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Vibration analysis of a Cracked I beam subjected to periodic load

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Abstract*- When a crack is present in a structure then the probability of failure of that structure is higher. Failure occurs when the natural frequency of the periodic force and the natural frequency of the structure are in a state of superposition. To avoid this phenomenon, it is essential to determine the natural frequency. The purpose of this study is to analyze the behaviour of natural frequency for various parameters such as crack position, crack depth, crack opening and mesh sensitivity. In this study the first five modes of vibration of both cracked and uncracked I beam has been extracted. A further analysis of resonance for a fixed vertical load has also been done. A combination of Hexahedral and wedge elements has been used for the analysis of the cracked structure. As problems regarding discontinuity are very difficult to solve analytically, hence one of the most popular finite element analysis software 'Abaqus CAE' was used for the analysis of cracked structure. The findings of this study are that the presence of crack reduces the natural frequency of beam, the reduction is related to the position of the crack, its opening and its depth. Another finding of this study is that the effect of vibration is significant for I beam when the crack reaches its web section. It was also found out that resonance occurs earlier if the crack depth is larger or the location of the crack is closer to the fixed end.*

Keywords: Natural Frequency, Resonance, Finite Element Method, Combined Meshing, Periodic load.

1.INTRODUCTION

. Natural frequency and resonance are the two most important parts of vibration analysis. I beam are used in structures very commonly. They can be continuous I beam or cantilever I beam. When periodic loads are applied on I beam they tend to vibrate. The vibration depends on the amplitude, frequency and other factors of the load. The response of a cantilever beam under periodic load would be different if there is a presence of crack in the structure. In order to prevent the collapse of any structure because of the resonance it is necessary to make a vibration analysis of that structure. As I beam are a very common part of any structure so it is essential to have knowledge about various natural frequencies of an I beam so that while applying periodic load, loads of certain frequencies can be avoided. Various researchers have done both numerical and experimental study on vibration analysis. The change in natural frequency for various crack location, crack opening, crack depth and mesh sensitivity was presented by Sumon, Shahidul and Ghosh[1].A parametric study of crack depth ratio and crack location was also presented. But there was no verification done regarding mesh sensitivity. Also the number of elements used was not mentioned. No analysis on the resonance frequency was done. For this study they considered the first three natural frequencies. Nitesh and Vaibhab[2] also presented the change in natural frequency for different crack depth, location and opening using ANSYS Workbench software. They also presented the parametric study for different crack location. They proposed a method for finding the crack location based on frequency contours. But no partition was used in meshing and no study about resonance frequency for a load was not presented in the paper. A method to determine the effect of two cracks on natural frequency was done for transverse vibration of the cantilever beam by Ostachowicz and Krawczuk[3]. But no analysis was done regarding various parameters in the paper.Rane,Barjibhe and patil[4] presented a method of determining crack location based on the natural frequencies. The Euler equation was solved numerically for both cracked and un-crack beam and the first three natural frequencies was calculated. Quila,Mondal and Sarkar[5] concentrated on the theoretical study of transverse vibration of a beam whose movement was restricted and then simulated the results through ansys. They also performed a parametric study. But there was no mentioning of mesh element type or size. Behzad,Meghdari and Ebrahimi[6] developed equations of motions and boundary conditions for a bent beam with

open edged crack. By using the newly developed model in conjunction with the Galerkin projection method the natural frequencies of beam had been calculated. It was seen from the result that the natural frequency reduces as the crack depth increases. But no study was done regarding the frequency ratio for various crack depth.
In this study the first five natural frequency of an I beam have been calculated. The mode shapes associated with transverse, lateral and torsional vibration was analyzed. The change in the value of frequency with response to various crack depth, meshing element, crack opening and crack location has been studied. A further analysis of resonance for different crack depth and crack location was also done. In short the impact of crack on natural frequency and resonance condition has been thoroughly studied in this paper.

2. METHODOLOGY

2.1 Geometry

There can be various types of cantilever beam depending on the geometry of the cross section. Here in this study an I shaped cross section has been used for designing the cantilever beam. For I shaped beam the dimensions were the same as the dimensions of a HE 1000×584 steel beam.

Table 1. Detailed dimension of cantilever beam

Property	Value
Flange thickness	0.064m
Web thickness	0.0356 m
Depth	1.056m
Width	0.314 m
Fillet radius	0 m
Length	3.2 m

2.2 Crack Design

A wedge shaped crack was used to analyze the behavior of vibration under cracks. The cracks were designed in solidworks 2017 and then the files were imported into Abaqus CAE.Three different openings of 0.002m,0.004m,0.010m were used. Cracks were designed at 0.7 m distance interval from the free end. Here crack opening of 0.002,0.004,0.006 and 0.010m were used and crack depth of 0.025,0.0375,0.050,0.0625 and 0.075m were used.

2.3 Material Selection

For the vibration analysis mild steel was used as a material because they are very frequently used in structural elements.

Table 2. Material properties

Property	Value
Modulus of elasticity	210 Gpa
Mass density	7860 kg/$m3$
Poisson ratio	0.3

2.4 Validation

The natural frequency analysis of a cantilever beam is validated by the natural frequency solution of M.S. Mia, M.S.Islam and U. Ghosh[1]

Table 3. Comparison between present data and reference paper for various crack depth

Crack depth (m)	Mode 1 Present data (cycle/ sec)	Reference Paper (cycle/ sec)	Error (%)
0.05	18.142	18.2	0.31
0.075	17.566	17.733	0.976
0.010	16.884	16.936	0.30
0.125	15.473	15.471	0.012
0.15	13.145	13.21	0.49
Crack depth (m)	Mode 2 Present data (cycle/ sec)	Reference Paper (cycle/ sec)	Error (%)
0.05	112.48	112.75	0.23
0.075	110.58	111.3	0.64
0.010	108.4	108.77	0.34
0.125	104.39	104.66	0.25
0.15	99.470	99.175	0.29
Crack depth (m)	Mode 3 Present data (cycle/ sec)	Reference Paper (cycle/ sec)	Error (%)
0.05	301.33	302.36	0.34
0.075	290.92	293.74	0.96
0.010	279.92	280.81	0.31
0.125	261.05	261.18	0.049
0.15	240.84	238.64	0.91

From the analysis it can be seen that the values of natural frequencies almost co-incide. For a crack depth of 0.050 m the 1st natural frequency of the current study is 18.142 cycle/sec and the natural frequency calculated by M.S. Mia, M.S. Islam and U. Ghosh is 18.2 cycle/sec. So the difference between the two values here is only 0.3 %. The highest deviation between two result is 0.96%.

3. RESULTS AND DISCUSSION

This section is dedicated to compare and discuss the result for various parameter

3.1 Natural frequency analysis based on Mesh elements

Without partition the I beam could not be analyzed using hexahedral and wedge elements. So only tetragonal mesh elements were used while analyzing without partition. When partition was used then both hexahedral and wedge elements were used for analysis. The crack was located at 1.4m location from the fixed end with an opening of 0.002 m and a depth of 0.05 m. Abaqus analysis results for different mesh elements are shown in table 4. It is observed that partitioned meshing causes greater change in natural frequency which can be related to the decreased natural frequency theorem for a discontinuous structure. So for further analysis combined meshing was used.

Table 4. Comparison of results for different types of meshing

	1st NF	2nd NF	3rd NF	4th NF	5th NF
Uncracked	18.8	30.54	95.64	97.89	113.73
Tetragonal	18.63	30.78	94.97	97.70	115.89
Partition	18.55	30.11	94.75	95.52	112.30

It can be seen from the table that when tetragonal elements were used then the 2nd and 5th natural frequency was higher than the natural frequency of the uncracked beam. But when partition is used then all 5 modes decrease. So it can be said that using partition would provide better accuracy in result.

3.2 Natural frequency analysis based on crack opening

The effect of crack opening size on natural frequency is shown in table 5

Table 5 Frequency for different crack opening size

	Frequency(cycle/sec)		
Crack opening size	1st mode	2nd mode	3rd mode
0.002	18.568	30.309	94.782
0.004	18.554	30.306	94.744
0.006	18.554	30.305	94.747
0.010	18.537	30.15	94.741
Crack opening size	4th mode	5th mode	
0.002	95.831	112.75	
0.004	95.743	112.74	
0.006	95.743	112.74	
0.010	94.786	110.95	

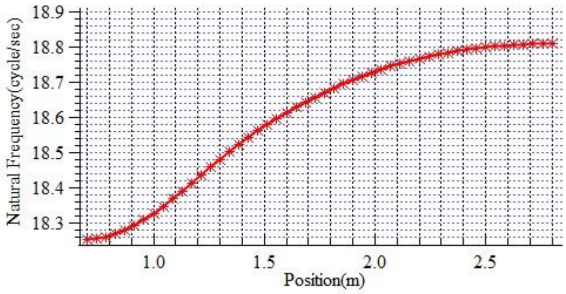
It can be seen from the table that the change in natural frequency is negligible unless the crack opening is significant. In this study for further analysis crack opening size of 0.010m is considered.

3.3 Natural frequency analysis based on crack location

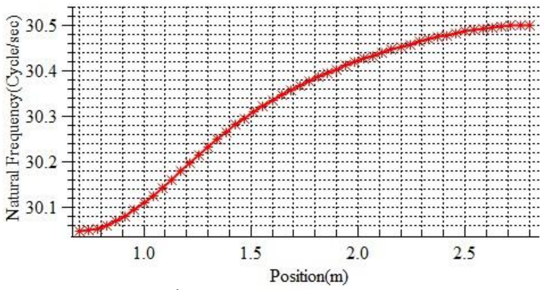
Effect of crack location for specified crack depth of 0.05m and crack opening of 0.010m is represented in table 6 and figure 1(a),1(b),1(c),1(d) and 1(e).

Table 6 Natural frequency for various crack location

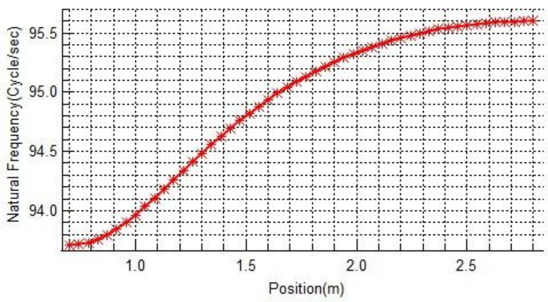
Location of crack from free end	1st NF	2nd NF	3rd NF
0.7	18.112	29.932	93.228
1.4	18.568	30.309	94.782
2.1	18.777	30.449	95.488
2.8	18.826	30.525	95.65
Location of crack from free end	4th NF	5th NF	
0.7	97.737	113.34	
1.4	95.831	112.75	
2.1	96.279	112.76	
2.8	97.856	113.69	



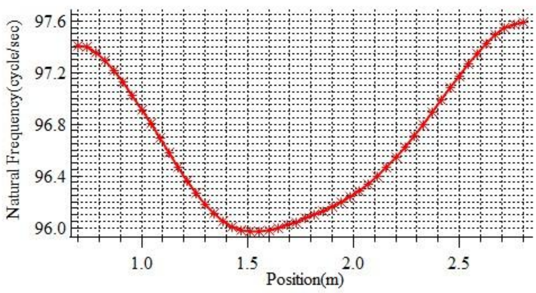
(a)1st Natural Frequency



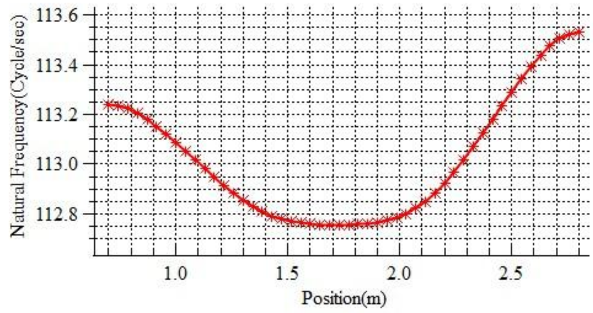
(b)2nd Natural Frequency



(c)3rd Natural Frequency



(d)4th Natural Frequency



(e)5th natural frequency

Figure 1. Natural frequency for various crack position

The graphs illustrate that the change in natural frequency for various crack position is not similar for all modes of vibration. For example, in the present case for the first three modes of vibration the natural frequency increases as the crack location moves away from the fixed end. But for the fourth and fifth mode of vibration the frequency decreases as the crack moves toward the middle section of the beam. Then increases as it moves towards the end of the beam .In this case natural frequency has been determined for five different crack locations and other points were determined using the interpolation function available in Igor Pro software.

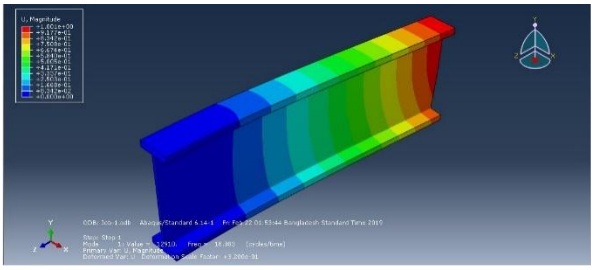


Figure 2 Mode 1 representation of I beam in Abaqus

3.4 Natural frequency analysis based on crack depth

Natural frequency for various crack depth at specified crack location (1.4 m) is represented in table 7

Table 7 Natural frequency for various crack depth at 1.4m crack location

Location of crack from free end	1st NF	2nd NF	3rd NF	4th NF	5th NF	
0.025	18.785	30.476	95.51	97.472	113.35	
0.0375	18.709	30.412	95.247	96.895	113.12	
0.05	18.555	30.307	94.744	95.747	112.74	
0.0625	18.148	30.07	92.738	93.738	111.95	
0.075	13.589	27.504	71.567	91.214	106.62	

The graph shows us that as the crack depth increases the natural frequency reduces for all modes of vibration which justifies the theory of decrease in natural frequency in presence of discontinuities. The graph also represents that the decrease is maximum when the crack reaches the web section of the beam.

3.5 Resonance frequency analysis based on crack location

The conditions applied for resonance frequency analysis are shown in table 8

Table 8 Applied Conditions for Resonance Frequency Analysis

Conditions	Value
Load	1 KN
Imposed Frequency	0-120 cycle/sec
Structural Damping	5%

In this section of the study a vertical force of 1 KN of various frequencies has been applied to the I beam and for various imposed frequency the displacement of the beam was studied. To avoid infinite displacement,5 percent structural damping was applied to the beam. The displacement of the beam for various crack location is presented in figure 3.

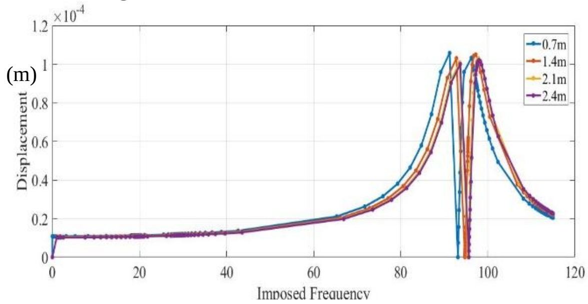


Figure 3. displacement for various imposed frequency at various crack position for 1kN vertical load

The graph and table shows that resonance frequency for 1 KN vertical load increases as the crack location moves away from the fixed end. Which is similar to the first three modes of natural frequency. There is a sudden decrease in displacement near the 90-100 range frequency. The 5 percent structural damping is responsible for that. In fact the frequency in which the displacement is zero is the real resonance frequency for this vertical load. As 5 percent structural damping has been applied hence resonance has shifted and the maximum displacement has also been reduced. Without damping the displacement will be very high resulting in the collapse of the structure. From the mode shape analysis, it can be said that the resonance frequency for the applied load is associated with the 3rd and 4th mode of vibration of the beam. It can also be said that resonance occurs earlier if the crack is located closer to the fixed end of the cantilever beam.

3.6 Resonance frequency analysis based on crack depth

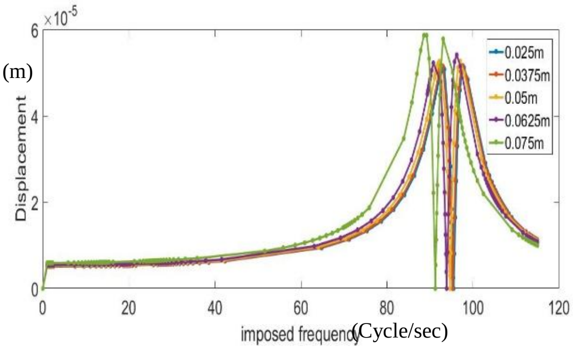


Figure 4. Displacement for different imposed frequency of 1 kN load for various crack depths

It can be seen from the figure 4 that resonance occurs earlier when the crack depth is larger. It can also be seen from the graph that for crack depth of 0.075 m displacement is reasonably higher than others. This is due to the fact that a crack of 0.075m reaches to the web section of the I beam.

4. CONCLUSION

The effect of cracks is very much significant in the vibration analysis. From this paper the following results are summarized

- When there is discontinuity in the structure in the form of crack then the natural frequency reduces. The amount of reduction depends upon the crack opening, crack depth a crack location
- For a certain location of crack, the natural frequency reduces as the crack depth increases
- While designing cracked structure mesh refinement should be considered for more accurate result
- As the number of elements increases the accuracy of the calculation of natural frequency increases
- Effect of crack is different for different modes of vibrations.
- For I beam natural frequency reduces significantly if the crack reaches the web section of the beam
- Resonance occurs at earlier imposed frequency if the crack is located closer to the fixed end
- Resonance occurs at lower imposed frequency if the crack depth increases.
- The effect of vibration will be significantly higher if the crack reaches the web section of an I beam.

5. REFERENCES

[1] M. S. Mia, M. S. Islam, and U. Ghosh, “Modal analysis of cracked cantilever beam by finite element simulation,” Procedia Eng., vol. 194, pp. 509–516, 2017.

[2] Nitesh A. Meshram and Prof. Vaibhav S. Pawar, “Analysis of Crack Detection of A Cantilever Beam using Finite Element Analysis,” Int. J. Eng. Res., vol. V4, no. 04, pp. 713–718, 2015.

[3] W. M. Ostachowicz and M. Krawczuk, “Analysis of the effect of cracks on the natural frequencies of a cantilever beam,” J. Sound Vib., vol. 150, no. 2, pp. 191–201, 1991.

[4] P. M. Jagdale and M. A. Chakrabarti, “Free Vibration Analysis of Cracked Beam,” vol. 3, no. 6, pp. 1172– 1176, 2013.

[5] M. Quila, P. S. Ch. Mondal, and P. S. Sarkar, “Free Vibration Analysis of an Un-cracked & Cracked Fixed Beam,” IOSR J. Mech. Civ. Eng., vol. 11, no. 3, pp. 76–83, 2014.

[6] M. Behzad, a Meghdari, and a Ebrahimi, “Archive of SID A NEW APPROACH FOR VIBRATION ANALYSIS OF A CRACKED BEAM Archive of SID,” Int. J. Eng., vol. 18, no. 4, pp. 319–330, 2005.

[7] S. Orhan, “Analysis of free and forced vibration of a cracked cantilever beam,” NDT E Int., vol. 40, no. 6, pp. 443–450, 2007.

6. NOMENCLATURE

Symbol	Meaning	Unit
NF	Natural Frequency	cycle/sec