CSI ANSYS Tip of the Week

"Sine-Sweep" Test Simulation in ANSYS using the Large-Mass and Direct-Displacement Methods

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INTRODUCTION

Vibration testing is a common requirement in the aerospace, automotive, and other industries. The sine-sweep test is used to help determine the natural frequencies of a system, and to verify that the structure will survive the expected vibration loads. The sine-sweep test can be modeled in ANSYS by running a harmonic response analysis using an acceleration base input. A proven method for applying this input is the large-mass method. In this method a large mass is added at the point of input, and then a force is applied that creates the desired acceleration load. A more direct method for applying an acceleration base input is the direct-displacement method, which uses a displacement input equal to the harmonic acceleration.

BACKGROUND

The following equations show the correlation between an imposed displacement and the resulting acceleration for harmonically excited structures:

The harmonic motion of a point as a function of frequency can be written as,

$$x(\omega t) = A\sin(\omega t) \quad (1)$$

where, x = displacement
A = amplitude of excitation
ω = frequency of excitation
t = time

Velocity and acceleration may be written as,

$$\dot{x}(\omega t) = \omega A\cos(\omega t) \quad (2)$$

$$\ddot{x}(\omega t) = -\omega^2 A\sin(\omega t) \quad (3)$$

Looking at peak response, and considering A=x because of the non-zero displacement constraint,

$$\ddot{x} = -\omega^2 x \qquad \ddot{x} = \left|\omega^2 x\right| \quad (4)$$

Therefore, for a given displacement, the acceleration changes as a function of frequency-squared.

ANALYSIS METHOD PROCEDURES

Large-Mass Method:

- Connect a large mass, approximately seven orders of magnitude larger than the total mass of the part, to the base of the model through a couple, or with a rigid member.

- To simulate the acceleration, apply a force F equal to the mass of the large-mass element times the desired acceleration (F=mass*acceleration).

- Displacement-based (i.e., displacement, strain, and stress) results will not need to be scaled.

- To view the acceleration results, scale the displacements by ω^2, where ω is the forcing frequency in radians.

- To view the acceleration results in g's, scale the displacements by ω^2/g, where g is the value of gravity for the set of units being used.

Direct-Displacement Method:

Remember that the input in a sine-sweep test is a constant acceleration. There are two techniques for simulating a constant acceleration in ANSYS when using the direct-displacement method:

A) Apply a unit base displacement for all frequencies. (Note: This was the method used for the verification example in this paper.)

  - To view the displacement-based (i.e., displacement, strain, and stress) results, multiply the peak response by $ACEL/\omega^2$, where ω is the forcing frequency in radians, and ACEL is the desired acceleration base input.

  - To view the acceleration results, scale the displacements by ACEL.

  - To view the acceleration results in g's, scale the displacements by ACEL/g, where g is gravity for the set of units being used.

B) Apply the desired constant acceleration directly.

  - This will require the user to apply a different displacement for each forcing frequency, where the displacements are computed using the following formula: $x=ACEL/\omega^2$, where x is the non-zero displacement constraint calculated for each forcing frequency, ACEL is the desired acceleration base input, and ω is the forcing frequency in radians.

  - Displacements-based (i.e., displacement, strain, and stress) results will not need to be scaled when using this technique.

  - To view the acceleration results, scale the displacements by ω^2, where ω is the forcing frequency in radians.

  - To view the acceleration results in g's, scale the displacements by ω^2/g, where g is the value of gravity for the set of units being used.

VERIFICATION MODEL

A model consisting of pipe elements and a few concentrated masses at key locations (see Figure 1) was created in ANSYS. This model was solved using both the large-mass and direct-displacement methods, and in each case, the full method for harmonic response analysis was used. The peak amplitudes were determined at the free end of the model (i.e., Node 1547). Figures 2 and 3 show the responses and stresses for the two methods, respectively, while Table 1 shows a comparison of the results.

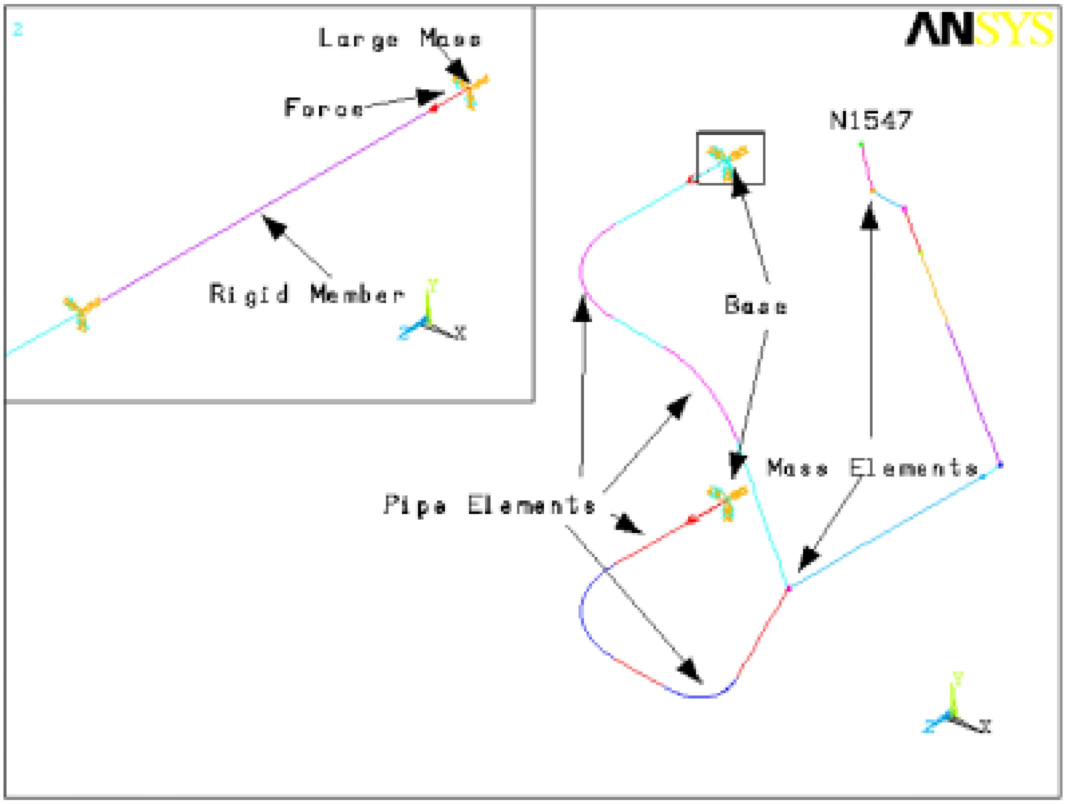

Figure 1. Pipe system finite element model

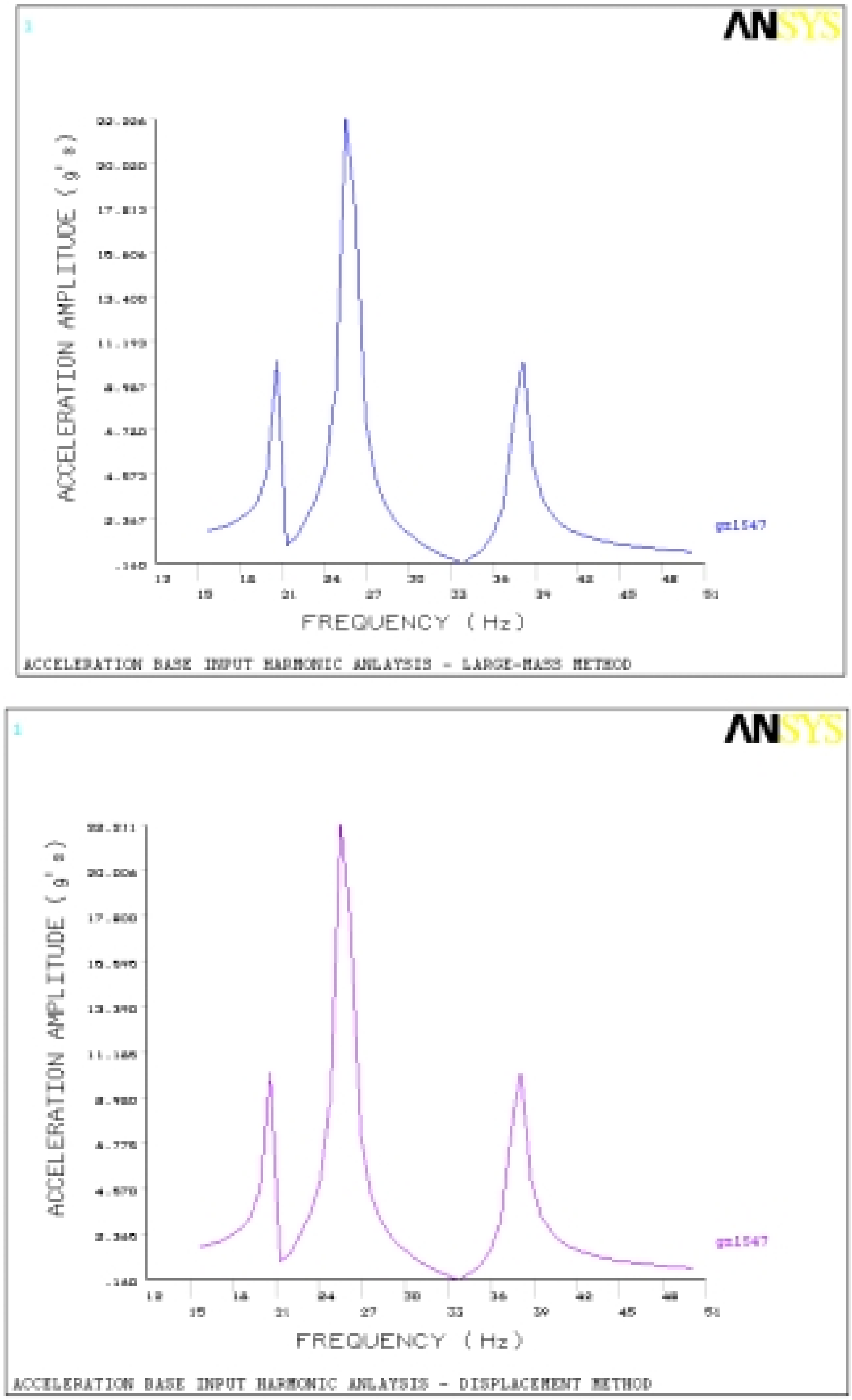

Figure 2. Harmonic response – output G's

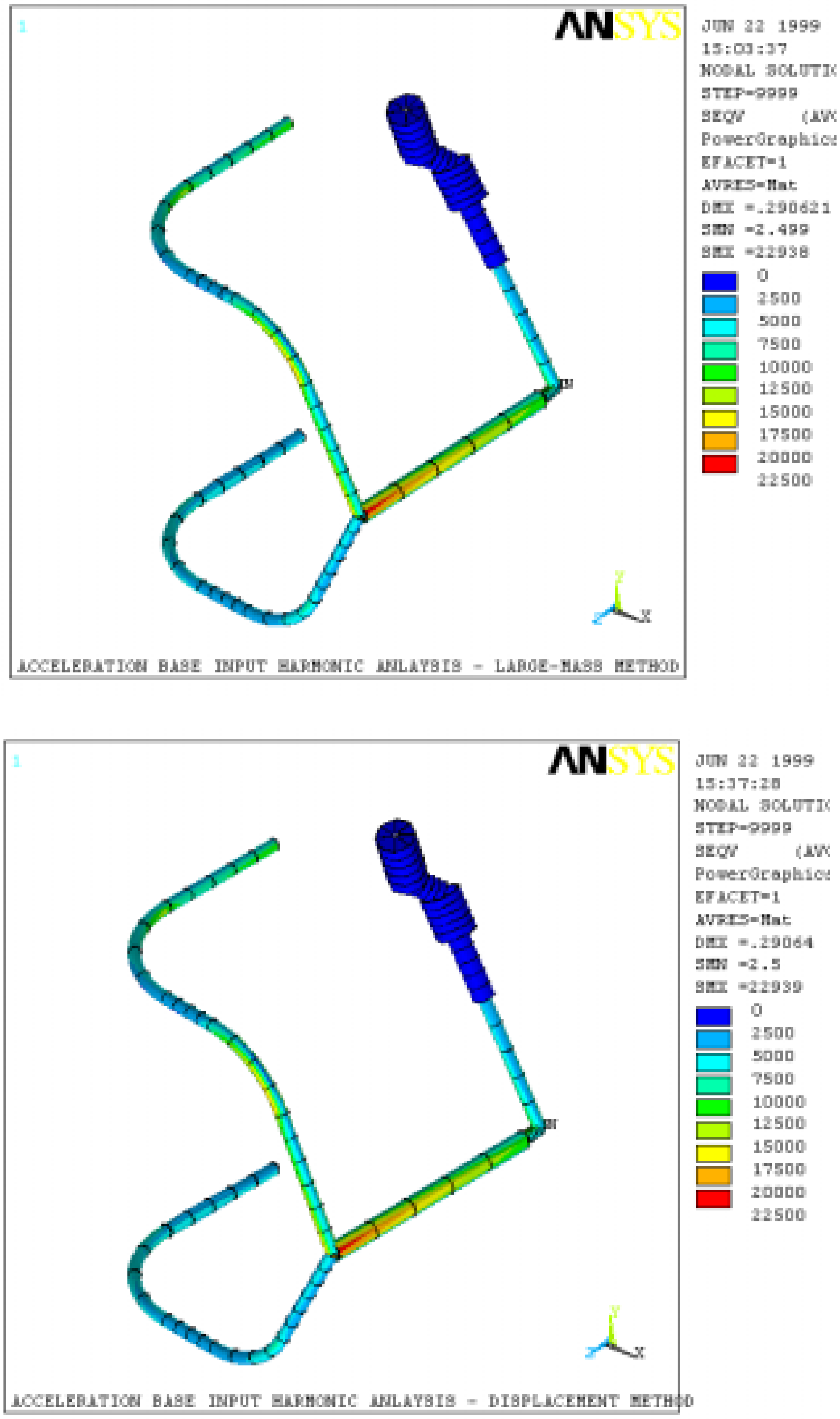

Figure 3. von-Mises stresses

METHOD	Frequency Range 15 - 50 Hz						
	Peak I (f=20.6 Hz)		Peak II (f=25.5 Hz)			Peak III (f=38.1 Hz)	
	Amplitude	Phase Angle	Amplitude	Phase Angle	Stress	Amplitude	Phase Angle
	(g's)	(deg)	(g's)	(deg)	(ksi)	(g's)	(deg)
Large-Mass	10.1531	110.7290	22.3285	138.7630	22.9380	10.0960	52.6027
Direct-Displacement	10.1537	110.7290	22.3300	138.7630	22.9390	10.0966	52.6025
Difference	0.0059%	0.00%	0.0067%	0.00%	0.0044%	0.0059%	0.00%

Table 1. Comparison of the large-mass and direct-displacement methods
at three peak amplitudes in the range of 15 to 50 Hz

CONCLUSION

Two methods exist to simulate a sine-sweep test: the large-mass and the direct-displacement methods. As shown above, these methods are comparable. In many cases, the choice of which method to use is arbitrary. However, if a harmonic response analysis using the modal superposition method is required, the large-mass method should be used since the modal superposition method does not allow for non-zero displacements. Lastly, remember that a harmonic response analysis is always linear in ANSYS, which allows for the direct scaling of results.

REFERENCES

1. ANSYS Finite Element Analysis Software, ANSYS Inc., 2000