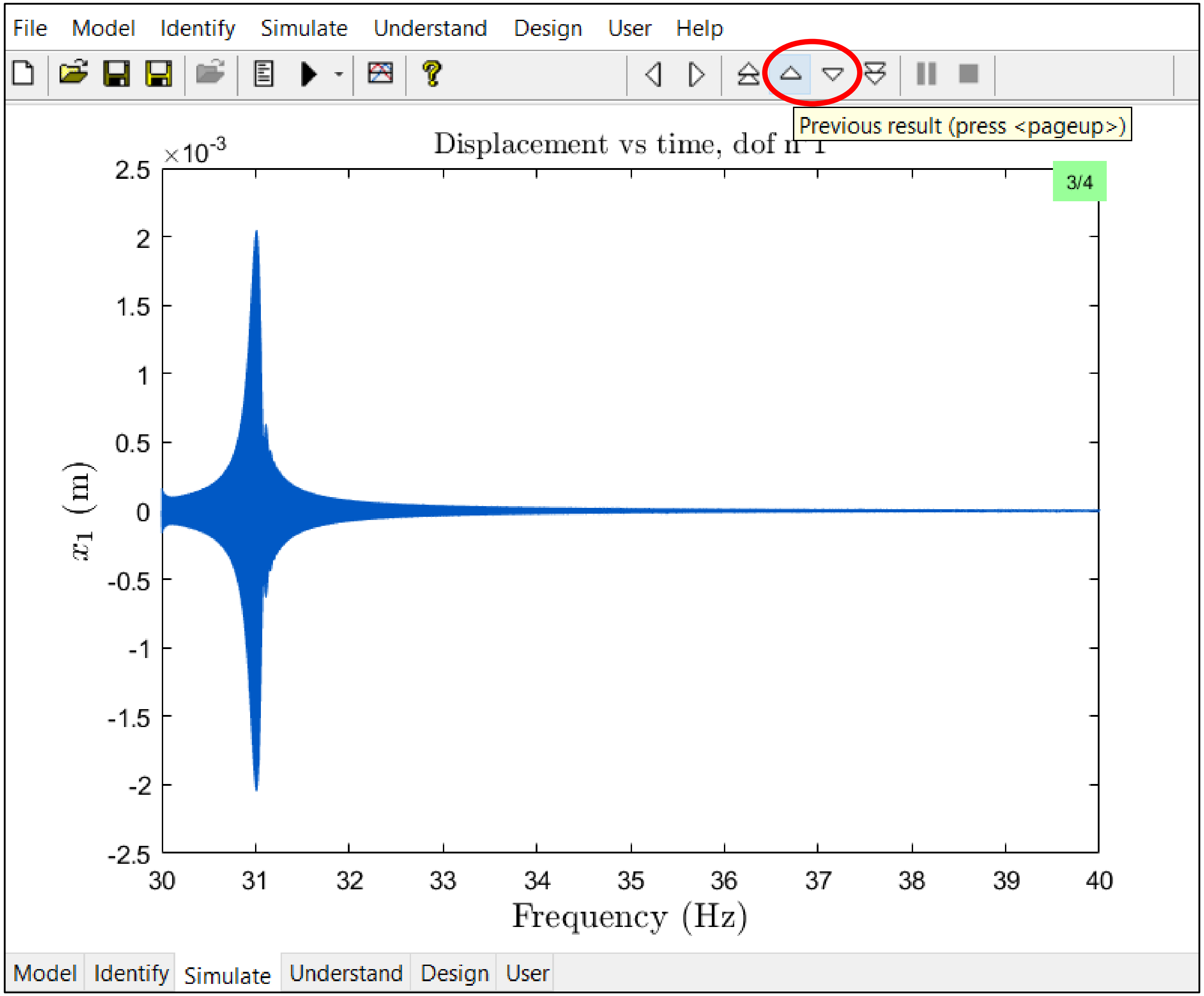
Run the Newmark Time Integration Again …



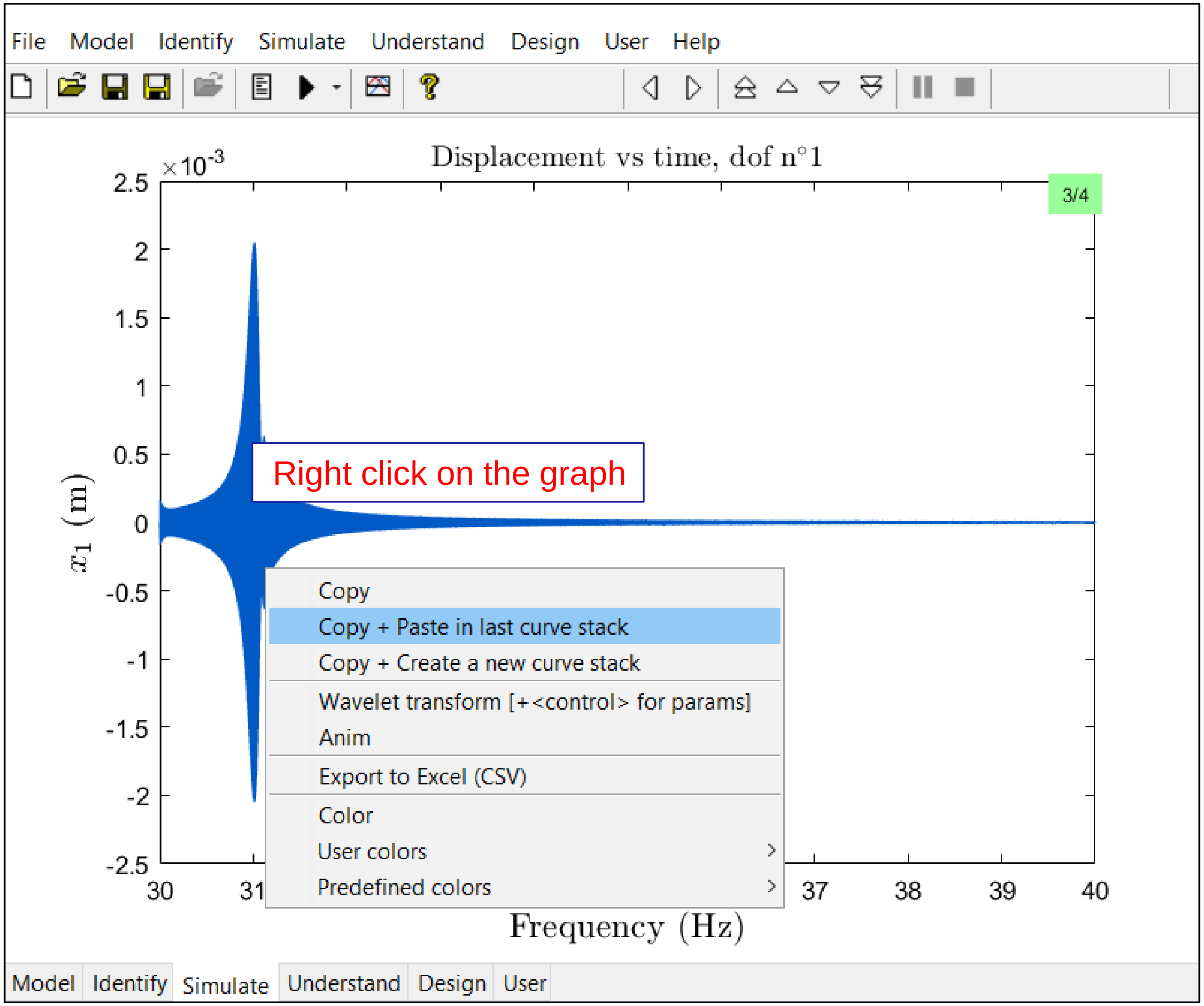
And Save Your Results For Comparison



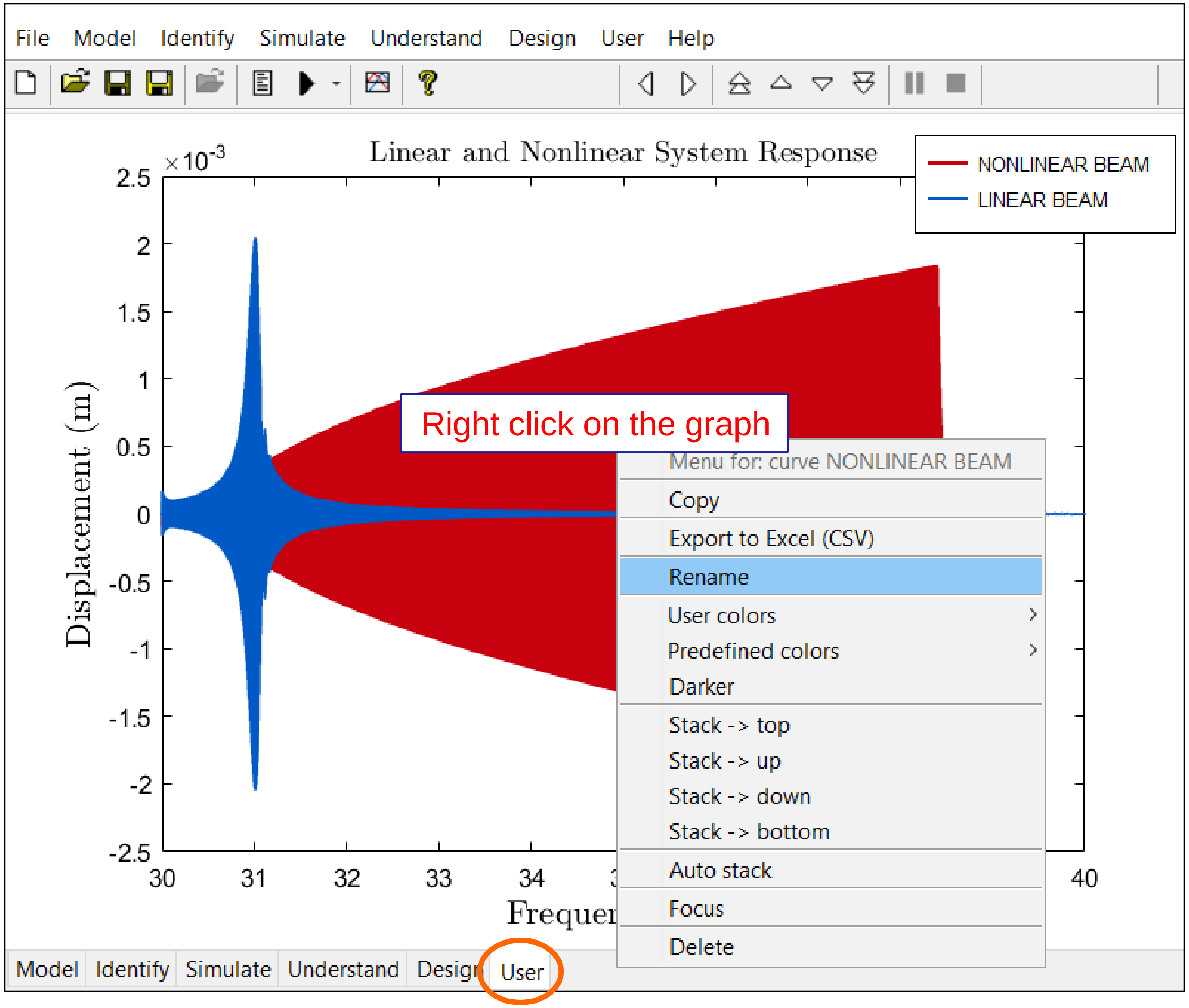
You Can Scroll through Previous Results



And Save Different Results in the Same Curve Stack

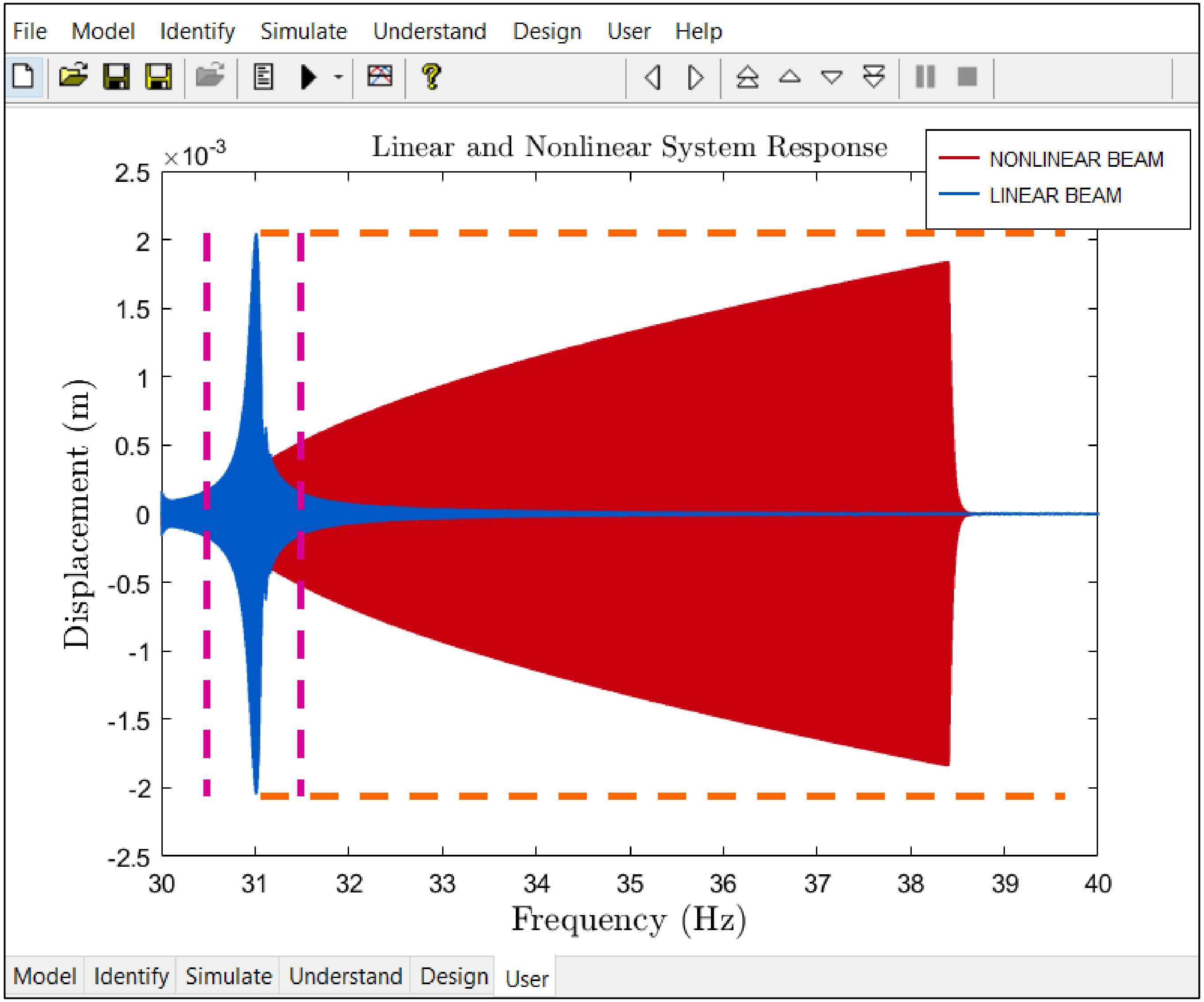


Rename and Arrange Everything in Your Graph …

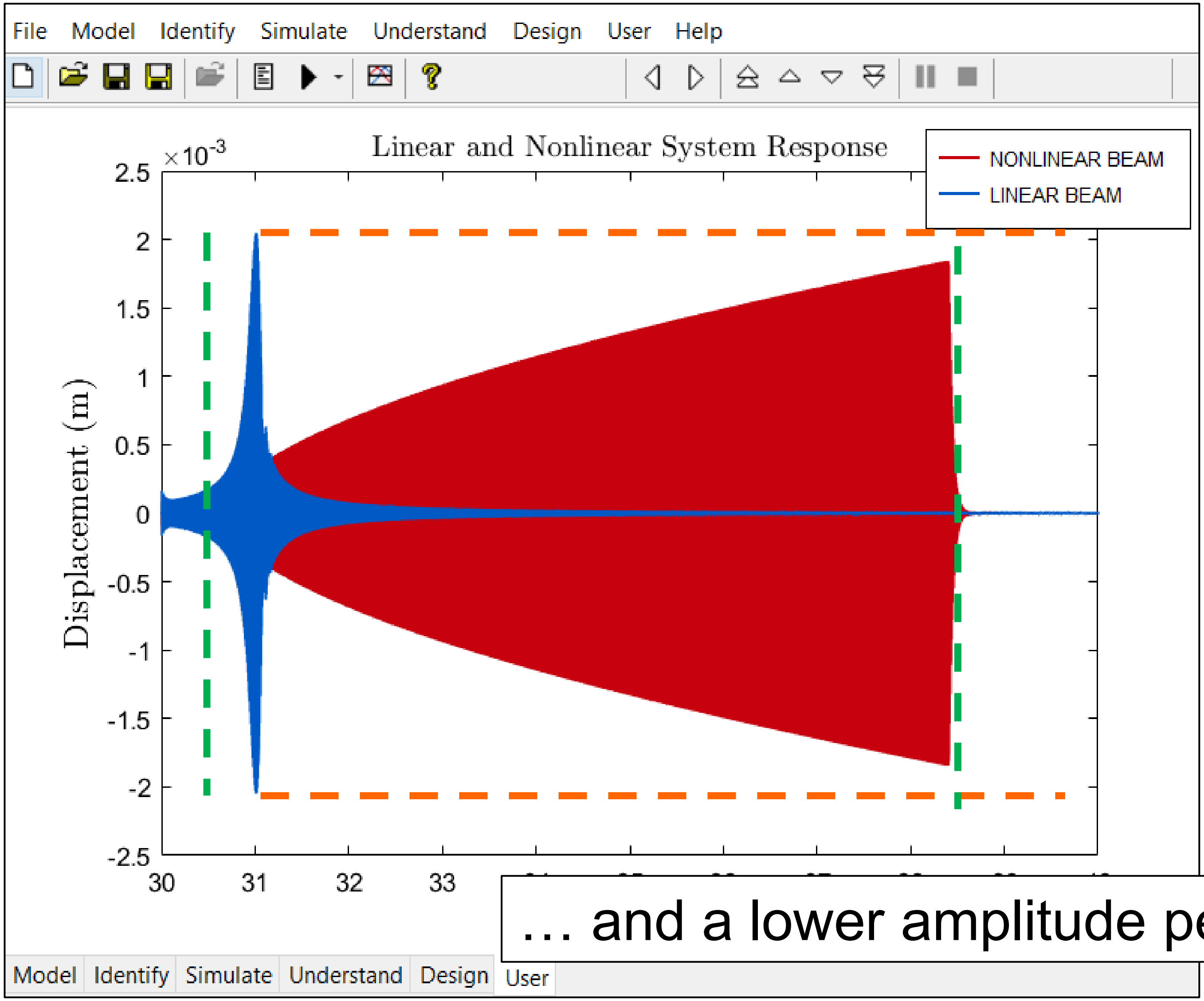


What can we observe?

Nonlinearity Introduces a Fundamental Change

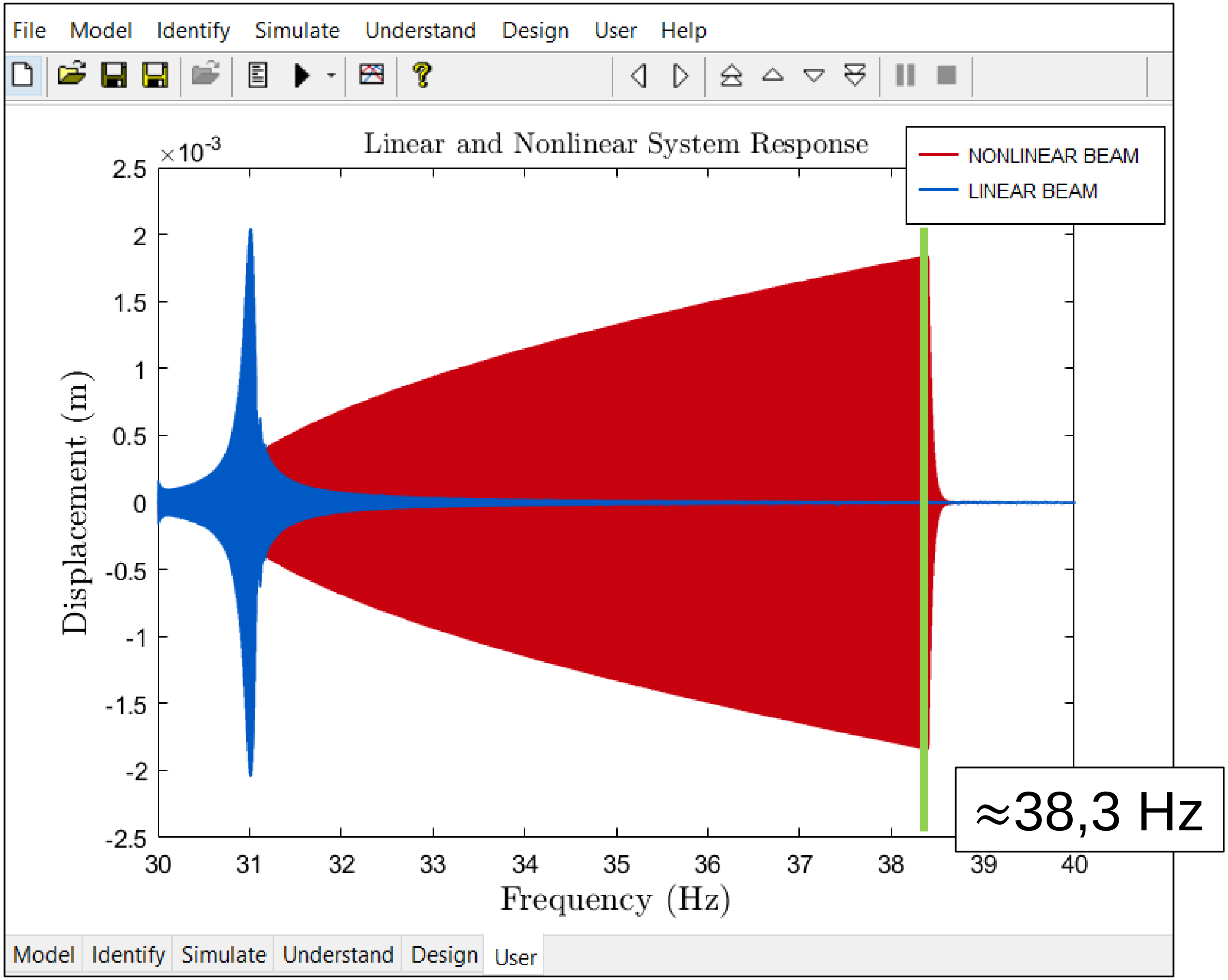


The Nonlinear System Response Has a Greater Bandwidth …

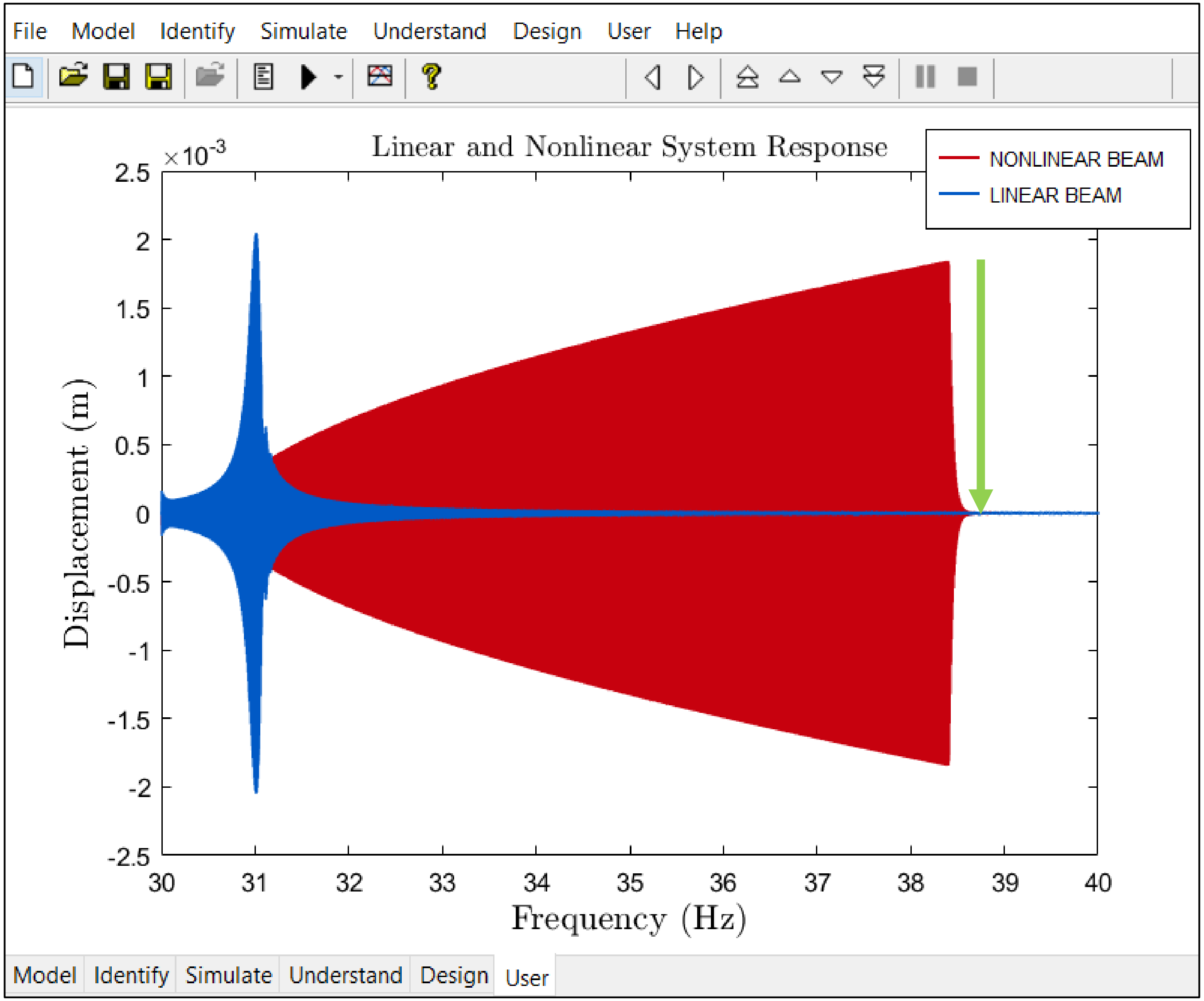


… and a lower amplitude peak

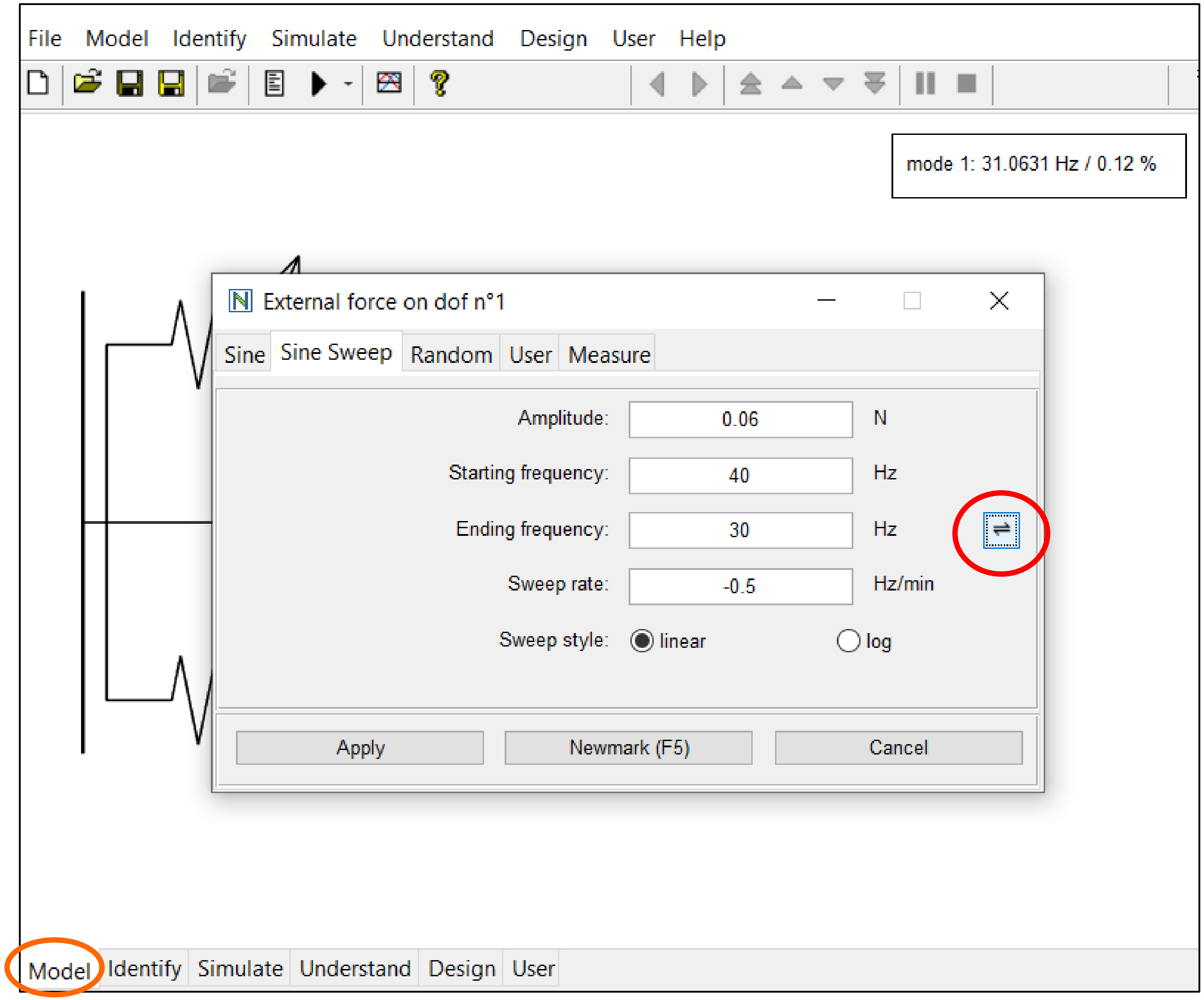
The Resonance Frequency Shifts



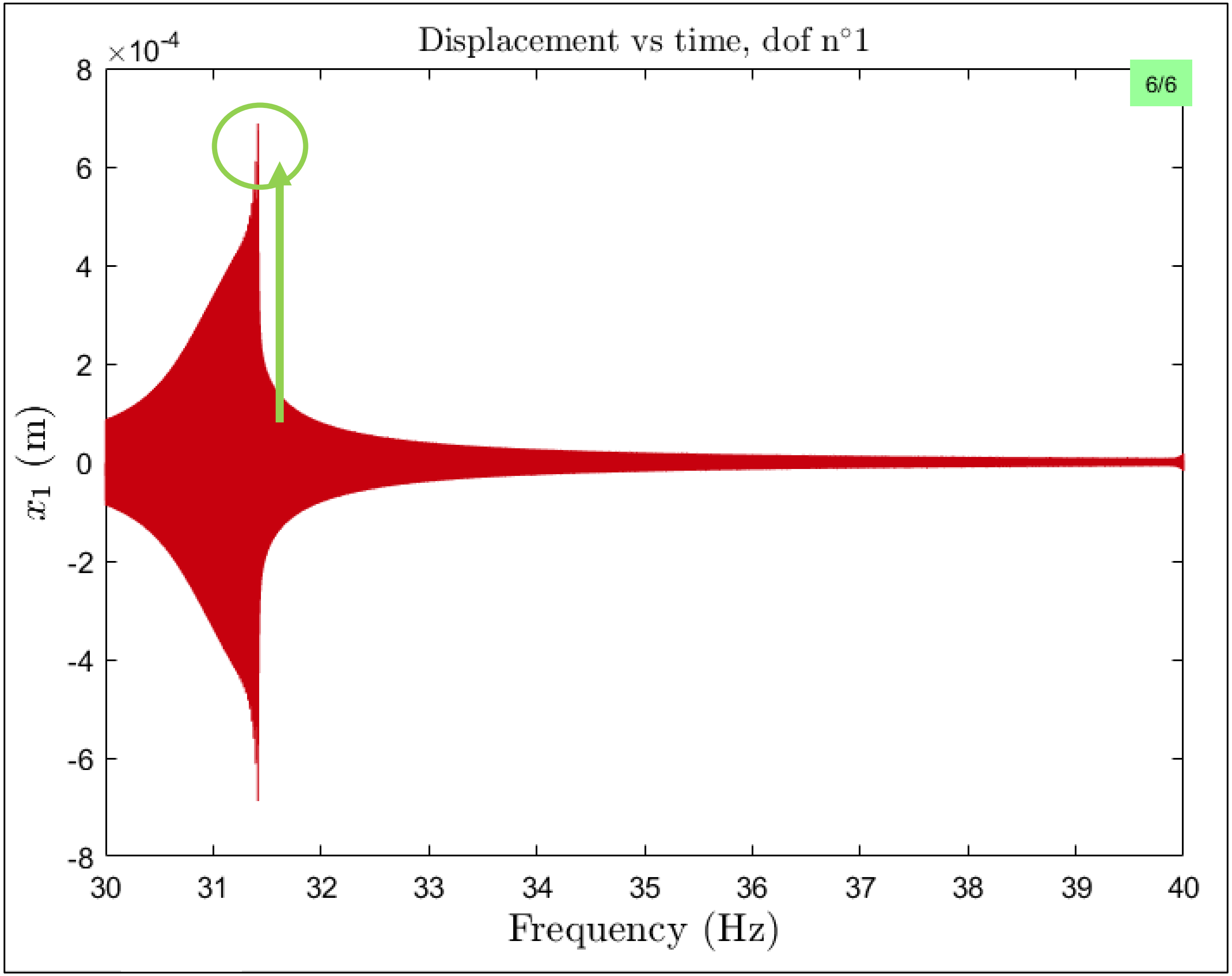
A Jump Downwards Can Be Observed



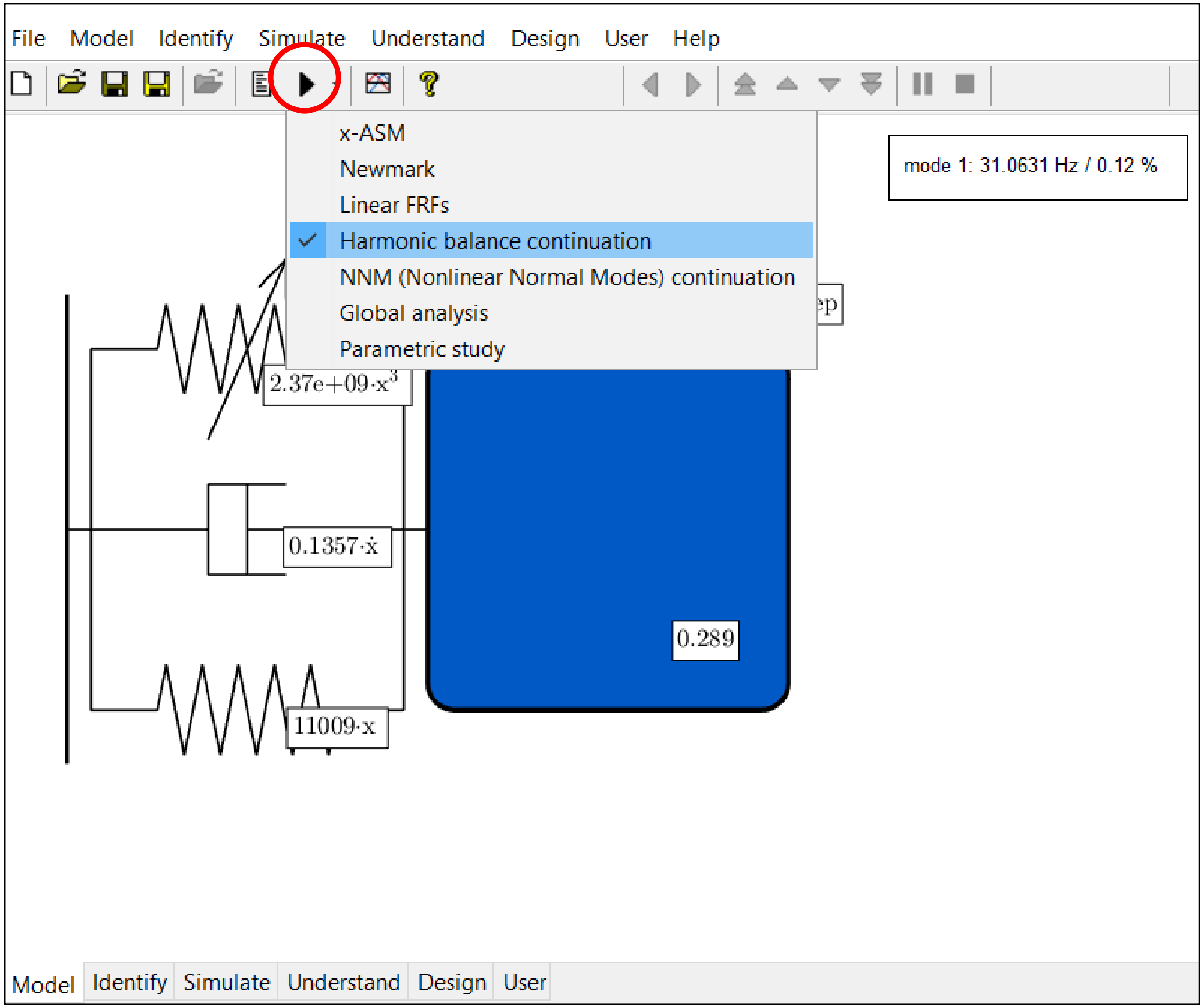
Let’s Reverse the Sweep



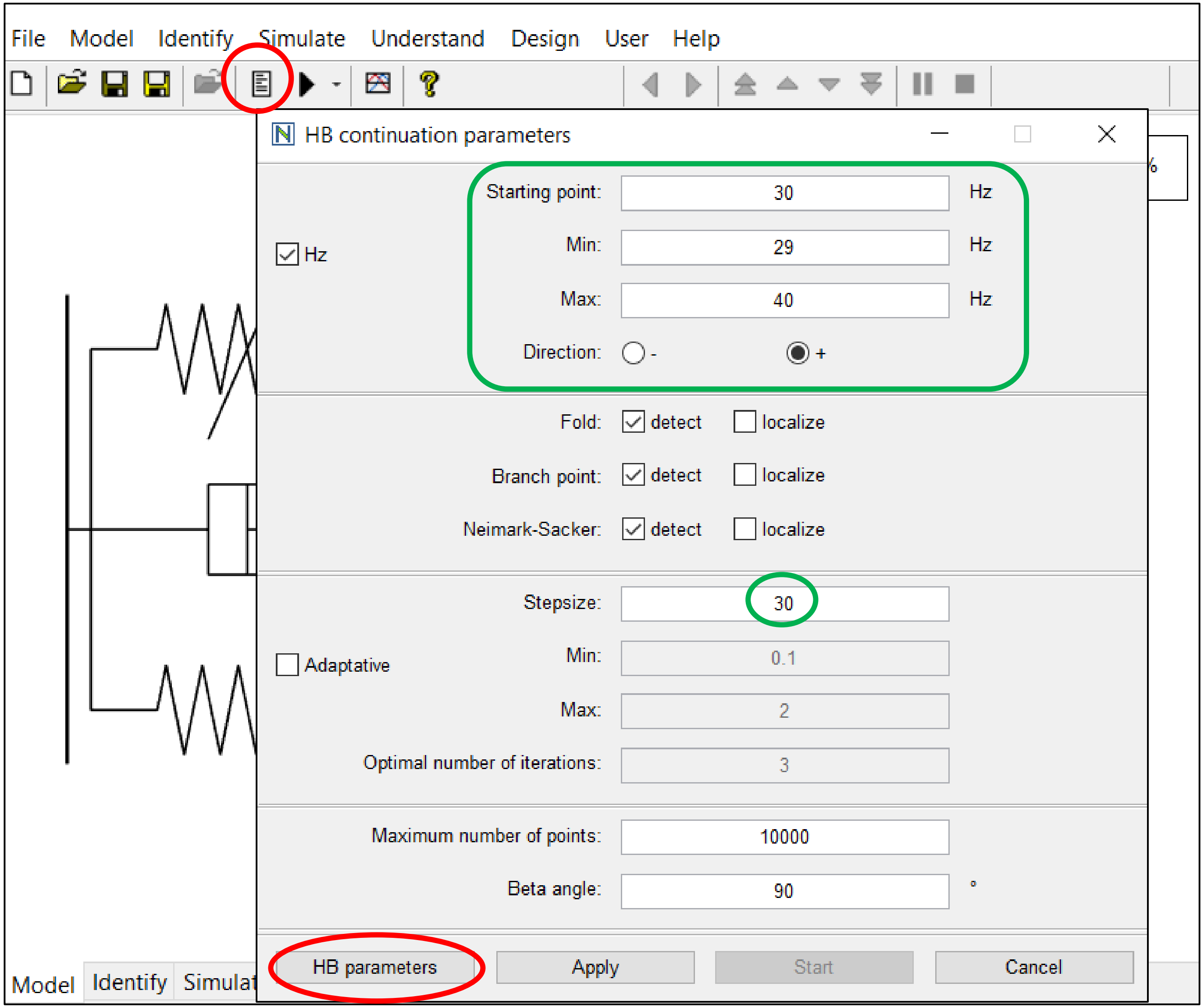
We Can Jump Up Too!



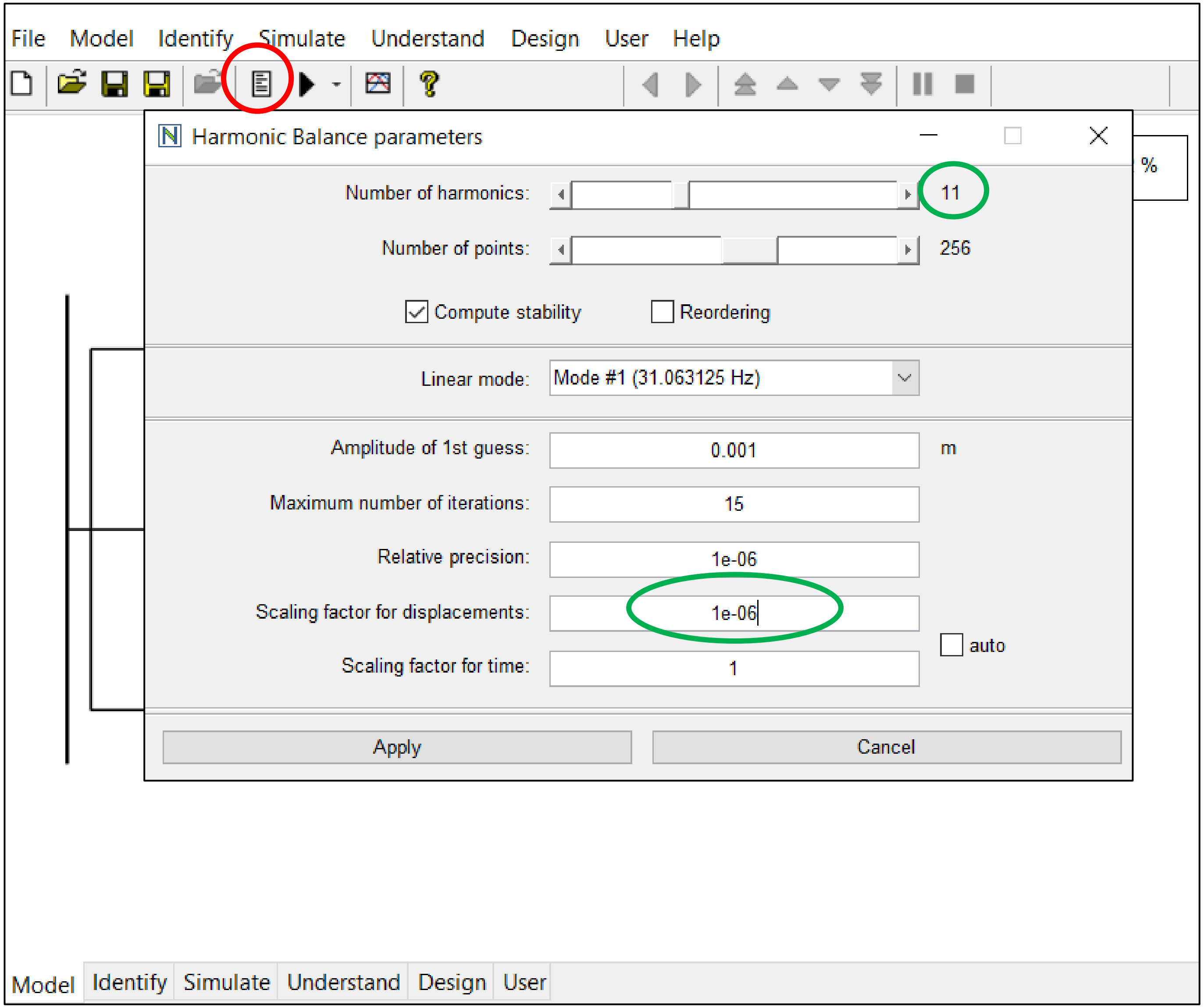
Calculate the Nonlinear FRF



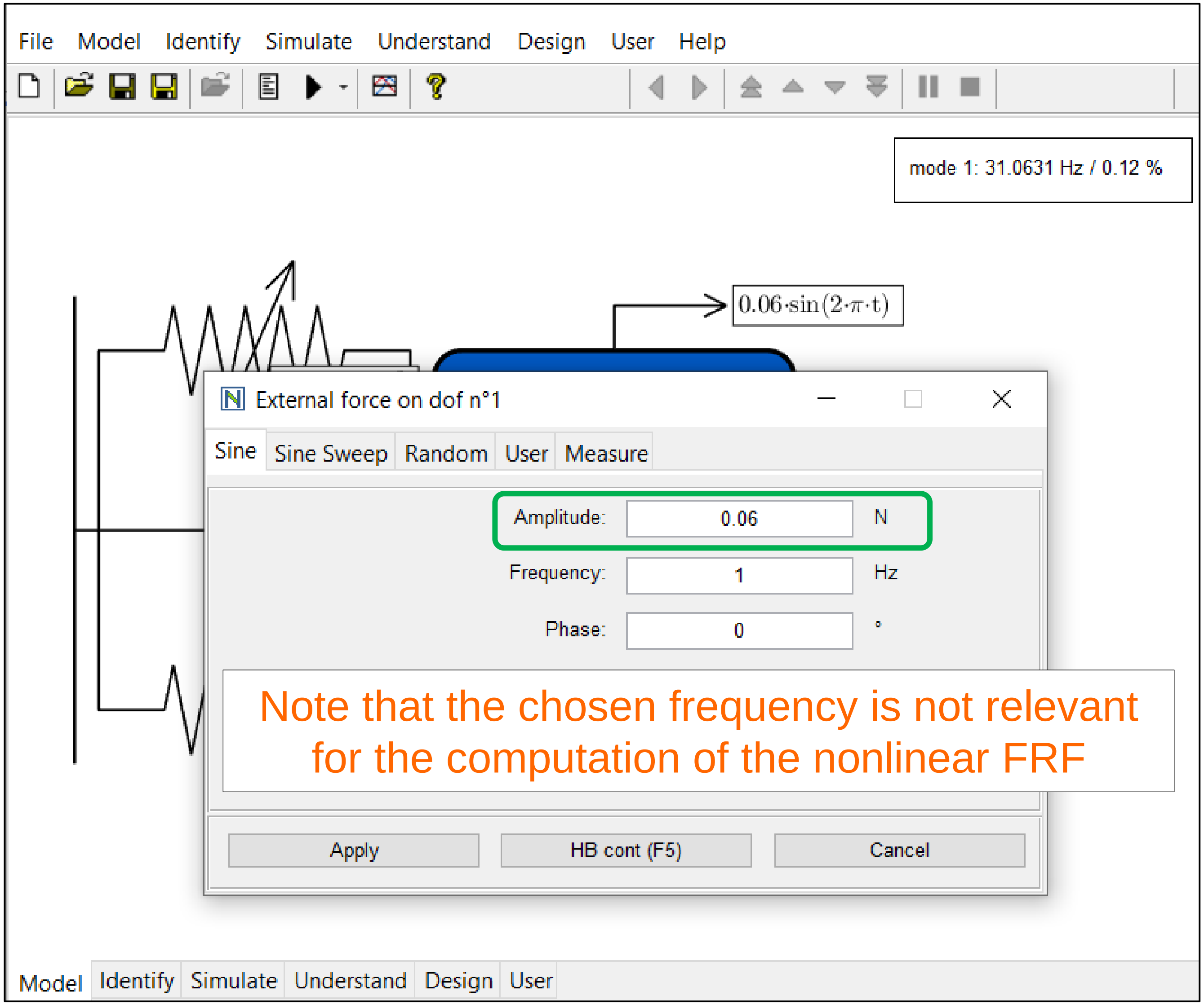
But Set Appropriate Numerical Parameters First



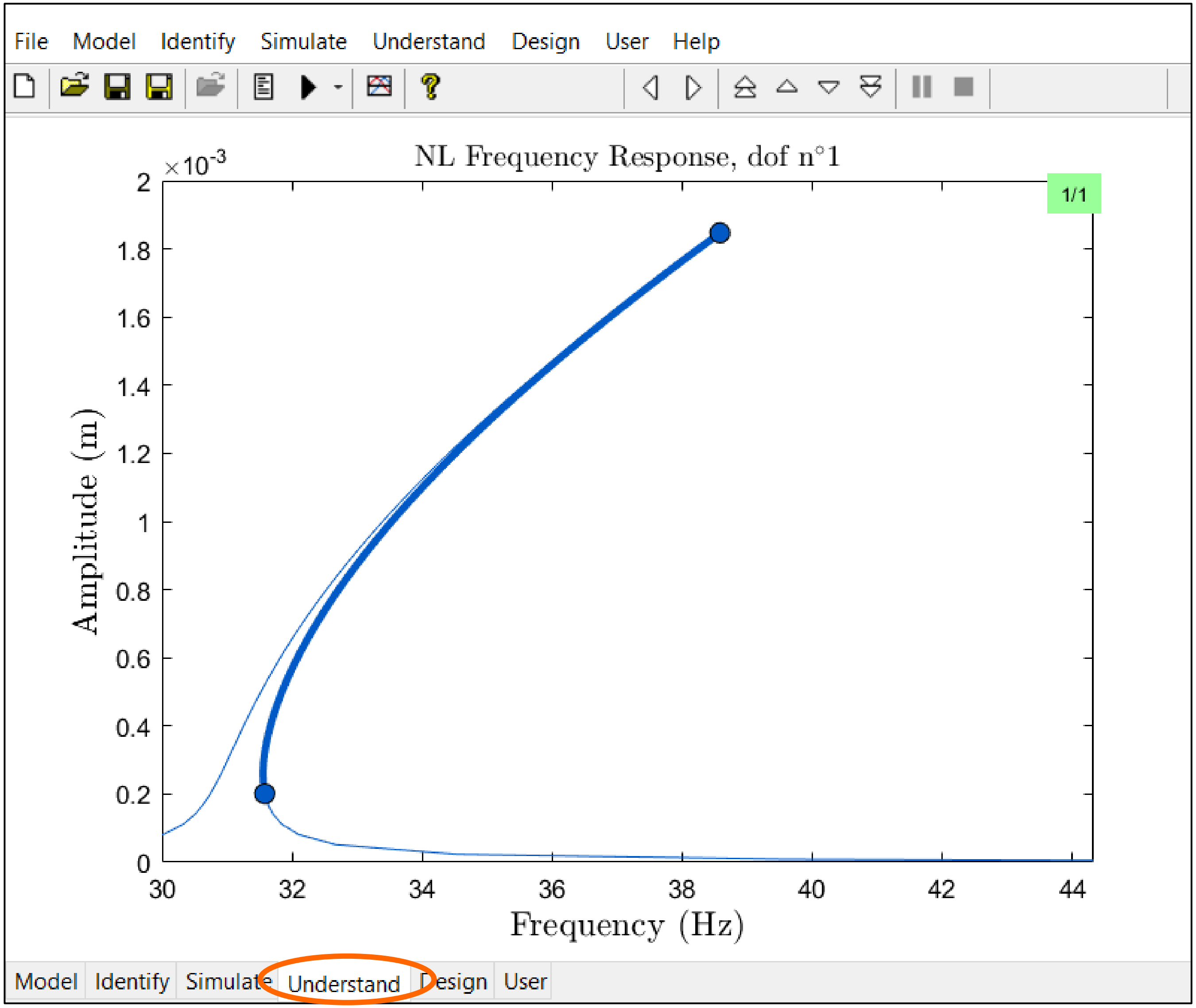
But Set Appropriate Numerical Parameters First



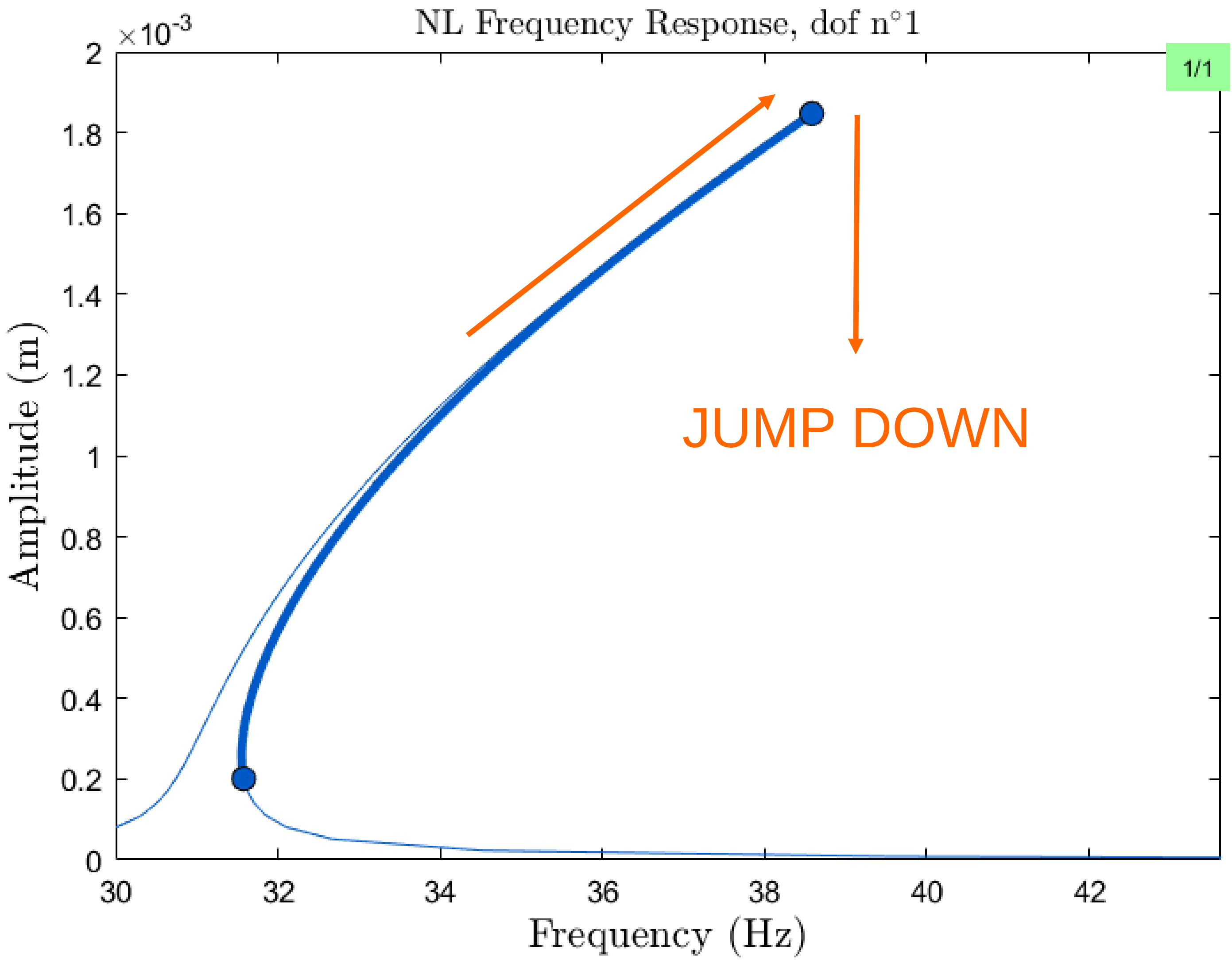
And Change the Excitation Signal to a Sine



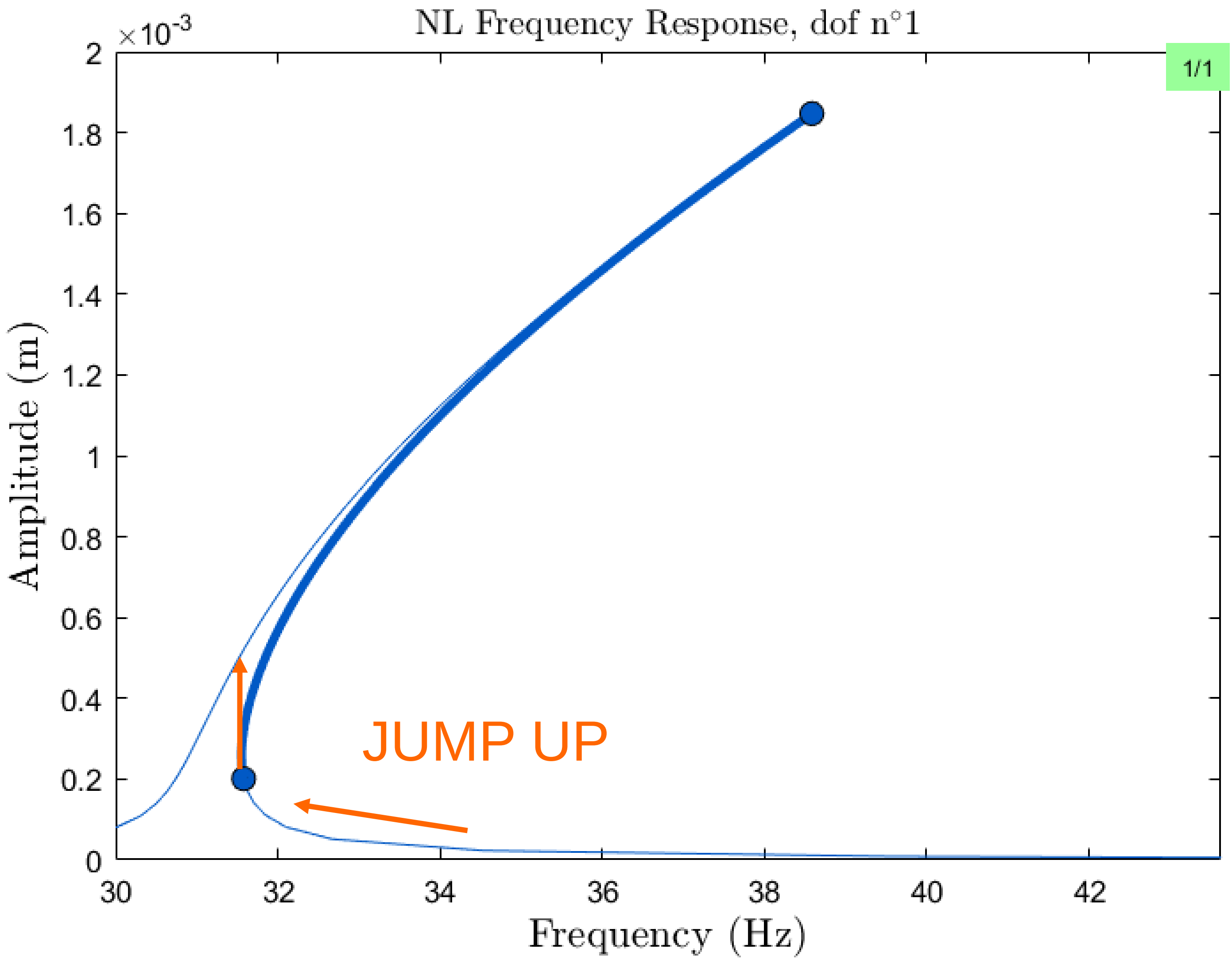
The Nonlinear FRF



The Jump Phenomenon Can Be Understood

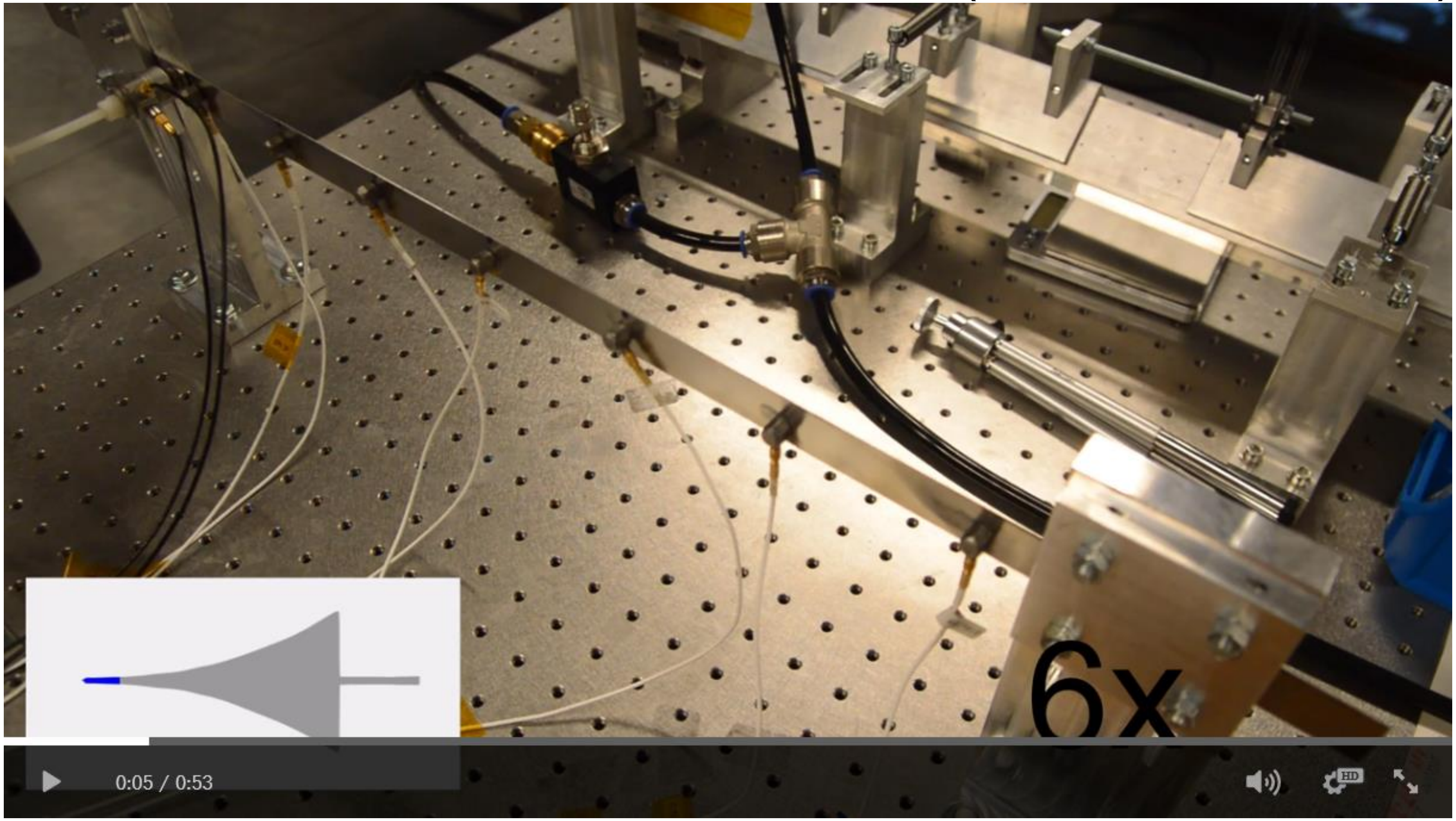


The Jump Phenomenon Can Be Understood



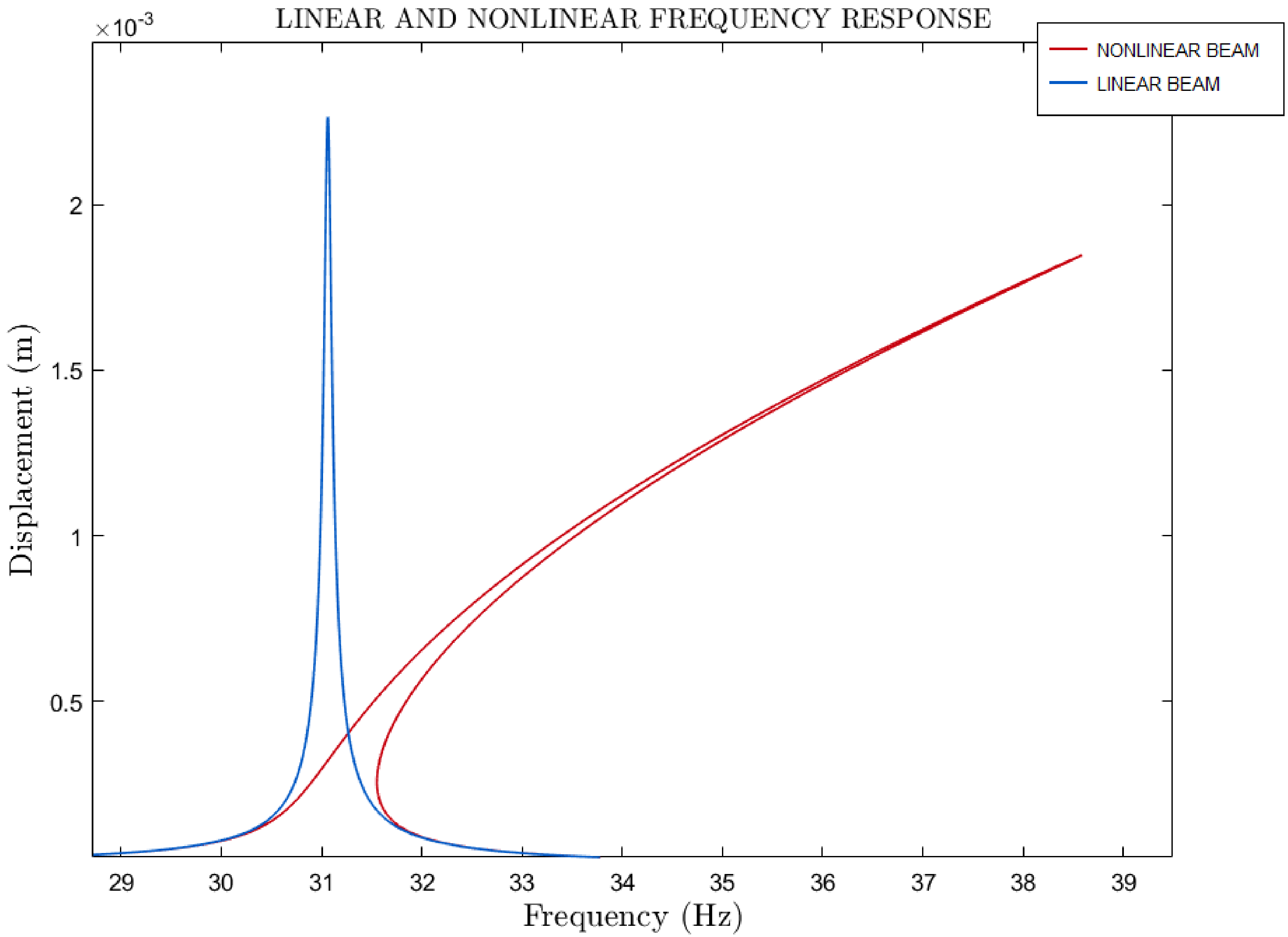
The Jump Phenomenon in Practice

(See the attached video)

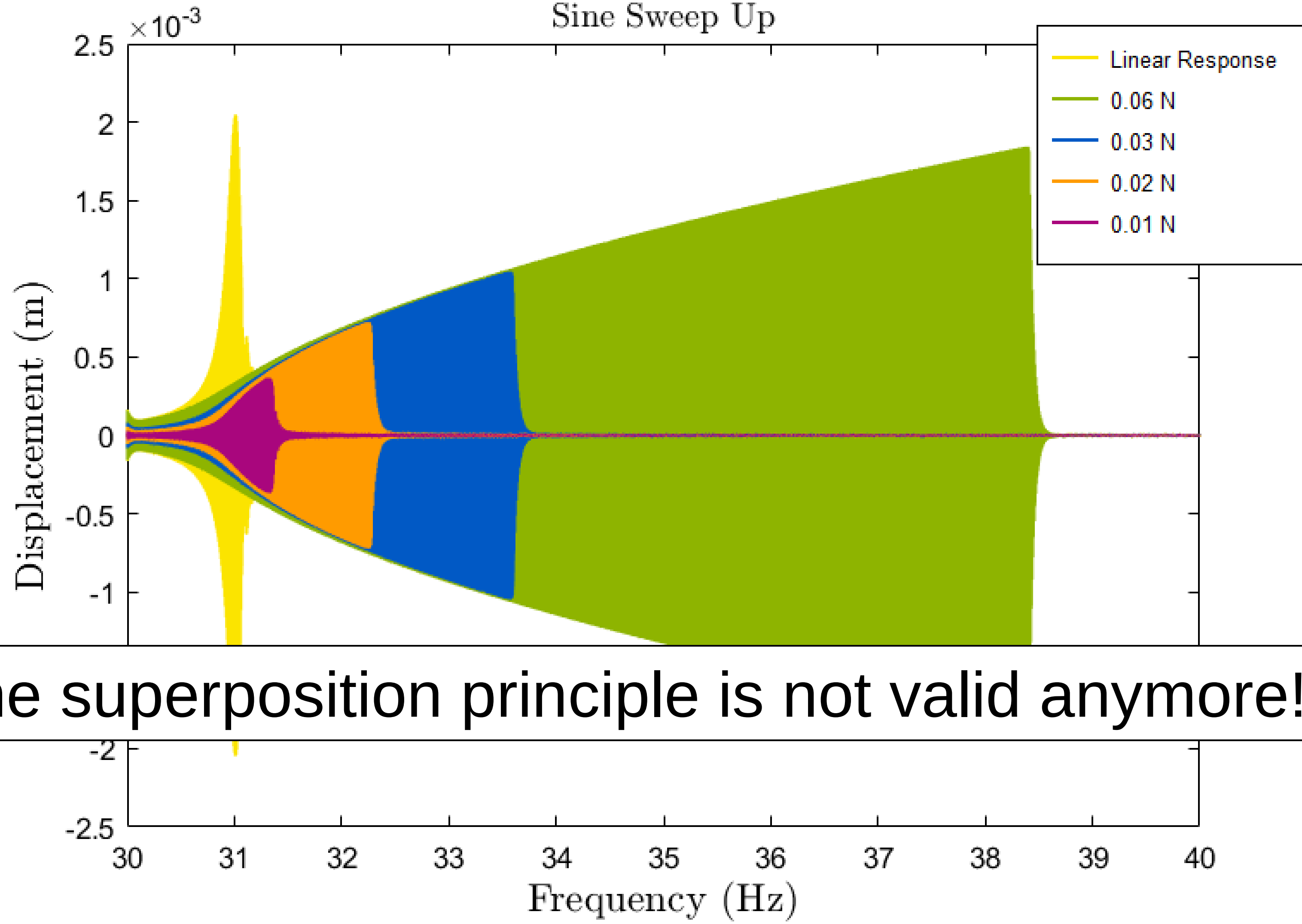


The video shows the dynamics of a clamped-clamped thin beam with geometrical nonlinearities during a sweep over the second beam mode.

Compare to the Linear Frequency Response



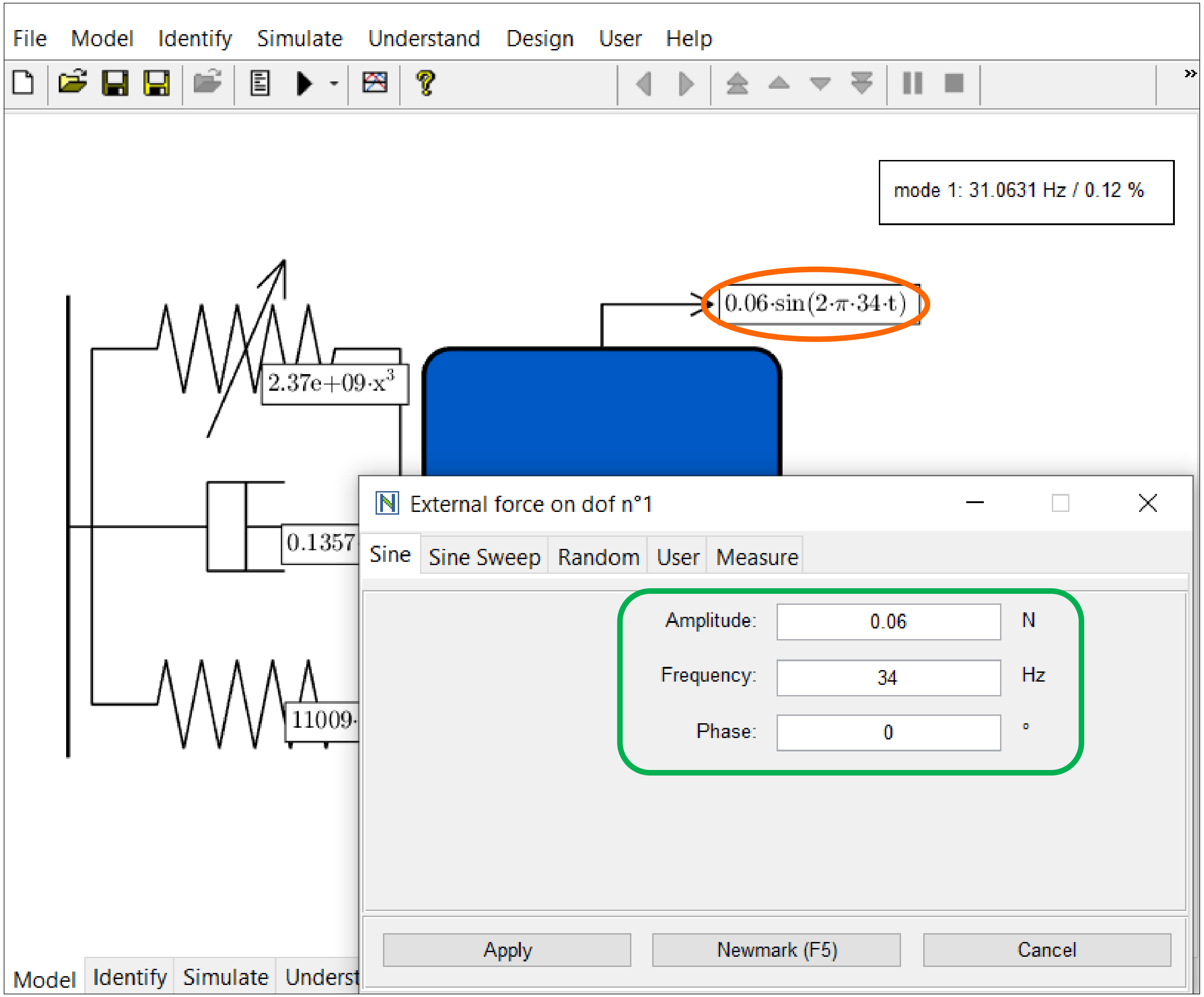
Sweep with Different Forcing Amplitudes



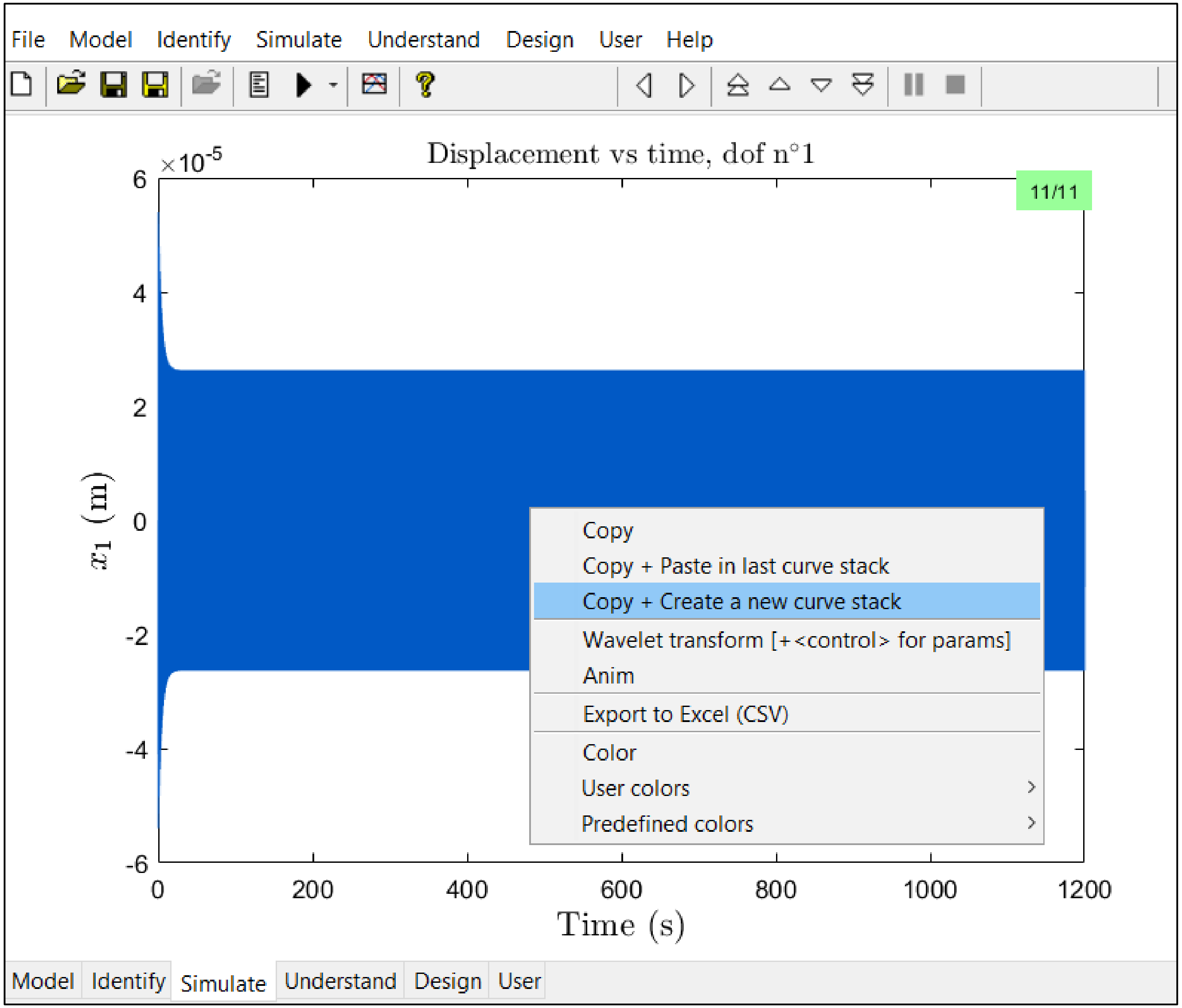
The superposition principle is not valid anymore!

Sine with a Fixed Frequency in the Multi-valued Region

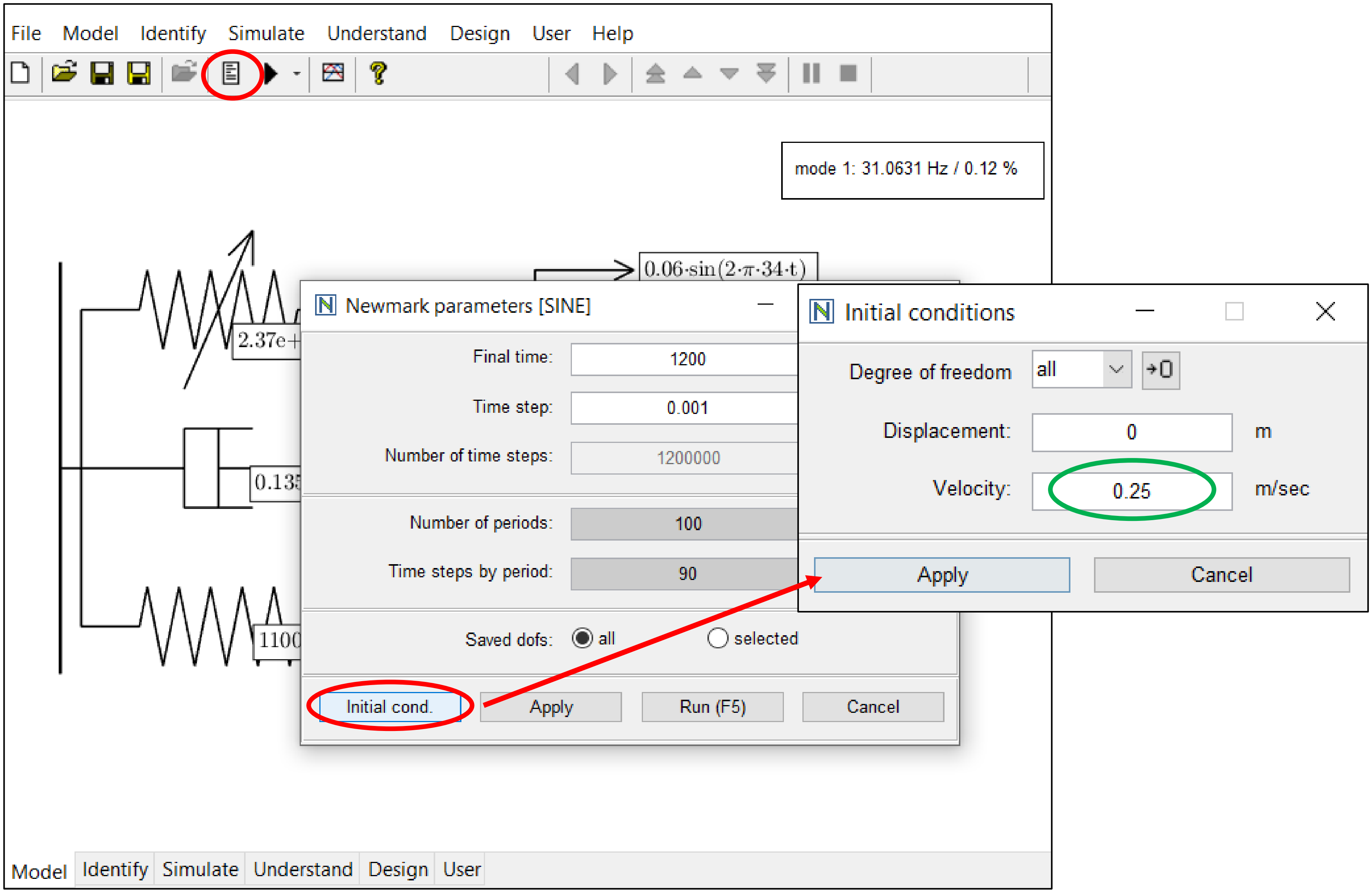
Now: Consider an Excitation with a Fixed Frequency



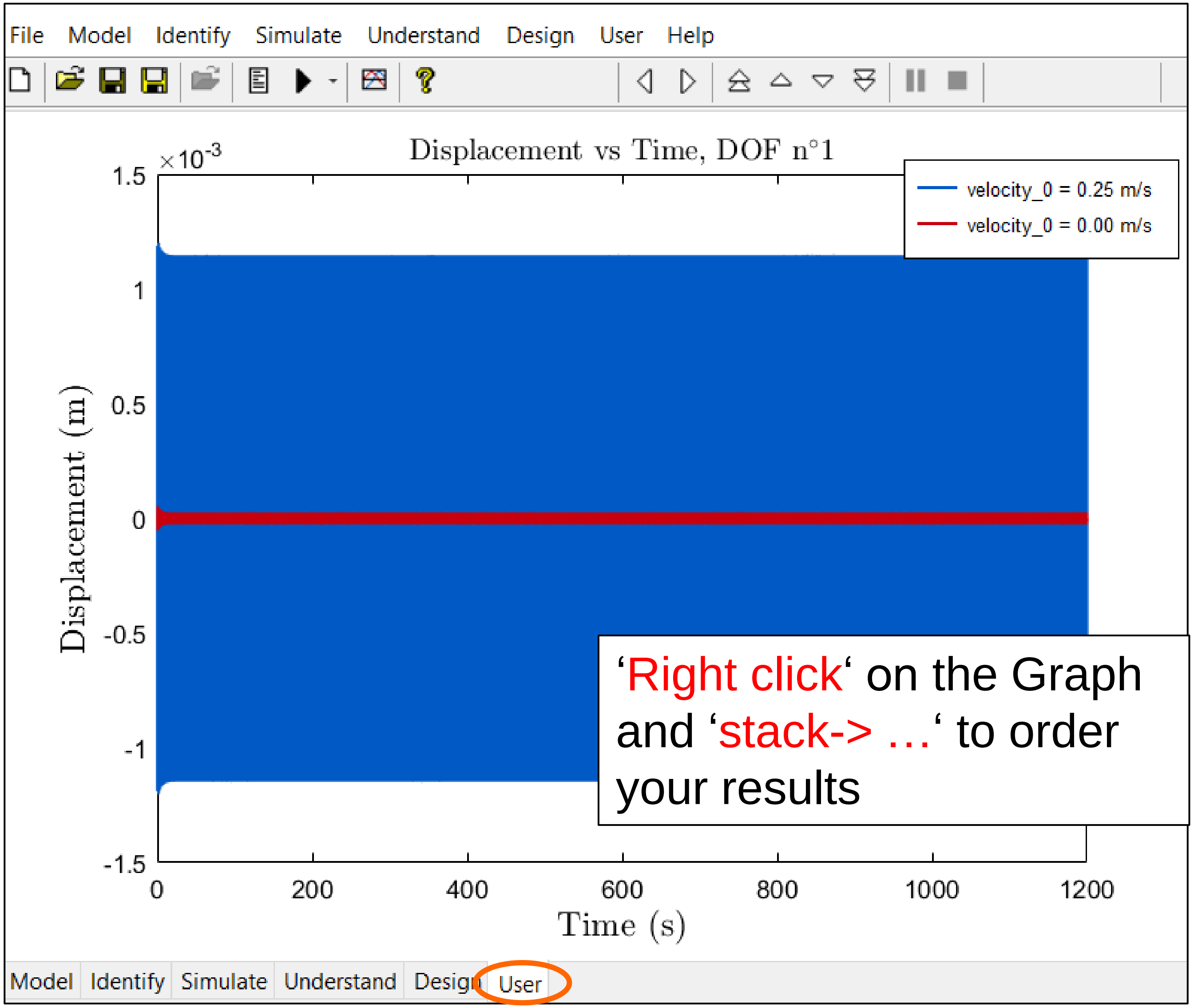
Run the Newmark Integration and Save



Change the Initial Conditions

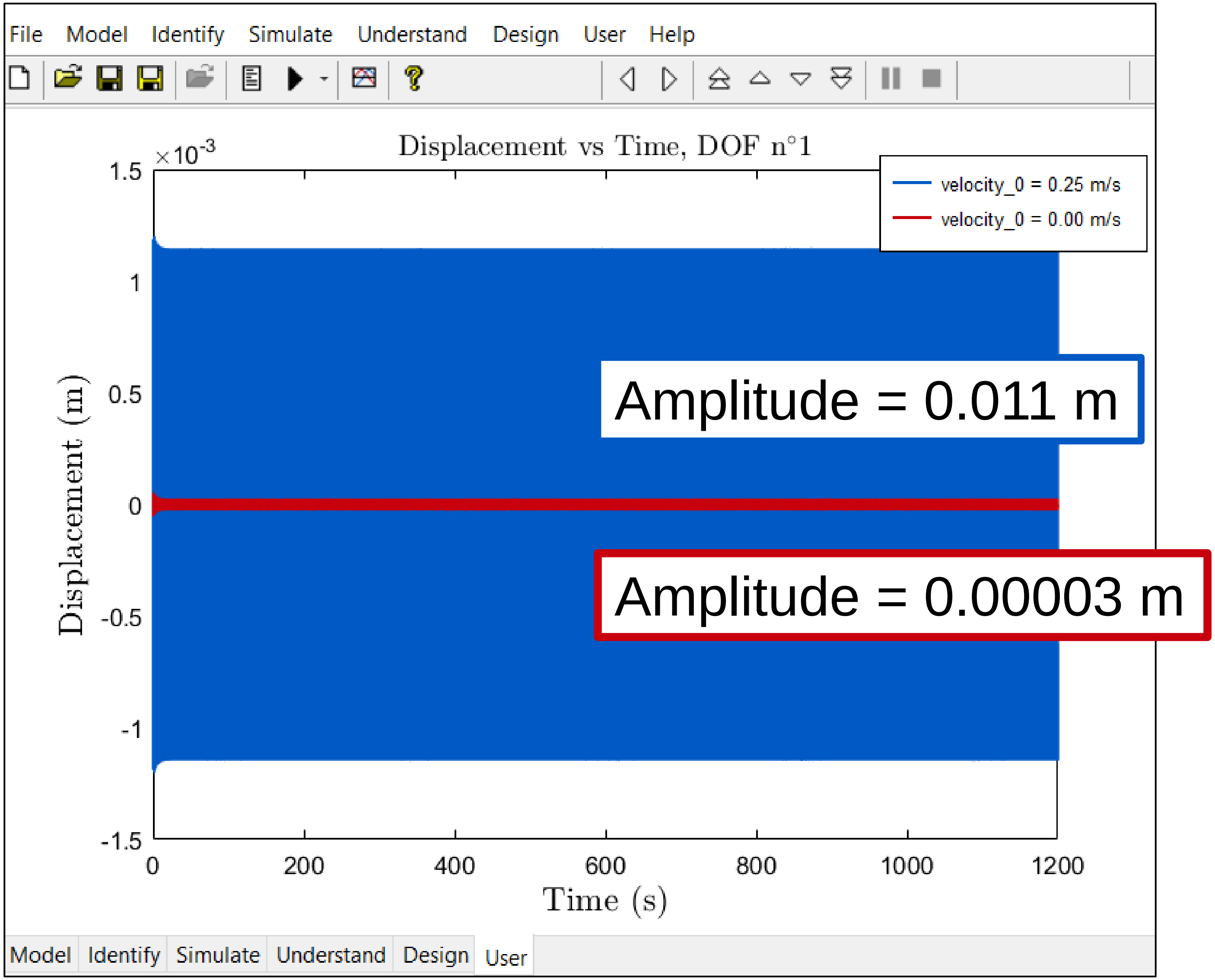


Run and Save in the Same Curve Stack



'Right click' on the Graph and 'stack-> …' to order your results

Compare



File Model Identify Simulate Understand Design User Help
Displacement vs Time, DOF n°1
×10^-3
1.5
1
0.5
0
-0.5
-1
-1.5
Displacement (m)
0
200
400
600
800
1000
1200
Time (s)
velocity_0 = 0.25 m/s
velocity_0 = 0.00 m/s
Amplitude = 0.011 m
Amplitude = 0.00003 m
Model Identify Simulate Understand Design User

The Nonlinear FRF Helps to Understand