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Modal analysis and damage assessment of cracked plates

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ABSTRACT

Dynamic characterization of cantilevered cracked plates assumes importance for a variety of applications including aging aerospace, mechanical and ship structural components. In this paper modal characteristics of isotropic plates with damage identified as cracks are investigated. The paper describes results obtained by finite element simulation of cracked plates. The frequency degradation as a function of the crack length is presented for selected aspect ratios. Some damage metrics are developed based on the modal parameters to describe the structural integrity of the plate type structures with root cracks. Frequency response analysis is presented to show the effect of the crack growth on the response of the plates. Some suggestions are developed based on the observations of the simulation for health monitoring of structural components.

Keywords: Modal Analysis and Damage Assessment of Cracked Plates

1. INTRODUCTION:

Damage detection and subsequent remedial action is important in the structural integrity assessment of structural components and in particular aging aerospace and ship structures. There have been several studies in the area of fracture mechanics, damage mechanics etc. addressing the structural integrity and safety issues. Structural components subjected to dynamic loads and alternating loads are more vulnerable to crack presence, often resulting in compromising the structural integrity. This study addresses the problem of detecting the presence of cracks in thin plates by means of some dynamic behavior of the plates.

In this paper, we study the behavior of isotropic cantilevered plates with cracks at the root or the clamped end. A finite element simulation is adopted in all the studies. The dynamic behavior of the cracked plates is studied, using both natural frequency analysis and frequency response analysis and assessment of the damage is outlined. Deterioration of the natural frequencies with various crack length size is presented. The frequency response and strain energy density variations are also presented to further show the effect of the crack on the natural frequencies of the plate.

2. PROBLEM DESCRIPTION AND FINITE ELEMENT MODELING:

Cantilevered plates with edge cracks are commonly occuring structural components in aerospace and ship applications. We first consider a square cantilevered plate as shown in Figure 1. A plate with thickness $t = 0.125$ $in.$ made of Aluminum with the following properties: $E = 10X10^6$ psi and $\nu = 0.33$ is used in the present analysis.

The plate is clamped along the left edge. MSC/NASTRAN and PATRAN software is

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used in all subsequent simulations. A quadrilateral shell element is used in modeling the plate with a total of 400 elements with 441 nodal points.

The edge crack is simulated by introducing the crack along the clamped edge. This is accomplished in increments of 10 percent of the length of the edge by releasing all degrees of freedom at those associated nodes at the clamped edge.

Free vibration analysis is performed for each crack length. Only the first six modes are reported here while first twenty modes were observed. The analysis is repeated for each increment of crack length till the crack is 50 percent of the clamped edge.

In order to correlate the damage with the strained state of the plate, the strain energy of each of the element and the corresponding total strain energy density for the whole plate is computed for each of the first six modes.

The plate is then subjected to a unit tip load at a corner of the free edge. Subsequently, the frequency response using modal method is performed. The frequency response at selected nodal points are presented to illustrate the plate behavior when edge cracks are developed in a structural component.

3. RESULTS:

Table 1 lists the first six natural frequencies computed from the present approach for the cantilevered plate described.

Figure 2 presents variation of the natural frequencies with different non-dimensional crack lengths. Six modes are presented in the figure. Figures 3 and 4 show the mode shapes for a selected crack length ratio of 0.4. Considerable movement in the modes may be observed due the presence of the 40 percent crack.

Figure 5 shows the variation of strain energy density for first six modes as a function of non dimensional crack length. It may be observed that the trends in both the variation of the natural frequencies and strain energies with changing cracl lengths are similar. Also, there is more substantial drop or deterioration in the higher modes for cracked plates, thereby indicating the need to monitor higher modes in assessing the damage presence in structural components.

Frequency response analysis under a unit tip load is performed for different non dimensional crack lengths, ranging from 0.1 to 0.5 in increments of 0.1. Figure 6 shows the response of the plate to a unit tip load at 408 HZ. Figure 7 shows tip displacement frequency response at the point of load application (Node 21), while Figure 8 shows the frequency response at the free edge corner of the plate (Node 441). Figure 9 shows the response of the plate at 608 HZ with crack length ratio of 0.4. Figure 10 through 12 show the frequency response of the nodes at the tip (Nodes 21 and 441) and a node close to the free crack surface near the clamped end. Again, substantial sensitivity is observed in the response as the crack propagates, thereby providing information to detect the cracks either by testing or monitoring the behavior of the structural component during its life-cycle.

4. CONCLUSIONS

Dynamic behavior of cracked plates is studied using a finite element software. The deterioration of the natural frequencies as crack assumes various lengths is presented as an indication of the damage. Other features such as strain energy density variations and higher mode frequency drops are also presented to indicated the damage presence. Frequency response analysis of cracks of various sizes indicates that method may be used in detecting the presence of cracks of various sizes and use of higher modes facilitates monitoring the crack growth as a function of the plate dimensions and defects.

Table 1. Natural Frequencies for a Cantilevered Plate; $a/b = 1$; $h = 0.125 in.$; $\rho = 0.1\, lb/in^3$

Mode	Frequency, Hz,	Generalized Stiffness
1	4.132295E+01	6.741281E+04
2	9.945837E+01	3.905192E+05
3	2.509548E+02	2.486285E+06
4	3.204941E+02	4.055084E+06
5	3.618955E+02	5.170424E+06
6	6.283971E+02	1.558935E+07

ACKNOWLEDGMENTS

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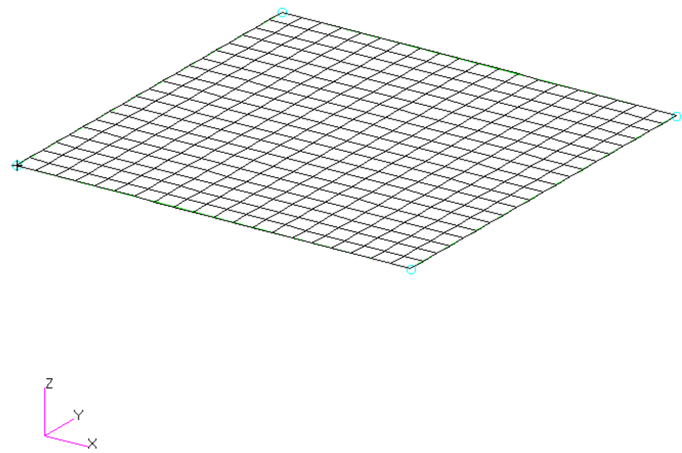


Figure 1. Finite Element Model of the Cantilever Plate

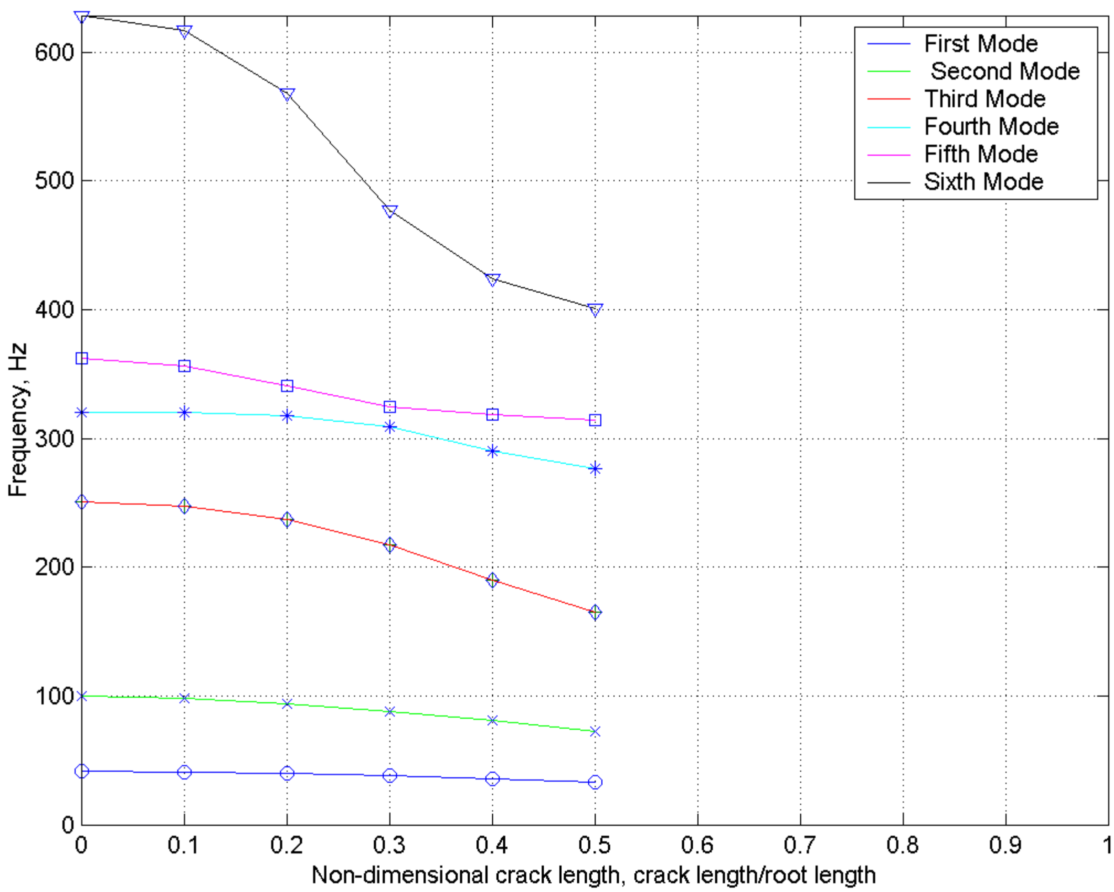
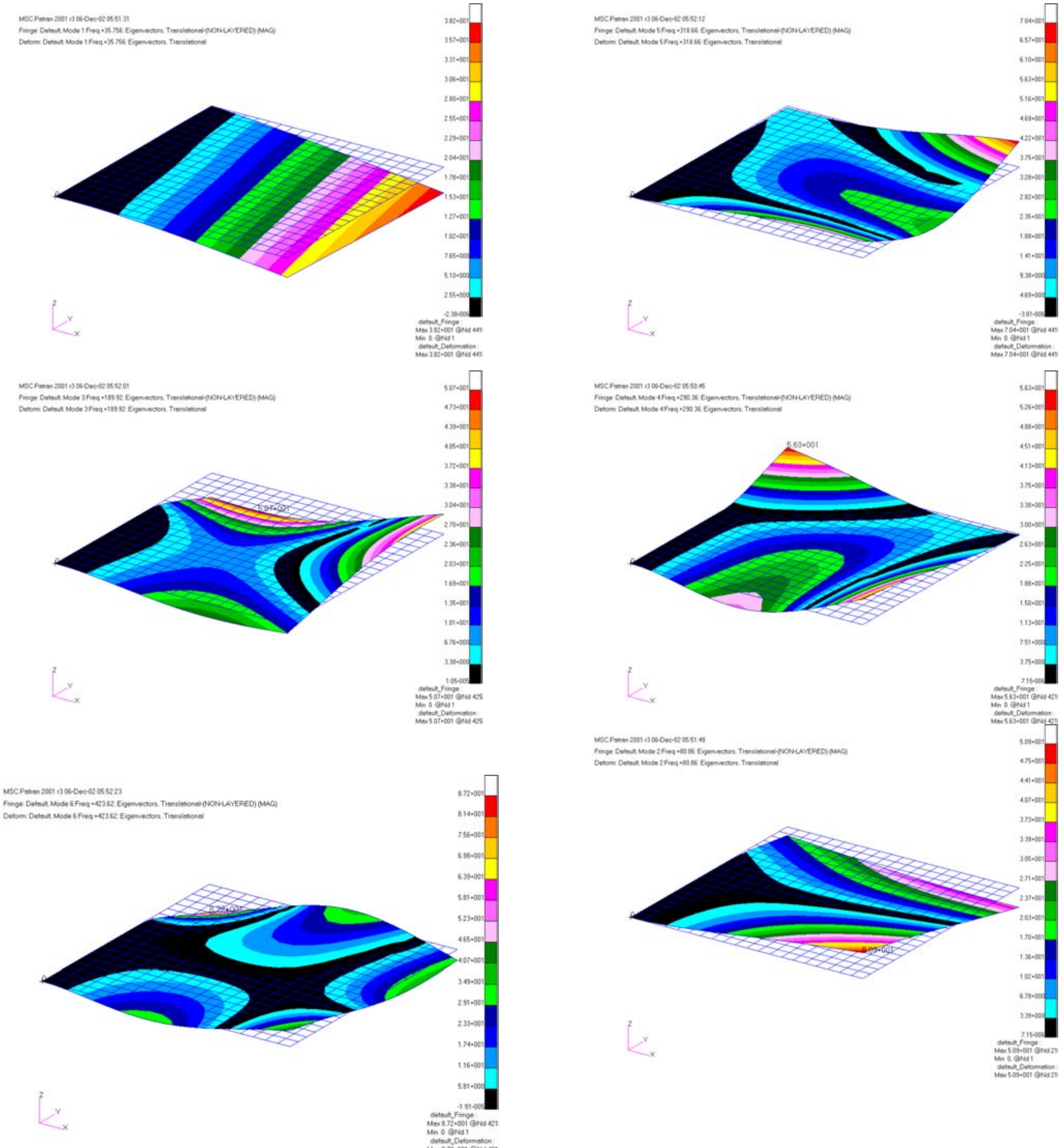


Figure 2 Variation of Natural Frequencies with non dimensional crack length



Figures 3 and 4: First six modes for crack length ratio=0.4

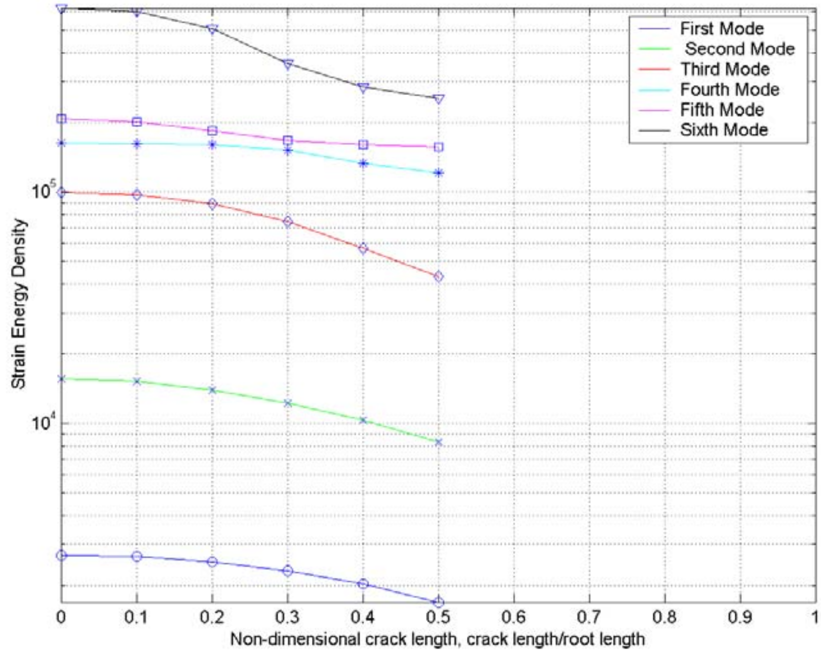


Figure 5 Strain Energy Density variation with non dimensional crack

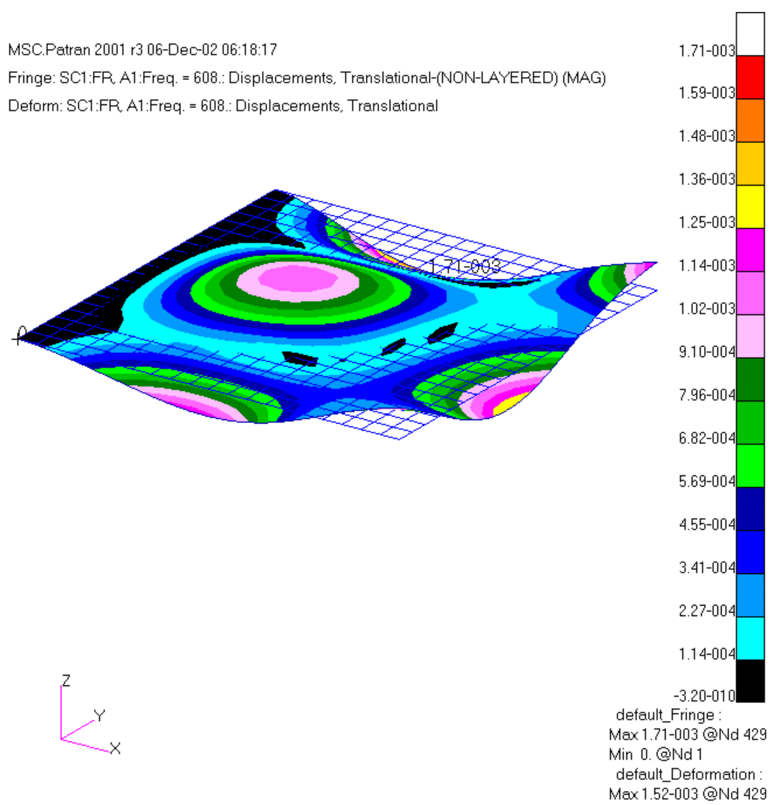


Figure 6 Frequency Response under a Unit Load at the tip

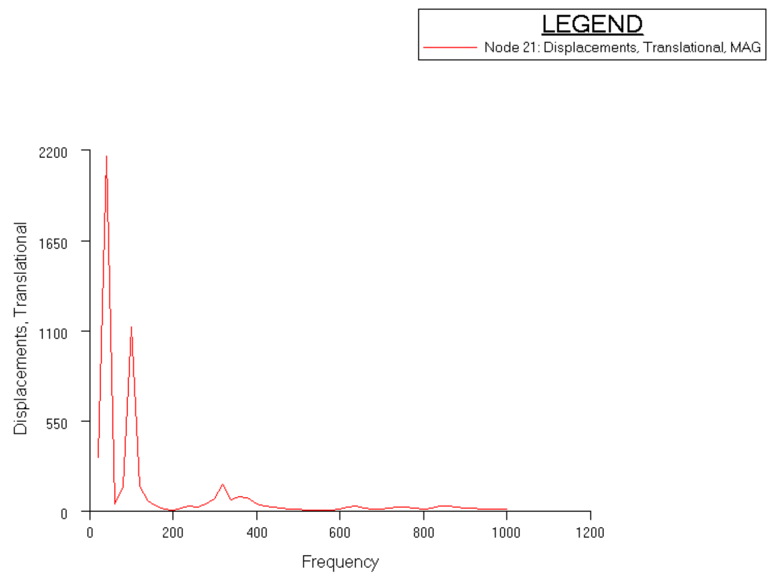


Figure 7 Frequency Response at the Point of Application of Load (Node 21)

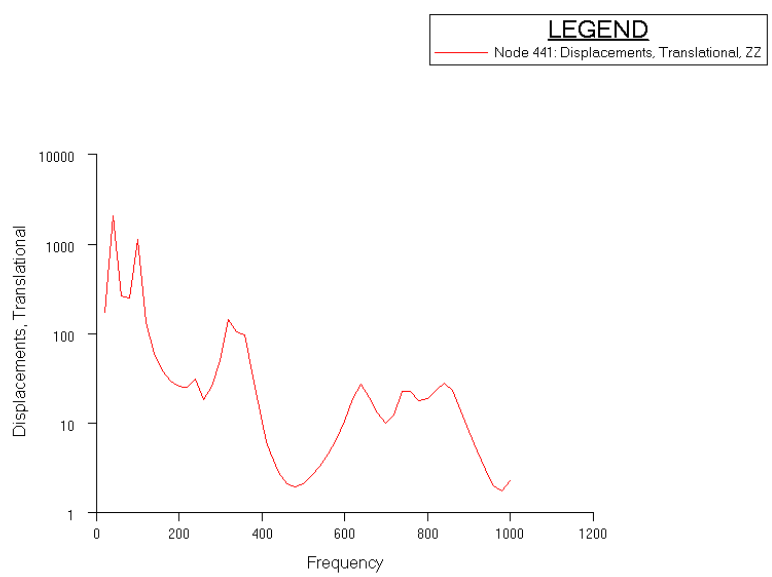


Figure 8 Frequency Response at the Free End (Node 441)

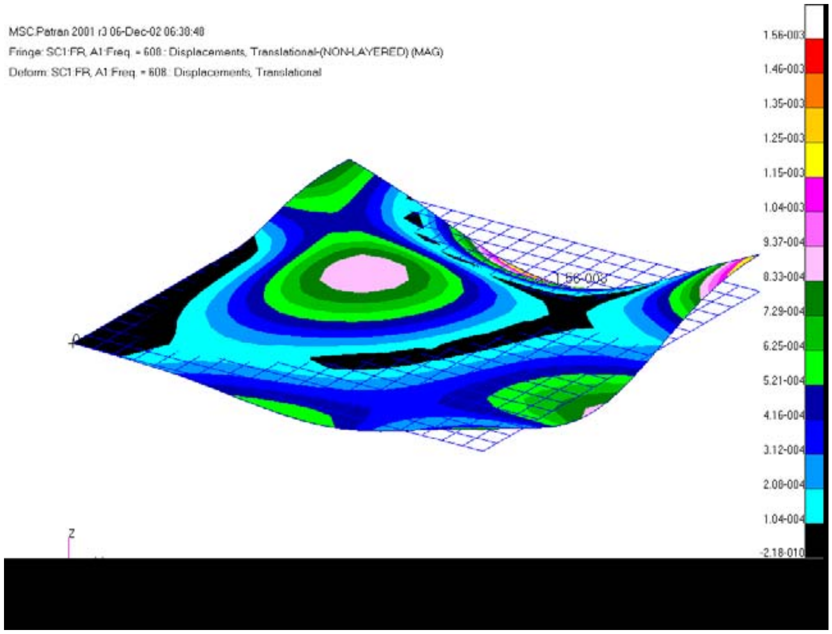


Figure 9 Frequency Response Under Unit Tip Load at Crack Length Ratio=0.4

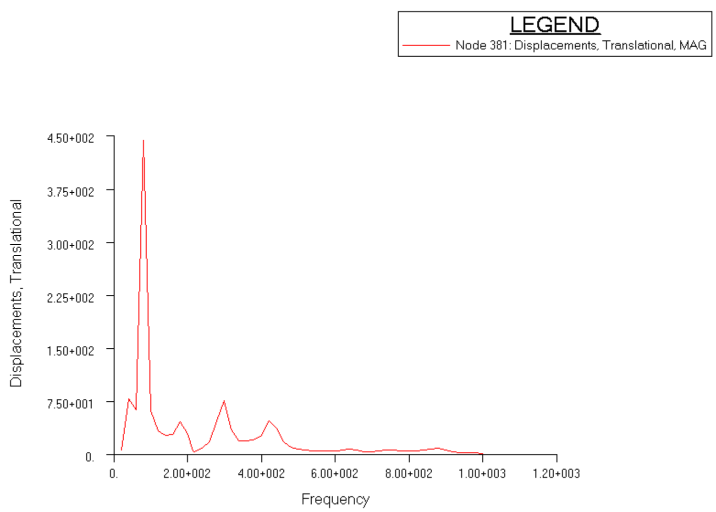


Figure 10 Frequency Response at the Node 381 (Close to the Clamped End Near the Fre Crack Surface)

(CRL=0.4)

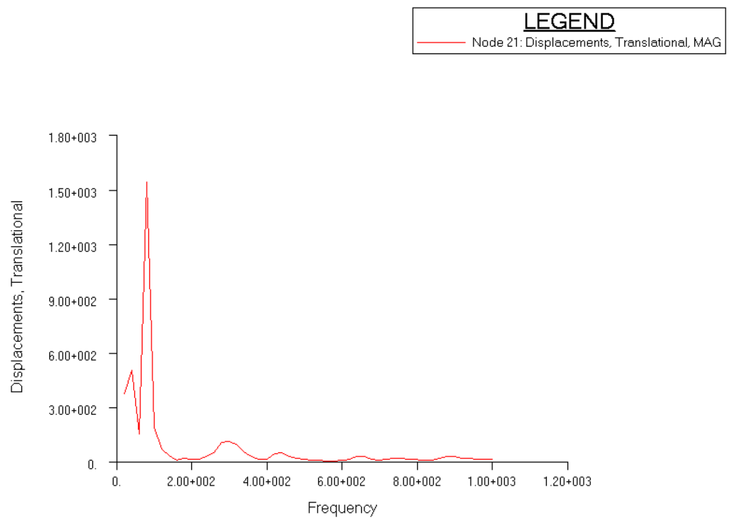


Figure 11 Frequency Response at the Node 21 (Load Application Point), (CLR=0.4)

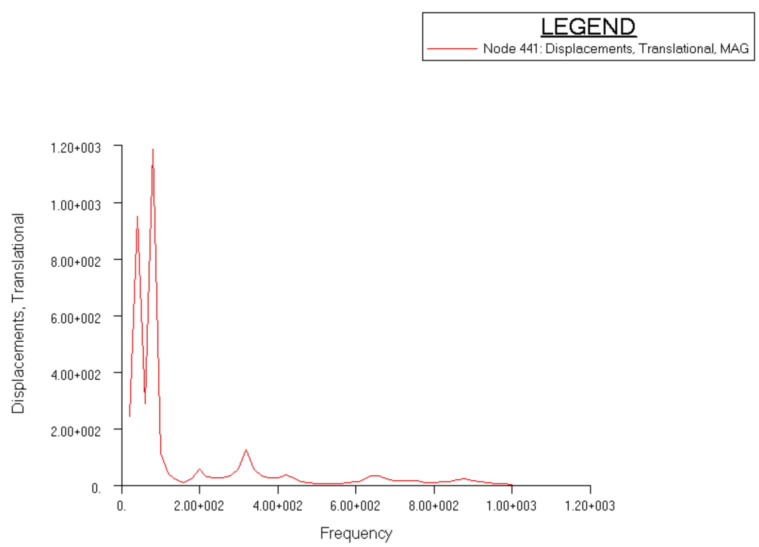


Figure 12 Frequency Response at Node 441 (Free End), CLR=0.4