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Vibration Analysis of Beam With Varying Crack Location

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Abstract— The importance of the beam and its engineering applications is obvious, and it undergoes different kinds of loading. Such loading may cause cracks in the beam. Crack depth and location are the main parameters for the vibration analysis of such beams. These cracks and their locations effect on the shapes and values of the beam frequency. So it becomes very important to monitor the changes in the response parameters of the beam to access structural integrity, performance and safety.

In the current work, the natural frequency of a simply supported beam with a triangular crack, is investigated numerically by finite element method using of FE analysis software ANSYS. Different crack location effects are considered and the results are compared with that of the simply supported beam without crack. The results obtained from the vibration analysis of the beam show that the lowest fundamental frequency of the beam without crack is higher than the lowest frequency obtained for beam with cracks. When the location of the crack varies from the either end of the simply supported beam to the centre of the beam the lowest natural frequency decreases.

Keywords— Vibration Analysis, ANSYS, Beam, Crack, natural frequency

INTRODUCTION

Many engineering components used in the aeronautical, aerospace and naval construction industries are considered by designers as vibrating structures, operating under a large number of random cyclic stresses. Cracks found in structural elements like beams and columns have different causes. They may be fatigue cracks that take place under service conditions as a result of the limited fatigue strength. They may be also due to mechanical defects, as in the turbine blades of jet engines. In these engines the cracks are caused by sand and small stones sucked from the surface of runway. Another group involves cracks which are inside the material. They are created as a result of manufacturing processes. The presence of vibrations on structures and machine components leads to cyclic stresses resulting in material fatigue and failure.

Experimental based testing has been widely used as a means to analyze individual elements and the effects of beam strength under loading. While this is a method that produces real life response, it is extremely time consuming and the use of materials can be quite costly. The use of finite element analysis to study these components has also been used. In recent years, however, the use of finite element analysis has increased due to progressing knowledge and capabilities of computer software and hardware. It has now become the choice method to analyze such structural components.

A crack on a structural member introduces a local flexibility which is a function of the crack depth. Major characteristics of structures, which undergo change due to presence of crack, are

The natural frequency b) The amplitude response due to vibration c) Mode shape.

Hence it is important to use natural frequency measurements to detect crack and its effects on the structure.

OBJECTIVE OF THE WORK

The objective of this study is to analyze the vibration behaviour of a simply supported beam using FEM software ANSYS subjected to a single triangular crack under free vibration. Material properties of steel are considered for the simply supported beam. Besides this, information about the variation in location and depth of cracks in cracked steel beams is obtained using this technique. Dynamic characteristics of damaged and undamaged materials are very different. For this reason, material faults can be detected, especially in steel beams, which are very important construction elements because of their wide spread usage construction and machinery. Cracks in vibrating components can initiate catastrophic failures. Therefore, there is a need to understand the dynamics of cracked structures. When a structure suffers from damage, its dynamic properties can change. Specifically, crack damage can cause a stiffness reduction, with an inherent reduction in natural frequencies, an increase in modal damping, and a change in the mode shapes. Since the reduction in natural frequencies can be easily observed, most researchers use this feature. Natural frequencies and mode shapes of the beam are also been determined.

LITERATURE REVIEW

The combination of rails, fitted on sleepers with a suitable fastening system and resting on ballast and subgrade is The effect of a crack on the deformation of a beam had been considered as an elastic hinge by Chondros and Dimarogonas [2].Variations of the natural frequencies were calculated by a perturbation method. A finite element model had been proposed , in which two different shape functions were adopted for two segments of the beam, in order to consider the discontinuity of deformation due to the crack. Cawley and Adams [1] showed that the stress distribution in a vibrating structure was non-uniform and was different for each mode of vibration. Therefore, any local crack would affect each mode differently, depending on the location of the crack. Chondros and Dimarogonas [3] used the energy method and the continuous cracked beam theory to analyze transverse vibration of cracked beams.

Ertugrul Cam et. al. [4], presented information about the location and depth of cracks in cracked beams. For this purpose, the vibrations as a result of impact shocks were analyzed. The signals obtained in defect-free and cracked beams were compared in the frequency domain. The results of the study suggest to determine the location and depth of cracks by analyzing the from vibration signals. Experimental results and simulations obtained by the software ANSYS are in good agreement. The first two natural frequencies were used by Narkis [5] to identify the crack and later Morassi [6] used it on simply supported beam and rods. Although it can be solved by using 2D or 3D finite element method (FEM), analysis of this approximate model results in algebraic equations which relate the natural frequencies of beam and crack characteristics.

Freud and Herrmann [9] modelled the problem using a torsional spring in the place of crack whose stiffness is related. The first model is used to Euler-Bernoulli cracked beam with different end conditions [7, 8, 10-24, 1] and recently on Timoshenko beams [15, 16]. Luay S. Al-Ansari [17] presented a comparison of the natural frequency between solid and hollow simple supported cracked beam for different crack depths and positions. Three methods utilized in this research experimental and two numerical method (Rayleigh Method and Finite Element Method (using ANSYS)).

The identification of location and the depth of crack in a beam containing single transverse crack was done by Pankaj Charan et al. [18] through theoretical and experimental analysis respectively. It was noticed that a crack in a beam has great effect on dynamic behaviour of beam. The strain energy density function was also applied to examine the few more flexibility produced to because of the presence of crack.

Muhannad Al-Waily [19] conducted studies on cracked of beam with different supports. The analytical results revealed the effect of a crack in a continuous beam and the parameters calculated were the equivalent stiffness, EI, for a rectangular beam to involve an exponential function with depth and location of crack effect, with solution of assuming equivalent stiffness beam (EI) by using of Fourier series method. And, the beam materials studied were low carbon steel, Alloys Aluminium, and Bronze materials with different beam length and depth. A comparison made between analytical results from theoretical solution of general equation of motion of beam with crack effect with numerical by ANSYS results, where the biggest error percentage is about (1.8 %).

MODELLING OF SIMPLY SUPPORTED BEAM

Design of Beam Without Crack:

A slender, elastic beam of length L, width W, and height H is considered for frequency analysis. For vibration analysis, the model has been built in ANSYS 12.1 Mechanical APDL. The length of the beam (L) is taken as 0.5 m, width (W) is taken as 15 mm, and height (H) is taken as 25 mm. Material of the simply supported beam is considered as steel and its properties taken are Young's elastic modulus as 207 GPa, Poisson's ratio as 0.3 and density as 7800 kg/m3. The beam considered for modelling in ANSYS is shown in Fig.1. and the volumetric model of the beam modelled in ANSYS is shown in Fig.2.

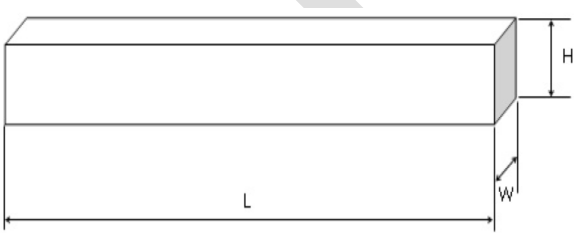

Fig.1. *Simply Supported beam without crack*

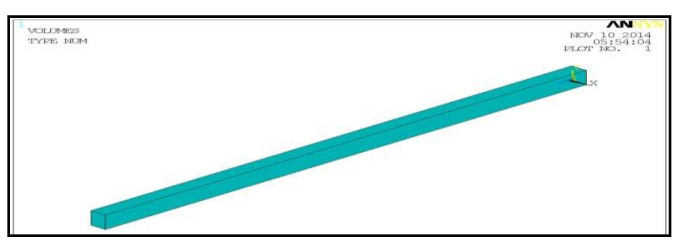

Fig.2. *Model of the Simply Supported Beam modelled in ANSYS*

Design of Beam With Crack:

For vibration analysis of a cracked beam, a triangular crack with a minimum depth of 10 mm and width of 5 mm is considered. The initial position of the crack is taken at a location 100 mm from one end of the beam. Later, for comparative analysis the crack location is varied between 100 mm to 450 mm with an increment of 50 mm for one criteria, and in a second criteria the crack depth is varied from 10 mm to 15 mm with an increment of 0.5 mm. The cracked beam considered with different parameters is shown in Fig.3 and the volumetric model of cracked beam built in ANSYS is shown in Fig.4.

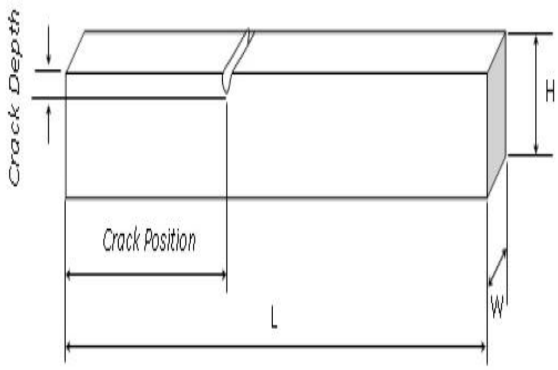

Fig.3. *Simply Supported beam with crack*

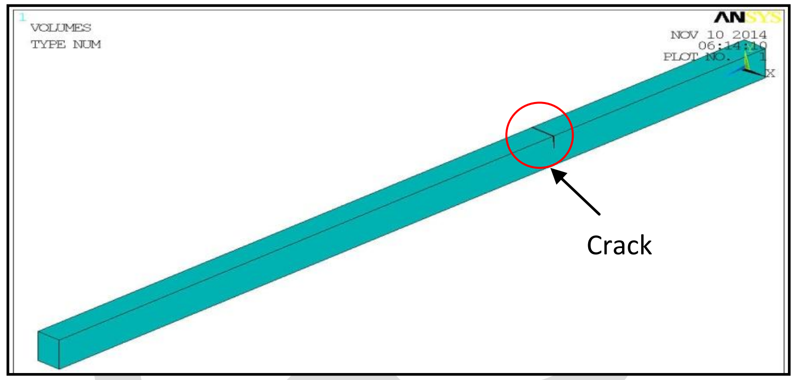

Fig.4. *Model of the Simply Supported Beam with crack modelled in ANSYS*

FE Modeling of Beam with and without crack:

The built volumetric model in ANSYS is discretized using SOLID 186 tetrahedral 20 node brick elements. The FE model of the simply supported beam consists of 201 elements and 543 nodes. The discretized beam model is shown in Fig.5. The beam model with crack is also discretized in a similar fashion of the beam discretized without crack. SOLID 186, 20 node tetrahedral brick node elements are used for generating the mesh. For accurate results, the generated mesh is refined at the internal areas of the crack. The FE model of the simply supported beam with crack consists of 354 elements and 926 nodes. The discretized beam model is shown in Fig.6.

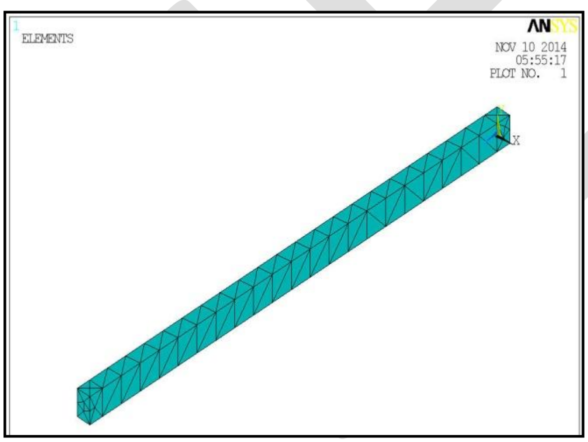

Fig.5. *Discretized Model of Beam*

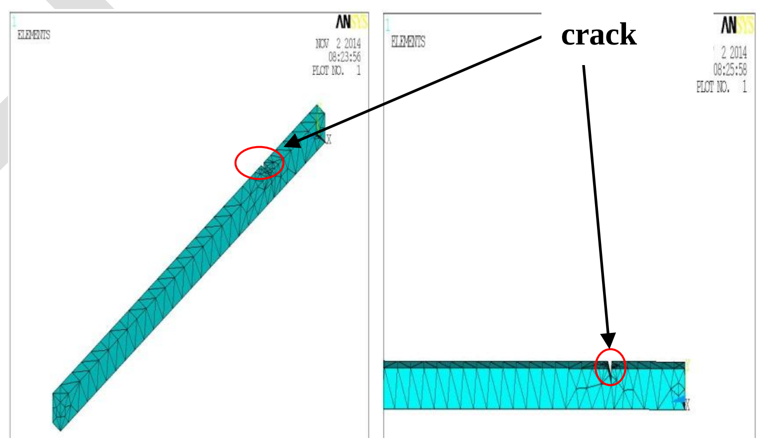

Fig.6. *Discretized Model of Beam with Crack*

VIBRATIONAL ANALYSIS OF BEAM MODEL

Boundary conditions:

The beam considered here is a simply supported beam. Hence, the vertical (Y-directional) displacements at the bottom edges of the beam model at both ends are to be restricted. The bottom edges at both the ends are constrained in the solution module as below. The edges of the simply supported beam constrained in UY direction is shown in Fig.7.

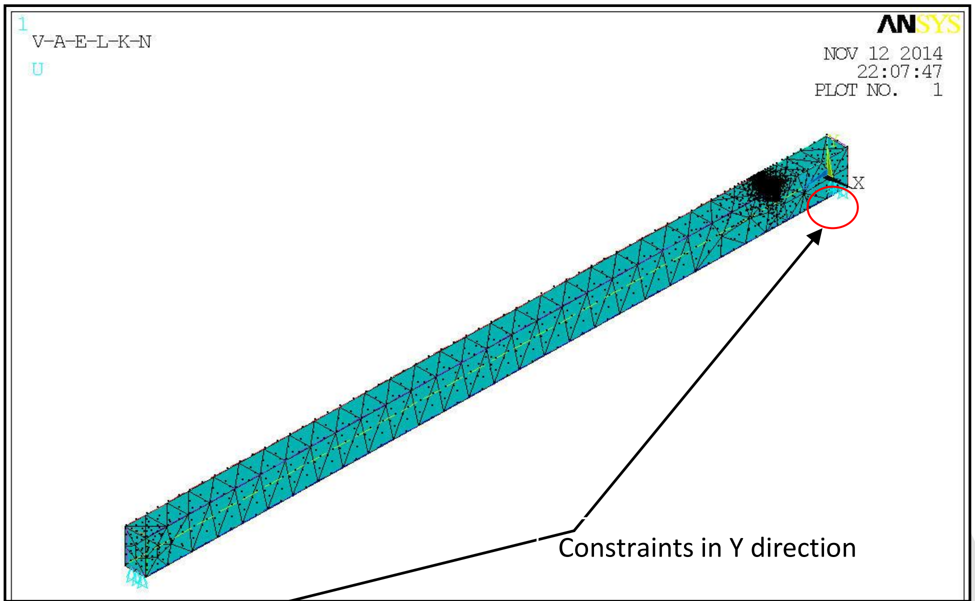

Fig.7. *Constrained Model of Simply Supported Beam*

Vibration Analysis of Beam without Crack:

The first step in the vibration analysis of the beam is to find its natural frequencies. In ANSYS, modal analysis used to find the eigen natural frequencies. Initially the beam is taken without any defect(crack). A minimum of first five mode shapes and natural frequencies are obtained and shown in Table 1. Block Lanczos method which is generally used in case of symmetric structures is used to find the fundamental frequencies. The lowest frequency of the simply supported beam is found to be 232.62 Hz with a maximum displacement of 1.165 mm. The mode shape and obtained lowest frequency for the simply supported beam without crack are shown in Fig.8. The maximum displacement can in case of lowest natural frequency can be observed at the centre of the beam.

Table 1: *Modes and Frequencies of simply supported beam*

Mode No.	Frequency (Hz)
1	232.62
2	316.96
3	870.37
4	919.03
5	1697.7

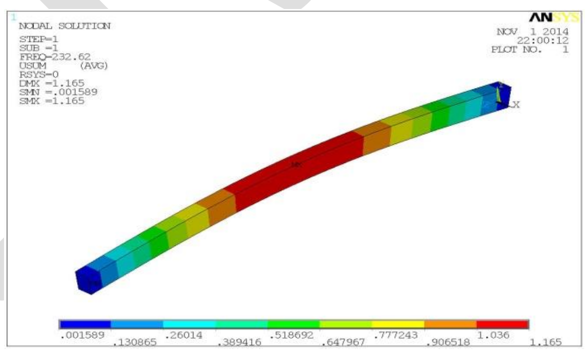

Fig .8 :*Mode 1 of Simply Supported Beam without crack*

Vibration Analysis of Beam with Varying Crack Location:

A triangular crack is introduced in the simply supported beam model for further eigen frequency vibration analysis. Initially the triangular crack is assumed to be located at 50 mm from the right end side of the beam model, which has been explained earlier. The dimensions of the triangular crack are shown in the table below.

Table 2: *Crack dimensions*

Crack Parameter	Value	Orientation
Crack Width	5 mm	along length of beam
Crack Depth	10 mm	along height of beam
Crack Length	15 mm	along width of beam

Under simply supported condition the first five natural frequencies and mode shapes of the beam are obtained in ANSYS modal analysis using Block Lanczos method. The lowest frequency is found to be 230.74 Hz. The location of the crack which is initially assumed to be 50 mm from the right end of the simply supported beam is varied step by step at 100 mm, 150 mm, 200 mm, 250 mm, 300 mm, 350 mm, 400 mm, 450 mm. Similarly, fundamental frequencies and mode shapes for the step by step crack locations are obtained. The first five frequencies for various crack locations from right end of the beam to left end of the beam are shown in tables 3 to 11.

Table 3: *Frequencies for crack location 50mm*

Mode No.	Frequency (Hz)
1	230.74
2	316.79
3	867.35
4	893.09
5	1682.3

Table 4: *Frequencies for crack location 100mm*

Mode No.	Frequency (Hz)
1	226.87
2	315.73
3	858.94
4	865.66
5	1665.2

Table 5: *Frequencies for crack location 150mm*

Mode No.	Frequency (Hz)
1	220.81
2	313.31
3	852.16
4	862.59
5	1680.6

Table 6: *Frequencies for crack location 200mm*

Mode No.	Frequency (Hz)
1	219.02
2	311.56
3	862.56
4	899.12
5	1686.3

Table 7: *Frequencies for crack location 250mm*

Mode No.	Frequency (Hz)
1	215.51
2	309.82
3	868.70
4	917.31
5	1665.3

Table 8: *Frequencies for crack location 300mm*

Mode No.	Frequency (Hz)
1	218.68
2	311.52
3	862.21
4	898.49
5	1688.0

Table 9: *Frequencies for crack location 350mm*

Mode No.	Frequency (Hz)
1	220.88
2	313.34
3	852.22
4	862.86
5	1680.4

Table 10: *Frequencies for crack location 400mm*

Mode No.	Frequency (Hz)
1	227.05
2	315.81
3	859.22
4	867.02
5	1665.1

Table 11: *Frequencies for crack location 450mm*

Mode No.	Frequency (Hz)
1	230.68
2	316.80
3	867.72
4	892.20
5	1684.1

The lowest frequency mode shapes obtained for each step varying at location 50 mm to 450 mm along the length of beam are shown from Fig.9 to Fig 17. It can be observed from the above results tables that the lowest fundamental frequency of the cracked beam decreases when the crack location varies from 50 mm to 250 mm, i.e. till the mid span of the beam and then it increases from the mid span of the beam to the crack location at 450 mm. The comparison of the lowest fundamental frequency of the cracked beam with varying crack location is shown in Table 12 and in the plot Fig.18.

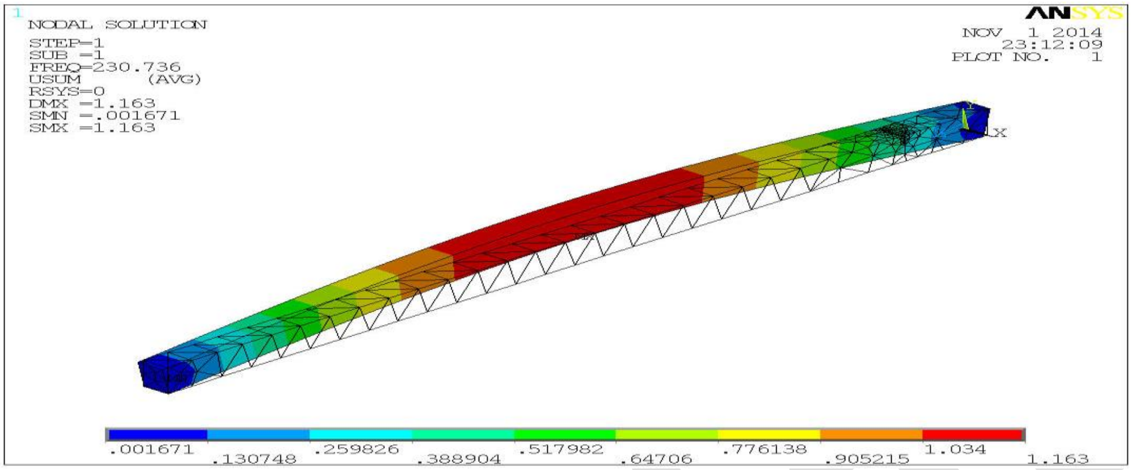

Fig 9. *Mode 1 of Simply Supported Beam with crack located at 50 mm from right end* **(***deformed and undeformed)*

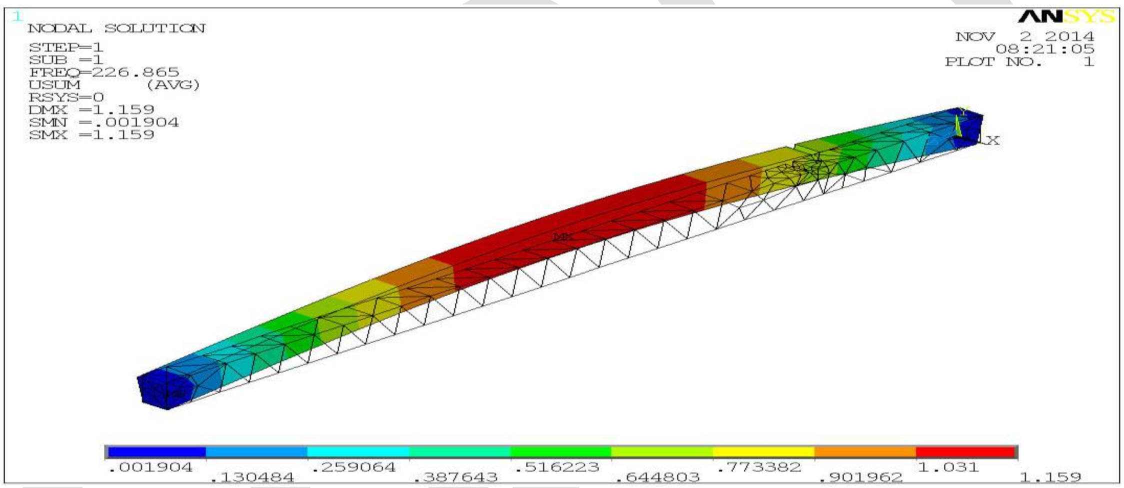

Fig .10. *Mode 1 of Simply Supported Beam with crack located at 100 mm from right end* **(***deformed and undeformed)*

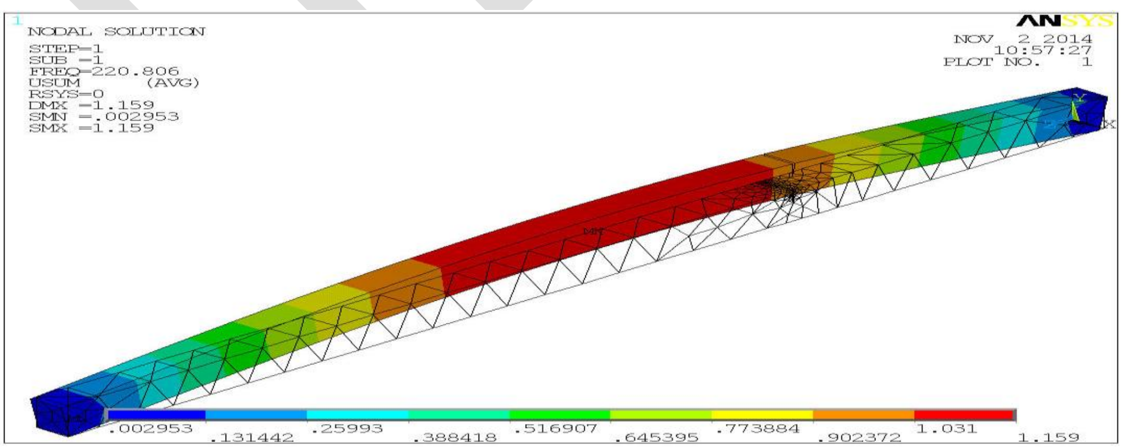

Fig.11. *Mode 1 of Simply Supported Beam with crack located at 150 mm from right end* **(***deformed and undeformed)*

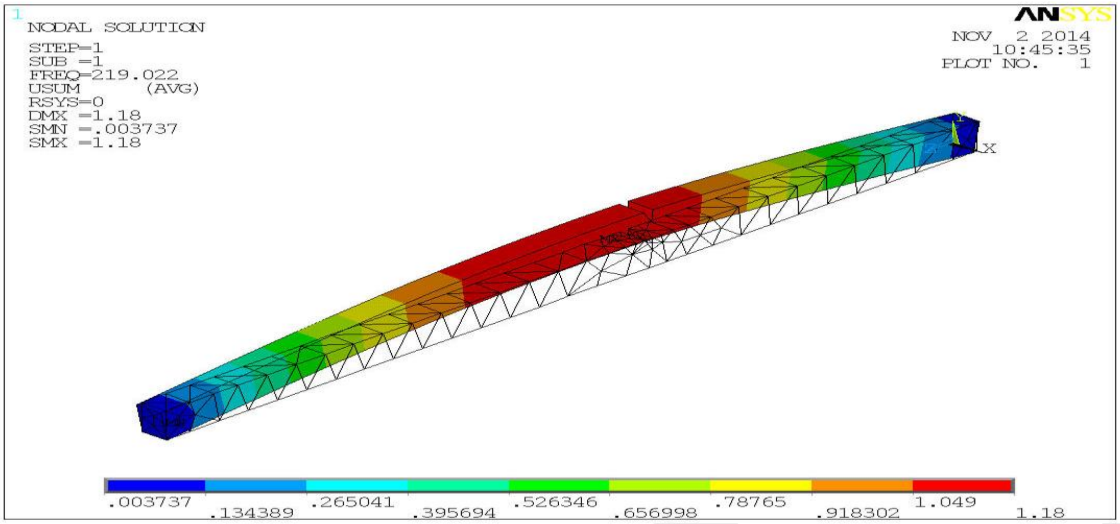

Fig.12. *Mode 1 of Simply Supported Beam with crack located at 200 mm from right end* **(***deformed and undeformed)*

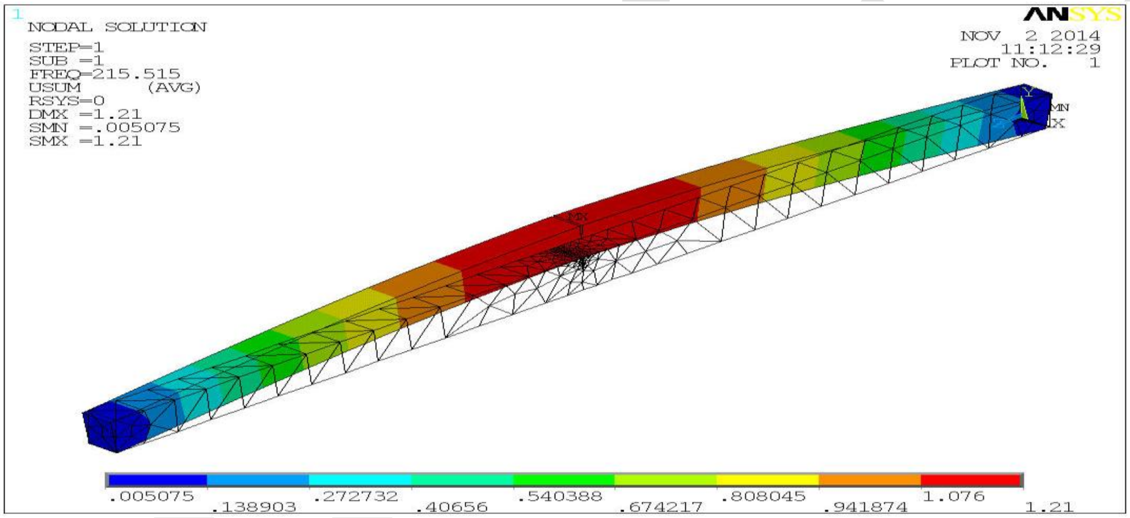

Fig.13. *Mode 1 of Simply Supported Beam with crack located at 250 mm from right end* **(***deformed and undeformed)*

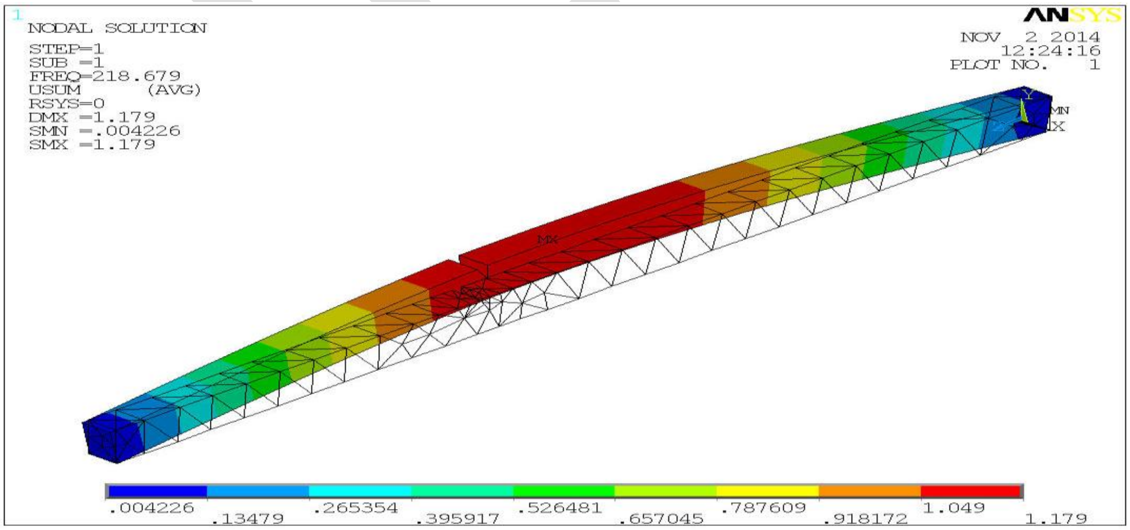

Fig.14. *Mode 1 of Simply Supported Beam with crack located at 300 mm from right end* **(***deformed and undeformed)*

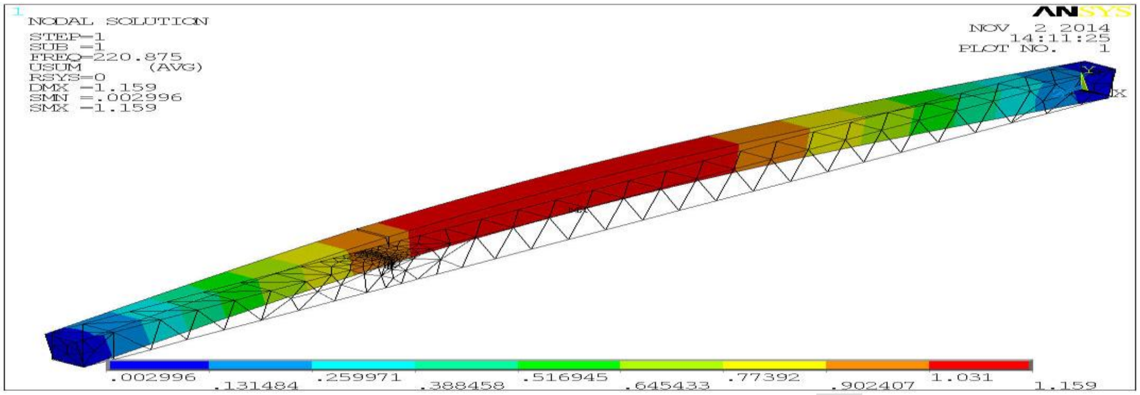

Fig.15. *Mode 1 of Simply Supported Beam with crack located at 350 mm from right end* **(***deformed and undeformed)*

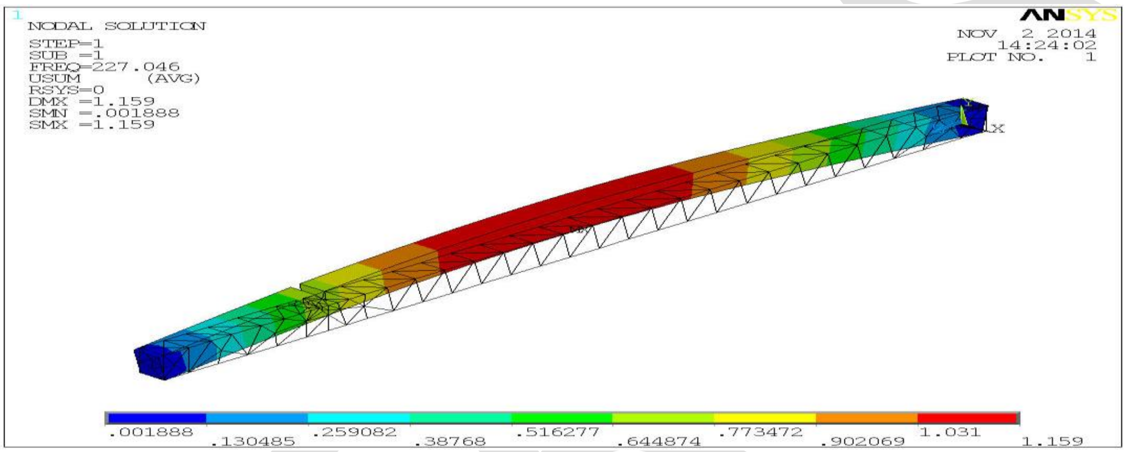

Fig.16 . *Mode 1 of Simply Supported Beam with crack located at 400 mm from right end* **(***deformed and undeformed)*

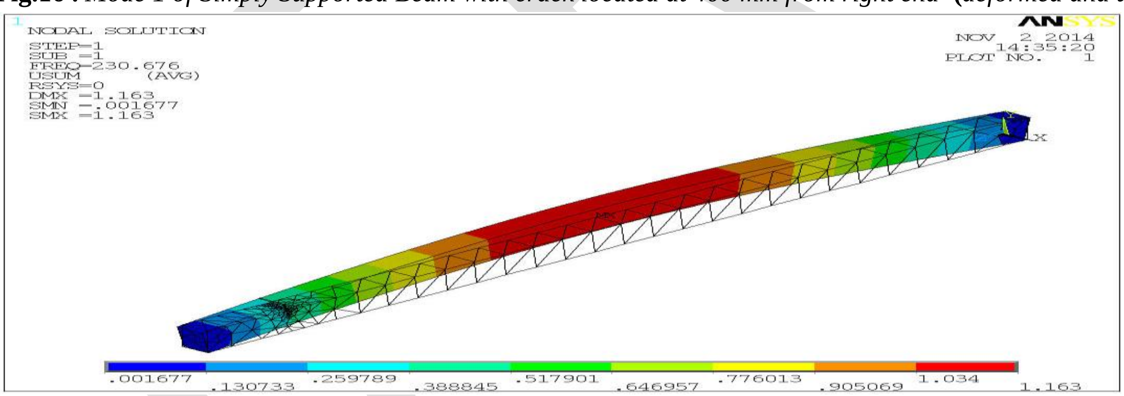

Fig.17 . *Mode 1 of Simply Supported Beam with crack located at 450 mm from right end* **(***deformed and undeformed)*

Table 12: *Comparison of Lowest Natural Frequencies with Varying Crack Location*

Crack Location from Right end of the beam in mm	Frequency of lowest Mode in Hz
50	230.74
100	226.87
150	220.81
200	219.02
250	215.51
300	218.68
350	220.88
400	227.05
450	230.68

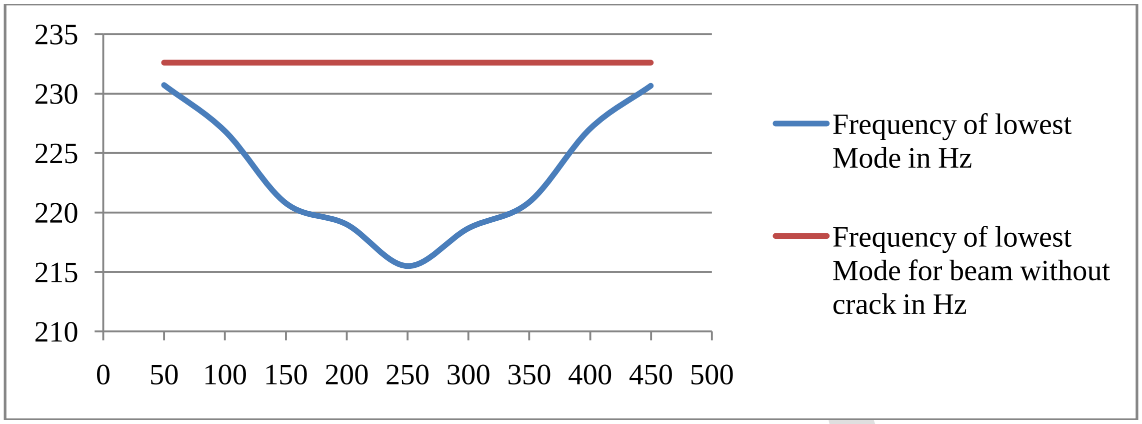

Fig.18. *Plot comparing lowest natural frequencies of beam without crack and with varying crack location from right to left end of the beam*

CONCLUSIONS

A slender, elastic steel beam of length(L) 0.5 m, width (W) 15 mm, and height (H) is 25 mm is considered for numerical analysis. Material properties of the simply supported beam are Young's elastic modulus is 207 GPa, Poisson's ratio is 0.3 and density as 7800 kg/m^3. Natural frequencies for beam without any crack defect are found and the lowest frequency is found to be 232.62 Hz. Then the beam model with a triangular crack located initially at 50 mm, and then the crack locations are varied at 50 mm step increment, i.e. crack locations are 100 mm,150 mm, 200 mm, 250 mm, 300 mm, 350 mm, 400 mm, and 450 mm respectively. The lowest frequencies found for each location of crack decrease from 50 mm to 250 mm, which is the mid span of the simply supported beam, and increase from there on.

Further it can be found that at symmetric positions of the crack position of the beam the lowest fundamental frequencies have almost equal value, i.e. for crack position at 50 mm the lowest frequency is 230.74 Hz and for crack position at 450 mm the lowest frequency is 230.68 Hz which is almost equal. This shows that the dynamic response of crack at symmetric locations of the beam is similar.

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