ANALYTICAL STUDY ON NATURAL FREQUENCY OF A CRACKED BEAM BY USING MODAL ANALYSIS

K VENU MANIKANTA 1*, Dr. DUMPA VENKATESWARLU 2*

1. *Student, Dept of CIVIL, GODAVARI INSTITUTE OF ENGINEERING AND TECHNOLOGY, RAJAHMUNDRY.*
2. *Head - Dept of CIVIL, GODAVARI INSTITUTE OF ENGINEERING AND TECHNOLOGY, RAJAHMUNDRY.*

Abstract: The presence of cracks 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. In this study, dynamic responses of a cracked beam and untracked be am under free vibration analysis are studied using ANSYS. A cracked beam with an open edge crack has been modeled for free vibration analysis. A parametric study has been carried out for cantilever beam, fixed beam and simply supported beam. The cracked beams with different boundary conditions and with varying crack depths have been analyzed. Variations of natural frequencies due to crack at various locations and with varying crack depths have also been studied. It has been observed that the natural frequency changes substantially due to the presence of cracks depending upon location and size of cracks. From the results of free vibration analysis, it has been observed that change in frequencies is not only a function of crack depth, and crack location, but also of the mode number.

Keywords– Free vibration, Crack, Natural frequencies, ANSYS

INTRODUCTION

Presence of cracks in a structural member causes local variations in stiffness, the magnitude of which mainly depends on the location and depth of the cracks. Presence of cracks causes changes in the physical properties of a structure which in turn alter its dynamic response characteristics. Cracks in a structure may be hazardous under static or dynamic loadings, so that crack detection plays an important role for structural health monitoring applications. Hence, the present study is carried ou t to study the effect of cracks on the dynamic response of the beam.

Based on the literature study, the following observations are made. Ruotolo et al. (1996) [2] investigated forced response of a cantilever beam with a crack that fully opens or closes, to determine depth and location of the crack. It was observed that vibration amplitude changes, when depth and location of the crack change. Zheng and Kessissoglou (2004) [3] studied the natural frequencies and mode shapes of a cracked beam using finite element method. The overall additional flexibility matrix instead of the local additional flexibility matrix is used to obtain the total flexibility matrix of a cracked beam. The stiffness matrix is then obtained from the total flexibility matrix. As a result, more accurate natural frequencies of a cracked beam are obtained. Suresh et al (2004) [4] studied the flexural vibration in a cantilever beam having a transverse surface crack. The modal frequency parameters are analytically computed for various crack locations and depths using a fracture mechanics based crack model. The sensitivity of the modal frequencies to a crack increases when the crack is near the root and decreases as the crack moves to the free end of the cantilever beam. Chandra Kishen,et al.(2004) [5] studied the fracture behavior of cracked beams and columns using finite element analysis. Assuming that failure occurs due to crack propagation when the first mode stress intensity factor reaches the fracture toughness of the material, the failure load of cracked columns are determined for different crack depths and slenderness ratios. Behera (2006) [6] carried out research work to develop the theoretical expressions to find out the natural frequencies and mode shapes for the cantilever beam with two transverse crack. Experiments have been conducted to prove the authenticity of the theory developed. Orhan Sadettin (2007) [7] studied the free and forced vibration analysis of a cracked beam in order to identify the crack in a cantilever beam for

single- and two-edge cracks. Dynamic response of the forced vibration better describes changes in crack depth and location than the free vibration. Chasalevris and Papadopoulos (2006) [8] studied the dynamic behavior of a cracked beam with two transverse surface cracks. Each crack is characterized by its depth, position and relative angle. Prathamesh M. Jagdale (2013) [9] analyzed cracked beam models with different boundary conditions, crack location and different crack depth. It has been observed that the natural frequency changes due to the presence of cracks.

The present study is carried out to study the variation in natural frequencies of cracked and uncracked beams due to variation in crack location, crack depth and boundary conditions. Dynamic response of the beam are analyzed using Finite Element software ANSYS. Finite element model is validated with Prathamesh M. Jagdale (2013). Then, parametric study has been carried out on beams with crack at various locations with different boundary conditions and crack depth

METHODOLOGY & VALIDATION

Crack Modeling

Cracks in the beam create changes in geometrical properties so it becomes complex to study the effect of cracks in the beam. Crack modeling is very important aspect and in this study crack is considered as open edge notch created on the top surface of the beam. Figure 1 shows the crack model created using ANSYS. Cracked beam has been modeled and free vibration analysis has been performed considering geometric and material non linearity.

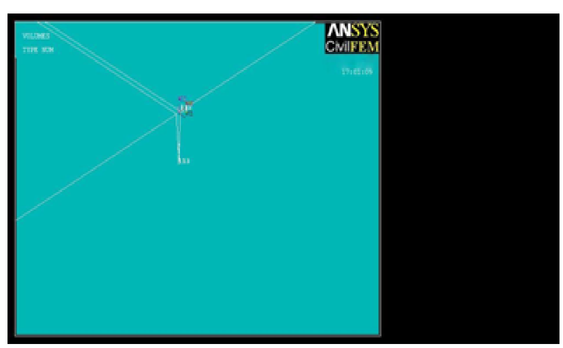

Figure 1 V-shaped edge crack on the top surface of the beam

Validation

The cracked cantilever beam with a single crack has been considered for the validation of model. Cantilever beam has been modeled, analyzed and the analysis outputs are compared with Prathamesh M. Jagdale (2013) Based on the convergent study, the number of divisions for meshing is taken as 100 divisions. The follo wing properties are taken from Prathamesh M. Jagdale (2013) for validation. Table 1 shows the properties for validation.

Properties	Values
Width of beam	0.23m
Depth of beam	0.5m
Length of beam	3m
Width of crack	0.5mm
Depth of crack	5mm
Elastic modulus of the beam	30 GPa
Poisson's Ratio	0.3
Density	25 KN/m3

Table1 Properties for validation

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Mode No	Natural Frequencies (Cycles/sec)		% Error
	Obtained Results from ANSYS	Results From Author Prathamesh M. Jagdale (2013)	
1	4.5082	4.7407	4.9
2	9.6817	9.7412	0.6
3	28.024	28.968	3
4	54.386	55.157	1

Table 2 Comparison of results obtained using ANSYS software

From the above table Maximum percentage error obtained is less than 5%.

PARAMETRIC STUDIES

Cantilever Beam

The effects of the crack on natural frequency of a cantilever beam were investigated for various crack depths and crack locations using ANSYS software. Comparison of beams is carried out between a beam without crack and with single, multiple crack and the results of different mode shapes and frequencies are compared in the further studies. Comparison has been carried out between single and multiple cracks of different mode shapes and varying depths for Natural frequencies and Maximum deflection.

Properties:

Width of the beam (b) = 0.23 m, Depth of the beam (d) = 0.35 m, Length of the beam (l) = 2.5 m, Width of the crack=0.3mm Depth of crack = d/2,d/4,d/8

Element type SOLID 65

Concrete used M25

Steel fe415

Type of crack created is 'V' Shaped crack

Type of mesh used is TETRAHEDRAL and no of divisions is 100

Mode	Type of crack	Natural Frequency (Cycles/Sec)			
		d/2	d/4	d/8	No crack
1	single	40.566	41.754	42.019	42.360
	multiple	40.191	41.582	41.981	42.360
2	single	53.417	61.444	62.760	63.446
	multiple	51.467	60.537	62.615	63.446
3	single	241.09	251.48	253.85	256.23
	multiple	226.61	245.83	252.05	256.23
4	single	300.84	351.70	362.50	368.16
	multiple	254.05	328.48	356.14	368.16

Table 3 Comparison of Natural Frequencies for cantilever beam with different mode shapes and varying depths

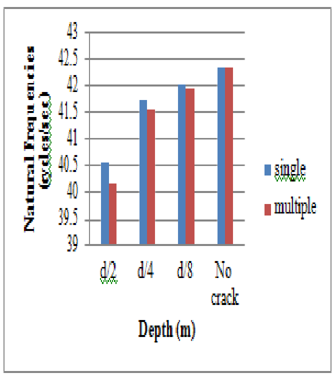


Figure 2 Variation of Natural frequencies in Mode shape 1

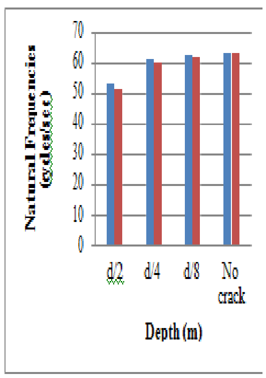


Figure 3 Variation of Natural frequencies in Mode

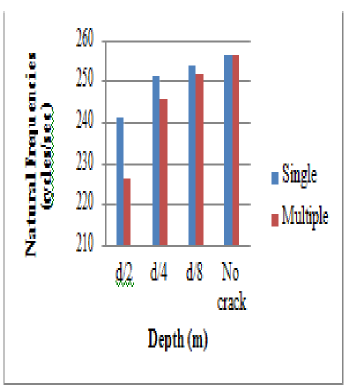


Figure 4 Variation of Natural frequencies in Mode shape 3

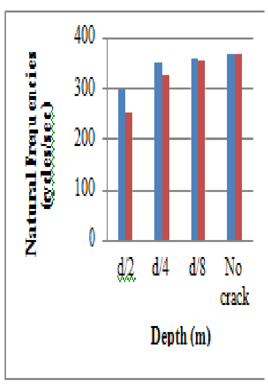


Figure 5 Variation of Natural frequencies in M

Mode	Type of crack	Maximum Deflection (mm)			
		d/2	d/4	d/8	No crack
1	single	0.09005	0.089274	0.08912	0.089011
	multiple	0.090952	0.089582	0.089201	0.089011
2	single	0.092708	0.089657	0.089088	0.08883
	multiple	0.095702	0.090659	0.089317	0.08883
3	single	0.086585	0.087983	0.088428	0.088727
	multiple	0.087306	0.088172	0.088553	0.088727
4	single	0.076467	0.085398	0.087368	0.088306
	multiple	0.083314	0.087192	0.088028	0.088306

Table 4 Comparison of Maximum Deflection for cantilever beam with different mode shapes and varying depths

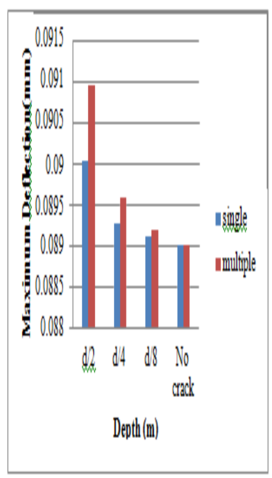


Figure 6 Variation of maximum deflection in Mode shape 1

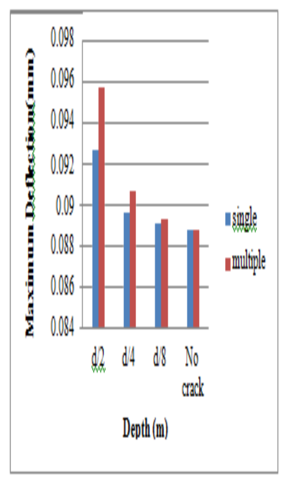
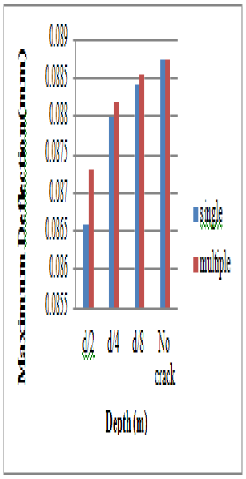


Figure 7 Variation of maximum deflection in Mode shape 2



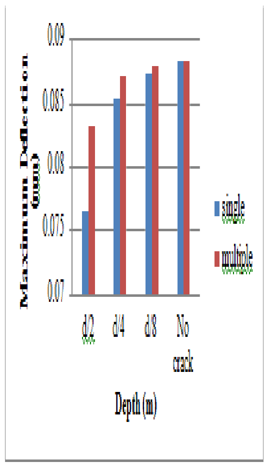


Figure 8 Variation of maximum deflection in Mode shape 3 Figure 9 Variation of maximum deflection in Mode shape 4

Fixed-fixed Beam

The effects of the crack on natural frequency of a Fixed-Fixed beam were investigated for various crack depths and crack locations using ANSYS software. Comparison of beams is carried out between a beam without crack and with single, multiple crack and the results of different mode shapes and frequencies are compared in the further studies. Comparison has been carried out between single and multiple cracks of different mode shapes and varying depths for Natural frequencies and Maximum deflection. The properties of beam is given below

Properties:

Width of the beam (b) = 0.23 m, Depth of the beam (d) = 0.35 m, Length of the beam (l) = 2.5 m, Width of the crack=0.3mm Depth of crack = d/2,d/4,d/8

Element type SOLID 65

Concrete used M25

Steel fe415

Type of crack created is 'V' Shaped crack

Type of mesh used is TETRAHEDRAL and no of divisions is 100

Mode	Type of crack	Natural Frequencies (Cycles/Sec)			
		d/2	d/4	d/8	No crack
1	single	246.58	253.84	256.02	257.89
	multiple	238.70	250.96	254.96	257.89
2	single	330.73	354.51	363.39	367.39
	multiple	320.03	345.58	360.11	367.39
3	single	644.36	661.00	666.02	670.69
	multiple	617.75	653.67	663.53	670.69
4	single	784.95	791.19	792.98	799.48
	multiple	688.33	788.63	791.58	799.48

Table 5 Comparison of Natural Frequencies for Fixed-Fixed beam with different mode shapes and varying depths

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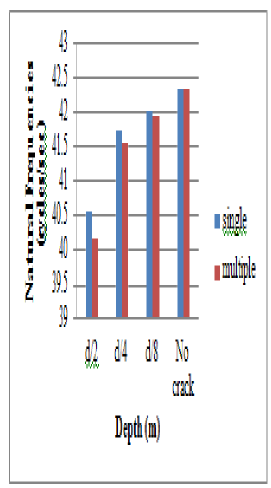

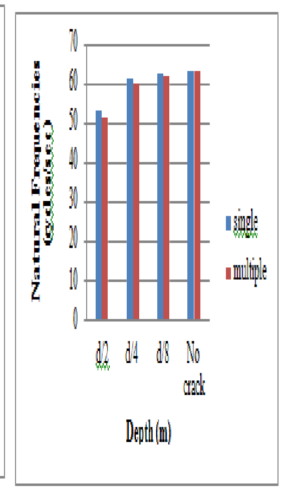

Figure 2 Variation of Natural frequencies in Mode shape 1 Figure 3 Variation of Natural frequencies in Mode shape 2

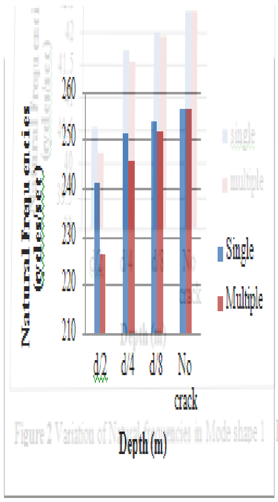

Figure 4 Variation of Natural frequencies in Mode shape 3

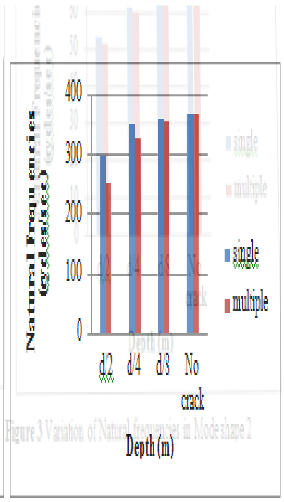

Figure 5 Variation of Natural frequencies in Mode shape 4

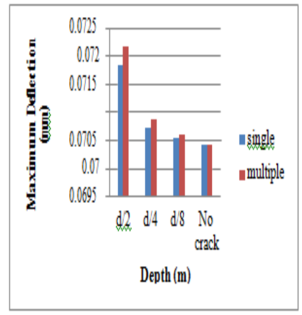

Figure 14 Variation of maximum deflection in Mode shape 1

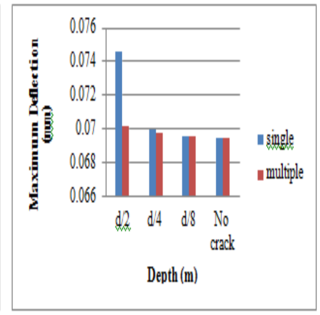

Figure 15 Variation of maximum deflection in Mode shape 2

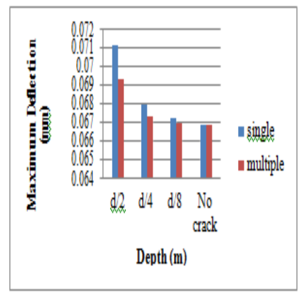

Figure 16 Variation of maximum deflection in Mode shape 3

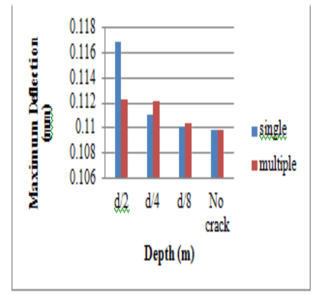

Figure 17 Variation of maximum deflection in Mode shape 4

Mode	Type of crack	Maximum Deflection (mm)			
		d/2	d/4	d/8	No crack
1	single	0.071843	0.070718	0.07054	0.070424
	multiple	0.07216	0.070881	0.070605	0.070424
2	single	0.074625	0.069984	0.06955	0.069482
	multiple	0.070193	0.069774	0.069561	0.069482
3	single	0.071087	0.067931	0.067188	0.066819
	multiple	0.069313	0.067324	0.066994	0.066819
4	single	0.116927	0.111019	0.110137	0.109802
	multiple	0.11224	0.112167	0.110458	0.109802

Table 6 Comparison of Maximum deflection for Fixed-Fixed beam with different mode shapes and varying depths

Table 4 Comparison of Maximum Deflection for cantilever beam with different mode shapes and varying depths

OBSERVATIONS

Natural frequencies of a Cantilever beam and fixed-fixed beam, for mode 1 is observed and the percentage Variation has been calculated for varying depths with conventional beam. For Single cracked cantilever beam the percentage Variation between conventional beam with varying depths (d/2,d/4,d/8) are 4.4,1.4,0.8. Similarly for multiple cracks cantilever beam the percentage error is 5.3, 1.8, and 0.9. From the above analysis output it is observed that the percentage error is less for d/8 in both the cases. Similarly for Fixed-Fixed beam the percentage between conventional beam and single, multiple crack beam is 4.5, 1.5, 0.7 and 8.0, 2.7, 1.1 in these case also the percentage error is less for d/8 only and for simply supported beam the percentage error is ZERO.

Maximum deflection of a Cantilever beam and fixed-fixed beam for mode 1 is observed and the percentage Variation has been calculated for varying depths with conventional beam. For Single cracked cantilever beam the percentage Variation between conventional beam with varying depths (d/2, d/4, d/8) are 1.1, 0.2, 0.1. Similarly for multiple cracks cantilever beam the percentage error is 2.1, 0.6, and 0.2. From the above analysis output it is observed that the percentage error is less for d/8 in both the cases. Similarly for Fixed-Fixed beam the percentage between conventional beam and single, multiple crack beam is 2, 0.4, 0.1 and 2.4, 0.6, 0.2 in these case also the percentage error is less for d/8 only.

We can also observed that in Natural frequencies for mode shapes the frequencies is more for conventional type whereas in case of maximum deflection for conventional beam maximum deflection is less compared with varying depth cracked beams.

CONCLUSION

It has been observed that the natural frequency changes substantially due to the presence of cracks depending upon location and size of cracks. It has been observed that the change in frequencies is not only a function of crack depth, and crack location, but also of the mode number. When there is increase in crack position subsequently there is decrease in frequencies in both single and multiple cases it means frequencies is inversely proportional to depth of crack. It has been observed that there is tremendous increase in frequencies of fixed-fixed beam when compared to cantilever beam. When the crack positions are constant i.e. at particular crack location, the natural frequencies of a cracked beam are inversely proportional to the crack depth. In actual practice structural members such as beams are highly susceptible to transverse cross- sectional cracks due to fatigue. Therefore this study can be further extended to beams with different mode shapes and different boundary conditions.

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