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Study on Natural Frequencies due to Inclined Crack with Variable Angles of Inclination and Varying Crack Depths using Numerical and Experimental Method

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Abstract: *An important assignment for engineers is to determine the effect of the damage like inclined cracks on the stability characteristic of beam structure. The Cracks in vibrating component can initiate disastrous failures. The presences of cracks change the physical characteristics of a structure which in turn alter its dynamic response characteristics. Therefore there is need to understand dynamics of cracked structures. This paper focuses on the vibration analysis of a beam with fixed free boundary condition and investigates the mode shape and its frequency. Finite element analysis using ANSYS software is adopted for the dynamic behavior of the beam. Variations of natural frequencies due to inclined crack with variable angles of inclination and with varying crack depths have been studied. After that the experimentation is carried out to verify Numerical Analysis.*

Keywords: *ANSYS, Cantilever Beam, Inclined crack, Mode shape, Natural Frequency, Simply Supported Beam.*

I. Introduction

It is required that structures must securely work during its service life. But, damages initiate a breakdown phase on the structures. Cracks are among the most encountered damage types in the structures. Cracks occurs in a structure can be perilous for static or dynamic loadings, so that crack detection plays an important role for structural strength monitoring applications. Beam type structures are being frequently used in construction and machinery industries. The literature study gives the idea regarding the structural safety of beams, especially, crack detection by structural health monitoring. Studies based on structural strength monitoring for crack detection deal with change in natural frequencies and mode shapes of the beam. The most common structural defect is the survival of a crack. Cracks are present in structures due to various reasons. The presence of a crack could not only cause a local discrepancy in the stiffness but it could affect the mechanical behavior of the entire structure to a substantial extent. Cracks may be caused by fatigue under service conditions as a result of the partial fatigue strength. They may also occur due to mechanical defects. Another group of cracks are initiated during the manufacturing processes. Generally they are small in sizes. Such small cracks are known to propagate due to fluctuating stress conditions. If these propagating cracks remain undetected and reach their critical size, then a sudden structural failure may occur. To avoid the unexpected or sudden failure, earlier crack detection is essential. Taking this ideology into consideration crack detection is one of the most important domains for many researchers. Previous researchers develop techniques for early detection of crack location, i.e. depth, size and pattern of damage in a structure. Some nondestructive methodologies for crack detection have been use in global. However the vibration based method is fast and inexpensive for crack/damage identification. Therefore it is possible to use natural frequency measurements to detect cracks. Dayal. R. Parhi, Prases. K. Mohanty, Sasmita Sahu and Amiya Kumar Dash have presented analytical as well as experimental methods to locate and quantify the size of damage in beam type structure from vibration mode.[1] Kaustubha V. Bhinge et. al, tried to establish a systematic approach to study and analyze the crack in cantilever beam. It is addresses the inverse problem of assessing the crack location and crack size in various beam structures. Measurement of natural frequency, is a global parameter and can be easily measured at any point conveniently on the structure.[2] D.Y. Zheng, N.J. Kessissoglou have studied on the natural frequencies and mode shapes of a cracked beam are obtained using the finite element method. To get the stiffness matrix the additional flexibility matrix' is used, instead of the 'local additional flexibility matrix' [3] Malay Quila et. al., have studied on cracks which causes changes in the physical properties of a structure which introduces flexibility, and thus reducing the stiffness of the structure with an inherent reduction in modal natural frequencies. Consequently it leads to the change in the dynamic response of the beam.[4] Ranjan K. Behera, Anish Pandey, Dayal R. Parhi in their research work has developed the theoretical expressions to find out the natural frequencies and mode shapes for the cantilever beam with two transverse cracks.[5] E.

Bahmyari, S. R. Mohebpour, and P. Malekzadeh have investigated on the dynamic response of laminated composite beams subjected to distributed moving masses using the finite element method (FEM) based on the both first-order shear deformation theory (FSDT) and the classical beam theory (CLT). Six and ten degrees of freedom beam elements are used to discretize the CLT and FSDT equations of motion, respectively using Newmark's scheme.[8] As discussed above the failure of machine component is loss of time, money and life. Most of the machine components failures are because of the crack. So there is necessity to predict such failures in advance so that losses because of failure are avoided or minimized. Condition based monitoring is one of the preventive maintenance method used in the plant maintenance. That's why there is a need to develop the methodology which can be used easily to predict the crack in the machine component from the machine condition such as vibration data. The present work is aimed at finding the natural frequency of a cantilever and simply supported beam with a single inclined crack with variation in angles and un-cracked using finite element analysis ANSYS software extent.

II. Objective

1. To model the beam structures having inclined edge crack at different locations with different crack inclination by taking Euler Bernoulli beam elements.
2. To find out the natural frequencies and mode shapes of cracked and un-cracked beam.
3. To study effect of crack inclination for inclined edge cracked beam.(Cantilever beam)
4. To study effect of crack inclination for inclined edge cracked beam.(Simply Supported beam)
5. To Validate the Numerical results with experimental Results of Cantilever beam and Simply Supported beam.

III. Approach toward the finite Element Analysis

The finite element method (FEM) is a numerical method for analyzing structures. It is firmly recognized as a influential popular analysis tool. It is most widely used in structural mechanics. The finite element procedure produces many simultaneous algebraic equations, which are generated and solved on a digital computer. The main rule that involved in finite method element method is "DEVIDE and ANALYZE". The greatest only one of its kind feature which separates finite element method from other methods is "It divides the entire complex geometry into simple and small parts, called "finite elements". These finite elements are the building blocks of the finite element analysis. Based on the type of analysis going to be performed, these elements divided into several types. Division of the domain into Elements are called "mesh". The forces and moments are transferred from one element to next element are represented by degrees of freedom (DOFs) at coordinate locations which are called as "nodes". Approximate solutions of these finite elements give rise to the solution of the given geometry which is also an approximate solution. The approximate solution becomes exact when:

1. The geometry is divided into numerous or infinite elements.
2. Each element of geometry must define with a complete set of polynomials (infinite terms).

The finite element method has become an vital tool for the numerical solution of a broad range of engineering problems. It has developed concurrently with the increasing use of high-speed electronic digital computers and with the growing importance on numerical methods for engineering analysis. This method started as a simplification of the structural idea to some problems of elastic continuum, is entrenched numerical method applicable to any continuum problem, stated in terms of differential equations or as an extranet problem.

A. Modeling of Beam Using Ansys

The Beam is modeled in ANSYS Software. Element SOLID45 is used for the 3-D modeling of solid structures. Material properties are provided which is briefly listed in Table I. After that 12 models are prepared with various inclination angles for crack with the location of crack as L/2 of beam. After that the beam is meshed (Fig. 2). The natural frequency of the cracked beam is found by the well known Finite Element (FEM) Software ANSYS. Modal analysis is carried out using the Block Lanczos method for finding the natural frequencies. First cantilever and Second simply supported boundary condition was applied by constraining the nodal displacement in both x and y direction. The results are tabulated in Table I, Table II and Table III. The five mode shapes of beam with and without crakes are shown in Fig.3, Fig.4 and Fig 5

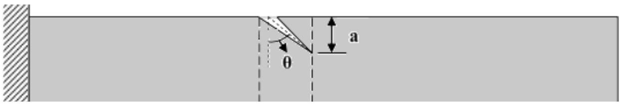

TABLE II
NATURAL FREQUENCIES OF UN- CRACKED BEAM

Natural Frequency in Hz

Condition	I st Mode	II nd Mode	III rd Mode	IV th Mode	V th Mode
Cantilever Beam	30.998	194.146	543.416	1064.620	1759.540

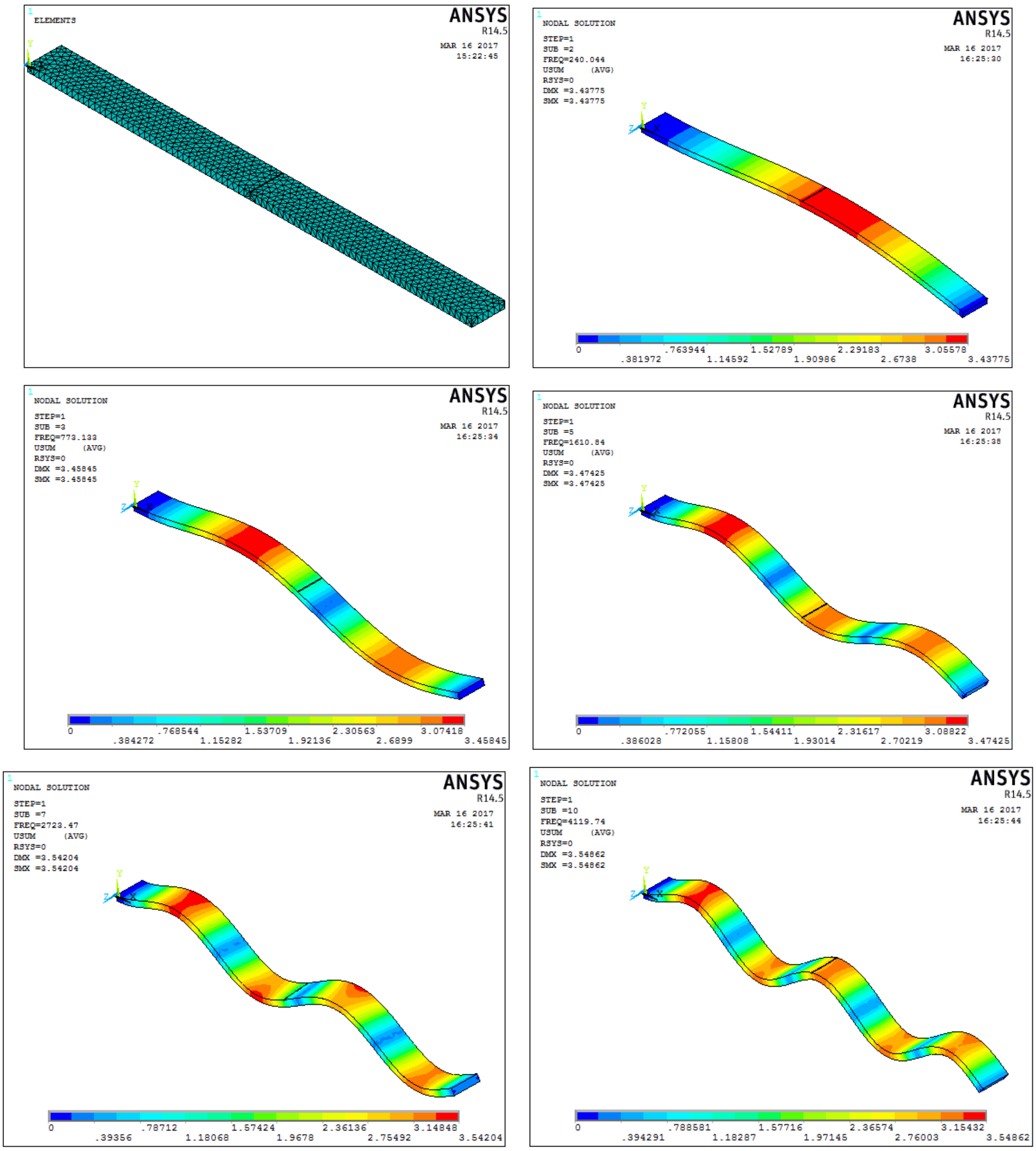

TABLE III
NATURAL FREQUENCIES OF CRACKED CANTILEVER BEAM WITH VARIES CRACK INCLINATION ANGLE AND DEPTH OF CRACK BY USING ANSYS

Crack angle θ	Relative Crack Depth (α = a/t)	Natural Frequency in Hz				
		I st Mode	II nd Mode	III rd Mode	IV th Mode	V th Mode
0	0.1	55.11	342.207	951.38	1867.4	3035.2
0	0.2	54.75	339.599	945.40	1854.5	3017.2
0	0.3	55.35	342.62	962.80	1868.5	3059.2
15	0.1	55.21	341.67	954.059	1866.5	3054.7
15	0.2	54.53	337.28	954.13	1855.5	3021.0
15	0.3	55.49	341.86	963.73	1863.8	3057.1
30	0.1	55.50	342.70	955.38	1865.6	3056.7
30	0.2	54.94	340.85	949.80	1859.5	3028.2
30	0.3	54.79	338.32	948.04	1843.6	3039.2
45	0.1	55.30	344.19	954.64	1880.9	3054.2
45	0.2	54.60	339.65	944.81	1858	3015.9
45	0.3	54.42	336.54	945.29	1845.0	3038.0

TABLE IV
NATURAL FREQUENCIES OF CRACKED SIMPLY SUPPORTED BEAM WITH VARIES CRACK INCLINATION ANGLE AND DEPTH OF CRACK BY USING ANSYS

Crack angle θ	Relative Crack Depth (α = a/t)	Natural Frequency in Hz				
		I st Mode	II nd Mode	III rd Mode	IV th Mode	V th Mode
0	0.1	240.11	771.29	1611.3	2711.7	4131.1
0	0.2	238.22	765.66	1598.0	2692.4	4093.9
0	0.3	241.20	776.54	1612.6	2730.7	4127.3
15	0.1	240.04	773.13	1610.8	2723.4	4119.7
15	0.2	237.06	766.87	1598.3	2692.0	4094.4
15	0.3	240.80	776.83	1607.7	2730.6	4112.4
30	0.1	240.63	775.30	1613.1	2728.6	4120.4
30	0.2	238.86	769.38	1602.3	2703.6	4108.1
30	0.3	237.72	766.82	1596.4	2701.7	4088.8
45	0.1	241.27	774.21	1622.0	2725.7	4148.3
45	0.2	238.04	763.65	1603.2	2688.4	4104.0
45	0.3	236.38	765.51	1593.2	2697.6	4082.2

IV. Approach toward the finite Element Analysis

An aluminum beam sample of dimension (0.4 x 0.03 x 0.006 m^3) has been taken for the experimental analysis by using FFT analyzer. FFT analyzer is manufacturer OROS company having bandwidth 40kHz and 24 bit. A number of experiments have been done on the cracked beam with different configurations of crack parameters (crack depths and crack inclinations means 12 samples) to measure the first five natural frequencies. The complete experimental setup is shown in Fig. 5. Earlier the beams surface has been cleaned and organized for straightness. Later, transverse and inclined crack is created at center of the beam in different specimens with the help of Wire EDM machine. The natural frequencies corresponding to 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} mode are noted with different crack depth at same crack locations and different crack inclinations in the cracked beam. After that experimentation is carried out with different boundary conditions.

TABLE V
EXPERIMENTAL VALUES OF NATURAL FREQUENCIES OF CRACKED CANTILEVER BEAM WITH VARIES CRACK INCLINATION ANGLE AND DEPTH OF CRACK

Crack angle θ	Relative Crack Depth (α = a/t)	Natural Frequency in Hz				
		I st Mode	II nd Mode	III rd Mode	IV th Mode	V th Mode
0	0.1	52.50	338.6	941.8	1854.0	3011.6
0	0.2	52.30	336.0	935.8	1841.1	2993.6
0	0.3	52.46	339.0	953.2	1855.2	3035.7
15	0.1	52.32	338.1	944.4	1853.2	3031.1
15	0.2	51.64	333.7	944.5	1842.2	2997.4

15	0.3	52.60	338.3	954.1	1850.5	3033.6
30	0.1	52.61	339.1	945.8	1852.2	3033.1
30	0.2	52.05	337.2	940.2	1846.2	3004.7
30	0.3	51.89	334.7	938.4	1830.3	3015.6
45	0.1	52.40	340.6	945.0	1867.5	3030.7
45	0.2	51.71	336.0	935.2	1844.6	2992.3
45	0.3	51.5	332.9	935.7	1831.6	3014.4

TABLE VI
EXPERIMENTAL VALUES OF NATURAL FREQUENCIES OF CRACKED SIMPLY SUPPORTED BEAM WITH VARIES CRACK INCLINATION ANGLE AND DEPTH OF CRACK

Crack angle θ	Relative Crack Depth (α = a/t)	Natural Frequency in Hz				
		I st Mode	II nd Mode	III rd Mode	IV th Mode	V th Mode
0	0.1	229.9	751.0	1581.4	2672.7	4083.5
0	0.2	228.1	745.4	1568.1	2653.4	4046.3
0	0.3	231.0	756.3	1582.7	2691.7	4079.8
15	0.1	229.9	752.9	1580.9	2684.4	4072.1
15	0.2	226.9	746.6	1568.4	2653.0	4046.9
15	0.3	230.6	756.6	1577.8	2691.6	4064.8
30	0.1	230.5	755.0	1583.2	2689.6	4072.8
30	0.2	228.7	749.1	1572.4	2664.6	4060.5
30	0.3	227.5	746.5	1566.5	2662.7	4041.2
45	0.1	231.1	753.9	1592.1	2686.7	4100.7
45	0.2	227.9	743.4	1573.3	2649.4	4056.5
45	0.3	226.2	745.2	1563.3	2658.6	4034.6

Fig.5 Experimental Setup

V. Result & Discussion

Figures 2, 3 and 4 shows that natural frequencies of the beam with out and with a inclined edge crack at various crack inclination and crack depths for first, second, third, fourth and fifth modes of vibration respectively with cantilever and simply supported boundary condition. Results show that there is an appreciable variation between natural frequency of cracked and un-cracked beam with cantilever and simply supported condition. It is observed that natural frequency of the cracked beam decreases both with increase in crack inclination and crack depth due to reduction in stiffness. It appears therefore that the change in frequencies is not only a function of crack depth and crack inclination but also of the mode number.

VI. Conclusion

It has been observed that the natural frequency changes significantly due to the presence of cracks depending upon inclination and depth of cracks. The results of the crack parameters have been obtained from the comparison of the results of the un-cracked and cracked cantilever beam during the Modal analysis using ANSYS software. The crack location and crack inclination are constant, but the crack depth increases. The natural frequency of the cracked beam decreases with increase the crack depth. It has been observed that the change in frequencies is not only a function of crack depth, and crack inclination, but also of the mode number. The experimentation is carried out to verify Numerical results. As largest effects are observed at the crack inclination 450 and depth ratio is 0.3 on cantilever beam we can say, decrease in frequencies is more for a crack located where the bending moment is higher.

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