# Implementation and Validation of Frequency Response Function in LS-DYNA®

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## Abstract

A new feature of frequency response function (FRF) computation, has been implemented in LS-DYNA. This feature provides user the opportunity to acquire a spectrum of structural response (displacement, velocity and acceleration) for applied unit harmonic excitations. The harmonic excitations are given in the form of nodal force, with varying frequencies. A benchmark example of a rectangular elastic plate is included to demonstrate the effectiveness and accuracy of this new feature. Effect of damping on the FRF computation is studied. This feature has application in industries involving vibration analysis and modal testing.

## 1. Introduction

Frequency response function (FRF) is a characteristic of a structure that has a measured or computed response resulting from a known applied harmonic input. Usually this function is given for a range of frequencies. The response can be given in terms of displacement, velocity, or acceleration. FRFs are complex functions, with real and imaginary components. They can also be expressed in the form of magnitude and phase angle pairs.

FRF can be computed using the method of mode superposition, in frequency domain. As the first step, modal analysis is performed for the structure, which provides natural frequencies and vibration modes of the structure. Intermittent modal analysis can be performed in case of existence of prestress. With the application of unit harmonic load condition, and with the analytical Fourier transform, the modal coordinates are obtained in frequency domain. The final solution of FRF is achieved as the sum of influence from all the involved modes.

System damping has important effect on FRF. Damping can be prescribed in a few ways, such as constant modal damping, frequency dependent modal damping or Rayleigh damping. Damping affects not only the magnitude of FRF, but also the phase angle of FRF.

FRF has many applications in industries involving vibration analysis and mode testing, such as auto industry.

## 2. Implementation of the feature in LS-DYNA

A new keyword *CONTROL_FREQUENCY_RESPONSE_FUNCTION has been introduced in LS-DYNA to activate FRF computation. Through this keyword, user provides information about the location, direction, range of frequencies for the harmonic nodal force excitation, and the location where the response function is desired. Damping information is also provided in the keyword input. The location of the excitation and response area can be given as node, or set of nodes, or set of segments. The direction of force excitation can be in any of the x, y, z directions or given as a vector by using *DEFINE_VECTOR. Currently we consider only the case where the excitation is given in the form of nodal force. This feature can work in a single input/multiple output mode, e.g. user can acquire the FRFs at many locations (using set_node or set_segment) simultaneously due to a single excitation input. For more details about the keyword *CONTROL_FREQUENCY_RESPONSE_FUNCTION, please refer to LS-DYNA® Keyword User's Manual.

As modal analysis is the first step for running this feature, the keyword *CONTROL_IMPLICIT_EIGENVALUE has to be included in the input. Some other keywords related to implicit solution may also be needed, depending on the type or analysis (linear or nonlinear, etc.).

The results are given in two ASCII database files frf_amplitude and frf_angle. They can be accessed by LS-PREPOST's xyplot function. The file frf_amplitude shows the spectrum of absolute value and frf_angle shows the spectrum of phase angle in the range of excitation frequencies.

## 3. A benchmark example

### *3.1 Description of problem*

Consider a rectangular plate in Figure 1. The size of the plate is given as $a$ = 0.36m, $b$ = 0.24m, $t$ = 0.002m. Material properties are given as density $\rho$ = 7870 kg/m$^3$, Young's modulus E = 207×10$^9$ Pa, Poisson's ratio $\gamma$ = 0.292. Shell element type 6 (S/R Hughes Liu shell) is adopted. Totally 651 nodes and 600 shell elements are used for the modeling. Frequency Response Functions (Compliance, Mobility and Accelerance) in the range of 1-400 Hz are computed and the modes with natural frequencies less than 2000 Hz are used in the computation.

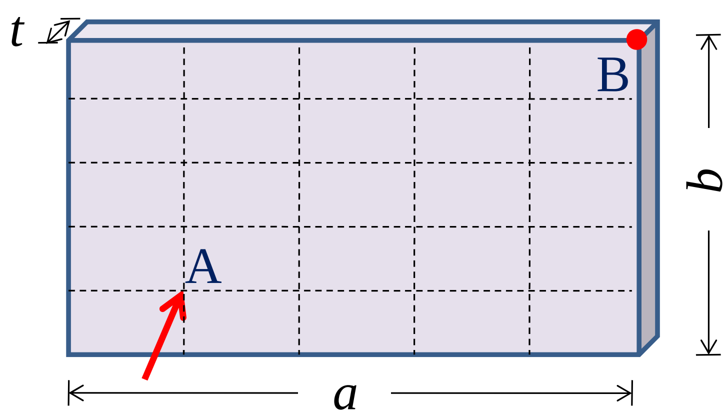

Figure 1. A rectangular plate with free boundaries

### *3.2 Verification of numerical results*

Wang and Tsao performed experimental modal analysis (EMA) and finite element analysis (FEA) for this benchmark problem [1]. In the finite element analysis, the software ANSYS was adopted and the convergence for different elements was studied.

The natural frequencies of the plate obtained with LS-DYNA match reasonably well with the analytical, experimental and ANSYS results given by [1] (see Table 1).

| Mode | Analytical | Experimental | ANSYS | LS-DYNA |
|---|---|---|---|---|
| 1 | 76.294 | 76.12 | 76.835 | 78.6163 |
| 2 | 81.865 | 83.00 | 81.624 | 81.3628 |
| 3 | 176.806 | 177.65 | 177.11 | 179.6108 |
| 4 | 190.602 | 201.50 | 189.88 | 188.6555 |
| 5 | 220.581 | 221.70 | 220.37 | 219.6902 |
| 6 | 255.791 | 261.41 | 254.96 | 255.1308 |
| 7 | N/A | 329.00 | 327.88 | 329.1959 |
| 8 | N/A | 383.23 | 377.43 | 379.2899 |

Table 1. Natural frequencies of the plate (Unit: Hz)

To compute the frequency response function, two cases are considered. In case 1, the point excitation force is applied at point A and the response is computed at the point A too. The function is called as point FRF. In case 2, the point excitation force is applied at point A and the response is computed at the corner point B. The function is called as transfer FRF.

In Figures 2 and 3 the Accelerance (acceleration/force) results (amplitude) from [1] (experimental and ANSYS) and from LS-DYNA computation are compared. The damping coefficient $\zeta = 0$ in the computation. It is found that LS-DYNA results match reasonably well with the experimental and ANSYS results, especially near each natural frequencies. The minor discrepancy between the results may come from the different element formulation between LS-DYNA and ANSYS, the truncation of the modes in FRF computation, and the fact that we ignored the influence of damping in computation. The peak responses always appear at the natural frequencies of the plate, as expected.

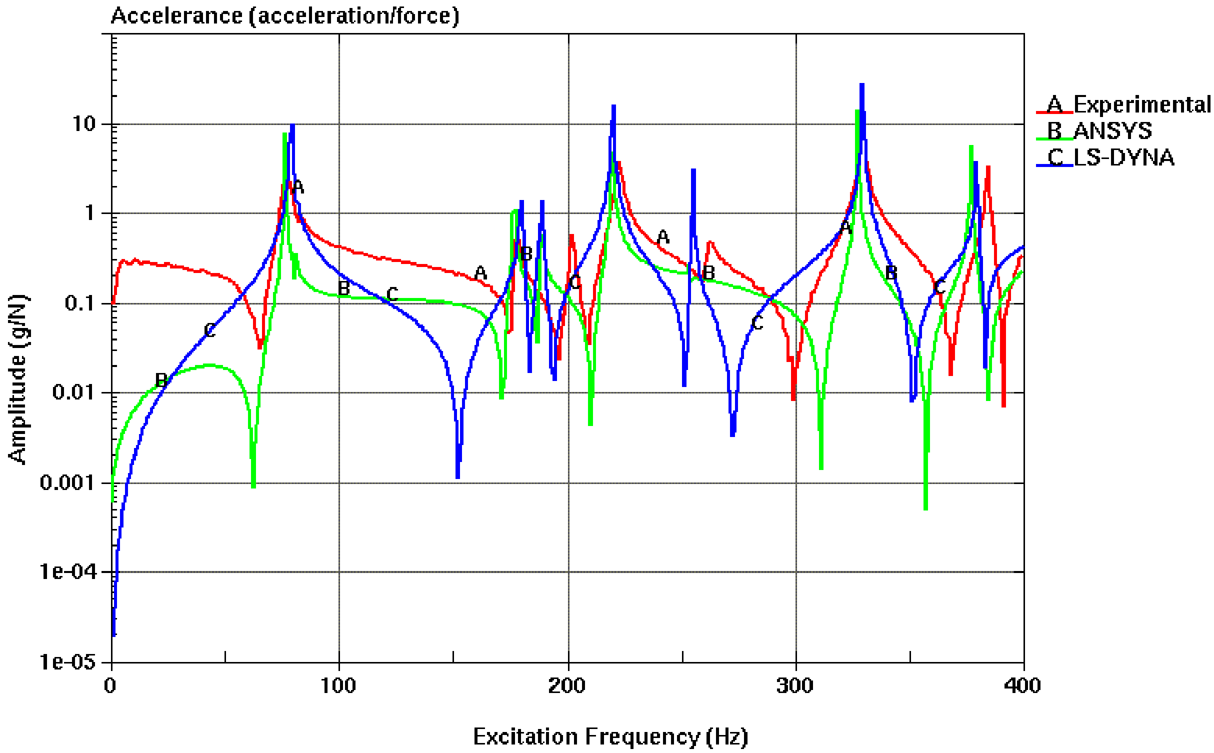


Figure 2. Amplitude of Accelerance for Case 1

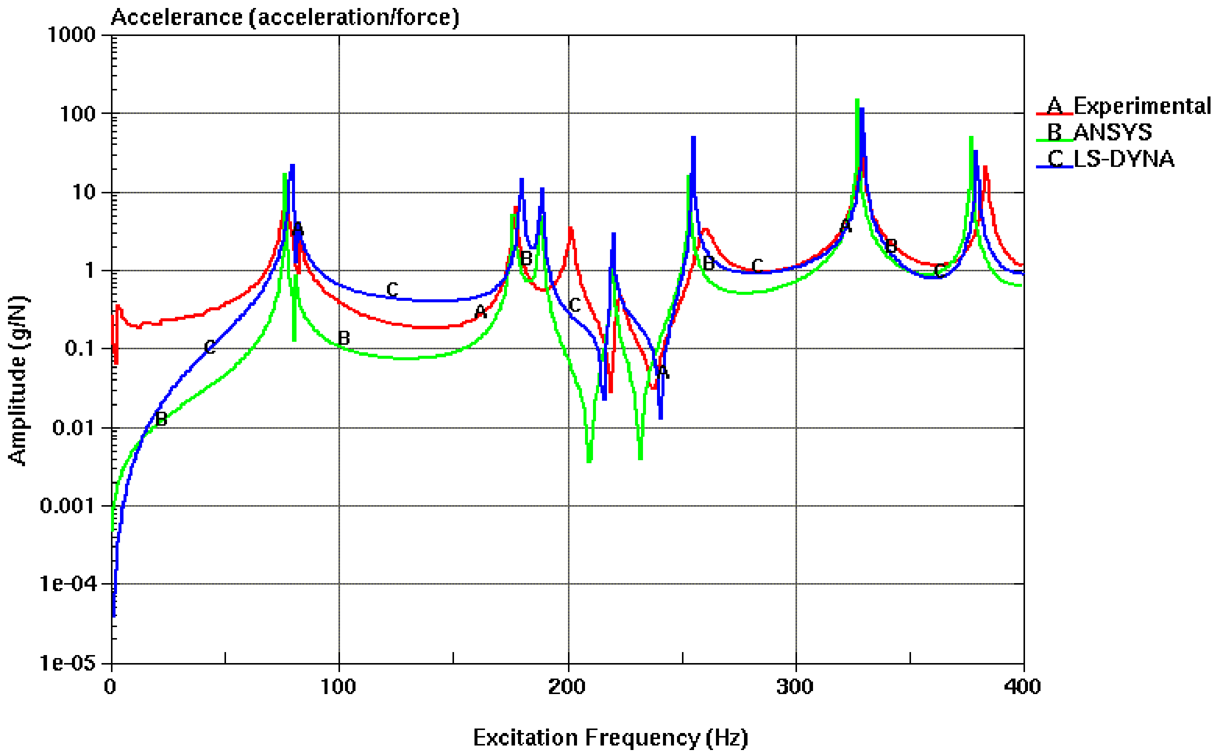


Figure 3. Amplitude of Accelerance for Case 2

### *3.3 Study on effect of damping*

To study the effect of damping, the example is re-considered with a constant mode damping ratio 0.01. The amplitude of Compliance (displacement/force) and Mobility (velocity/force) for Case 1 and Case 2, with and without damping, are given in Figures 4-7.

It is apparent that with consideration of damping, the response becomes smaller than the response without damping.

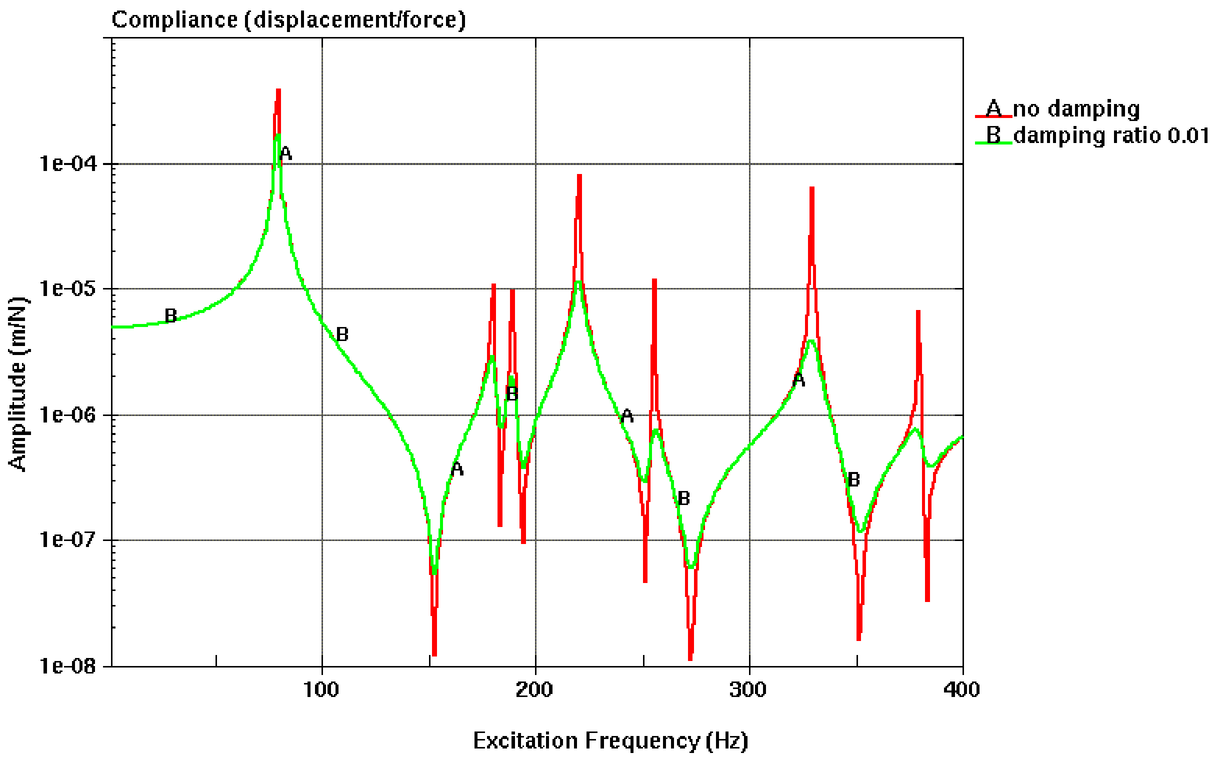


Figure 4. Amplitude of Compliance for Case 1

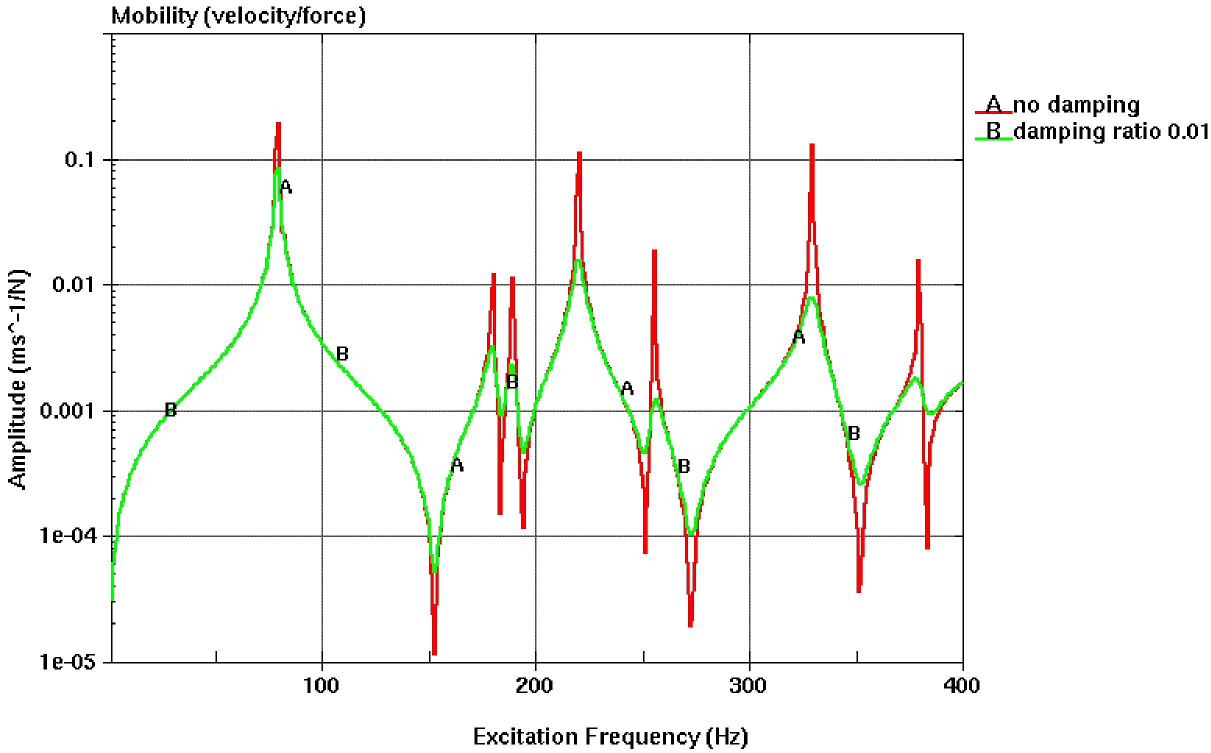


Figure 5. Amplitude of Mobility for Case 1

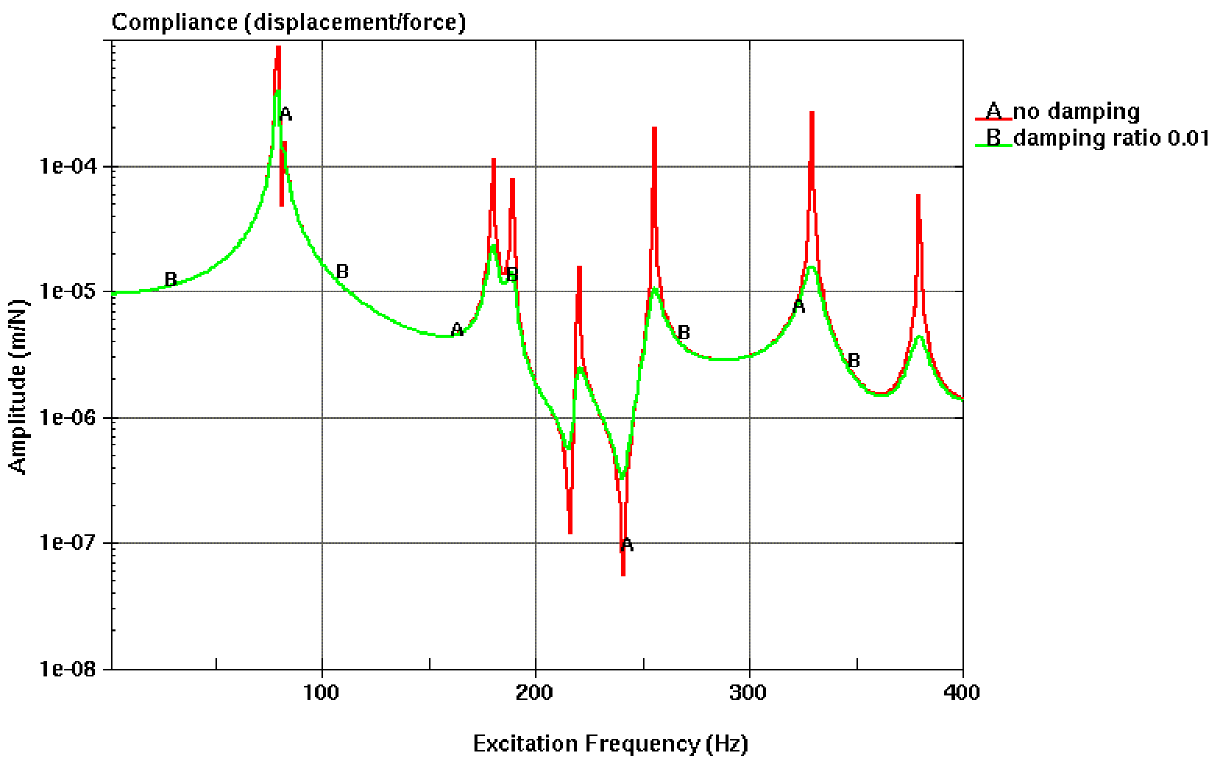


Figure 6. Amplitude of Compliance for Case 2

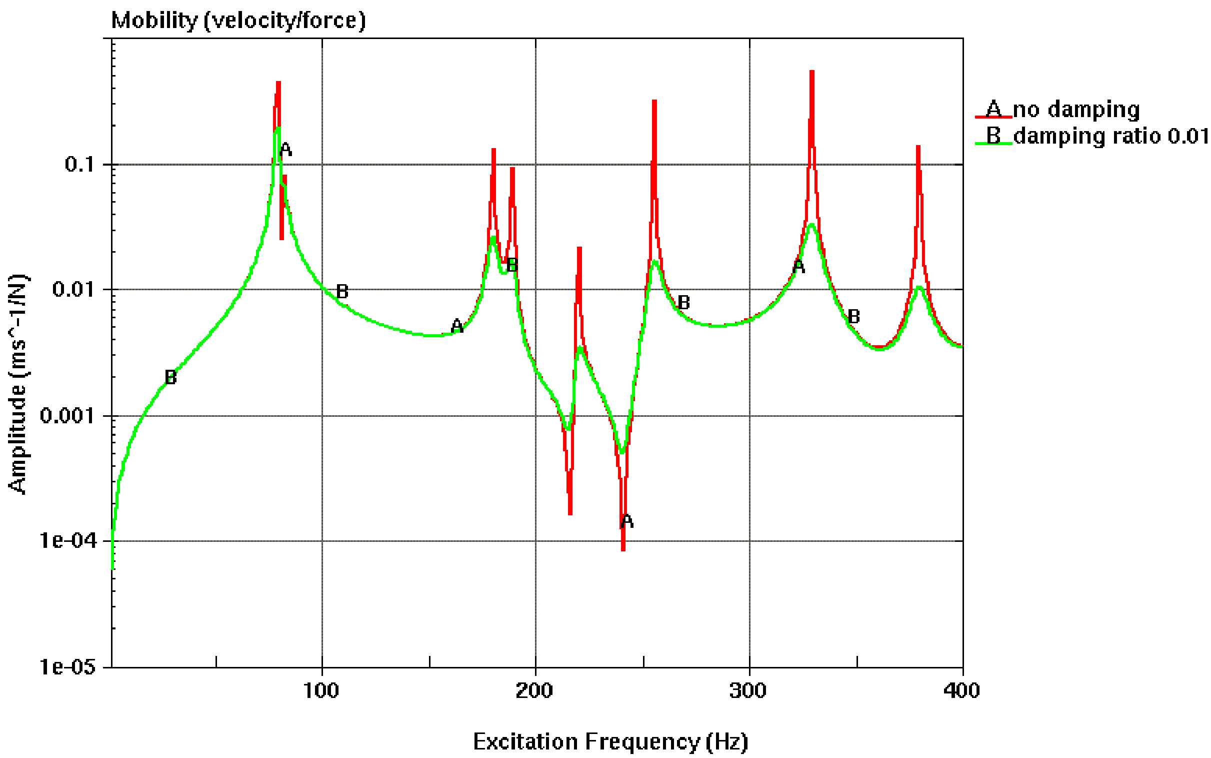


Figure 7. Amplitude of Mobility for Case 2

## Conclusion

This paper introduces the implementation and validation of a new feature in LS-DYNA, FRF (frequency response function). For the benchmark example, the numerical results by LS-DYNA match reasonably well with experimental results, and results obtained with ANSYS. Effect of damping on FRF is studied. It is shown that with damping, all the responses have reduced amplitude.

**Reference**:

1. Bor-Tsuen Wang, Wen-Chang Tsao, Application of FEA and EMA to Structural Model Verification. *Proceeding of the 10th CSSV Conference Taiwan*, 2002; 131-138.