Finite element analysis of beam having crack at various locations

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Abstract- Beam like structures have wide application in engineering field. Earliest detection of damage is to avoid catastrophic failure in the structures. To predict the failure, changes in the dynamic responses are required to be analysed by using vibration analysis. Beam like structures have different type of loadings that may cause cracks in the beam. To ensure durable, safety and flawless performance during the lifetime of the beam like structures, it is mandatory to take care of cracks, inherent flaw and air voids in the structure. In case, if there is a pre-existing crack in the structure, mass and stiffness of the structure gets altered there by mode shape and natural frequency of the structure gets changed. In this work, vibration analysis of both un-cracked and cracked cantilever beam were done by commercially available Finite Element Analysis (FEA) software ANSYS. Natural frequency of the beam was obtained from vibration analysis. Beam having single edged notch at various locations were analysed and the results were compared with un-cracked beam. From the results, it is inferred that the fundamental frequency of the cracked beam reduces when the crack location moves from free end to fixed end and it is due to the stiffness reduction of the beam.

Index Terms- Finite Element Analysis, ANSYS, crack location, Fundamental Frequency, Vibration Analysis

I. INTRODUCTION

In aerospace and aeronautical industries, many engineering components are considered as vibrating structures under the cyclic stresses. In these structures, cracks may produce different causes. Mainly they may be fatigue cracks due to limited fatigue strength of the material and also due to mechanical defects in turbine blades of jet engines. In this, cracks are caused by small stones and sand sucked from the runway surface. At the time of manufacturing processes another group of cracks are created inside of the material. Structures and machine components under vibration leads to failure by cyclic stresses.

Many examples of structures like tall buildings, long span bridges, robot arms, beams that may be modelled with beam like structures. If damage occurs in the structures, physical properties like mass and stiffness of the structure changes as well as changes the modal properties like mode shape and natural frequency. It can lead catastrophic failure to the structure. To predict the Failure, vibration analysis can be used to detect changes in the dynamic responses of the structure.

In this work, the natural frequencies of cracked and un-cracked beams have been calculated by using Finite element software ANSYS Mechanical APDL 15.0. Dimensions of the beam and crack dimensions are taken from [7] Yamuna P. and Sambasivarao K. (2014).

The objectives of the work includes,

1. To analyse the FE model of un-cracked cantilever beam and cracked cantilever beam with single edged notch using FEM software ANSYS under free vibration.
2. To obtain the vibrational parameters at various crack locations in the beam using modal analysis.
3. To compare the results from vibration analysis of cracked beam with un-cracked beam.

II. METHODOLOGY

The methodology adopted for this work has been represented in the form of flow chart as shown in Figure 1.

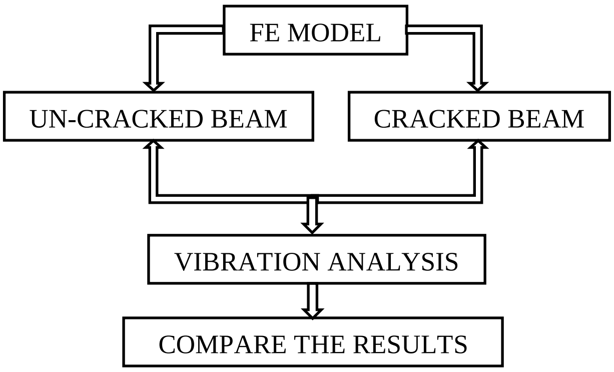
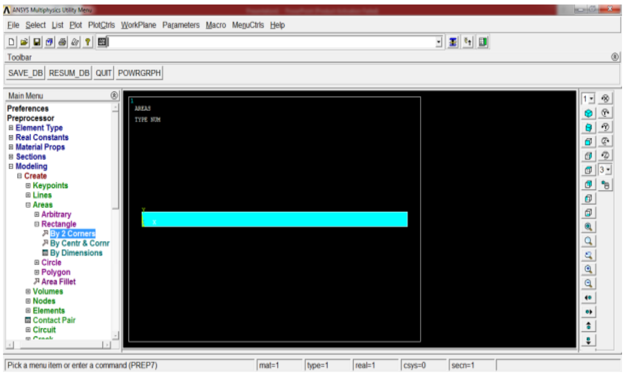


Fig 1 Flow Chart for Methodology

A. FE Modelling of Un-cracked Beam

An elastic, slender beam having Width (W) 0.015m, Height (H) 0.025m and Length (L) 0.5m is modelled by using FEA software ANSYS 15.0 Mechanical APDL. Initially the elements of quadrilateral 4 node PLANE 182 and brick 8 node SOLID 185 are selected. An area has been drawn by the use of Rectangle command as shown in Figure 2. Length of the beam has been taken as width of the Rectangle and height was same as like as beam.



Pick a menu item or enter a command (PREP7) mat=1 type=1 real=1 csys=0 secn=1

Fig 2 Areal Model

Meshing is done by the use of Mesh Tool. Smart size was selected and the range is set as 4 in Mesh Tool tab. Click mesh option in the tab and select the area drawn then the area should be discretized and again meshed. Figure 3. shows that discretized areal model of the un-cracked cantilever beam.

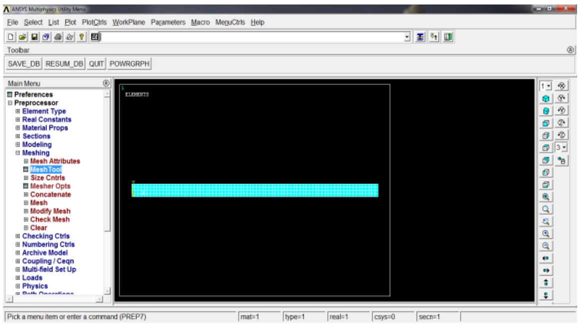


Fig 3 Discretized Areal Model

Then Select the Extrude option and the discretized areal model was selected and change the element from PLANE 182 to SOLID 185. Select the XYZ offset option and give the value of 0.015m in z-direction. Then volumetric discretized model had been made and shown in Figure 4.

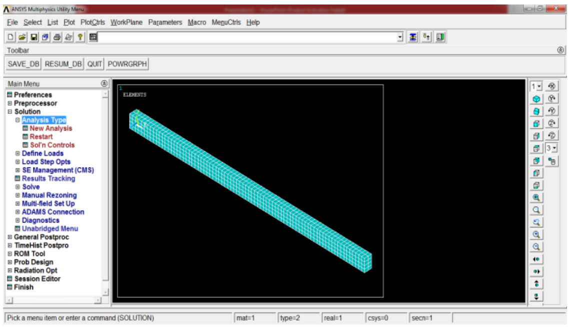


Fig 4 Discretized Volumetric Model

B. *FE Modelling of Cracked Beam*

Element Type and Material properties are same as like as Un-cracked beam. Areal model was created like Un-cracked beam and triangular area created at the top of the beam. Triangular area having width, depth and length are 0.005m, 0.01m, 0.015m respectively. Then the triangular area was subtract from the total area. This will produce a notch in the beam and it acts like a crack. Figure 5 shows that the areal model of cracked cantilever beam.

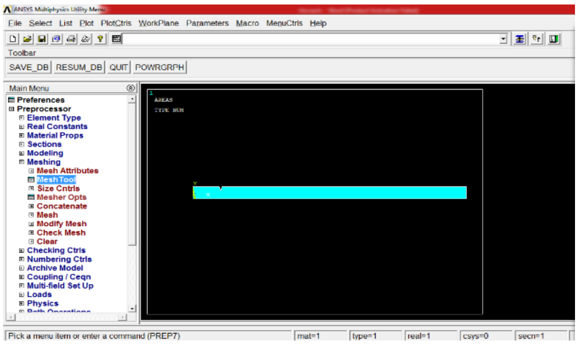


Fig 5 Cracked Areal Model

Initially the crack location was 0.05m from the left end. Later, Change the location of the crack along the length of the beam from 0.05m to 0.45m by the increment of 0.05m for comparative analysis. Meshing and volumetric model is same as like as Un-cracked beam. Figure 6 shows that the discretized volumetric model of cracked cantilever beam.

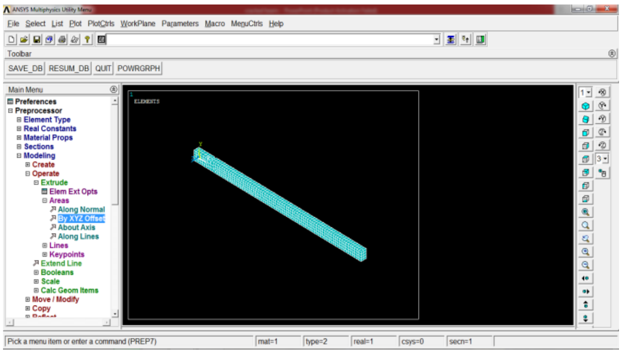


Fig 6 Discretized Volumetric Model of Cracked Beam

C. *Support Conditions*

Here the beam is considered as cantilever beam. So the support conditions of the cantilever beam are one end is fixed and another end is free. In a fixed end, displacements along all the directions are restricted. After the application of boundary conditions, constrained beam model has been created and it is shown in Figure 7.

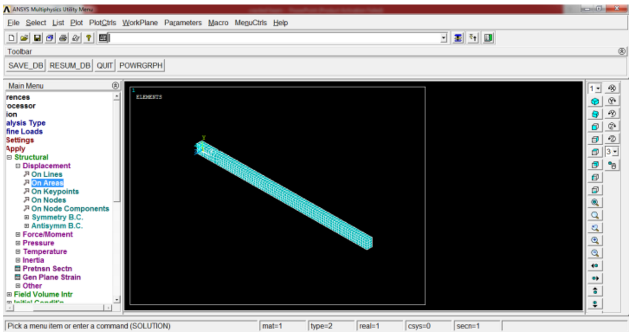
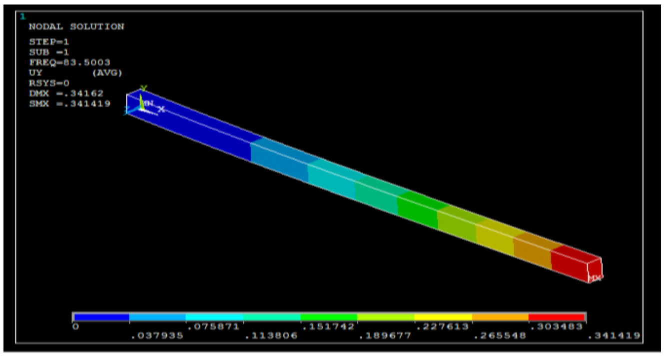


Fig 7 Constrained Model of Cantilever Beam

D. *Vibration Analysis of Un-cracked Beam*

To find natural frequencies of the beam is the first step of vibration analysis. In ANSYS, Eigen natural frequencies of the beam was found out by modal analysis. Initially, Un-cracked beam is taken for vibration analysis. Natural frequencies of first five modes are obtained by Block Lanczos method as shown in Table 1. It is the general method used to find the fundamental frequencies of symmetric structures. The fundamental frequency is found to be 83.5 Hz and as shown in Figure 8.



```
NODAL SOLUTION
STEP=1
SUB =1
FREQ=83.5003
UY        (AVG)
RSYS=0
DMX =.34162
SMX =.341419
```

Fig 8 Mode 1 of Un-cracked Beam

Table 1 Frequencies of Un-cracked Beam

Mode No	Frequency (Hz)
1	83.50
2	98.23
3	517.43
4	605.92
5	1424.00

E. *Vibration Analysis of Cracked Beam*

A notch was introduced into the cantilever beam model for vibration analysis. Initially, it was located 0.05m from the left end of the beam model. The first five natural frequencies are obtained by modal analysis using Block Lanczos method in ANSYS. Similarly first five natural frequencies are obtained for various crack locations of 0.1m, 0.15m, 0.2m, 0.25m, 0.3m, 0.35m, 0.4m and 0.45m from the left end of the cantilever beam model. The first five natural frequencies of the cracked cantilever beam having various crack locations are shown in Tables 2 to 10.

Table 2 Frequencies of Crack Location 0.05m

Mode No	Frequency (Hz)
1	76.78
2	95.64
3	504.23
4	600.14
5	1418.40

Table 3 Frequencies of Crack Location 0.1m

Mode No	Frequency (Hz)
1	78.69
2	96.38
3	518.23
4	605.89
5	1404.00

Table 4 Frequencies of Crack Location 0.15m

Mode No	Frequency (Hz)
1	80.31
2	97.01
3	513.11
4	604.46
5	1367.6

Table 5 Frequencies of Crack Location 0.2m

Mode No	Frequency (Hz)
1	81.40
2	97.52
3	498.73
4	599.93
5	1393.9

Table 6 Frequencies of Crack Location 0.25m

Mode No	Frequency (Hz)
1	82.34
2	97.87
3	488.70
4	596.69
5	1424.60

Table 7 Frequencies of Crack Location 0.3m

Mode No	Frequency (Hz)
1	83.08
2	98.14
3	491.53
4	597.04
5	1384.40

Table 8 Frequencies of Crack Location 0.35m

Mode No	Frequency (Hz)
1	83.48
2	98.31
3	501.00
4	600.32
5	1340.70

Table 9 Frequencies of Crack Location 0.4m

Mode No	Frequency (Hz)
1	83.70
2	98.44
3	512.86
4	604.06
5	1369.50

Table 10 Frequencies of Crack Location 0.45m

Mode No	Frequency (Hz)
1	83.79
2	98.54
3	518.10
4	606.45
5	1417.30

The fundamental frequency of the cracked beam having various crack locations of 0.05m to 0.45m along the length of the beam are shown in Figures 9 to 17. From the results in tables show that the fundamental frequency of the cracked beam reduces when the crack location varies from 0.45m to 0.05m.

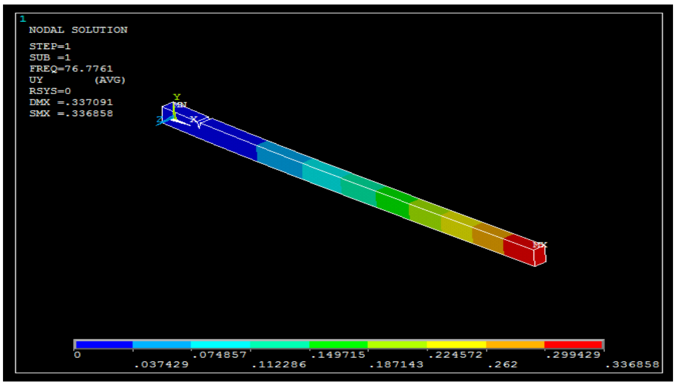


Fig 9 Mode 1 of Cracked Beam having Crack Location of 0.05m

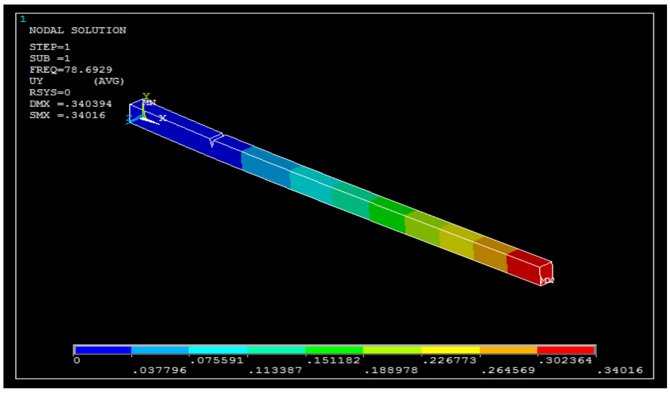


Fig 10 Mode 1 of Cracked Beam having Crack Location of 0.1m

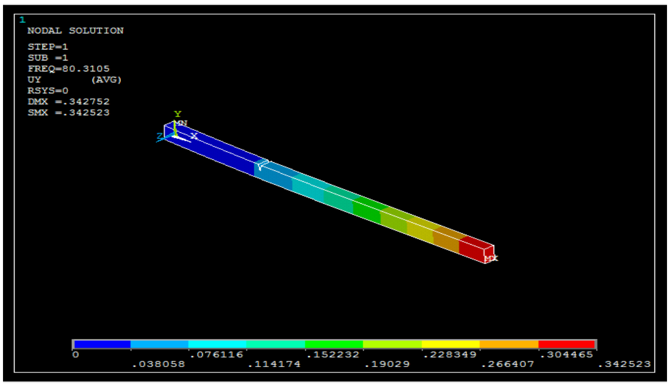


Fig 11 Mode 1 of Cracked Beam having Crack Location of 0.15m

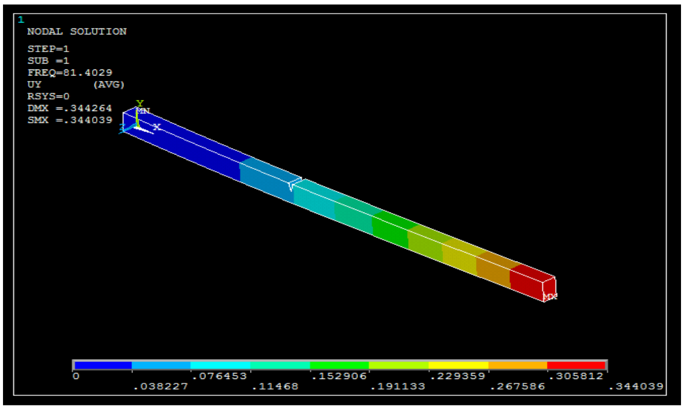


Fig 12 Mode 1 of Cracked Beam having Crack Location of 0.2m

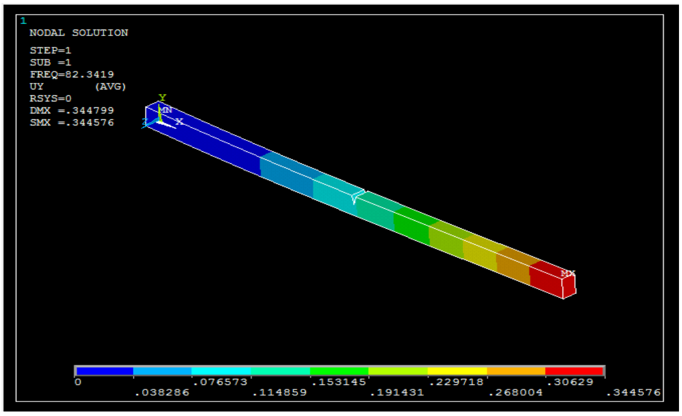


Fig 13 Mode 1 of Cracked Beam having Crack Location of 0.25m

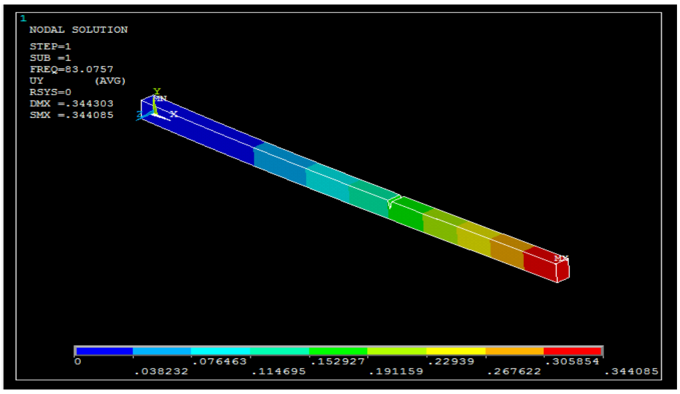


Fig 14 Mode 1 of Cracked Beam having Crack Location of 0.3m

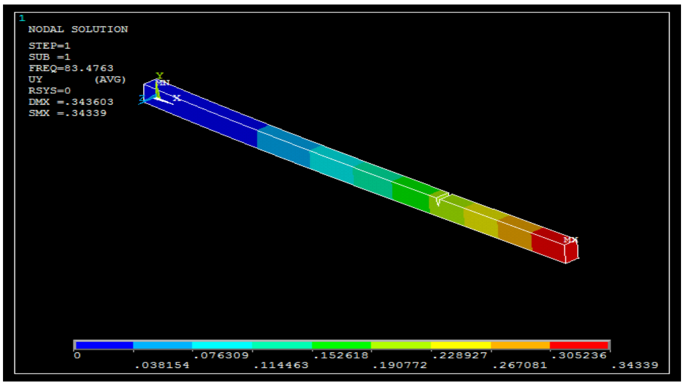


Fig 15 Mode 1 of Cracked Beam having Crack Location of 0.35m

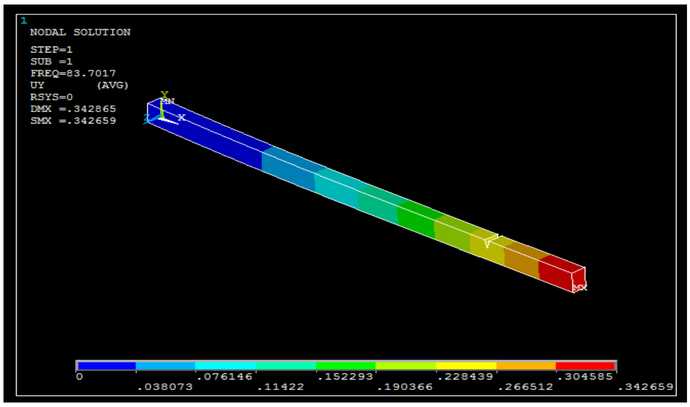


Fig 16 Mode 1 of Cracked Beam having Crack Location of 0.4m

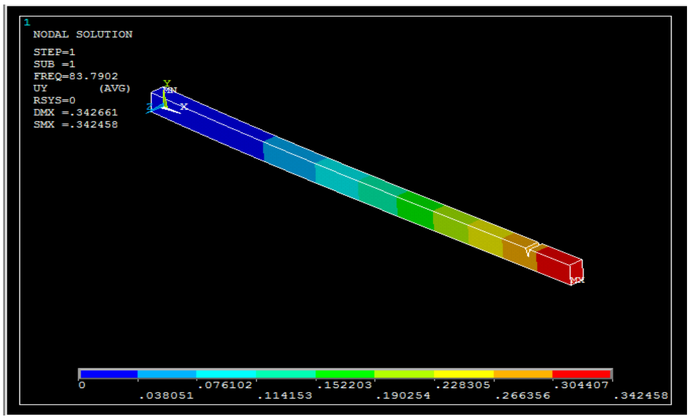


Fig 17 Mode 1 of Cracked Beam having Crack Location of 0.45m

F. *Compare the Results*

The fundamental frequency of various crack locations are compared in Table 11.

Table 11 Comparison of Fundamental Frequency of Cracked Beam having Various Crack Locations

Crack Location From Left End of the Beam (m)	Fundamental Frequency (Hz)
0.05	76.78
0.10	78.69
0.15	80.31
0.20	81.40
0.25	82.34
0.30	83.08
0.35	83.48
0.40	83.70
0.45	83.79

A graph plotted between the crack locations from the left end of the beam in ‘m’ versus fundamental frequency of the beam in ‘Hz’ as shown in Fig 18. And also the fundamental frequency of the cracked beam having various crack locations are compared with fundamental frequency of the un-cracked beam. It shows that the lowest frequency of the beam reduces when the position of notch moves from free end to fixed end.

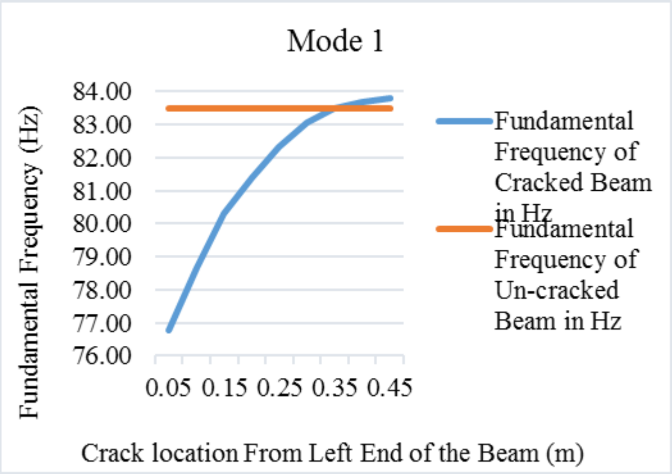


Fig 18 Plot Comparison of Lowest Frequency of Un-cracked beam and Cracked Beam having Various Crack Locations from the Left End

III. CONCLUSION

A slender cantilever beam of Width (W) 0.015m, Height (H) 0.025m and Length (L) 0.5m are considered for vibration analysis using FEM software ANSYS under free vibration. Material properties of aluminium are considered for cantilever beam and its properties are Young’s modulus (E) 70GPa, Poisson’s ratio (μ) 0.35, Density (γ) 2700 kg/m^3. Natural frequencies of un-cracked beam are found and the lowest natural frequency is found to be 83.5 Hz. Then cantilever beam with single edged notch has been analysed. Initially notch was located at 0.05m from the left end and then the locations are varied at step increment of 0.05m.The frequencies of the cracked beam having various crack locations were compared with the un-cracked beam and the results proved that natural frequency of beam changes due to different positions of notch. From the results, it is inferred that the fundamental frequency of the cracked beam reduces when the crack location moves from free end to fixed end it is due to the stiffness reduction of the beam.

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