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Vibration Analysis of Beam with Varying Crack Location by Finite Element Method

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Abstract :- Crack Location and depth are very important consideration in the vibration analysis of beam. The crack present in the beam or structure changes the physical nature of beam and dynamic response. In the present study vibration analysis of cantilever beam using aluminium material with and without crack. Here Ansys is used to finding the natural frequencys and amplitude of beam with and without crack and compare this result for different boundary condition. The natural frequencies of free vibration of the beam with multiple cracks are computed. It is observed that with increase in number of cracks, the natural frequency decreases. The effect of cracks is more pronounced when the cracks are near to the fixed end than free end.

I. INTRODUCTION

Cracks may appear on structures due to the corrosion, fatigue and other reasons, and the vibration characteristics of structures will be altered. The frequencies of the cracked structures may be close to the frequencies of exciting forces, which will cause significant increment of the amplitude of structure vibration and even damage the equipment. Therefore, the investigation of frequency changes due to the crack should be performed for the safe operation of equipment.

Many different methods have been developed in the area of crack identification and repair. Generally these methods can be categorized into frequency domain and time domain methods. These groups may be subdivided into different areas depending on the parameters used or method performed in the damage detection process.

A. Crack

A crack in a structural member introduces local flexibility that would affect vibration response of the structure. This property may be used to detect existence of a crack together its location and depth in the structural member. The presence of a crack in a structural member alters the local compliance that would affect the vibration response under external loads.

Based on geometries , cracks can be broadly classified as follows,

- **Transverse crack** : These are cracks perpendicular to beam axis. These are the most common and most serious as they reduces the cross section as by weaken the beam. They introduce a local flexibility in the stiffness of the beam due to strain energy concentration in the vicinity or crack tip.
- **Longitudinal cracks** : These are cracks parallel to beam axis. They are not that common but they pose danger when the tensile load is applied at right angles to the crack direction i.e perpendicular to beam axis.
- **Open cracks** : These cracks always remain open. They are more correctly called “notches”. Open cracks are easy to do in laboratory environment and hence most experimental work is focused on this type of crack.
- **Breathing crack** : These are cracks those open when the affected part of material is subjected to tensile stress and close when the stress is reversed . The component is most influenced when under tension. The breathing of crack results in non-linearity in the vibration behavior of the beam. Most theoretical research efforts are concentrated on “transverse breathing” cracks due to their direct practical relevance.
- **Slant cracks** : These are cracks at an angle to the beam axis , but are not very common. There effect on lateral vibration is less than that of transverse cracks of comparable severity.
- **Surface cracks** : These are the cracks that open on the surface. They can normally be detected by dye-penetrates or visual inspection.
- **Subsurface cracks** : Cracks that do not show on the surface are called subsurface cracks. Special techniques such as ultrasonic , magnetic particle , radiography or shaft voltage drop are needed to detect them.

B. Smart Materials

Smart materials are defined as materials that are capable of automatically and inherently sensing or detecting changes in their environment and responding to those changes with some kind of actuation or actions. These characteristics provide several possible applications for these materials in aerospace, manufacturing, civil infrastructure systems, and biomechanics. Active vibration and acoustic transmission control, active shape control, and active damage control are some of the areas that have found innovative applications for smart materials and structures. Examples of specific applications is micro positioning, vibration isolation, fast acting valves and nozzles, transducers, luxury car shock absorbers, and active engine mounts in aircraft. Some of the benefits of using smart materials are system integration, reduction of mass and energy requirements, elimination of moving parts in actuators, and collocation between actuator and sensor. There are four types of smart materials that have been described as below.

II. LITERTURE SURVEY

K.B.Waghulde and Dr. Bimlesh Kumar,*[2011]*have studied the smart structures and smart materials. These materials has been an emerging area of research for last few decades. A smart structure would be able to sense the vibration and generate a controlled actuation to it, so the vibration can be minimized. For this purpose, smart materials are used as actuators and sensors. In this paper, some literature review is given about smart structure and smart material. Piezoelectric material is used as smart material and cantilever beam is considered as a smart structure. Different positions are considered for the model analysis. In this case, the modal analysis are found out by using ANSYS and MATLAB.

K.B.Waghulde and Dr. Bimlesh Kumar,*[2012]* have studied, the locations of actuators and sensors over a structure determine the effectiveness of the controller in controlling vibrations. If we need to control a particular vibration mode, we have to place actuators and sensors in locations with high control. In many cases of vibration control, low frequency modes are considered to be important. Hence, we only need to consider a certain number of modes in the placement of actuators and sensors. We extended the methodology for finding optimal placement of general actuators and sensors over a flexible structure. For vibration analysis ANSYS software is used. Experimentation is done for control vibration and to find optimal position of piezoelectric actuator/sensor over a thin plate. To obtain frequency response from PZT actuators and sensors, Spectra plus software is used.

K. Hari Prasad, Dr.M.Senthil Kumar, *[2009],* investigates the accuracy of predicting the dynamic response by finite element modeling of structures with cracks. Steel and composite materials are widely used in various construction elements and composites in particular have increased substantially over the past few years. These materials are subjected to various types of damage, mostly cracks. These result in local changes of the stiffness of elements from such materials and consequently their dynamic characteristics are altered. The cracks are modeled as such in case of stress analysis to study the stress pattern at those local regions of crack, while in case of dynamic analysis an equivalent model is built with many assumptions. While there are many literatures available on these, there is literally none that has investigated the effect on the results of the analysis with such models.

L. Rubio, *[2009],*developed an effective crack identification procedure based on the dynamic behavior of a Euler–Bernoulli cracked beam. It is very well known that the presence of a crack in a structure produces a change in its frequency response that can be used to determine the crack properties (position and size) solving what is called an inverse problem. In this work, such an inverse problem has been solved by the use of the classical optimization technique of minimizing the least square criterion applied to the closed-form expression for the frequencies obtained through the perturbation method. The advantage of this method with respect to the ones derived previously is that the knowledge of the material and its properties (Young's modulus and mass density) is not necessary, not even the behavior of the uncracked element. The methodology has been successfully applied to a simply supported Euler–Bernoulli beam.

III. FINITE ELEMENT METHOD (FEM)

Finite element method can be said to be a numerical method to solve different equation. The engineering problem are analyzed by forming differential equation for different processes and solving the same by applying suitable boundary condition. Finite element method are used in vibration analysis to getting the natural frequencies, resonant frequencies and dynamic response of system to time varying load. A straight beam element with uniform cross section is shown in Figure. 3.1. The Euler-Bernoulli beam theory is used for constituting the finite element matrices. The longitudinal axis of the element lies along the x axis. The element has a constant moment of inertia I, modulus of elasticity E, density r and length l. Two degrees of freedom per node, translation along y-axis (y_1, y_2) and rotation about z-axis (y_1^I,y_2^I) are considered.

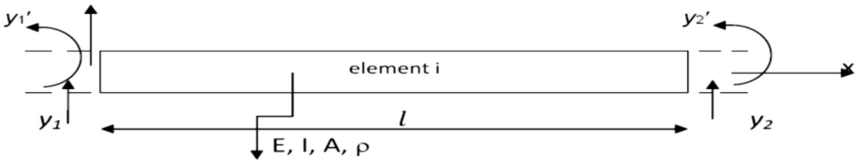


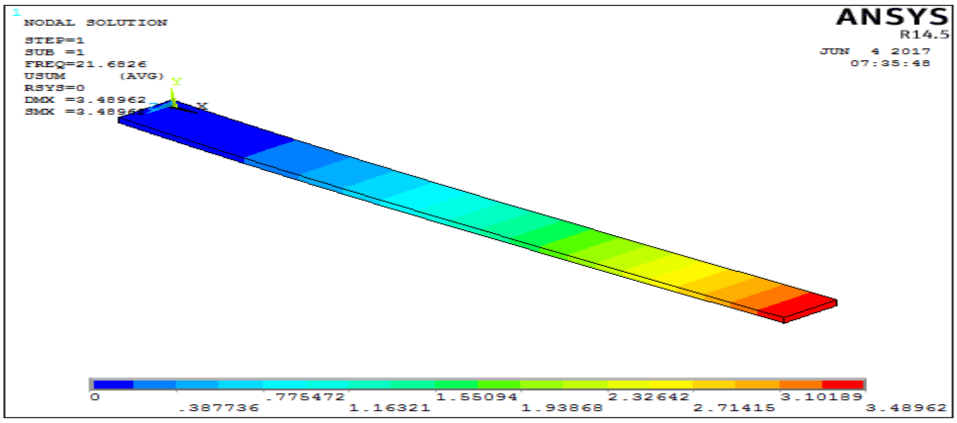
Fig. 3.1 Straight Beam Element

Table 3.1 Material Properties and Dimensions of Aluminum Beam

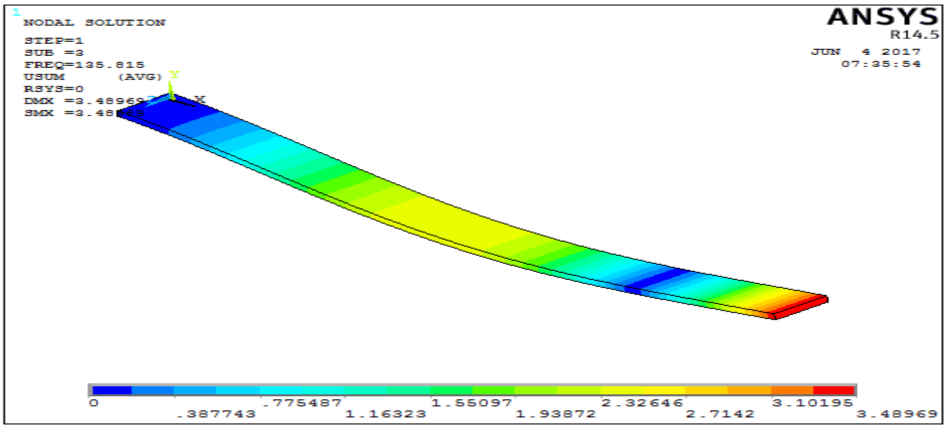
Dimensions/Properties	**Aluminum**	**Piezoelectric actuator**
Length	0.5m	0.0762 m
Width	0.04 m	0.0254 m
Thickness	0.006 m	0.5×10^{-3} m
Density	2700 kg/m^3	7600 kg/m^3
Young modulus	70 Gpa	76 GPa
Poisson's ratio	0.3	---------
Piezoelectric Stain Constant	---------	-247×10^{-12} m/V

IV. IMPLEMENTATION OF FINITE ELEMENT METHOD

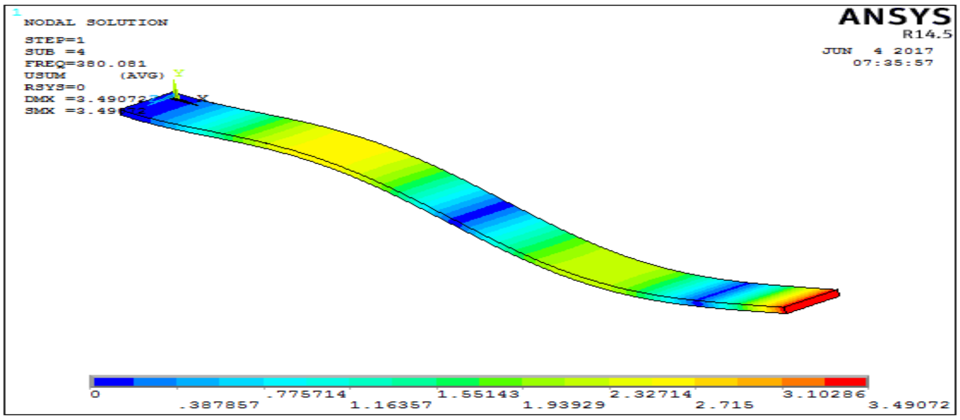
The model is prepared by using commercial FE software ANSYS. In ANSYS, the beam is modeled with a 2-D elastic beam element. Material properties are taken from the Table 3.1. A unit step force is applied in the positive vertical direction at the tip of the beam. The Beam is considered to have three DOF, two translational and one rotational. Figure 3.2 shows mode shapes for the healthy model for beam. Table 3.2 shows the natural frequencies for healthy beam. Figure 3.3, 3.4, 3.5 shows the mode shape at 125mm location for 1mm, 2mm and 3mm depth. Similarly Figure 3.6, 3.7, 3.8 shows the mode shape at 125mm and 250mm location for 1mm, 2mm and 3mm depth. Similarly Figure 3.9, 3.10, 3.11 shows the mode shape at 125mm for 1mm, 2mm and 3mm depth.



Ist mode shape

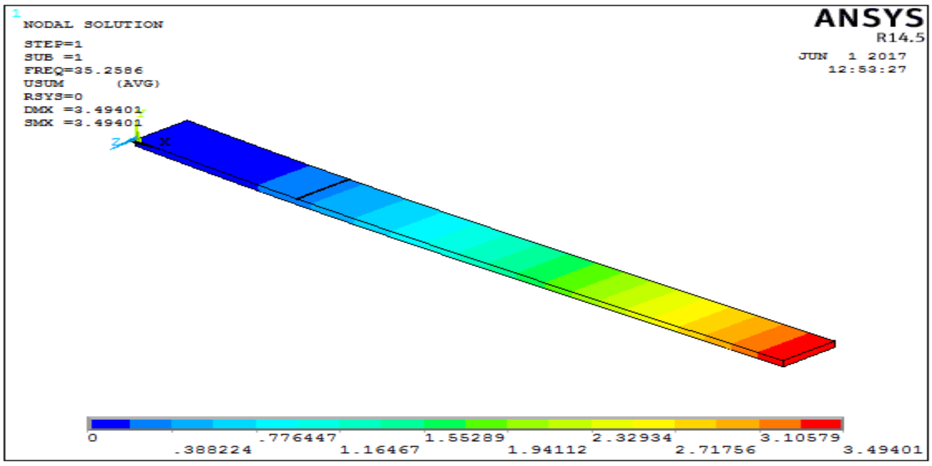


IInd mode shape



IIIrd mode shape

Fig. 3.2 Mode Shapes for Uncracked Cantilever Beam Model



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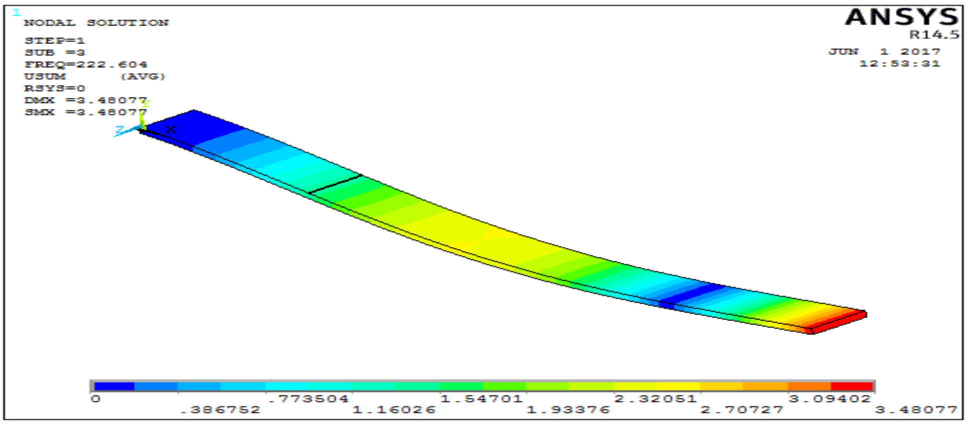

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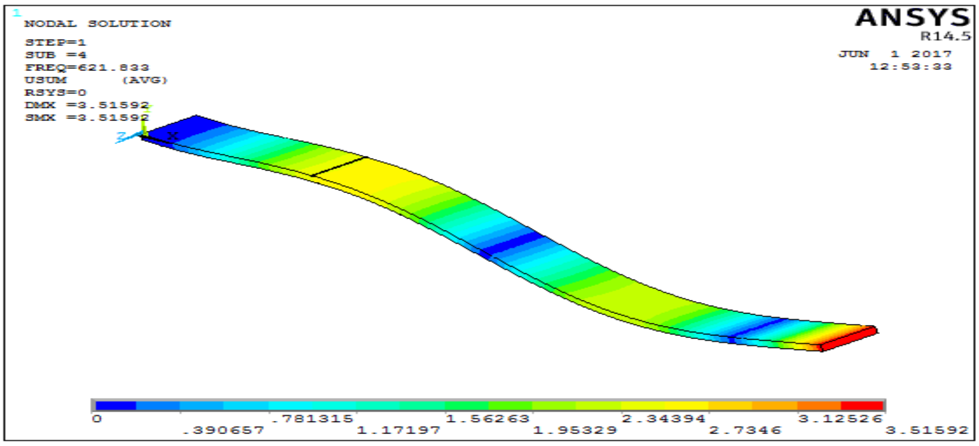
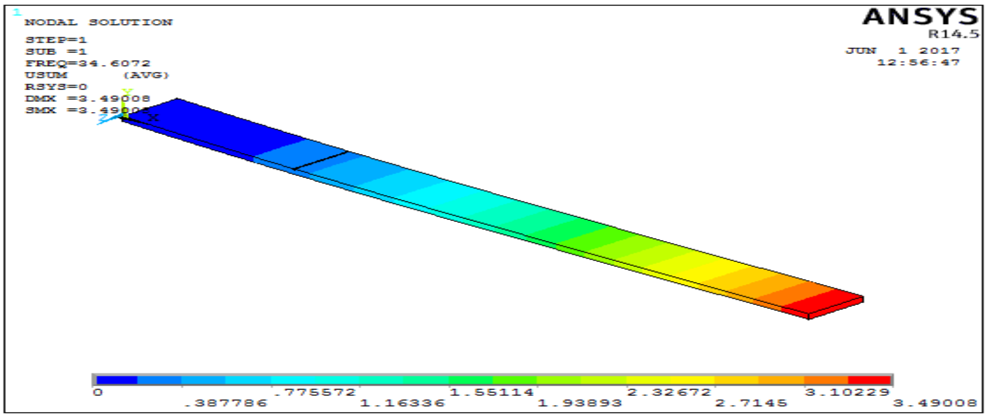


IIIrd mode shape

Fig. 3.3 Mode Shapes for 1mm crack for Cantilever Beam Model(L=125mm)



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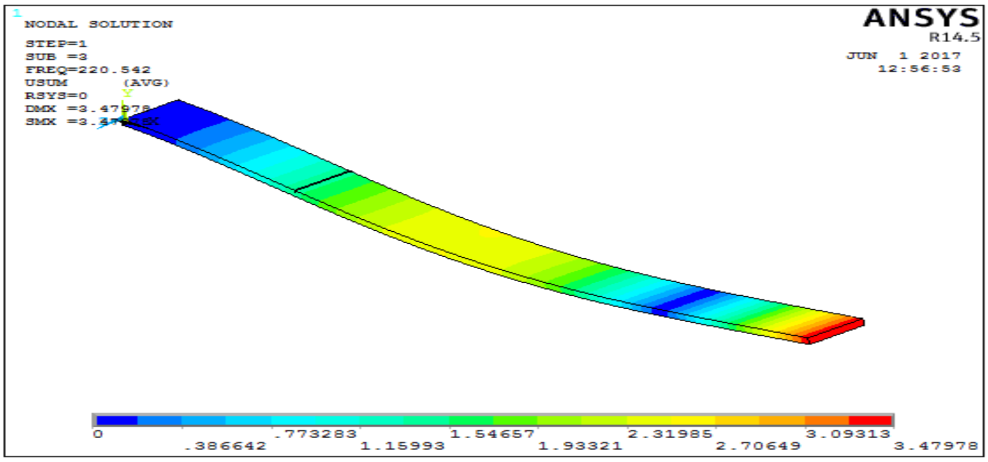

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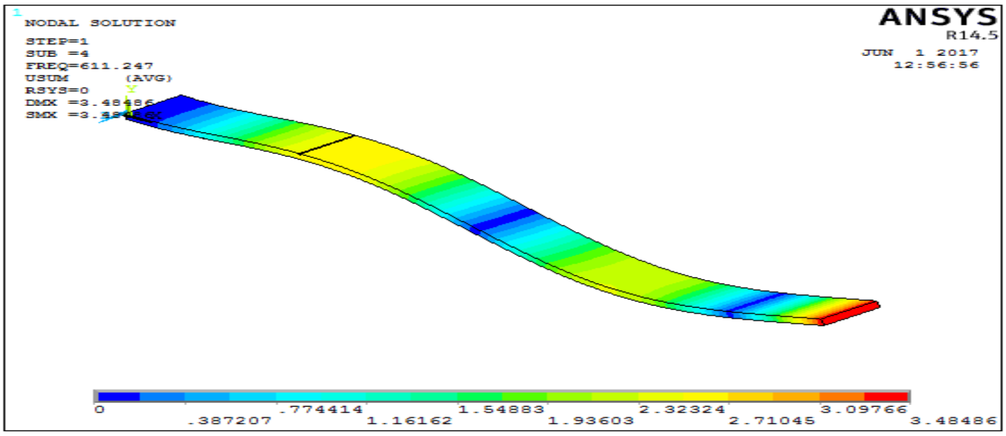
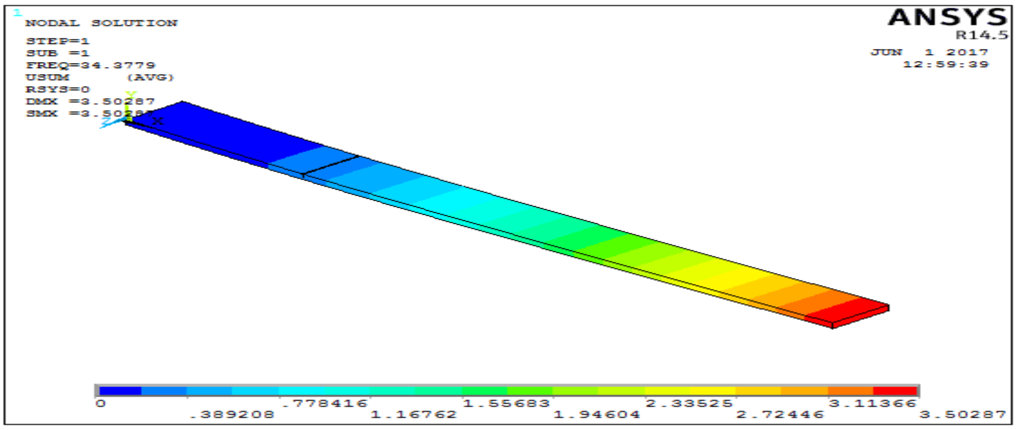


IIIrd mode shape

Fig. 3.4 Mode Shapes for 2mm crack for Cantilever Beam Model(L=125mm)



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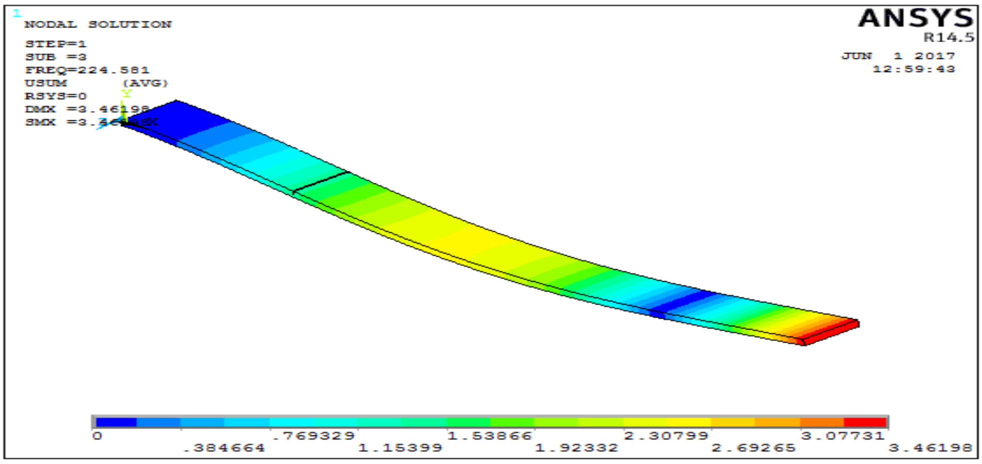

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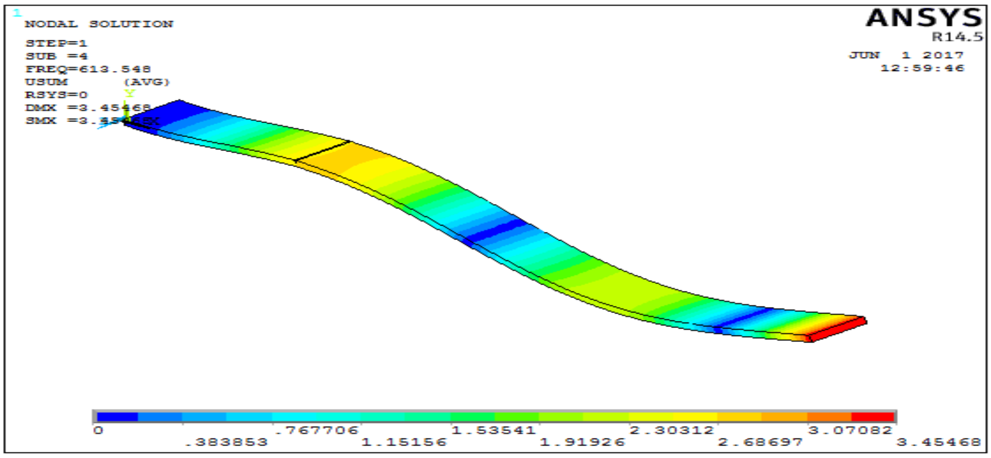
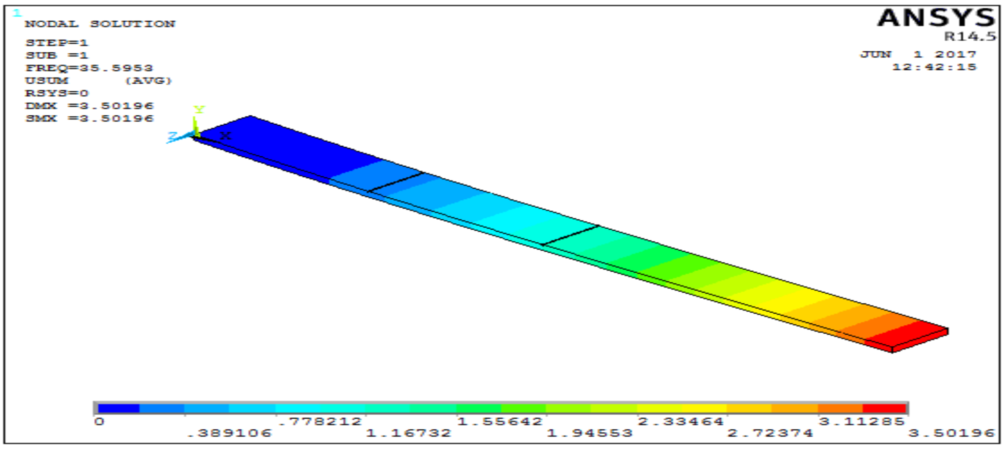


IIIrd mode shape

Fig. 3.5 Mode Shapes for 3mm crack for Cantilever Beam Model(L=125mm)



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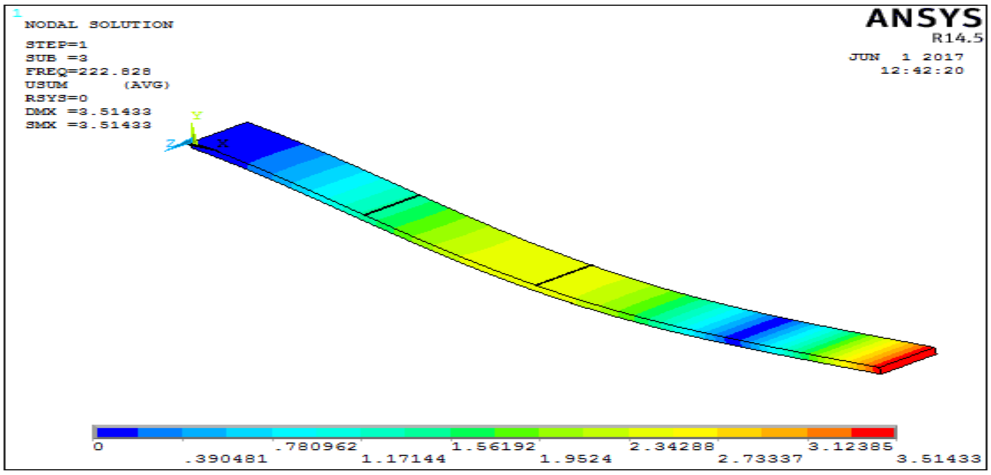

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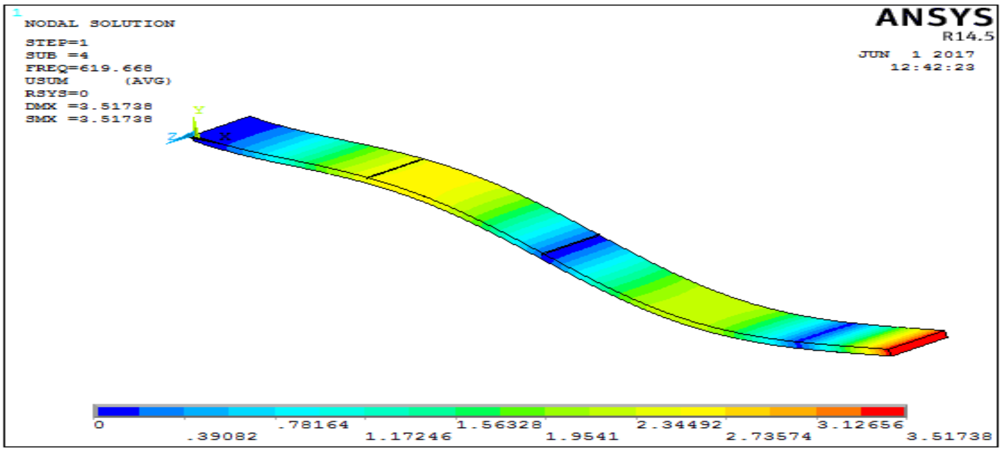
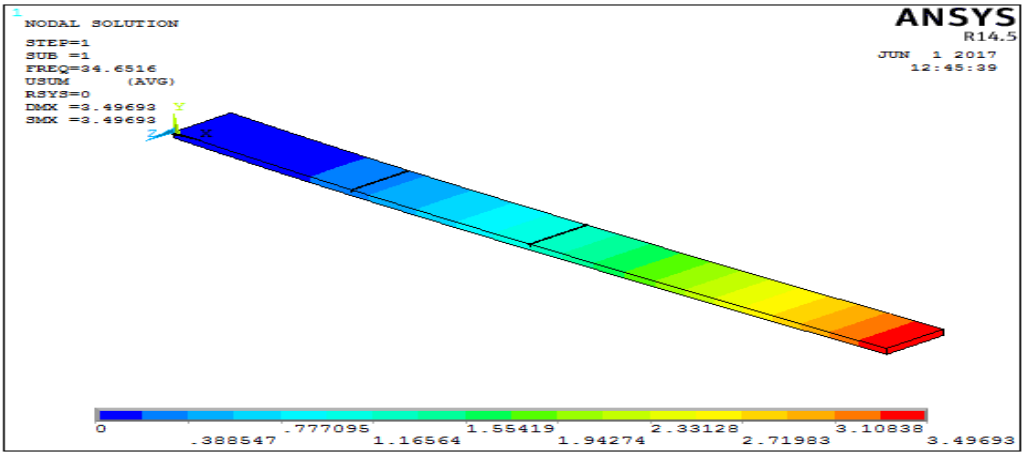


IIIrd mode shape

Fig. 3.6 Mode Shapes for 1mm crack for Cantilever Beam Model(L=125and 250mm)



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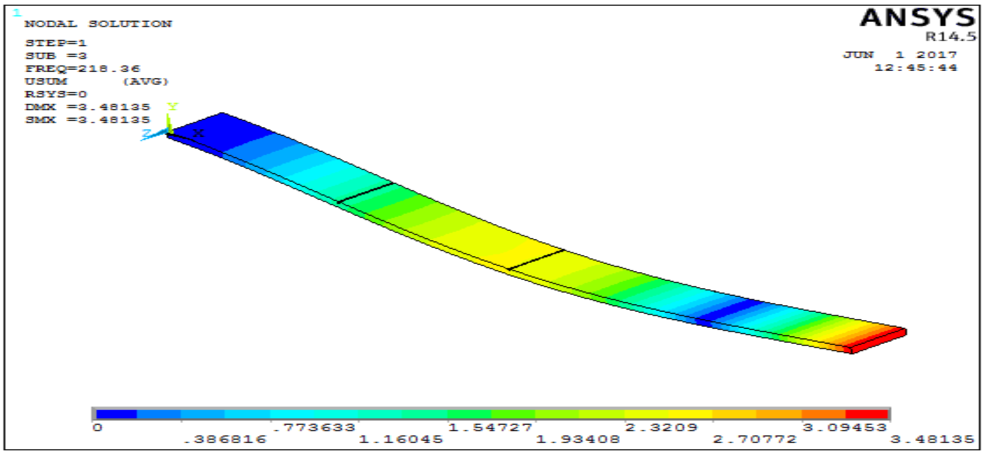

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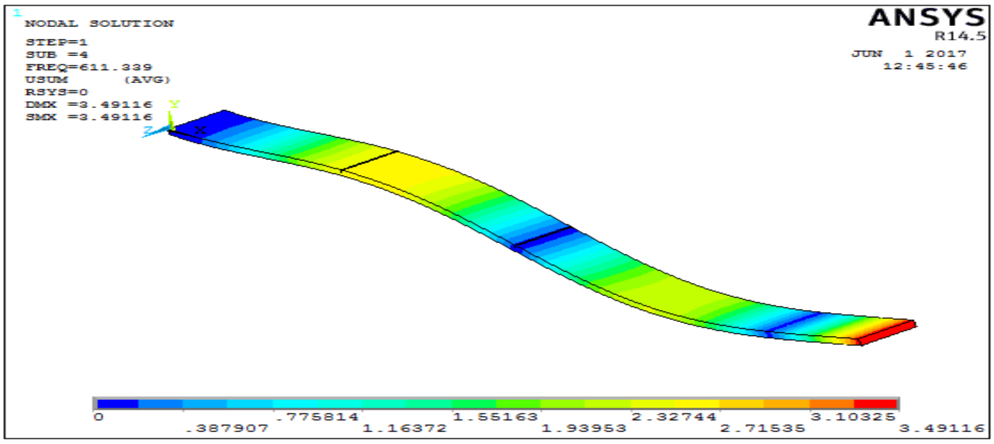
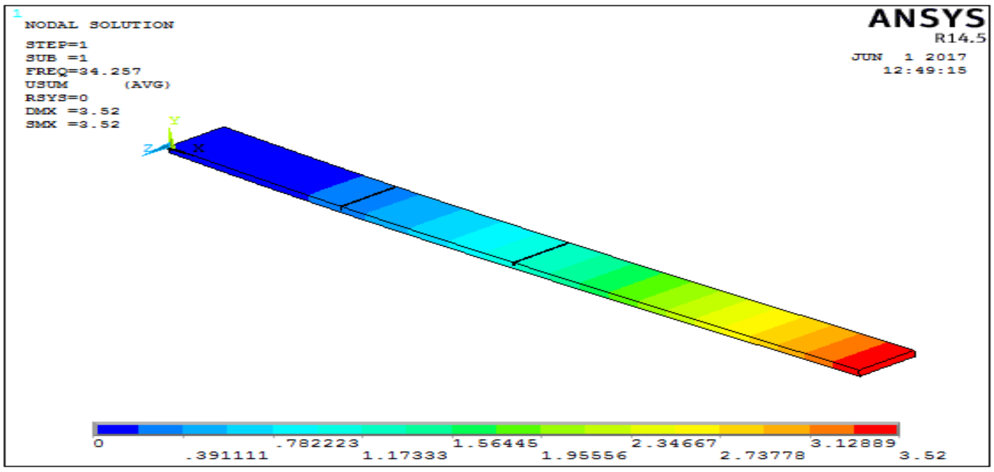
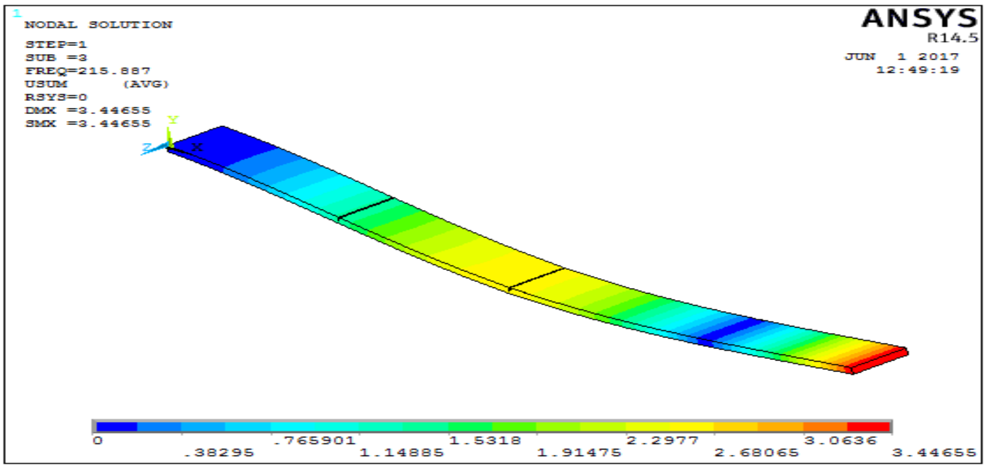


IIIrd mode shape

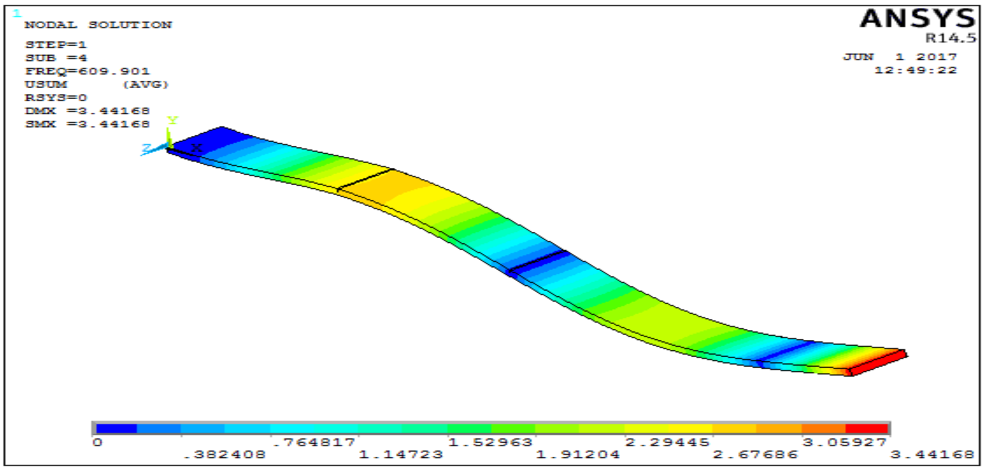
Fig. 3.7 Mode Shapes for 2 mm crack for Cantilever Beam Model(L=125and 250mm)



Ist mode shape

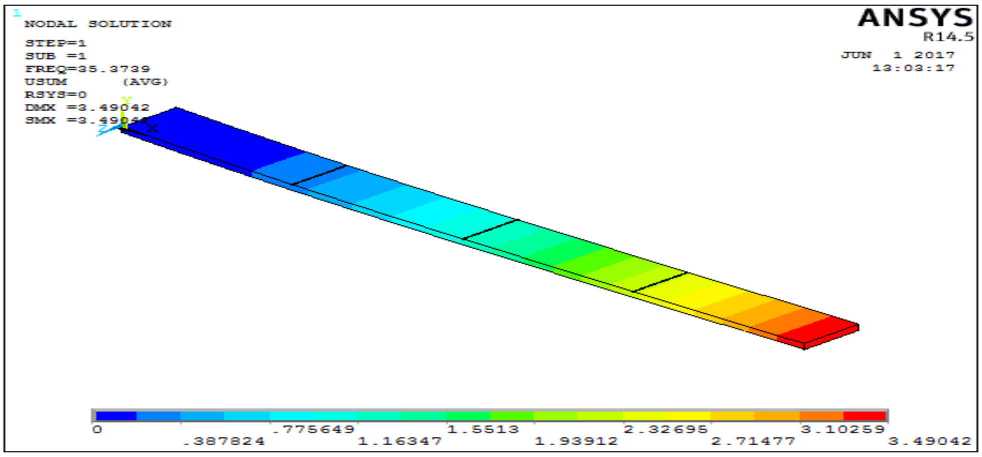


IInd mode shape

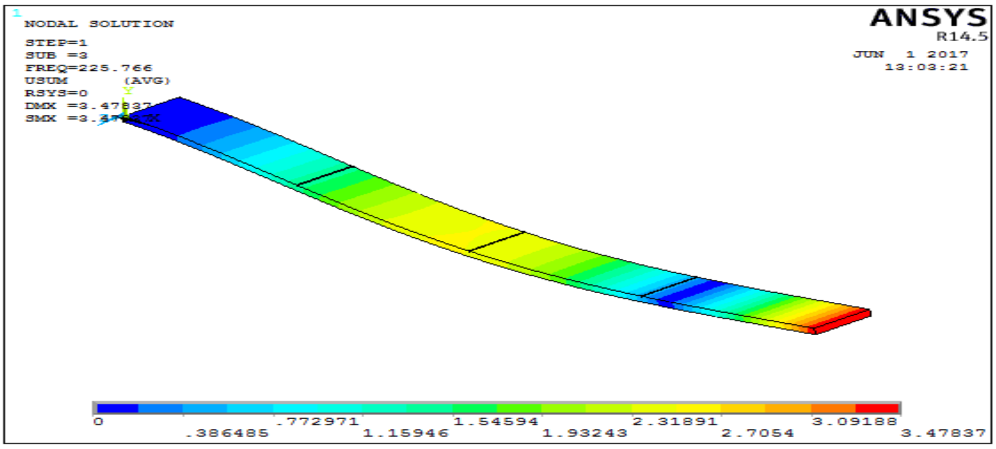


IIIrd mode shape

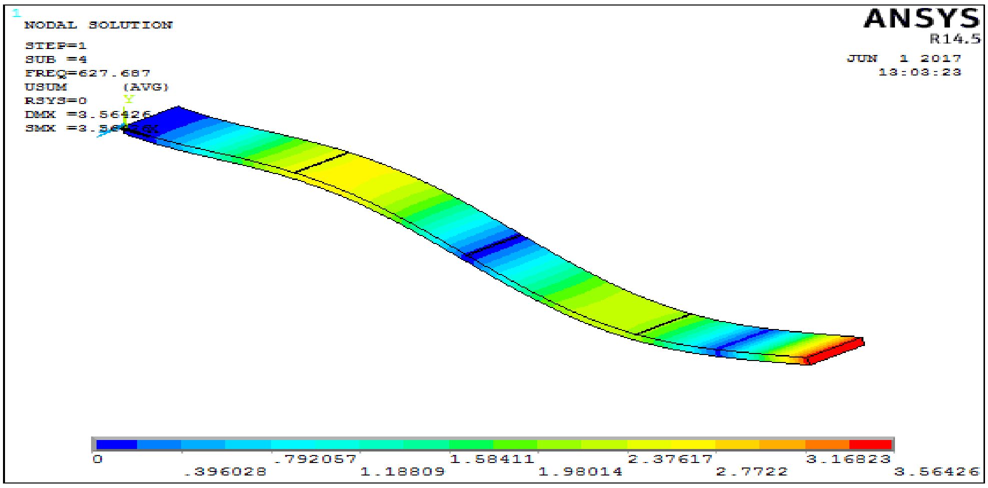
Fig. 3.8 Mode Shapes for 3 mm crack for Cantilever Beam Model(L=125and 250mm)



Ist mode shape

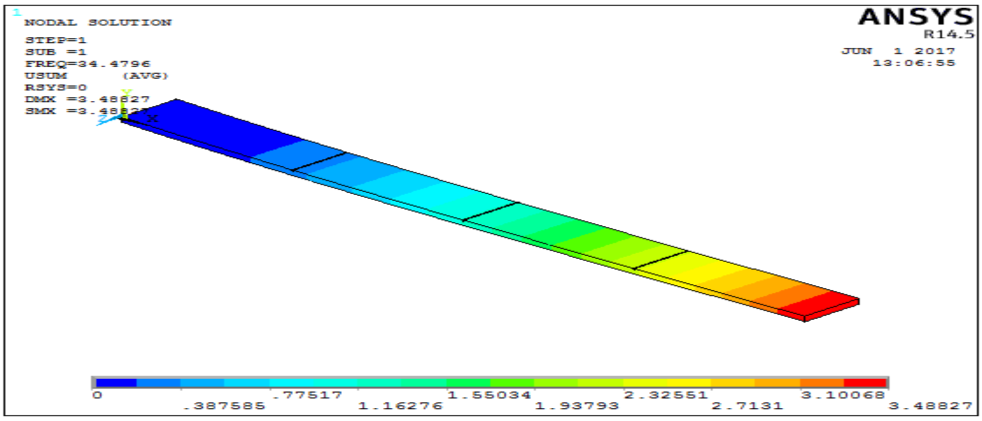


IInd mode shape



IIIrd mode shape

Fig. 3.9 Mode Shapes for 1 mm crack for Cantilever Beam Model(L=125,250 and 375mm)



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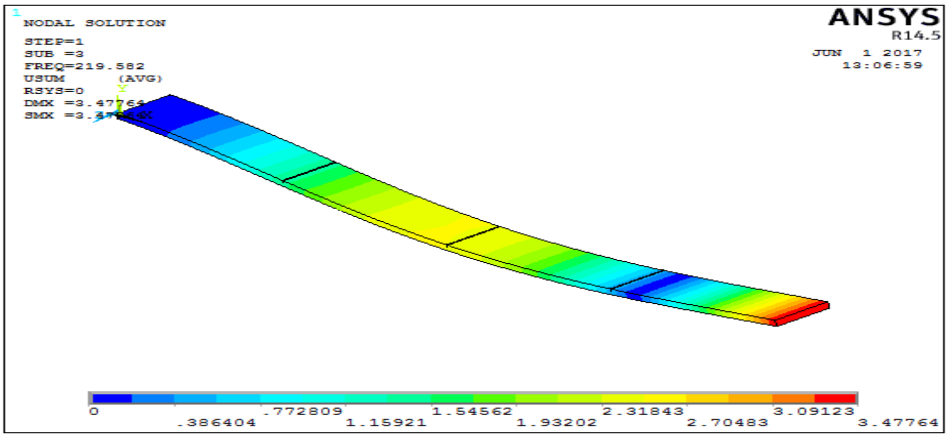

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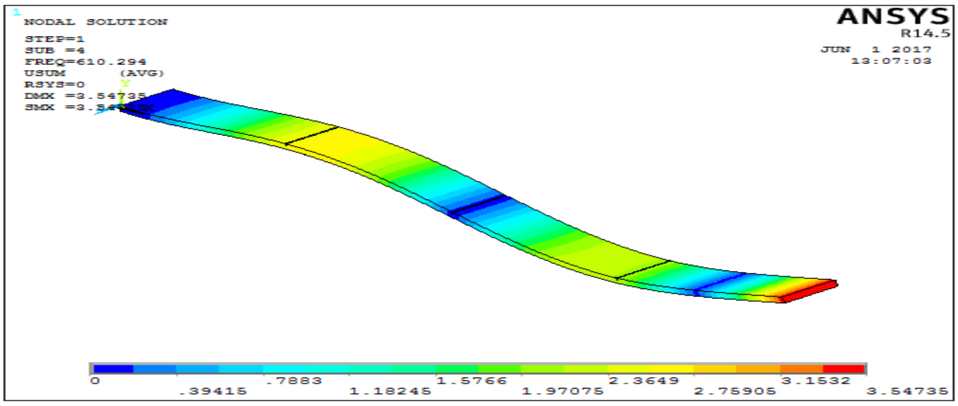
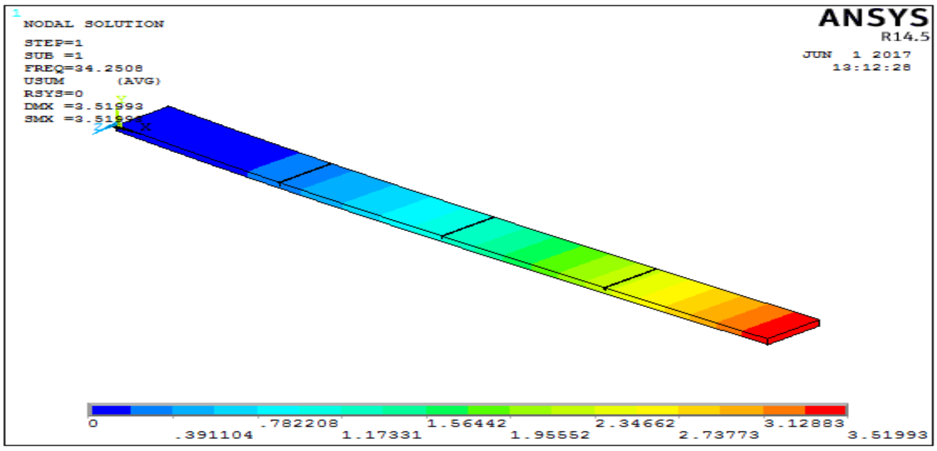


IIIrd mode shape

Fig. 3.10 Mode Shapes for 2 mm crack for Cantilever Beam Model(L=125,250 and 375mm)



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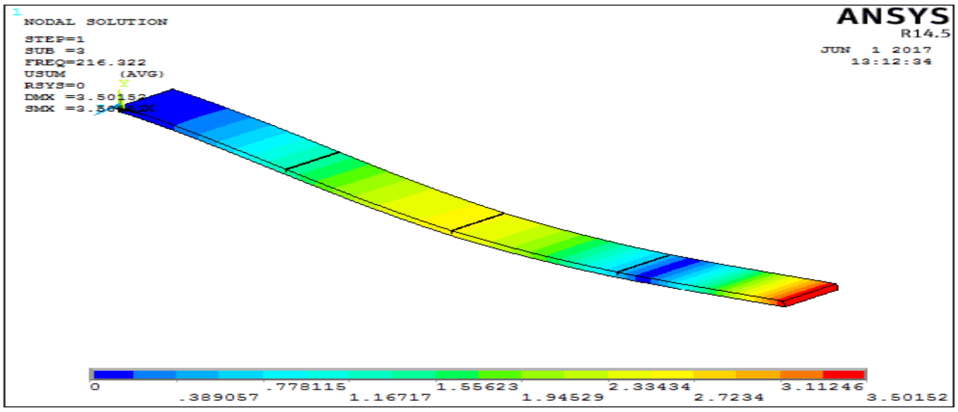

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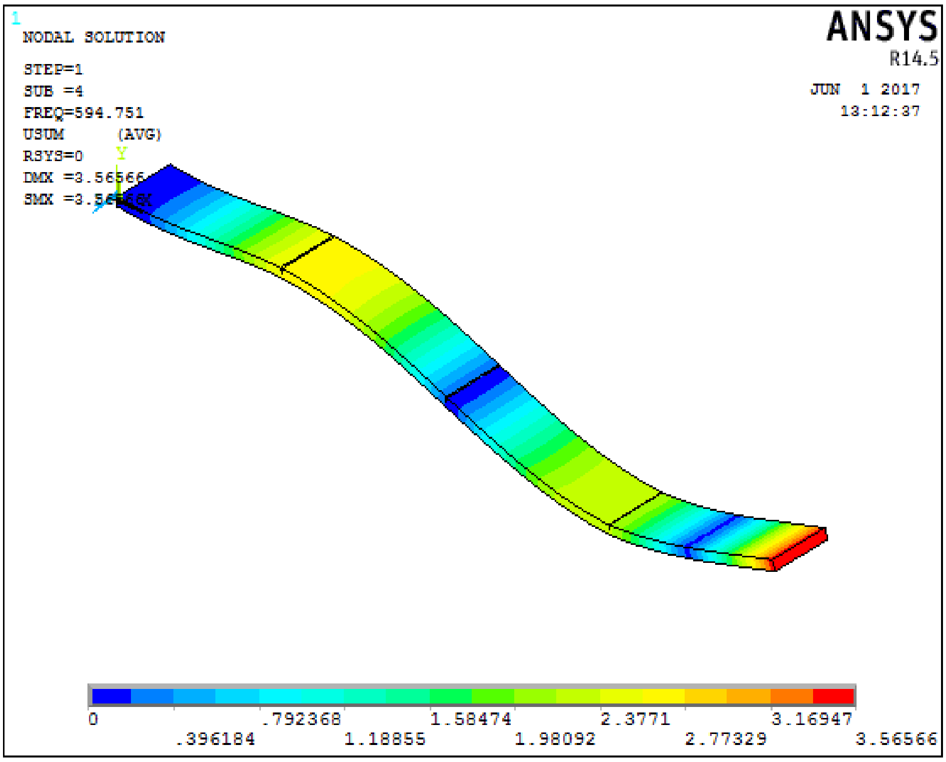

IIIrd mode shape

Fig. 3.11 Mode Shapes for 3 mm crack for Cantilever Beam Model(L=125,250 and 375mm

Table-3.2 Natural Frequencies for Uncracked Beam by FEM

CRACK POSITION	DEPTH	NATURAL FREQUENCY				
		1st mode	2nd mode	3rd mode	4th mode	5th mode
		Ansys	Ansys	Ansys	Ansys	Ansys
UN-CRACKED	0mm	21.68	135.81	380.08	744.32	1229.6

Table-3.3 Natural Frequencies for different Crack Depth at L_1=125mm by FEM

CRACK POSITION	DEPTH	NATURAL FREQUENCY				
		1st mode	2nd mode	3rd mode	4th mode	5th mode
		Ansys	Ansys	Ansys	Ansys	Ansys
125mm	1mm	35.25	222.60	621.83	1219.71	1990.54
	2mm	34.60	220.64	611.24	1204.1	1971.01
	3mm	34.37	224.58	613.54	1197.61	1996.71

Table-3.4 Natural Frequencies for different Crack Depth at L_2=125 and 250mm by FEM

CRACK POSITION	DEPTH	NATURAL FREQUENCY				
		1st mode	2nd mode	3rd mode	4th mode	5th mode
		Ansys	Ansys	Ansys	Ansys	Ansys
125&250mm	1mm	35.59	222.82	619.66	1218.75	1971.88
	2mm	34.65	218.36	611.33	1190.45	1990.86
	3mm	34.25	215.88	609.90	1150.59	1977.7

Table-3.5 Natural Frequencies for different Crack Depth at L_1=125 ,250 and 375mm by FEM

CRACK POSITION	DEPTH	NATURAL FREQUENCY				
		1st mode	2nd mode	3rd mode	4th mode	5th mode
		Ansys	Ansys	Ansys	Ansys	Ansys
125mm & 250mm & 375mm	1mm	35.37	225.76	627.28	1227.68	1999.45
	2mm	34.47	219.58	610.29	1183.02	1977.62
	3mm	34.25	216.32	594.75	1120.6	1996.37

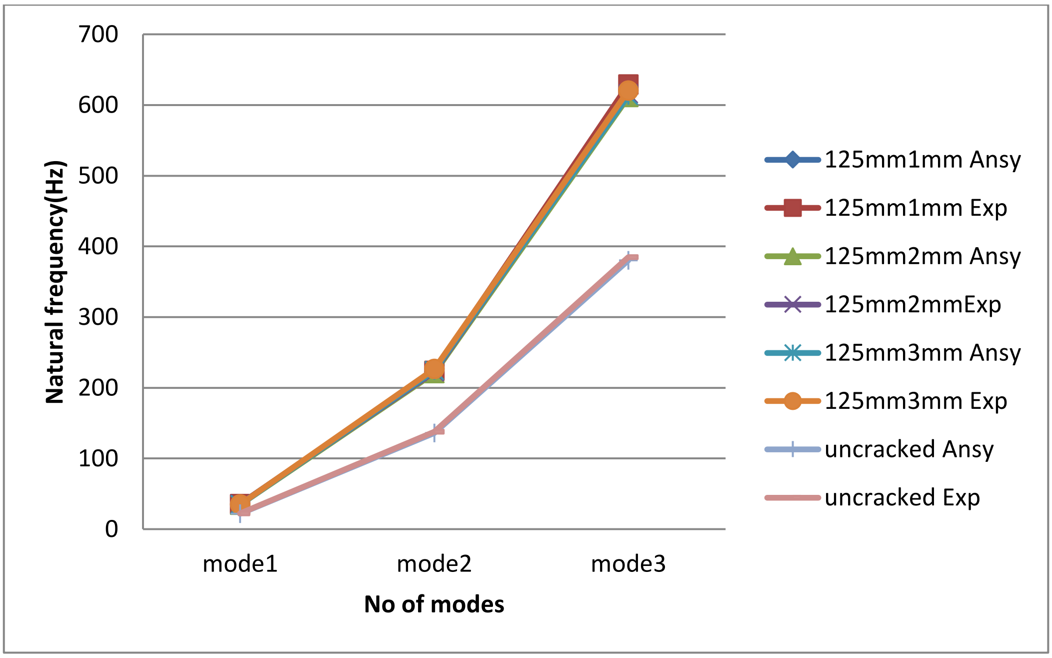

Fig. 3.12 Comparison for Natural Frequencies for uncracked Beam with Crack Beam L = 125mm

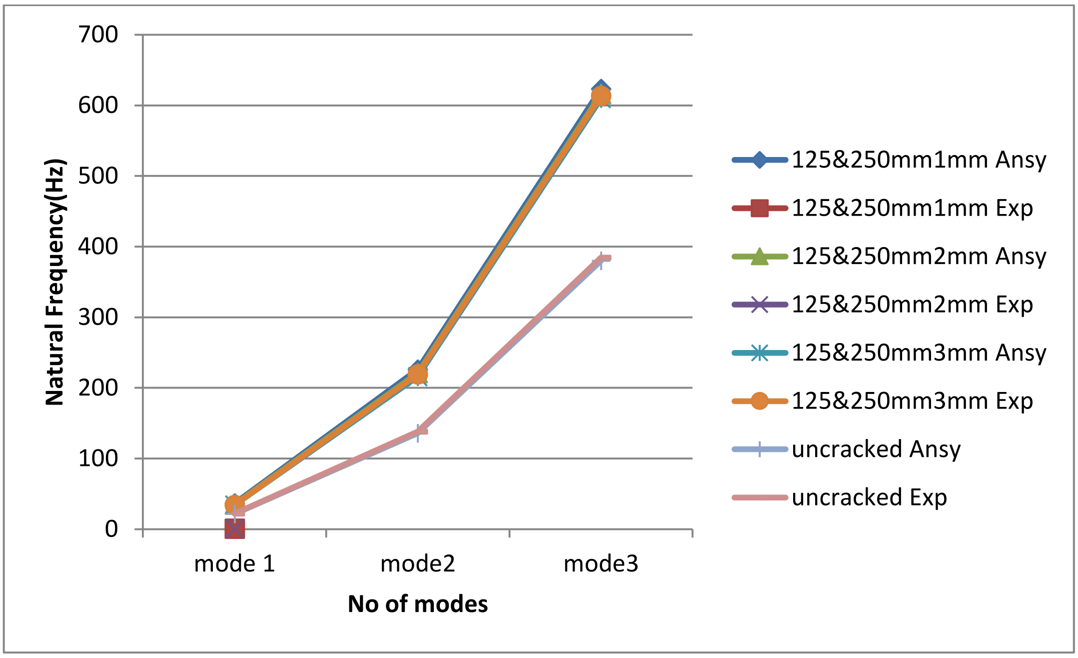

Fig. 3.13 Comparison for Natural Frequencies for uncracked Beam with Crack Beam L = 125mm&250mm

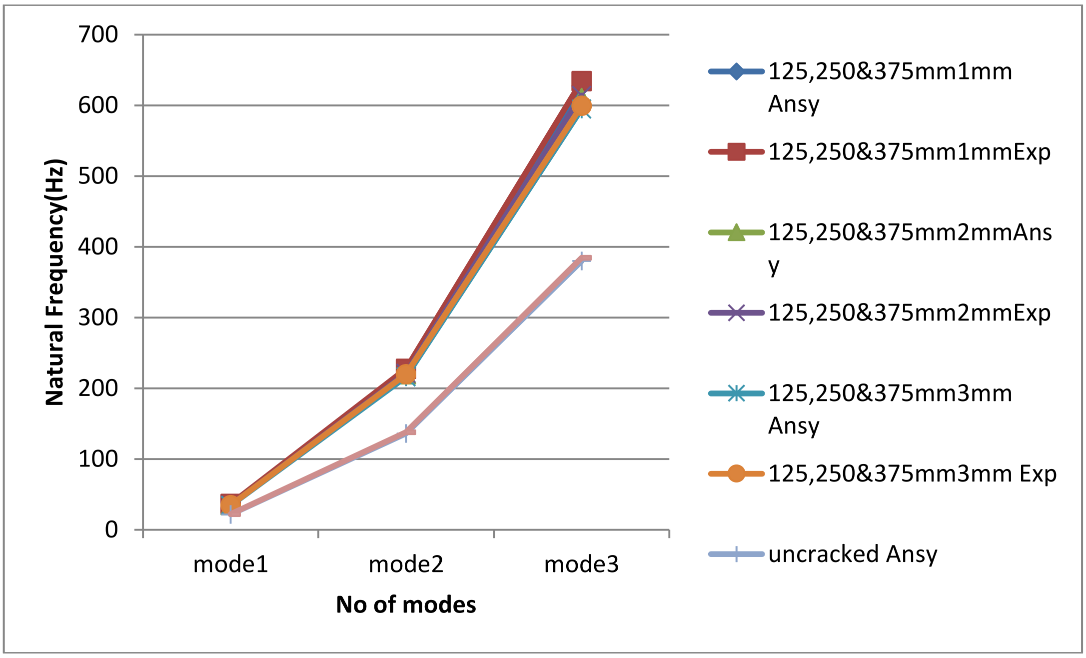

Fig. 3.14 Comparison for Natural Frequencies for uncracked Beam with Crack Beam L=125,250&375mm

The natural frequency obtained Experimentally compared with FEM both the results was with close agreement. The variation between ANSYS results and Experimental results are due to different crack depth and crack distance. The fundamental mode shapes for vibration of cracked and un-cracked beams are plotted. The results obtained from the Experimental and FEA analysis are presented in graphical form. The first to fifth natural frequencies corresponding to various crack locations and depths are obtained. The lowest frequency was in mode 1. The frequency was increasing with each subsequent mode of vibration. The percentage of error was also decreasing as frequency is increasing. Results show that there is an appreciable variation between natural frequency of cracked and un-cracked cantilever beam.

V. CONCLUSION

The difference in deflection value is found to be maximum at the crack section and this information may therefore be used to detect the resistance of a crack including its location and the severity of the crack. The proposed method is simple and easy to implement as it entails only static effect measurements. Repair is carried out by placing a small piezoelectric patch directly under the crack so as to induce a local moment upon application of a suitable voltage to the piezoelectric actuators.

The vibration analysis of a structure holds a lot of significance in its designing and performance over a period of time. In aluminum cantilever beam with one end fixed and one end free, it was seen that the results were in good co-ordinance with FEA by ANSYS and Experimental by spectra plus software values. It is seen that the natural frequency changes substantially due to the presence of cracks. The changes depending upon the location and depth of cracks. In the FEA and Experimental setup, crack depth and crack location are taken as the input and the structural natural frequencies are taken as output. From the both methods, it is observed that the first natural frequency increases as the crack location moves from the clamped end to the free end when the crack depth is kept constant. Whereas, the second to fifth natural frequencies decreases as the crack depth increases.

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