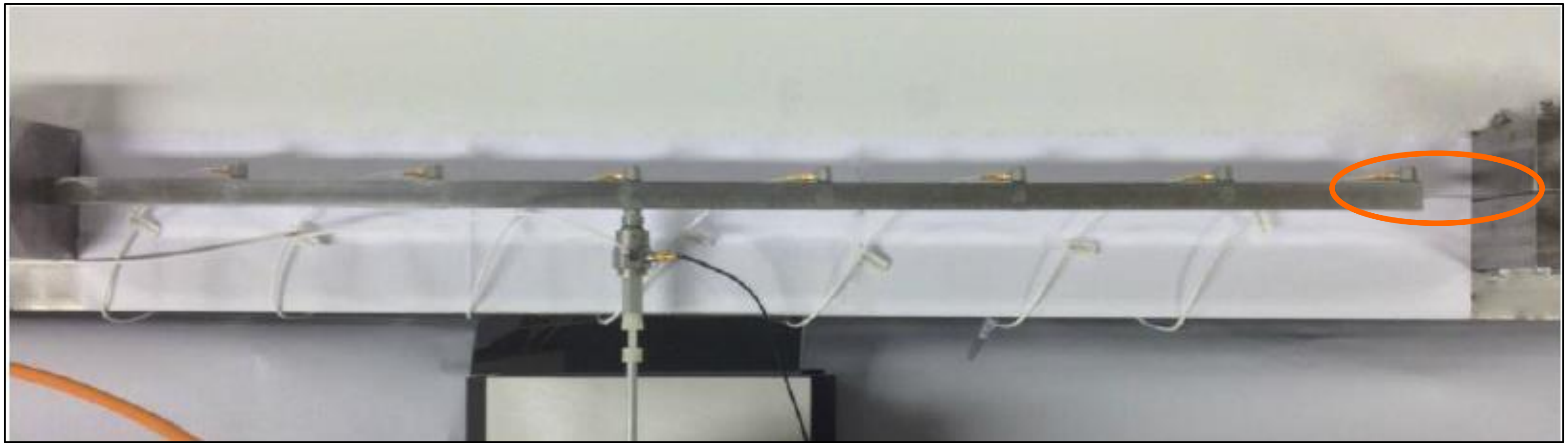
Nonlinear Vibrations of Aerospace Structures

Tutorial 02

Nonlinear Symptoms

Nonlinear Identification to Design
Software

Nonlinear Model of the 1st Beam Mode

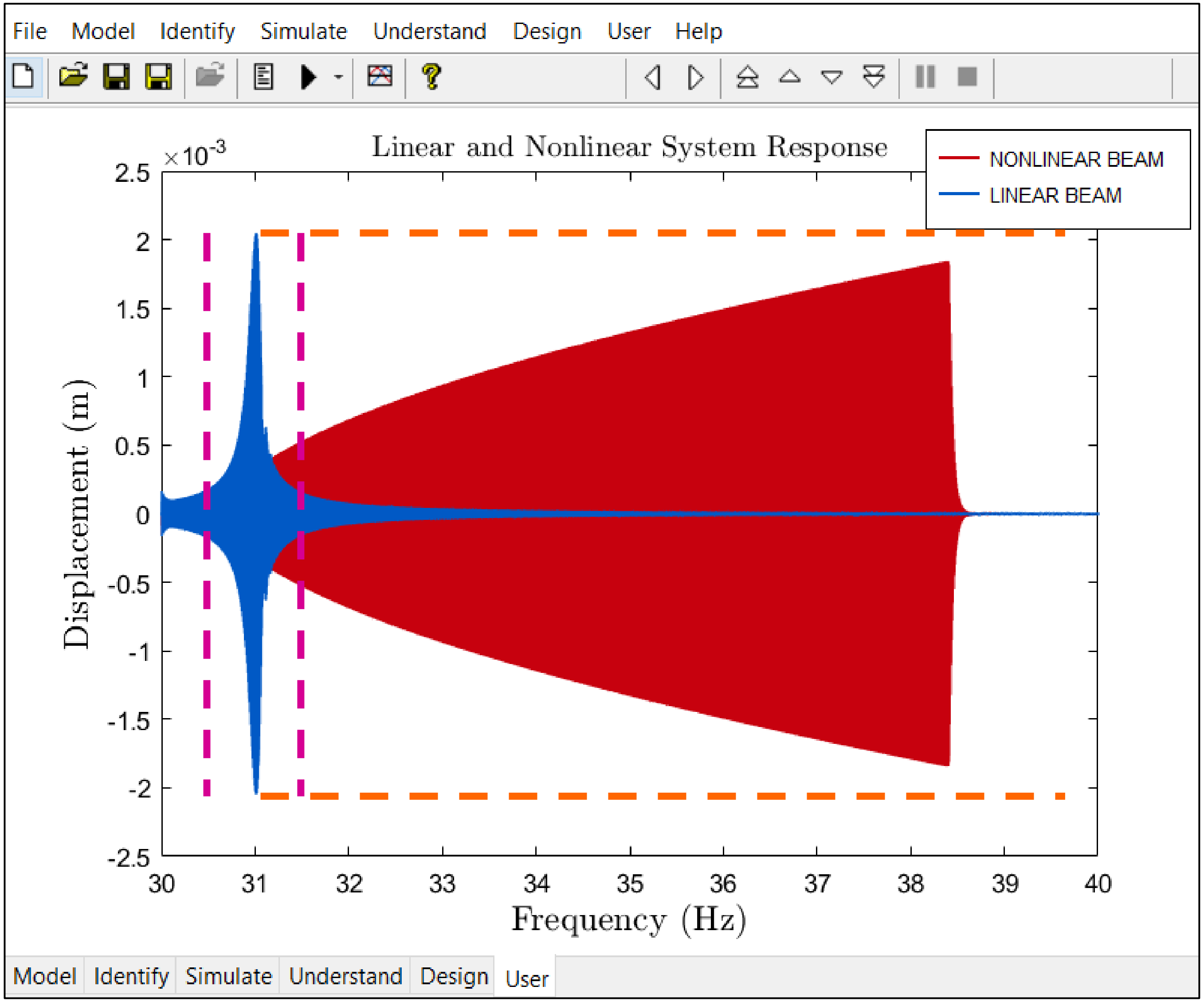


Linear model identified at low level (31 Hz, 0.12%):

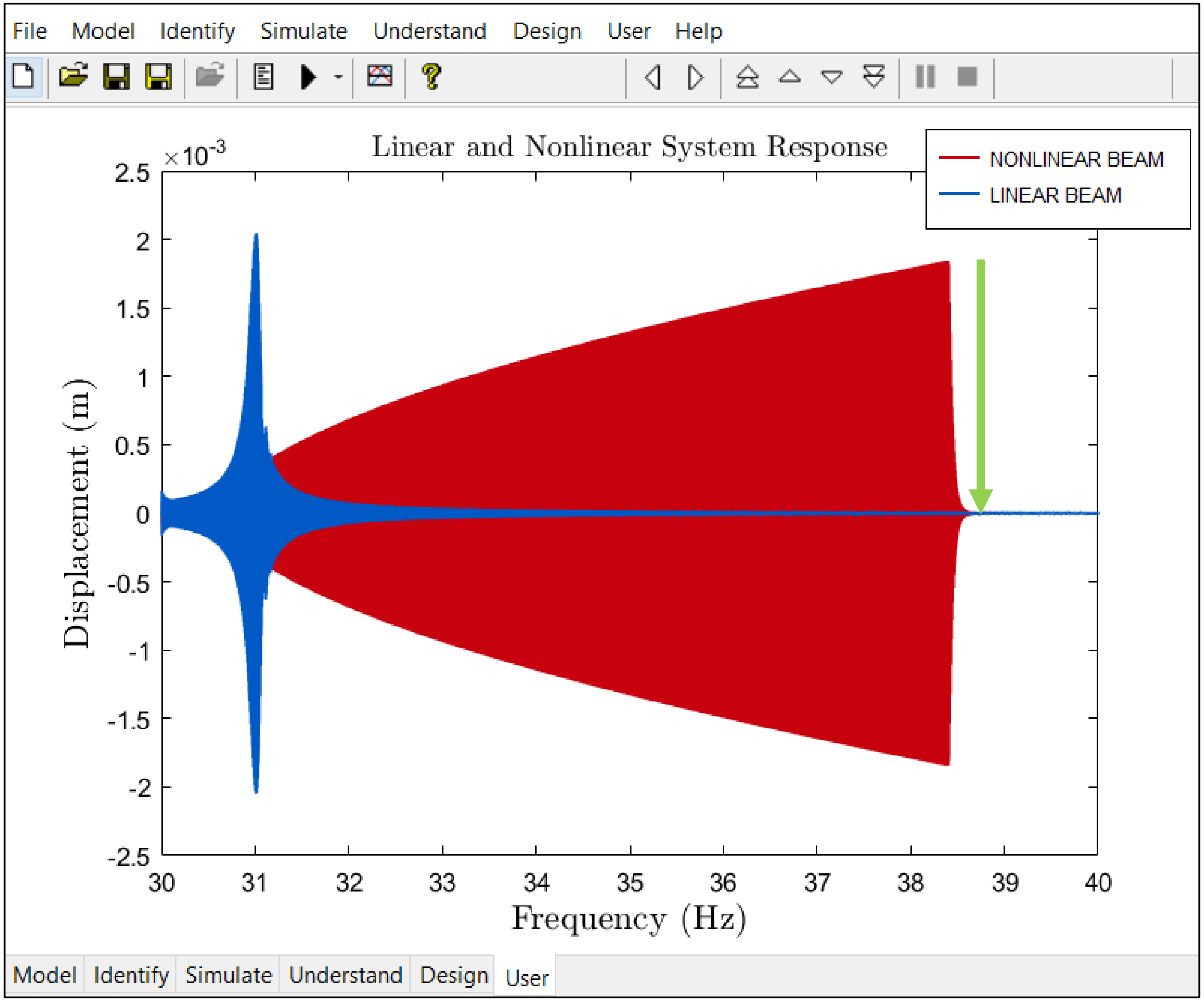
$$0.289\ddot{x} + 0.1357\dot{x} + 11009x = F\sin\omega t$$

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

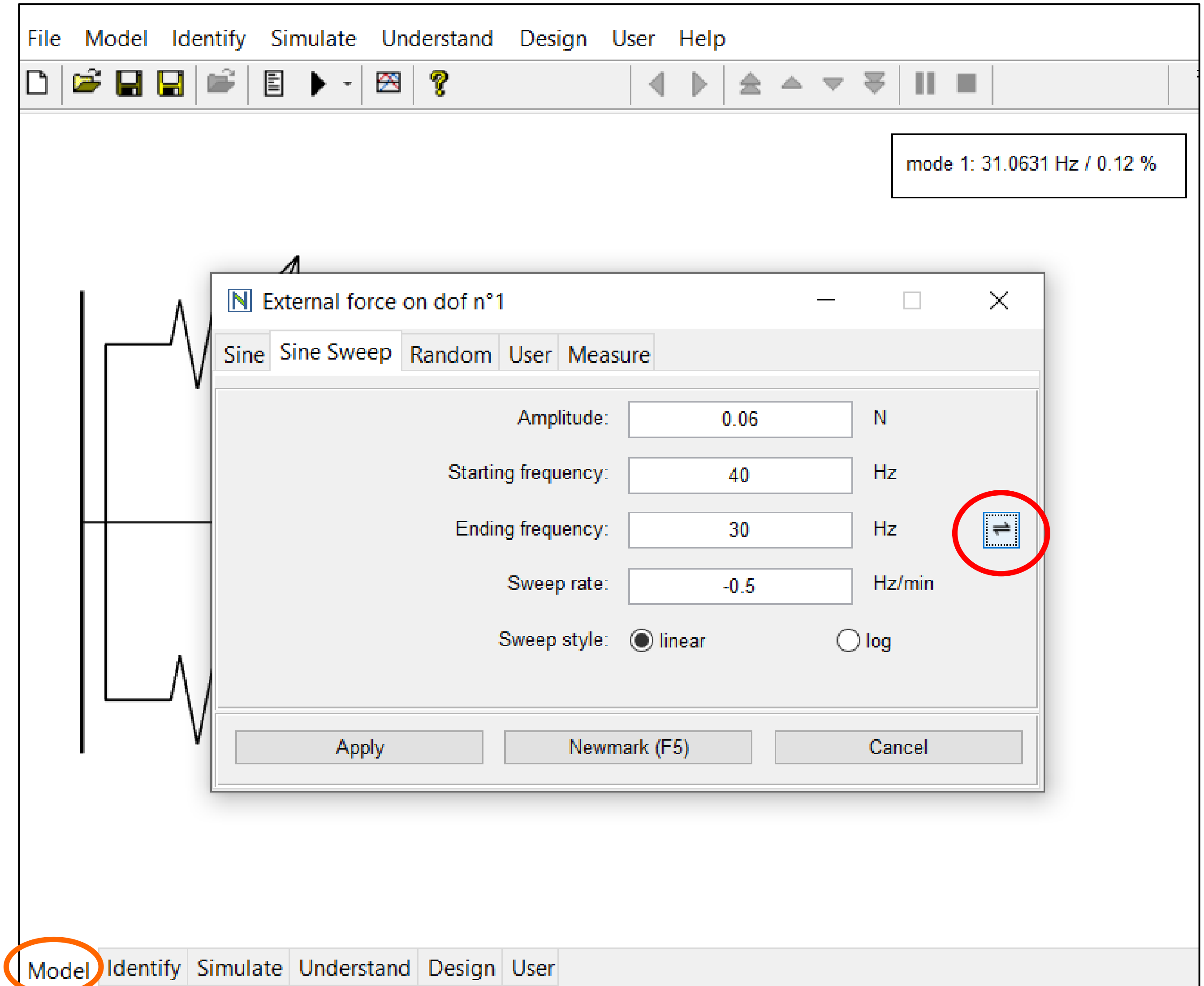
Nonlinearity Introduces a Fundamental Change



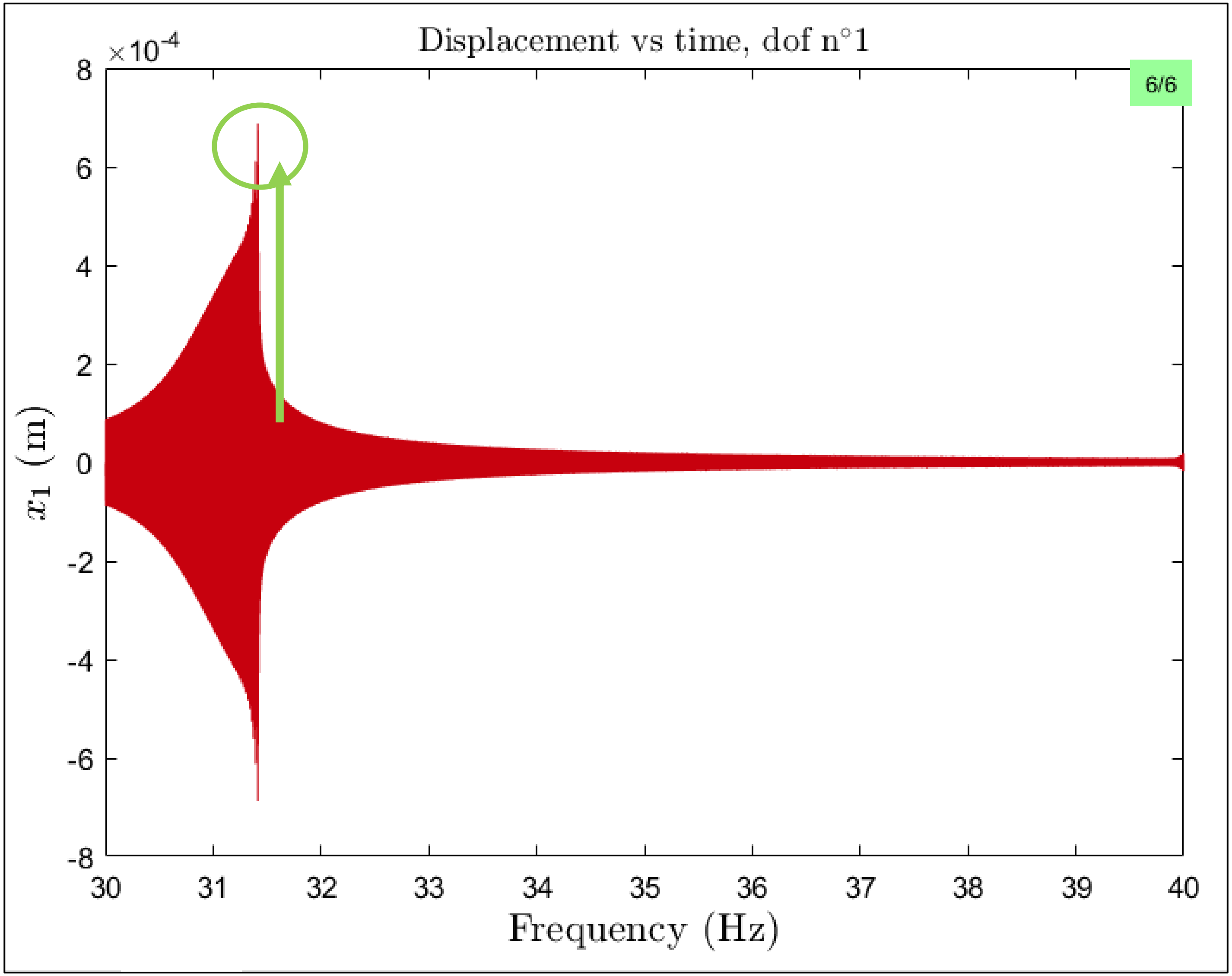
A Jump Downwards Can Be Observed



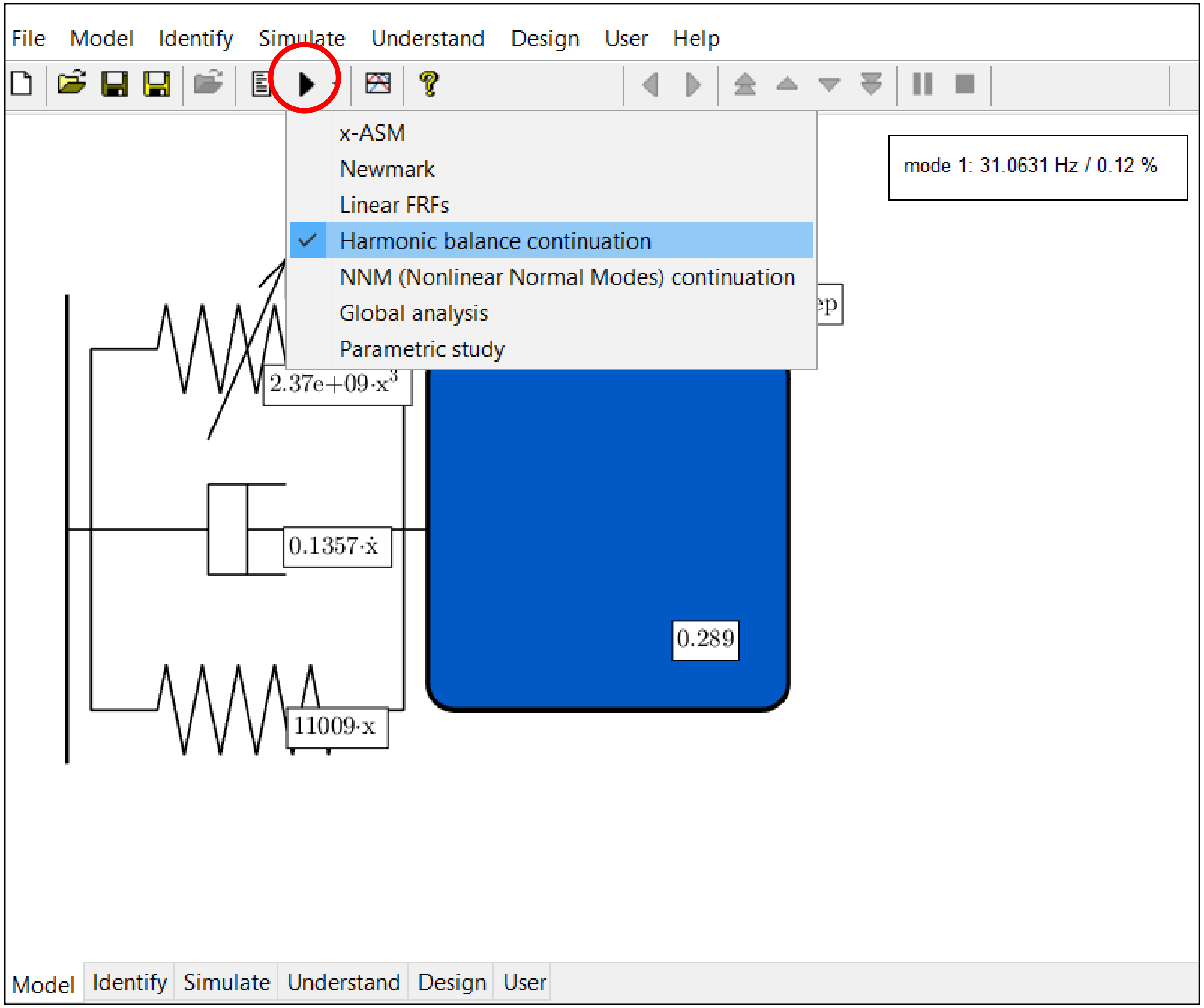
Let's Reverse the Sweep



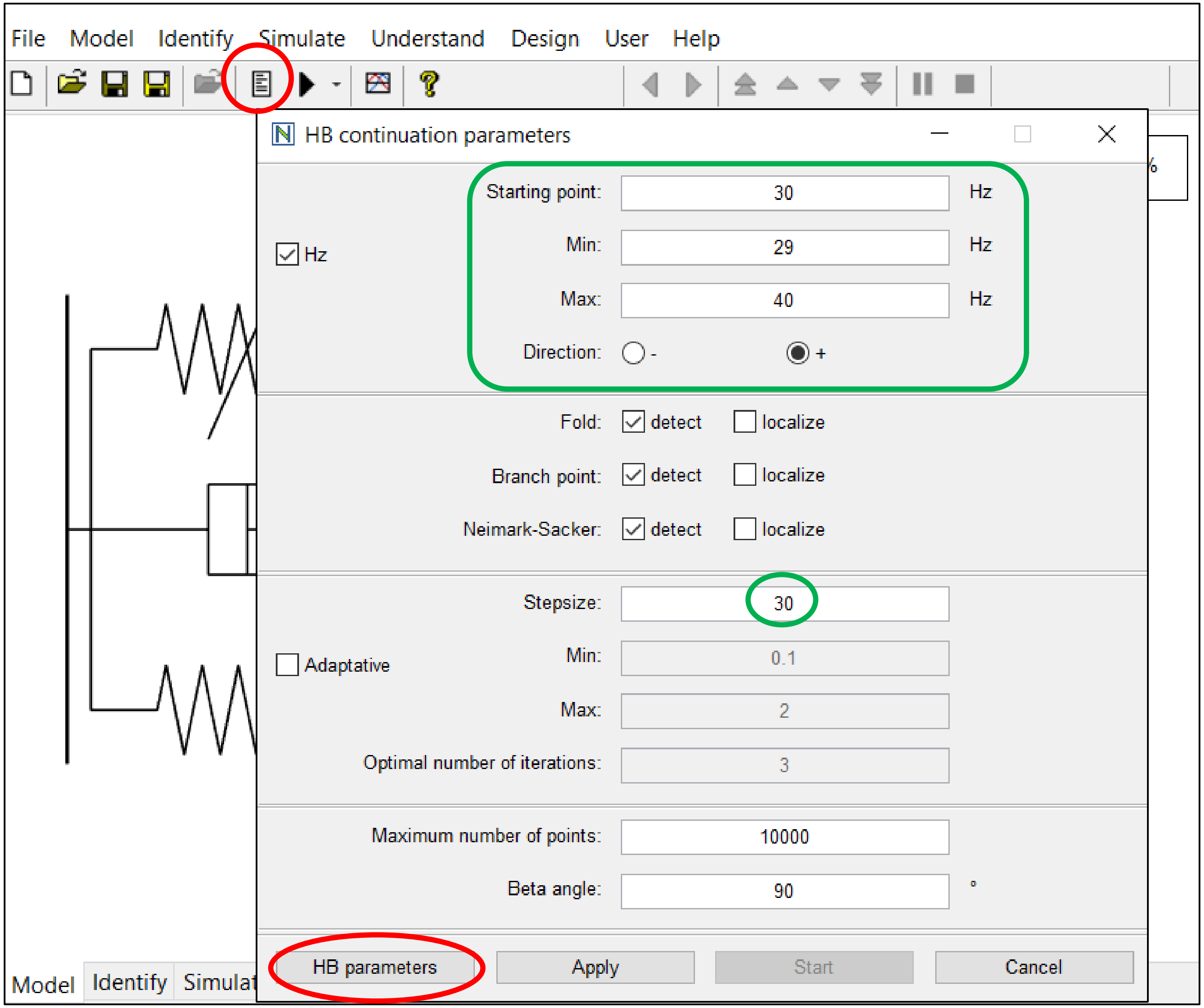
We Can Jump Up Too!



Calculate the Nonlinear FRF



But Set Appropriate Numerical Parameters First



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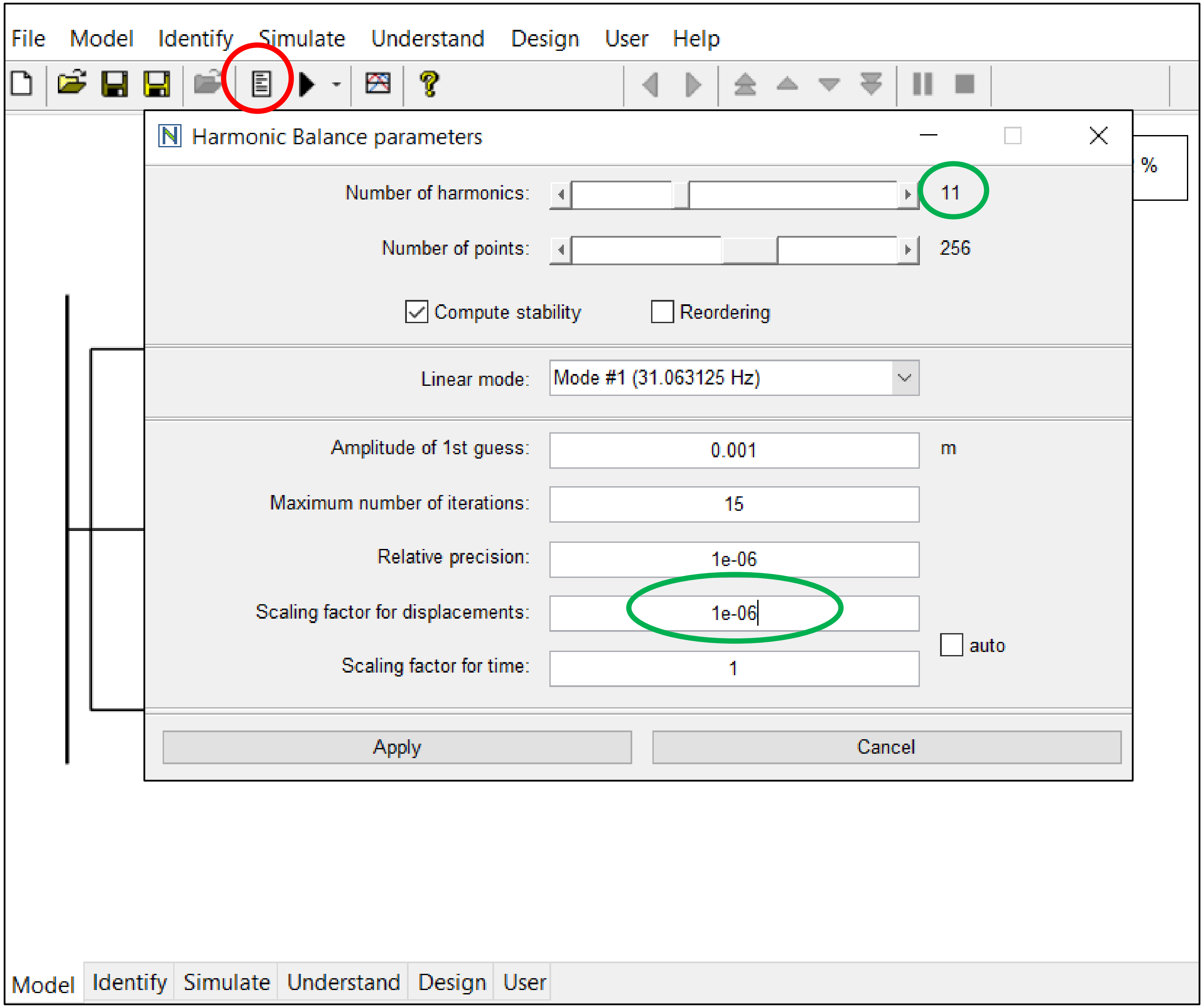
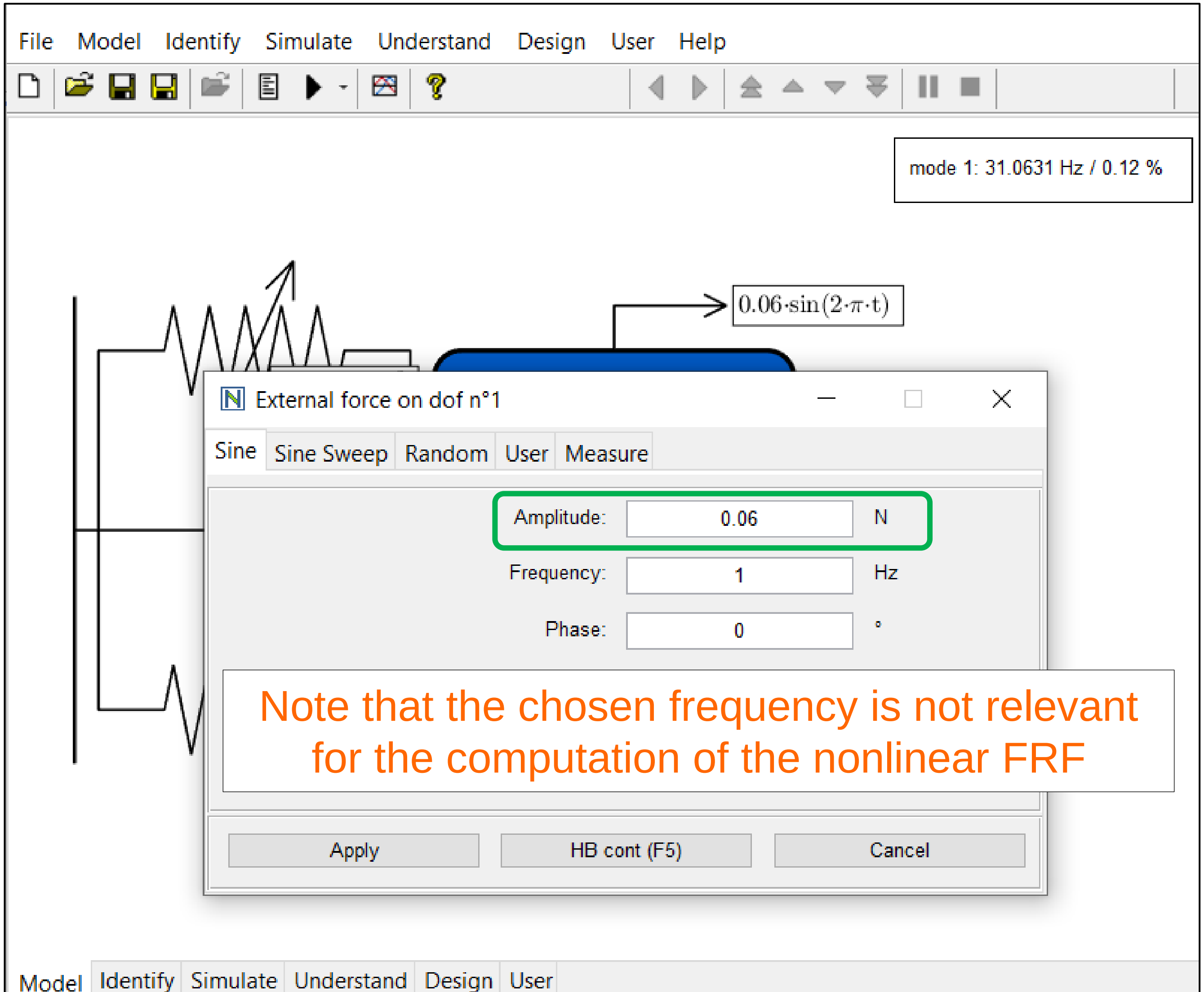
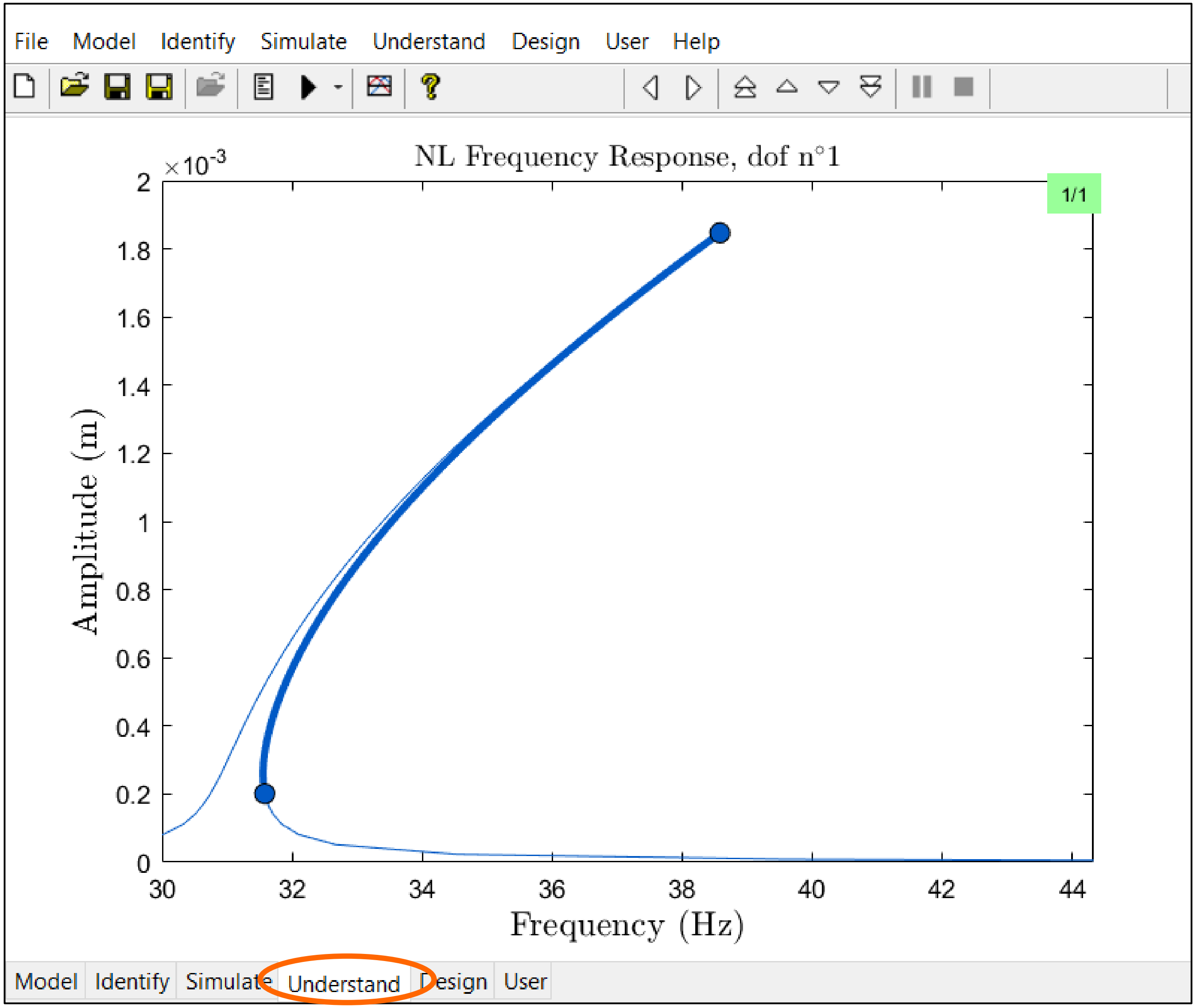


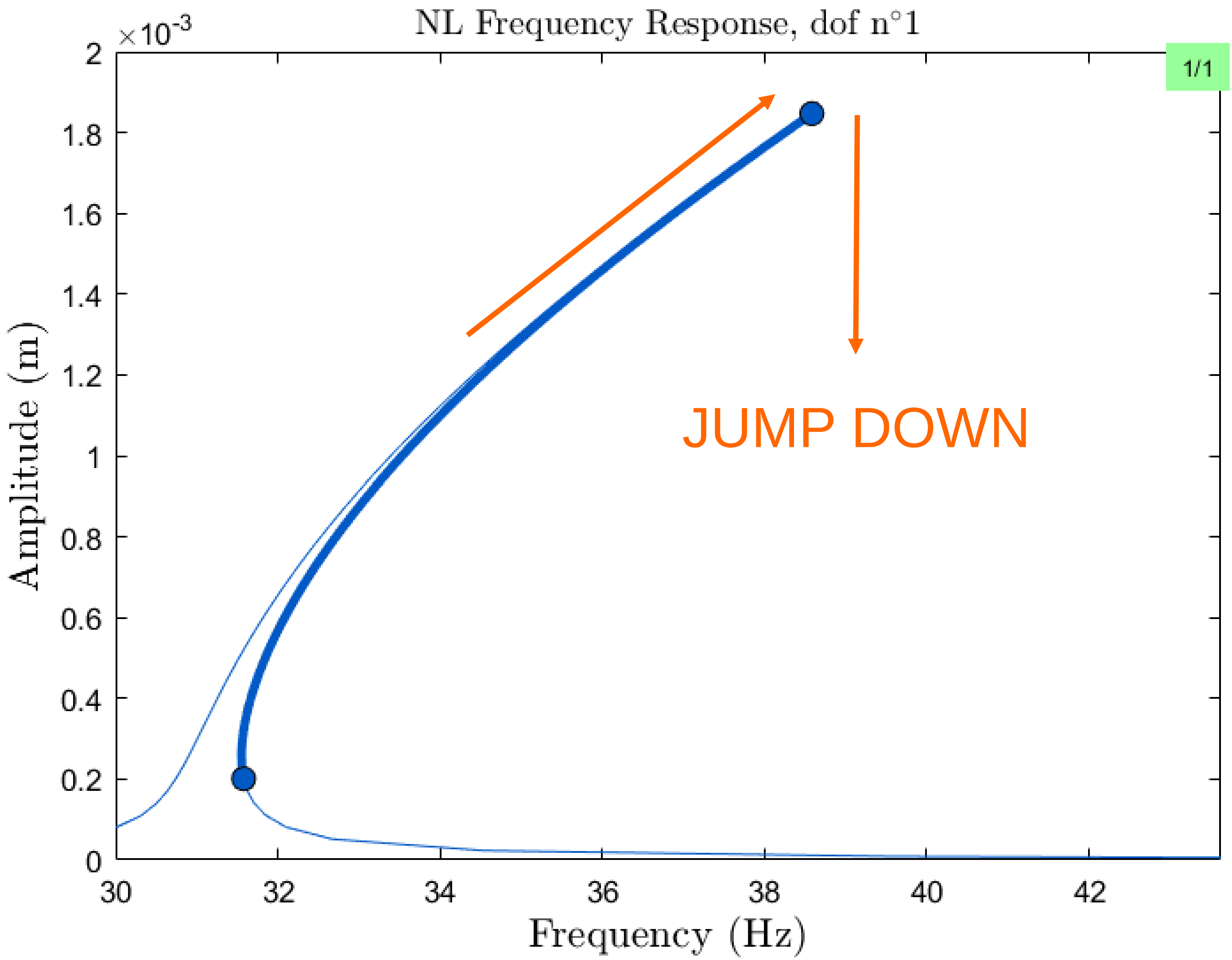
And Change the Excitation Signal to a Sine



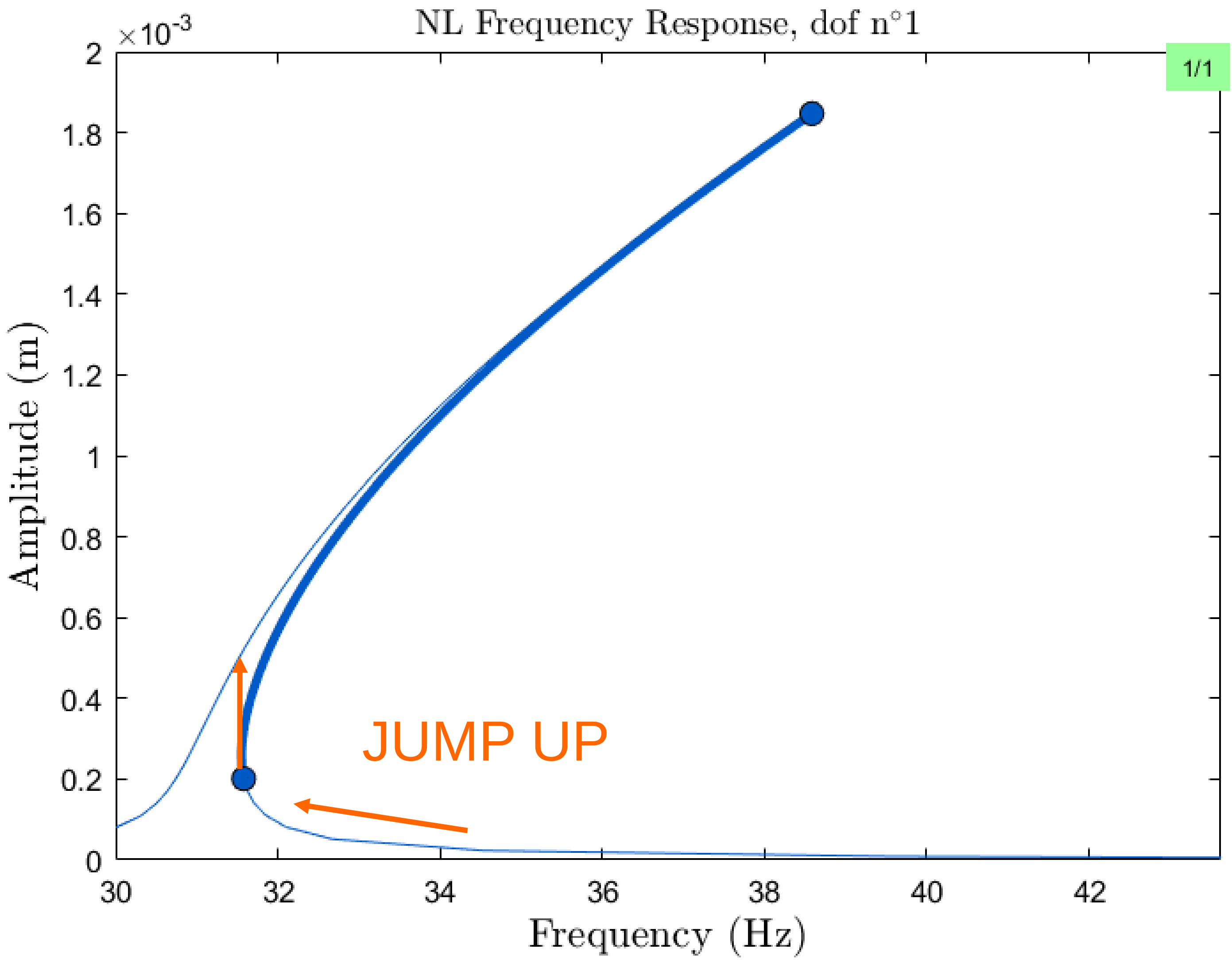
The Nonlinear FRF



The Jump Phenomenon Can Be Understood

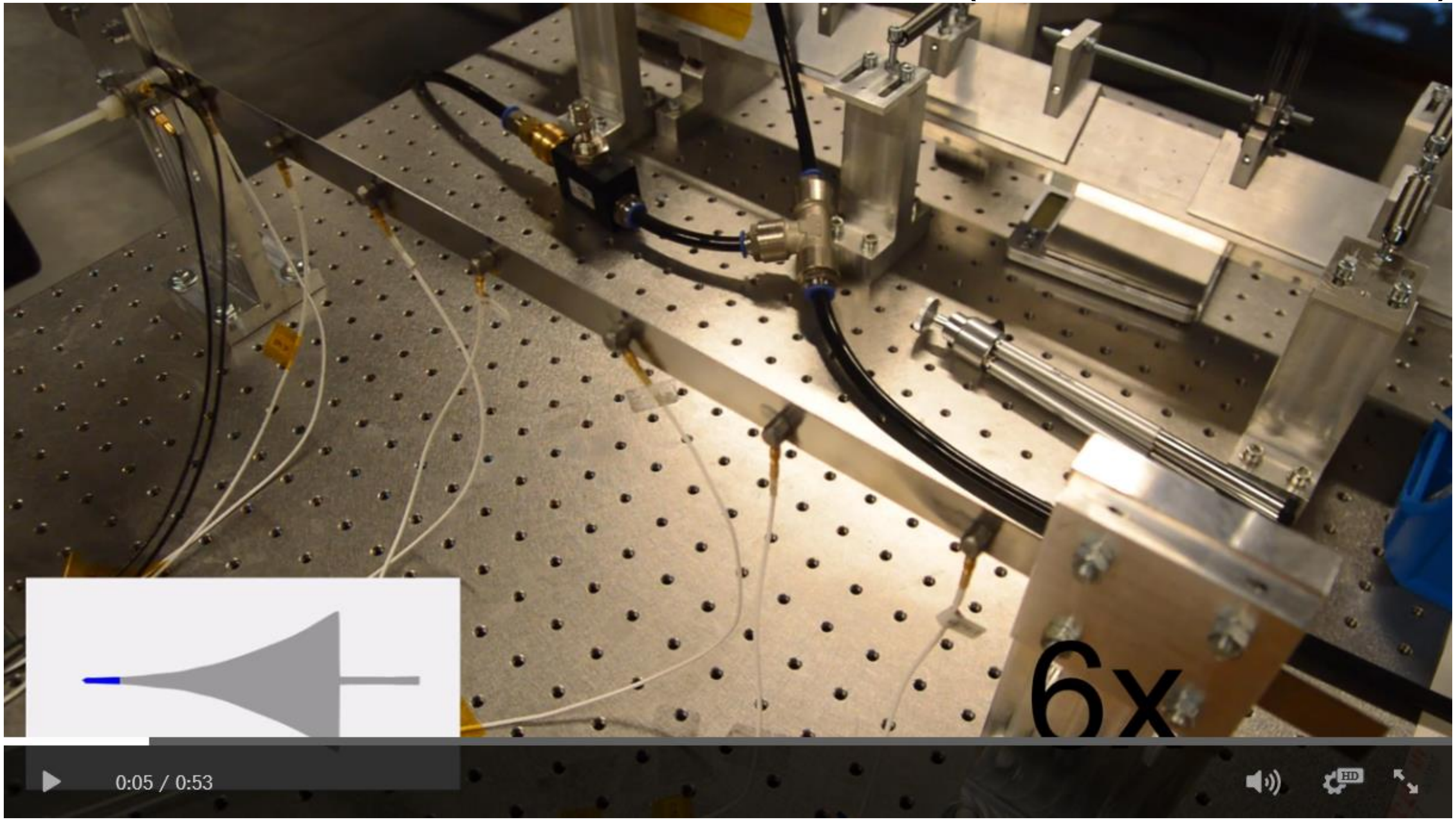


The Jump Phenomenon Can Be Understood



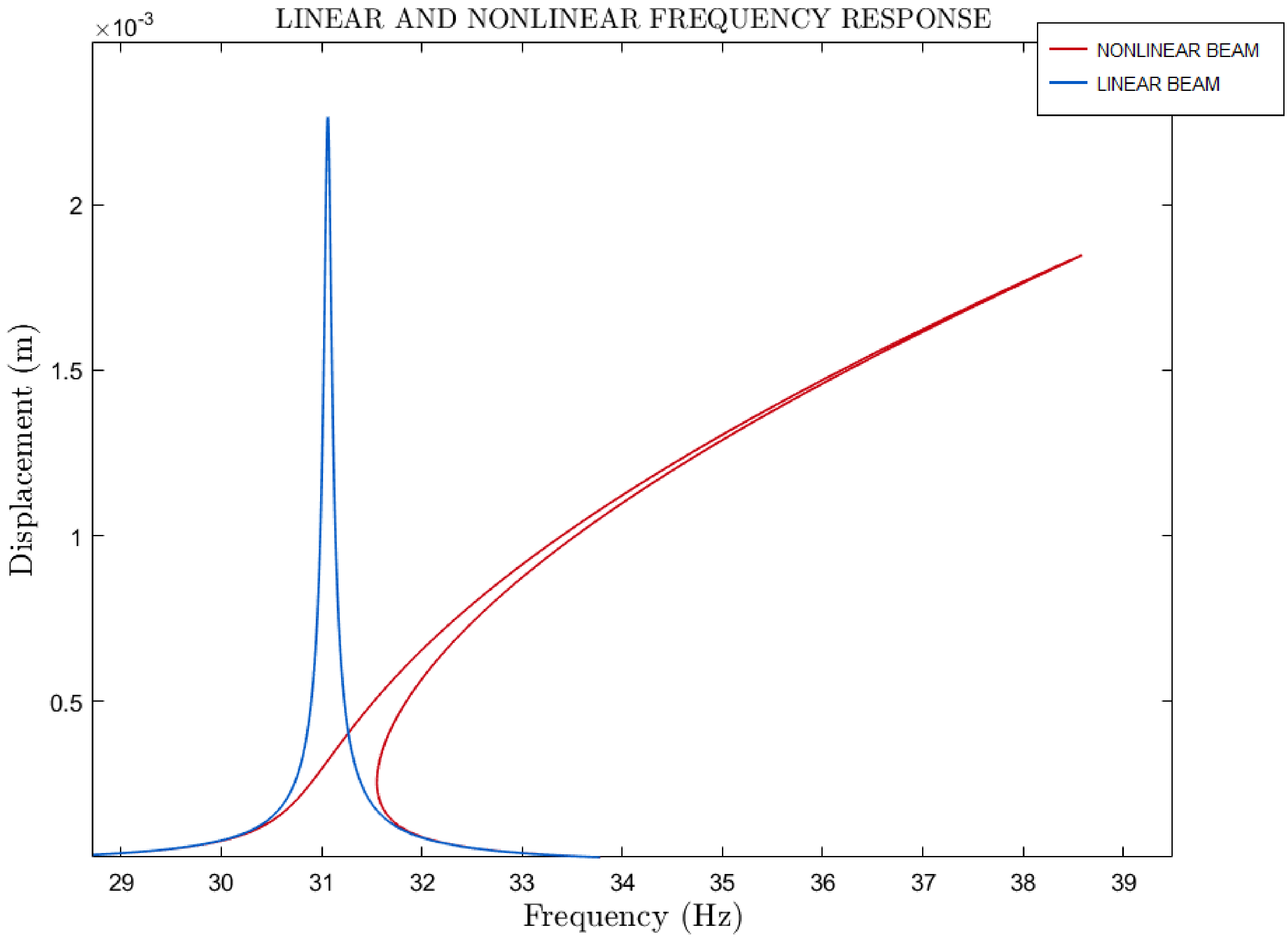
The Jump Phenomenon in Practice

(See the attached video)



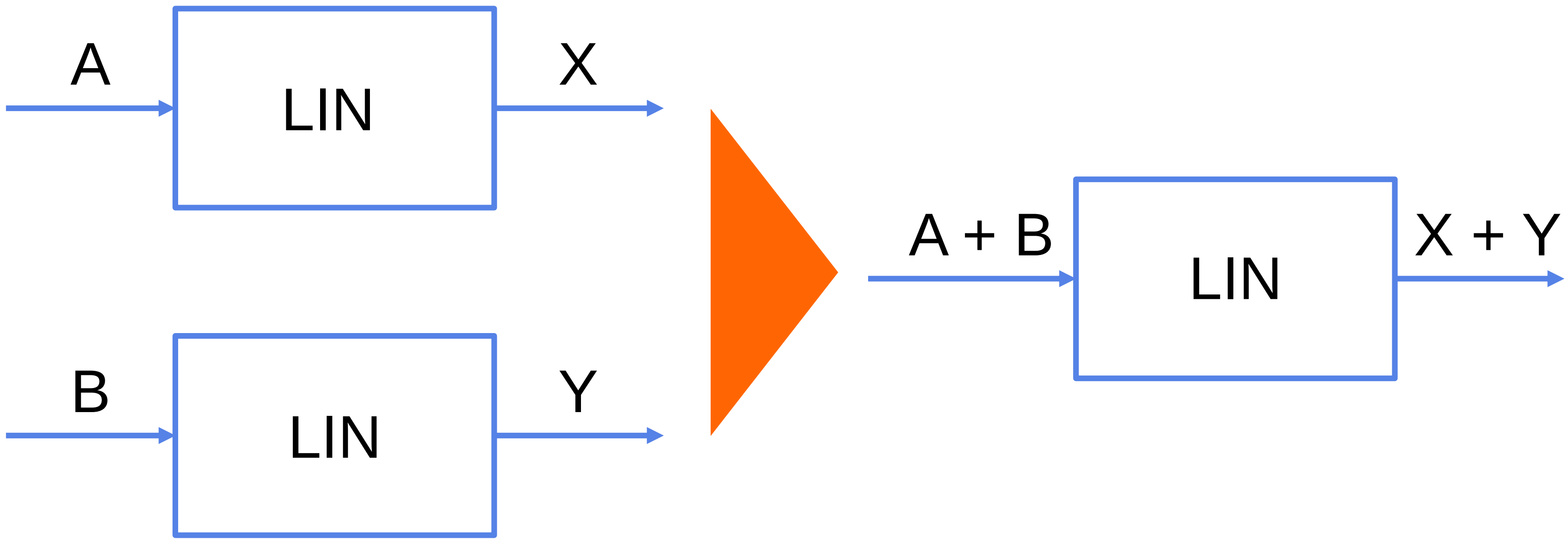
The video shows the dynamics of a clamped-clamped thin beam with geometrical nonlinearities during a sweep over the second beam mode.

Compare to the Linear Frequency Response

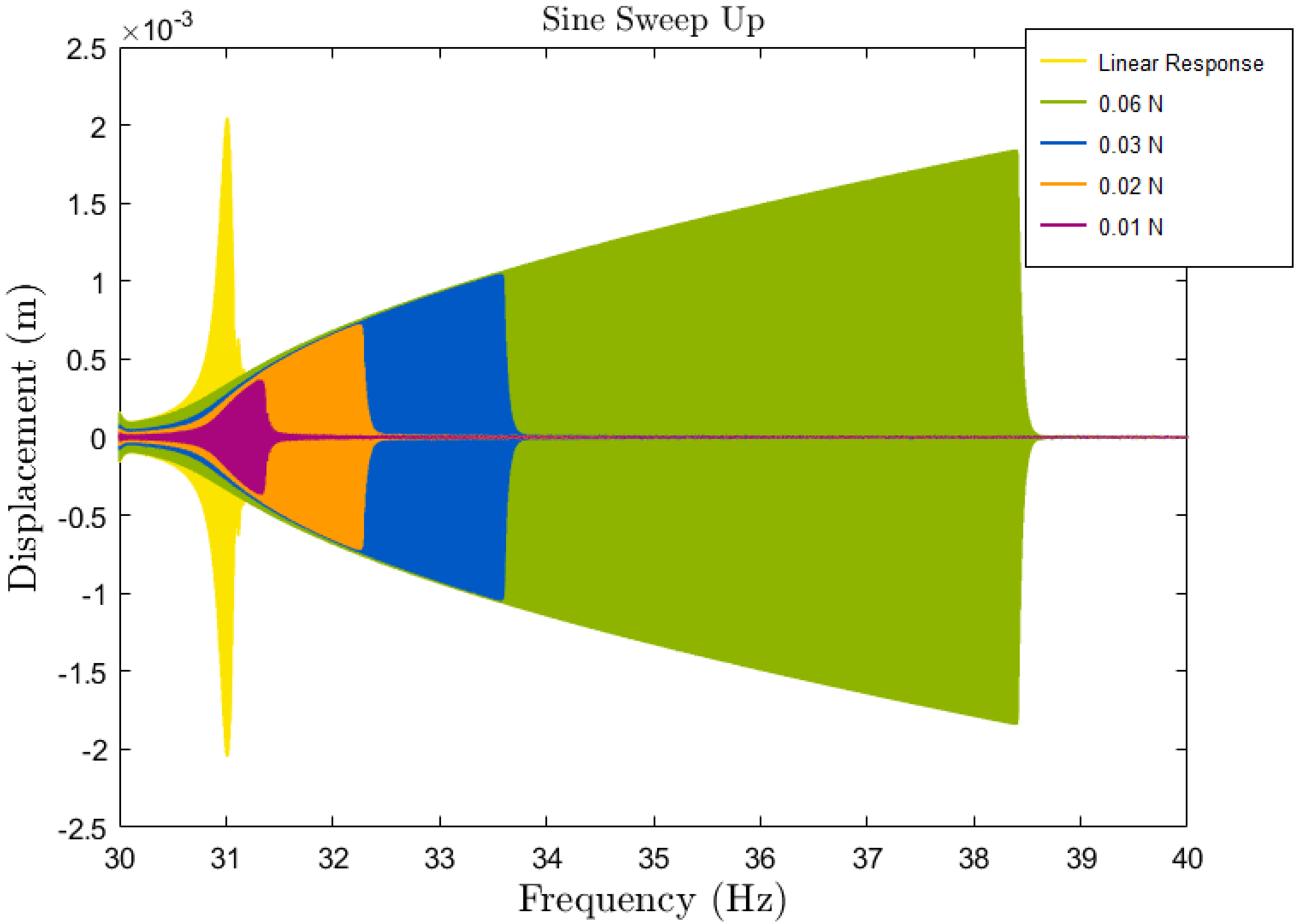


The Superposition Principle

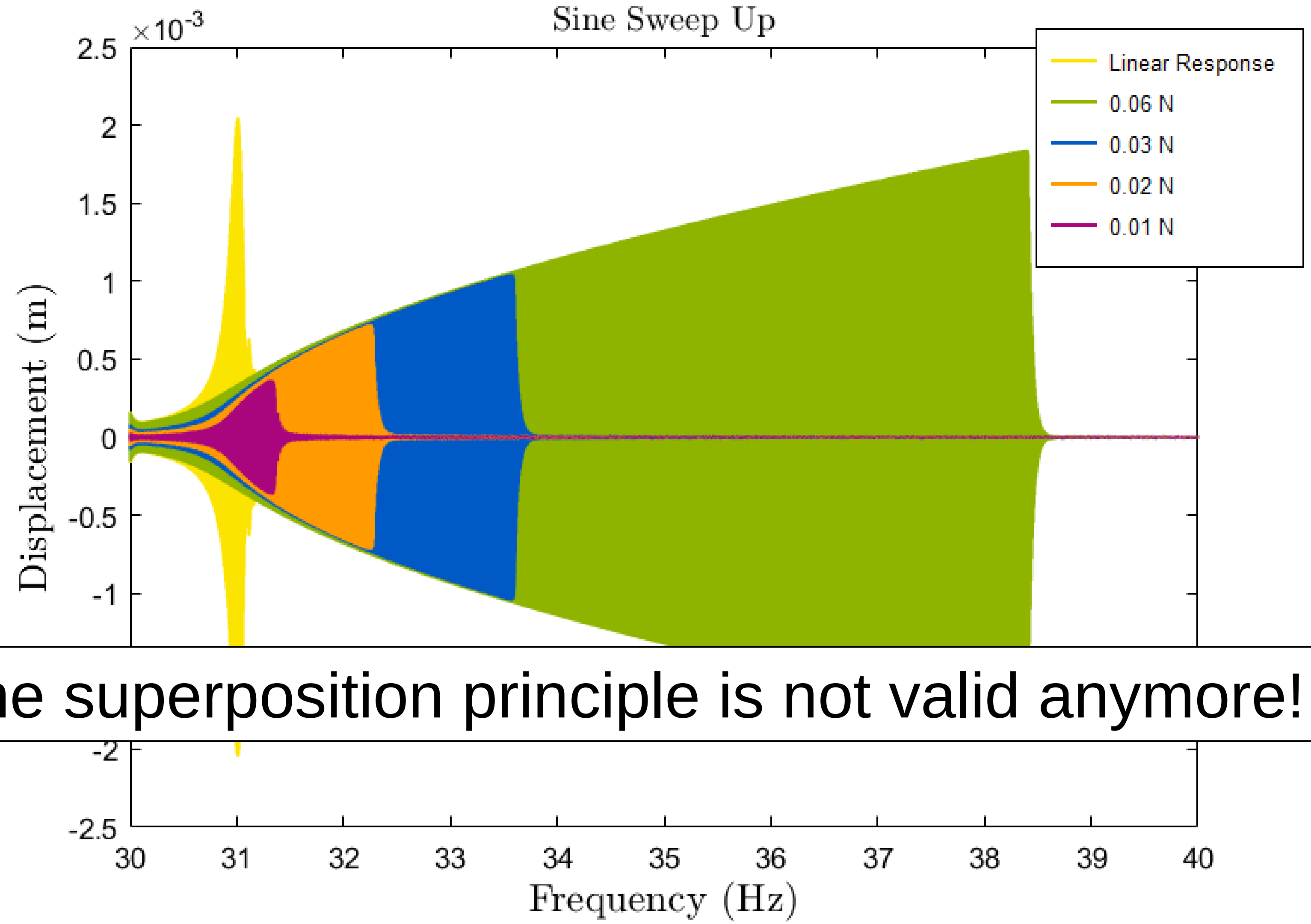
Cornerstone of linear theory:



Sweep with Different Forcing Amplitudes



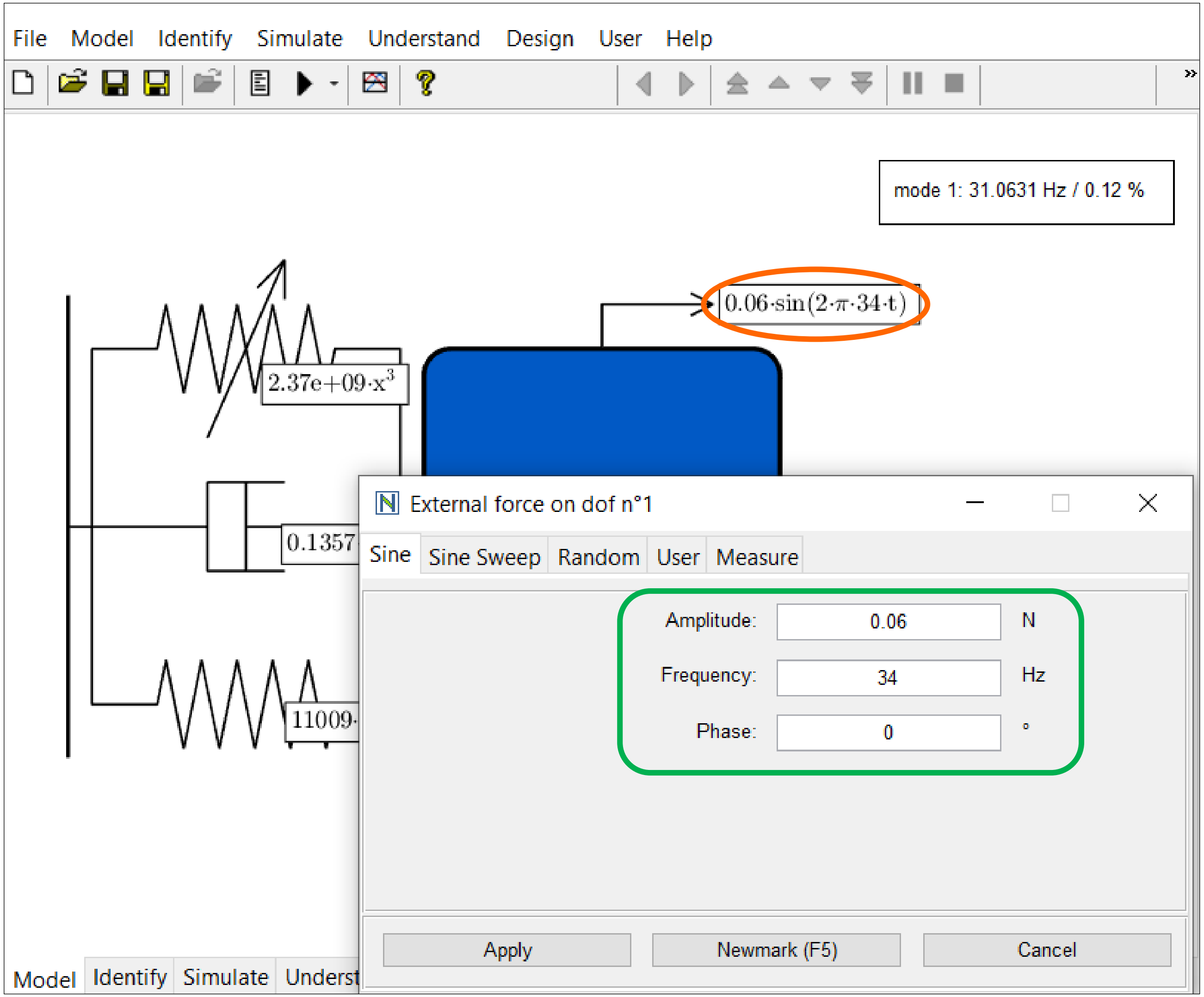
Sweep with Different Forcing Amplitudes



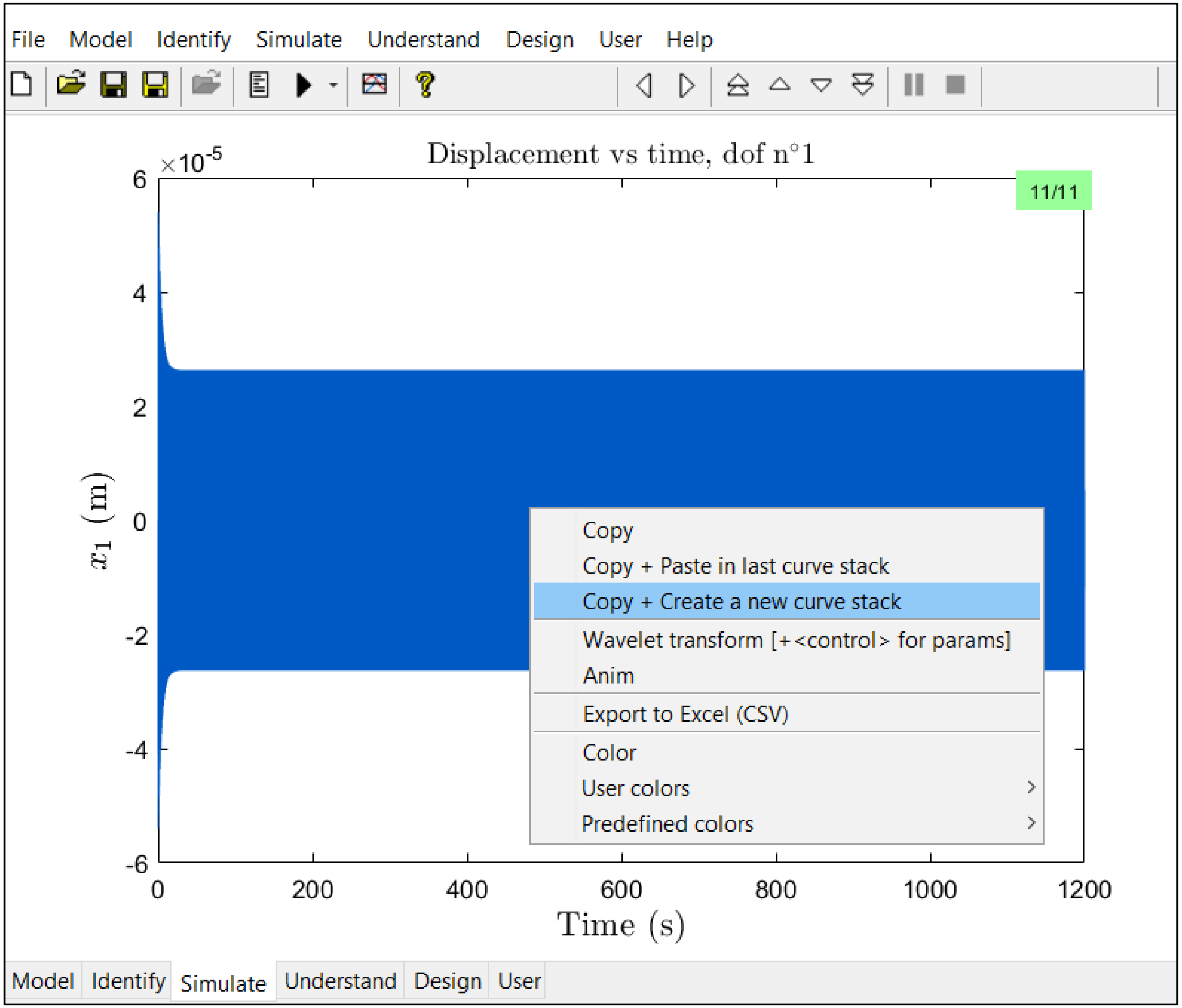
The superposition principle is not valid anymore!

Sine with a Fixed Frequency in the Multi-valued Region

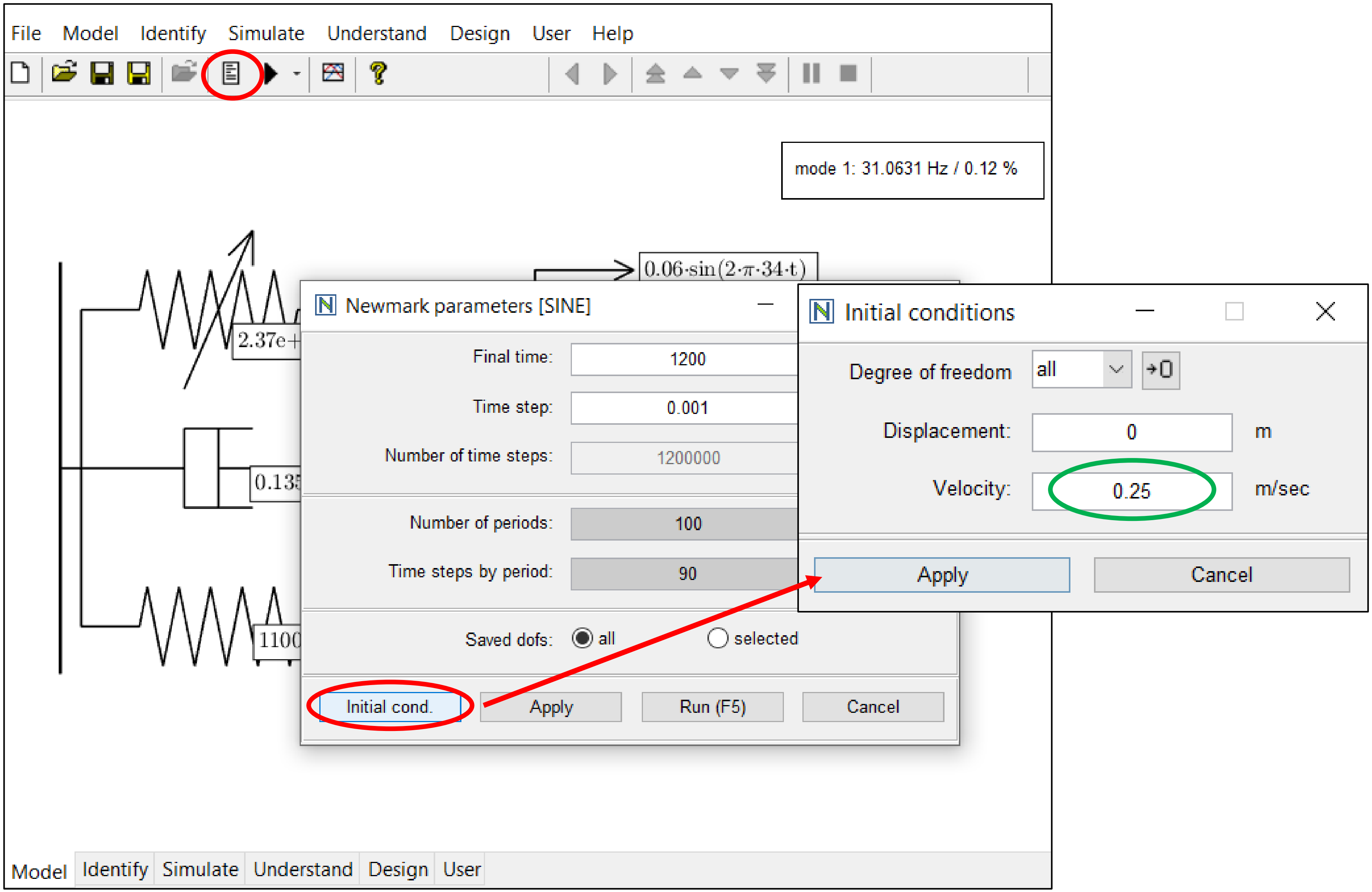
Now: Consider an Excitation with a Fixed Frequency



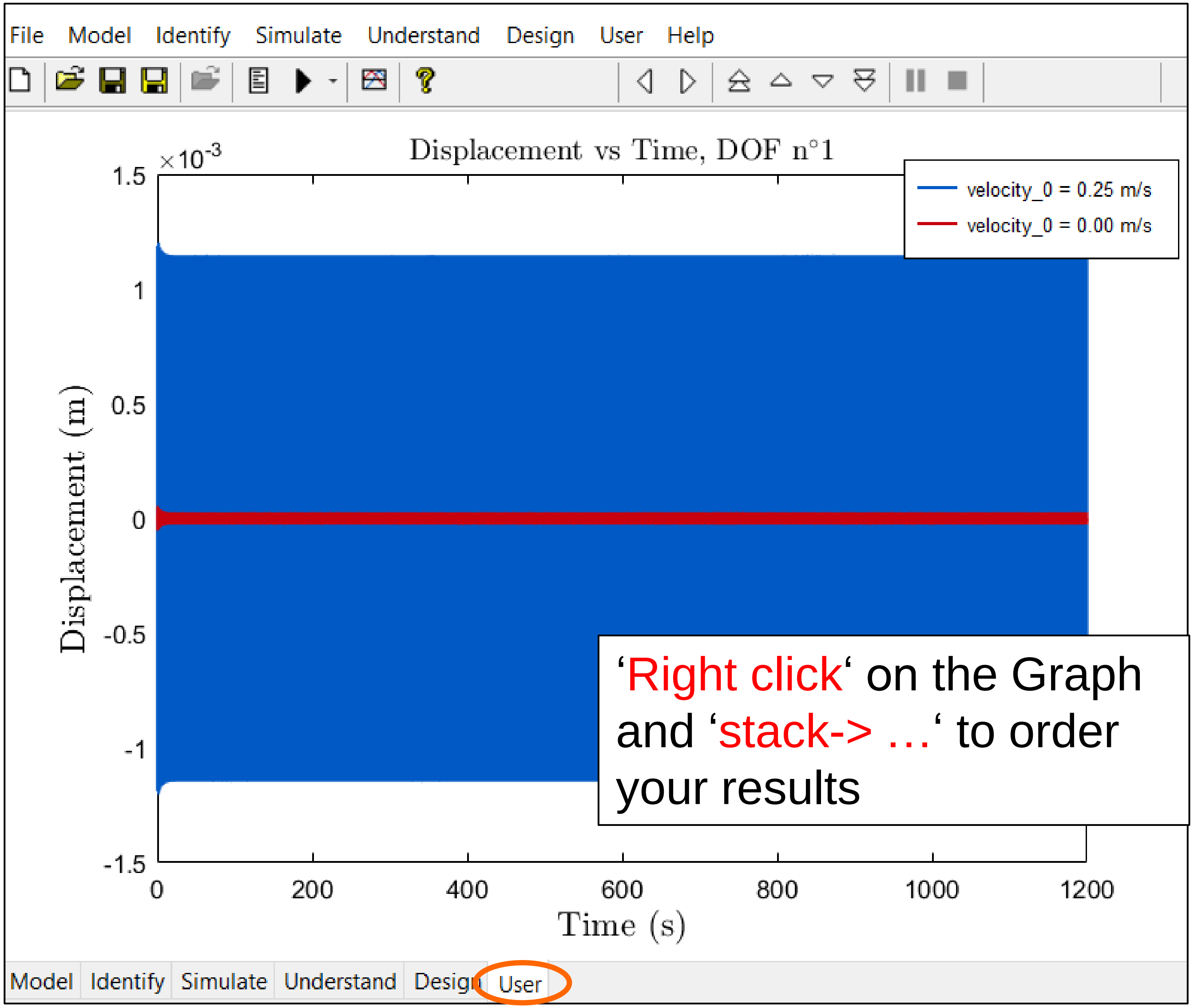
Run the Newmark Integration and Save



Change the Initial Conditions

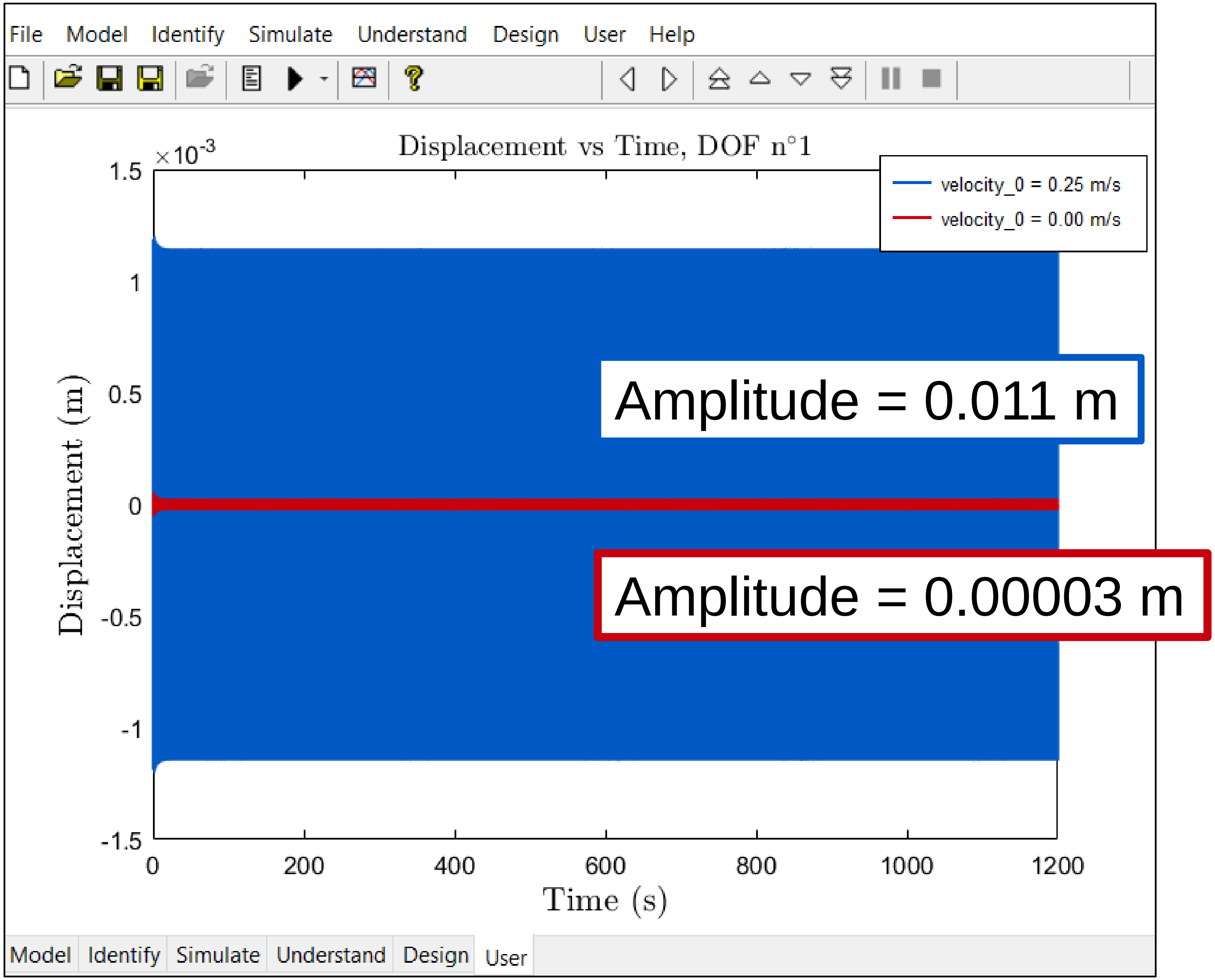


Run and Save in the Same Curve Stack

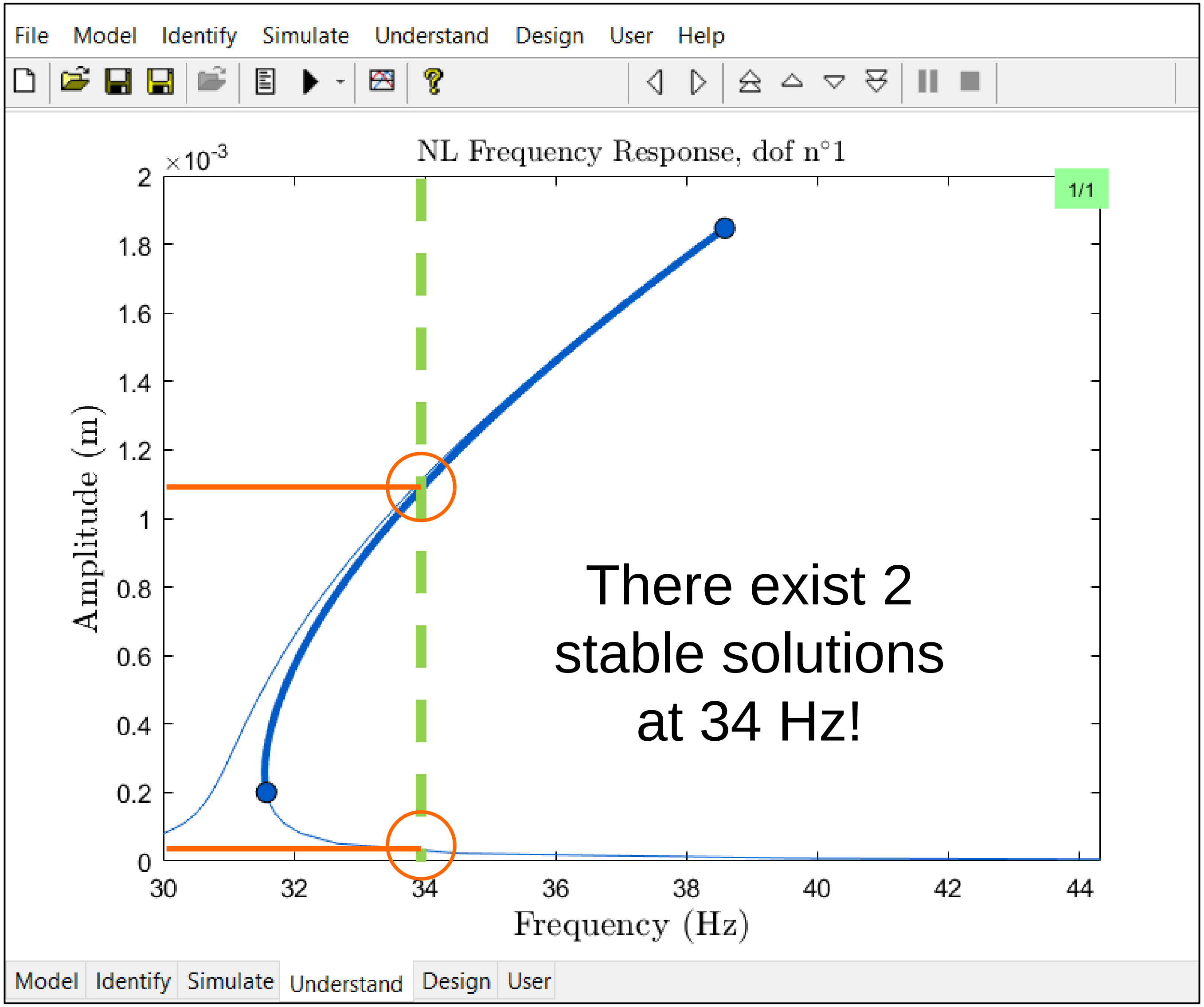


'Right click' on the Graph and 'stack-> …' to order your results

Compare

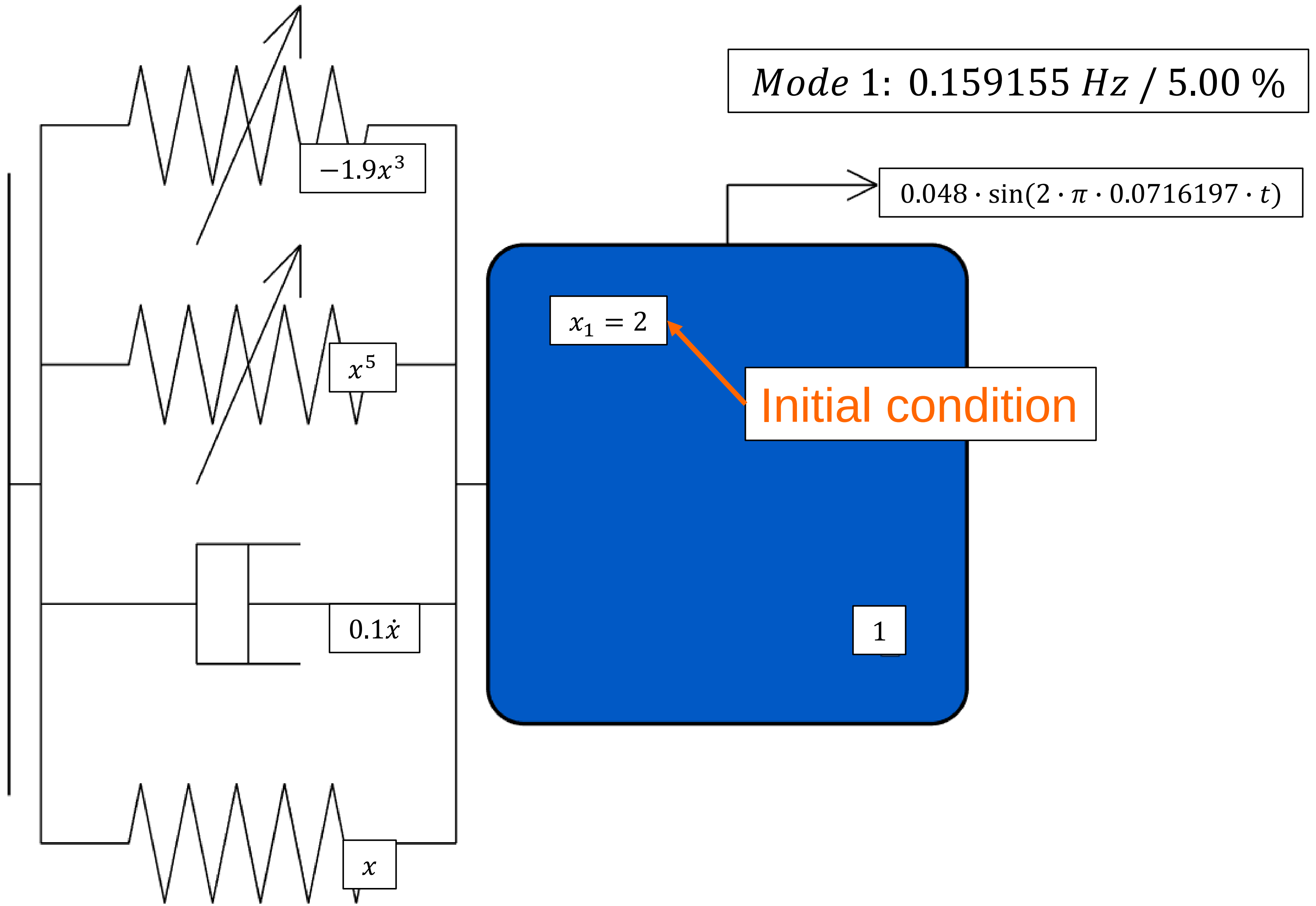

File Model Identify Simulate Understand Design User Help
Displacement vs Time, DOF n°1
×10^-3
1.5
1
0.5
0
-0.5
-1
-1.5
Displacement (m)
0
200
400
600
800
1000
1200
Time (s)
velocity_0 = 0.25 m/s
velocity_0 = 0.00 m/s
Amplitude = 0.011 m
Amplitude = 0.00003 m
Model Identify Simulate Understand Design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

The Nonlinear FRF Helps to Understand

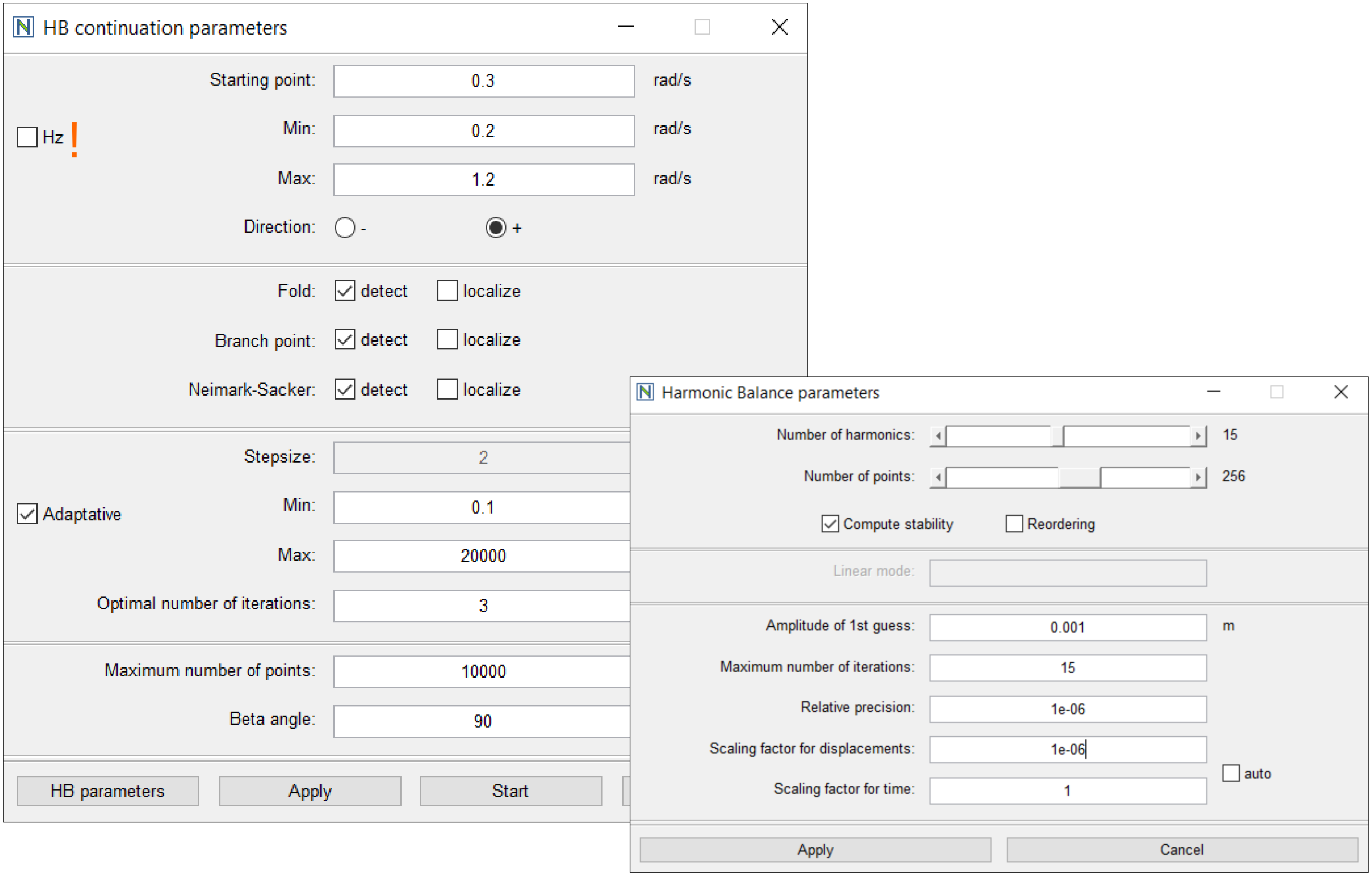


A New System in NI2D

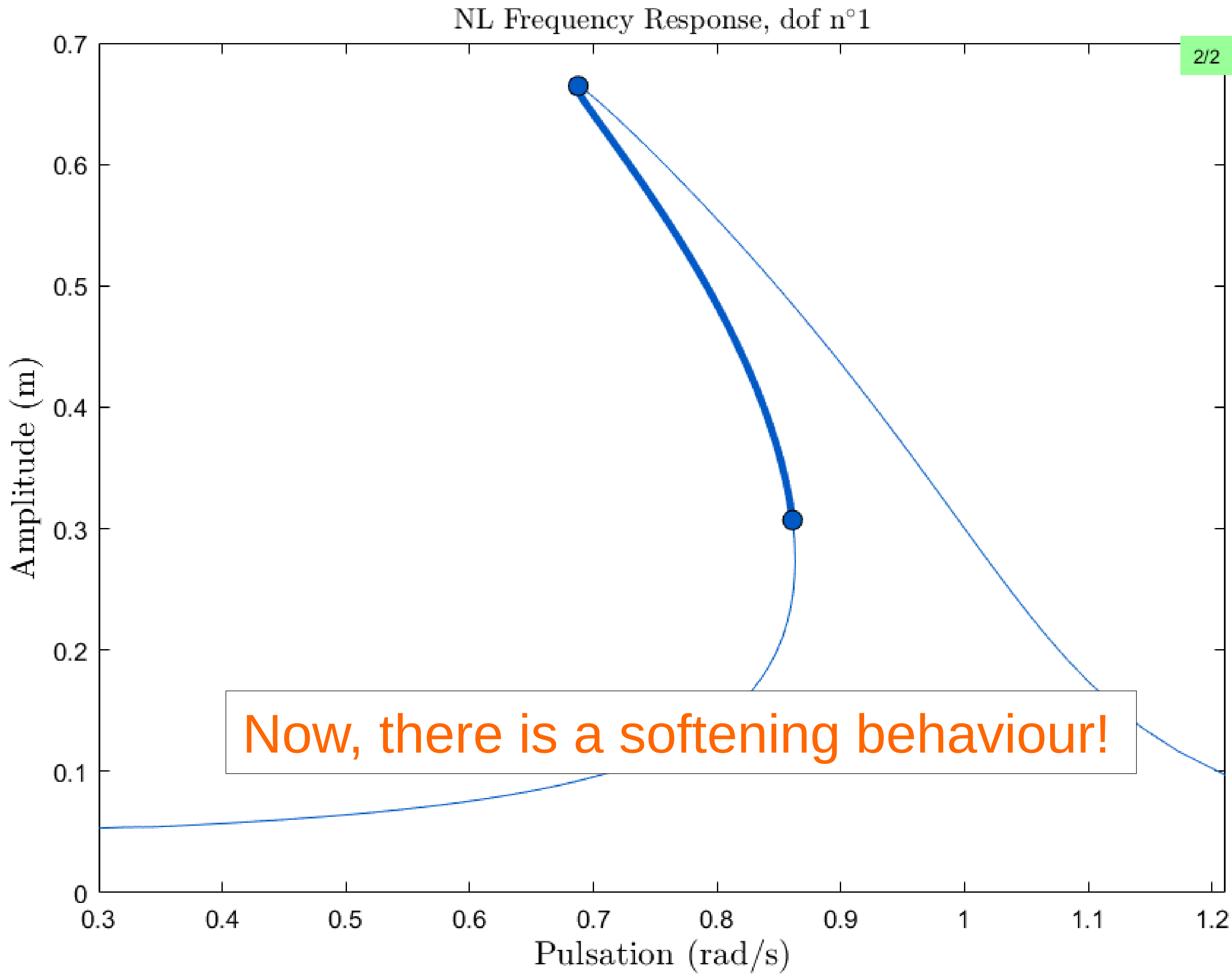
The New 1 DOF-system



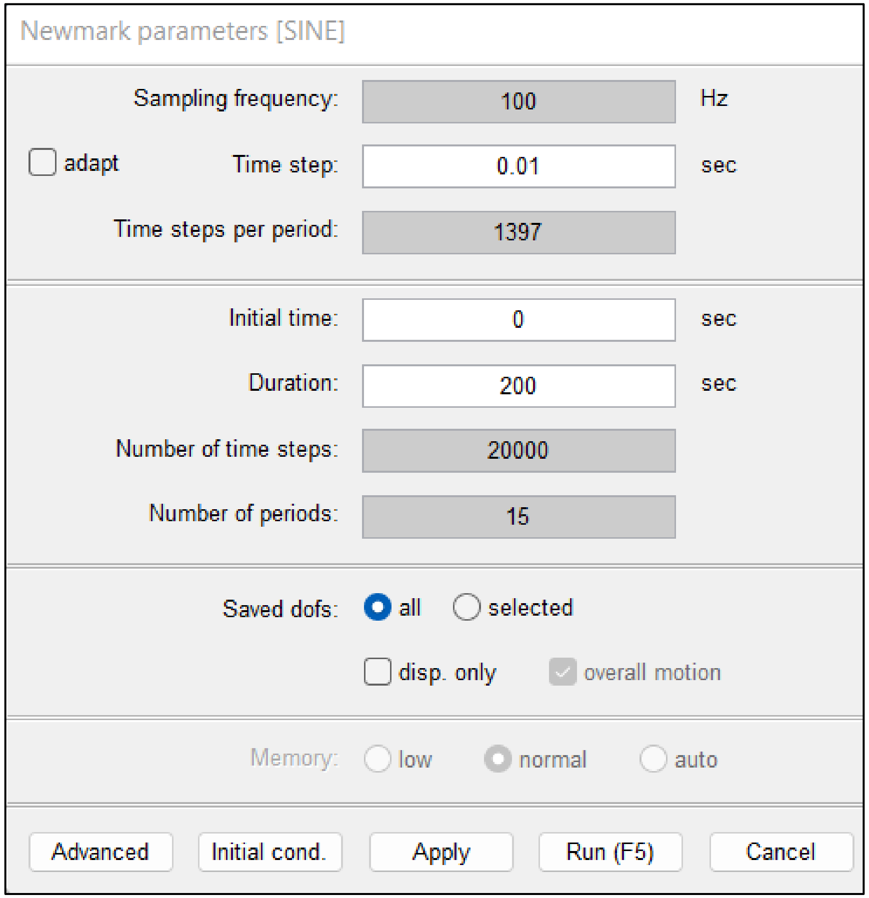
Parameters for Nonlinear FRF Calculation



The Nonlinear FRF

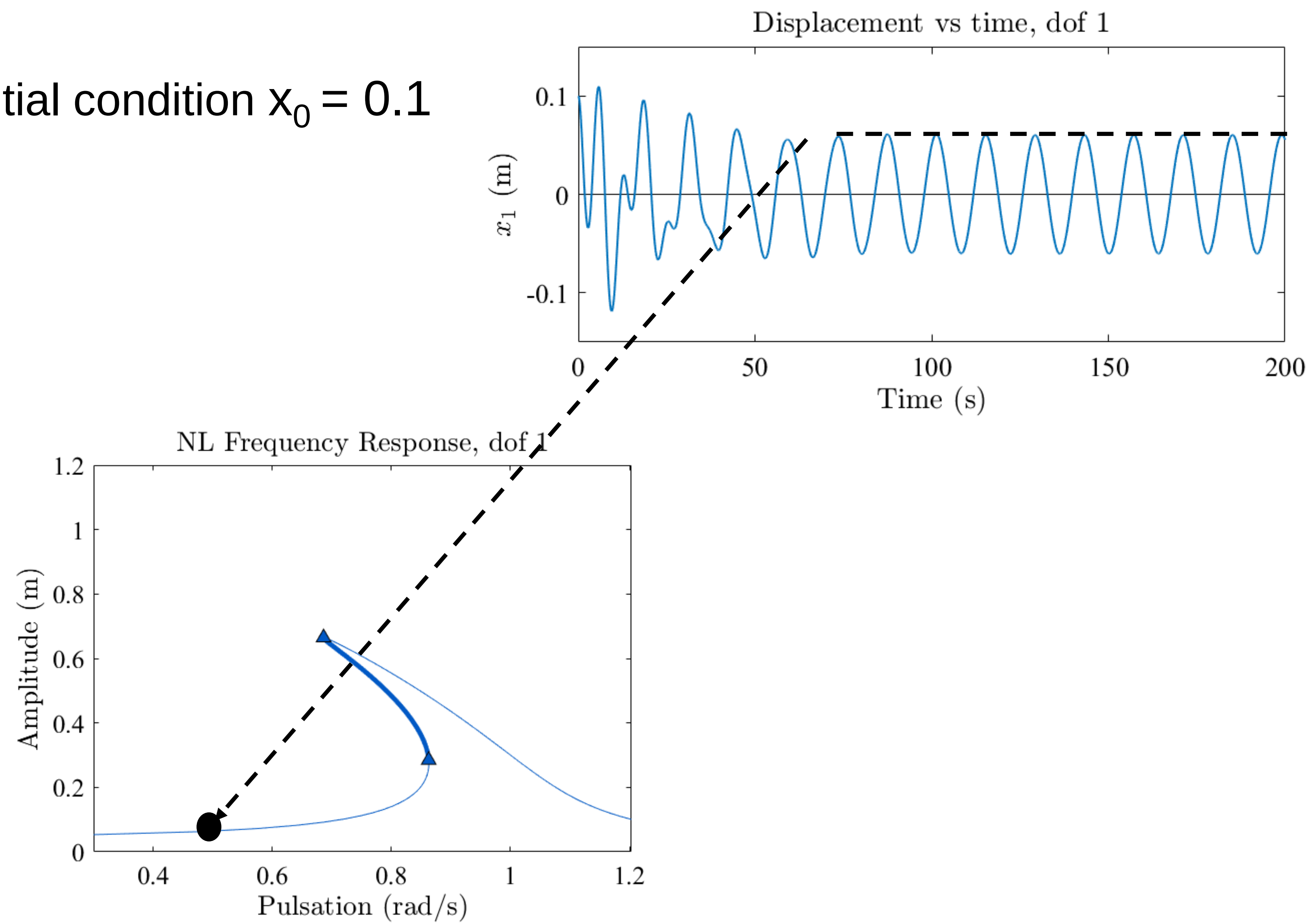


Nonlinear Time Integration



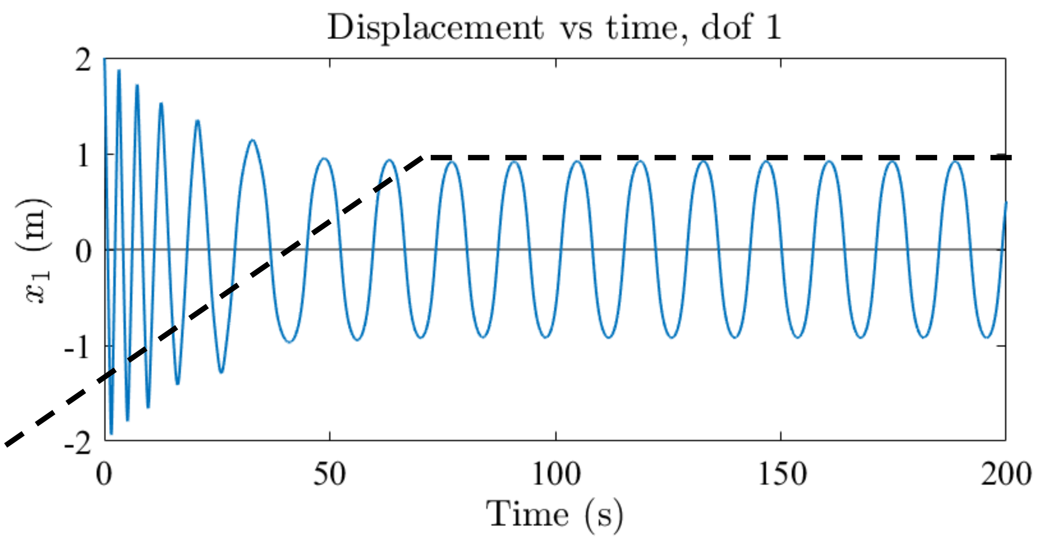
First Nonlinear Time Integration

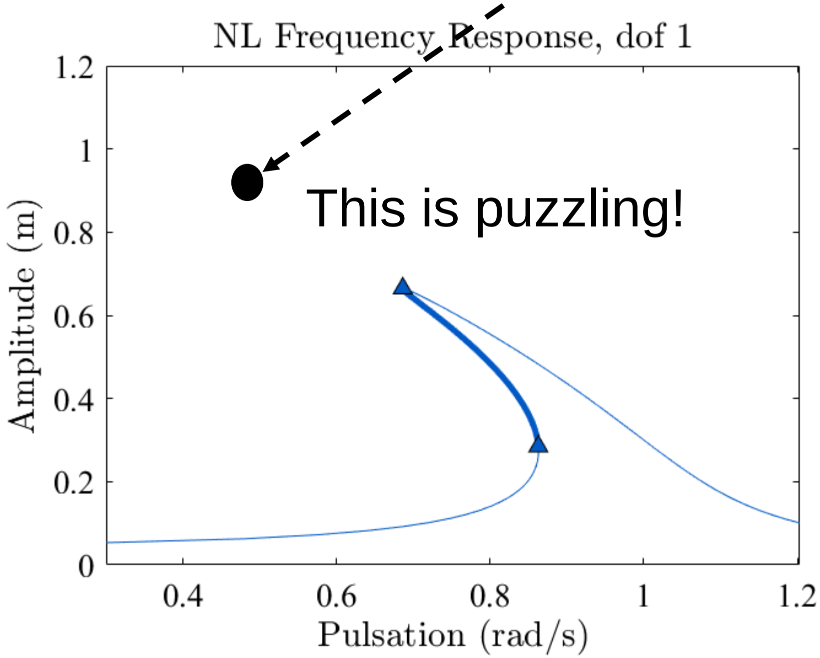
Initial condition $x_0 = 0.1$



Second Nonlinear Time Integration

Initial condition $x_0 = 2$





This is puzzling!

Nonlinear Time Integration with Different x_0