DETECTION OF MULTIPLE CRACKS IN CANTILEVER BEAM BY NATURAL FREQUENCY

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ABSTRACT. This paper examines the natural frequencies of multiple cracks in cantilever beam under different crack size and crack location. Two dimensional finite element models of multiple cracks in cantilever beam were established and the natural frequency of the model were studied. The model was developed by using ANSYS and the finite element mesh model was divided into six nodes or eight nodes plane element by using PLANE183. The verification of the model were carrired out with previous experiment and simulation data to ensure the model being develoved were realiable and acceptable. The modal analysis of the cantilever beam were performed using ANSYS to obtain the natural frequencies under the difference crack size and crack location. The results showed that the natural frequency of the cantilever beam was decreased when the crack size increased while the natural frequency increased as the crack location far away from the fixed end cantilever beam. These studies establish good information for multiple cracks detection of cantilever beam.

KEYWORDS: natural frequency; cracks; finite element; cantilever beam

1 INTRODUCTION

Many engineering application use beam widely and it is considered as one of the important structural element used in industry. It is regarded as a horizontal engineering structure having the ability to withstand loads by resisting bending. There are many different types of beams and categorised based on how they are supported. One type of beams is the beam that have support at both ends and are free to rotate are referred to as simply supported beams. Another one is fixed beams where it is supported and fixed from both ends. A continuous beam has two supports and more throughout the beam, whereas an overhanging beam extends past its support on one end. For cantilever beam, only one end is fixed supported while the other end is free.

The cantilever beam are commonly used in a variety of engineering application and there are subjected to a variety of loads which can cause cracks. Cracks can weaken the cantilver beam and the failure of the beams affects the reliability and security of the structure system. Thus, it is important to detect the cracks earlier before it lead to fracture.

An efficient and affordable non-destructive test for structures is modal analysis, which can be used to find structural flaws like cracks. The modal analysis of cracked beam has drawn the interest of many researchers in this field. Thus for this study, the cantilever beam model having multiple cracks were developed using ANSYS and then the natural frequencies of multiple cracks in cantilver beam under different crack size and crack location were analyzed. The results of this study will be used to develop a better understanding of how crack size and crack location affects the natural frequency of cantilever beam. This information can be used to develop more effective methods for cracks detection in cantilever beam.

2 LITERATURE REVIEW

Most of engineering problems can be solved using the finite element method (FEM) which is a numerical approach and procedure. The development of modern FEM dates back to the early 1900s, when some researchers used discrete equivalent elastic bars to approximate and describe elastic continua. Courant, however, is credited in a study written in early 1940s as being the pioneer to develop

FEM. In order to study torsion problems, Courant used piecewise polynomial interpolation across triangular sub-regions (Moaveni 2020).

The cracks detection due to the damage has been extensively investigated and many methods for identification were proposed (Dimarogonas 1996). Ostachowicz and Krawczuk (1991) proposed a numerical approach to compare the natural frequencies of cracked cantilever beams with single and multiple cracks at various sites. The results of the computation demonstrated that the cantilever beam's cracks' location and size will undoubtedly alter the natural frequencies.

Ruotolo and Surace (1997) suggested using modal analysis of the smaller modes for detection of crack size in beams without causing any damage on beam. By using the structure's finite element model, it was possible to compute the dynamic behavior analytically, express the inverse problem in terms of optimization, and then use genetic algorithm-based solution techniques. Lee (2009a) investigated an easy approach according to the massless rotating spring model for the crack, the finite element method as well as the Newton-Raphson technique in order to identify multiple cracks in beams while Yoon et al. (2009) suggested the mode shape curvature approach to determine the crack in free-free beam.

In their study, Shao et al. (2013) examined the impact of fractures on two dynamic gear parameters. When tooth cracks in the gear appear, the dynamic parameters such as natural frequencies and vibration shape are examined. The effects of crack position and length on the dynamic parameters of the gear structure are also discussed. The results showed that when a crack developed, the natural frequency reduced and the mode shape was larger than the crack length. Sawant et al. (2017) studied the effect of presence of crack at different locations and different depth on natural frequency. The study showed that the presence of crack decreases the natural frequency of the beam and at some particular locations.

3 METHODOLOGY

For this study, the cantilever beam was modelled and simulated to detect multiple cracks in it using one of the most sophisticated and complete finite element programs, called ANSYS. Three phases were taken to complete this study using ANSYS which were pre-processing, solution, and post-processing. The phases were displayed in Figure 1.

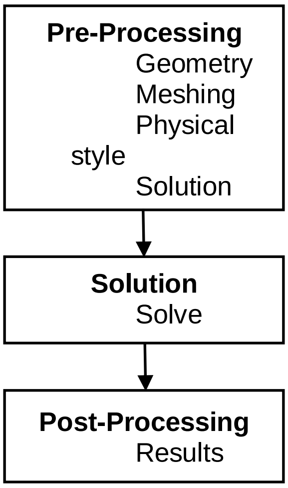

Figure 1: Three phases used in ANSYS

Verification is a necessary step to ensure that the output data is accurate. The outcomes of the ANSYS simulation used in this study were compared to the data from previous simulation and experiment. For modal analysis of multiple cracks in cantilever beam, the natural frequencies data generated were studied. In previous experiment, Ruotolo and Surace (1997) measured the natural frequencies of cantilever beams with and without cracks. The cantilever beam was built using C30 steel with dimensions of $0.02 \times 0.02 \times 0.8$ m^3. The specifications of the two cracks in the cantilever beams were $\alpha_1 = 0.2$, $\alpha_2 = 0.3$, $\beta_1 = 0.3182$ and $\beta_2 = 0.6812$ where α was a dimensionless crack size and β was a dimensionless crack location. Lee (2009b) later research was carried out to simulate Ruotolo and Surace (1997) experimental findings.

$$\%\,\text{error} = \frac{\text{presentdata} - \text{previousdata}}{\text{previousdata}} \times 100 \qquad (1)$$

Table 1: The natural frequency from previous experimental and simulation

	Condition of Beam	1st mode natural frequency f_1 (Hz)	2nd mode natural frequency f_2 (Hz)	3rd mode natural frequency f_3 (Hz)
Experimental Data (Ruotolo and Surace 1997)	Undamaged	24.175	152.103	424.455
	Cracked	24.044	149.268	409.287
Simulation Data 2D Model ANSYS (Lee 2009b)	Cracked	24.108	149.09	408.73

Another modelling and simulation were run based on the research by Ruotolo and Surace (1997) and Lee (2009b) as shown in Table 1 to compare and verify the results with the previous studies. Figure 2 shows the establishment of a two-dimensional cantilever beam with two cracks of length *L* and thickness *h*. The ANSYS software was used to model and simulate the cantilever beam. The first crack was at s_1 and measured a_1, while the second crack was at s_2 and measured a_2. The cantilever beam's dimensions were maintained as the previous one and shown in Table 2. The crack size was set in dimensionless unit, α ($\alpha = \frac{a}{h}$) while dimensionless crack location, β is $\frac{s}{L}$. The percentage errors of the results data between the present study and both previous study were calculated as shown in (1) in order to prove whether the model developed are acceptable and reliable for further study.

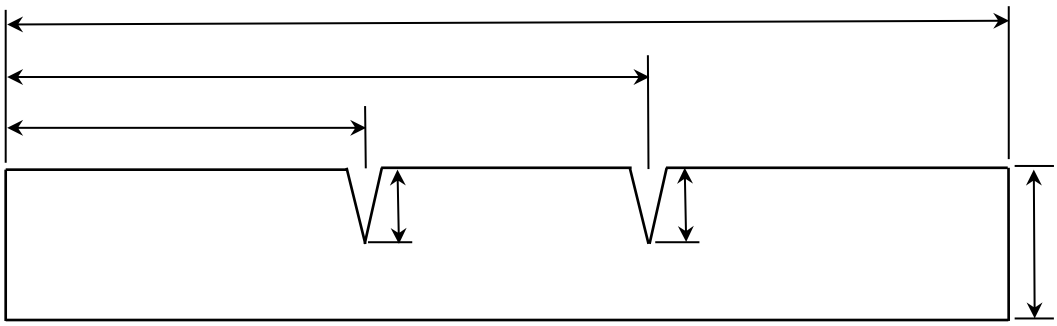

Figure 2: Cantilever beam geometry with two cracks

Table 2: The cantilever beam's dimensions used for verification

Item	Dimension (m)
L	0.8
s_1	0.25456
s_2	0.54496
h	0.02
a_1	0.004
a_2	0.006

The 2D model of cantilever beam consists two cracks after meshing by using ANSYS was shown in Figure 3.

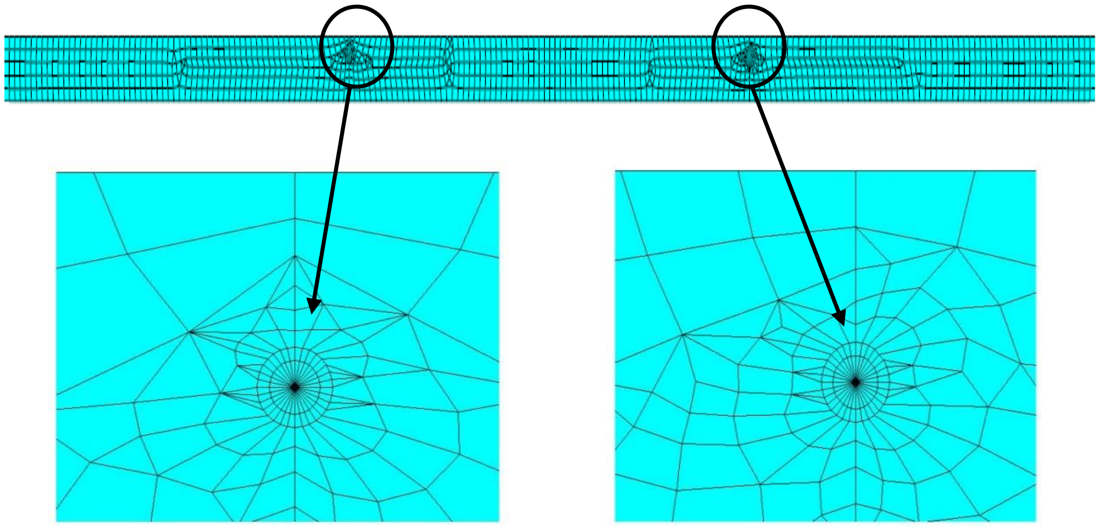

Figure 3: 2D model of cantilever beam consist two cracks after meshing using ANSYS

The further study was carried out to study the natural frequency of the cantilever beam having two cracks under different crack size and crack location. The simulation of the model had been carried out using ANSYS software and the natural frequency data was generated. The material properties consist of Young modulus, E = 181 GPa, density, ρ = 7860 kg/m3 and poisson's ratio, v = 0.29 were used.

The cantilever beam was divided into six nodes or eight nodes plane element by using PLANE183. The cantilever beam was constrained at one end and free at another end. The external load was applied to the cracked cantilever beam and the model was simulated to see the influence of different crack size and different crack location on the natural frequency of the model. The data generated were illustrated in graph in next chapter.

4 RESULTS AND DISCUSSION

The verification of the model develop by ANSYS was required to ensure that the results obtained from this simulation was reliable and acceptable. The verification process of this simulation was conducted by compared the current study with the previous research. The results of verification were shown in Table 3.

Table 3: Result of verification of the model

	Condition of Beam	1st mode natural frequency f_1 (Hz)	2nd mode natural frequency f_2 (Hz)	3rd mode natural frequency f_3 (Hz)
Experimental Data (Ruotolo and Surace, 1997)	Undamaged	24.175	152.103	424.455
	Cracked	24.044	149.268	409.287
Simulation Data 2D model ANSYS (Lee, 2009b)	Cracked	24.108	149.090	408.730
Present Study (2D model ANSYS)	Undamaged	24.215	151.320	421.680
	Cracked	24.028	148.63	407.640

Based on the Table 3 above, the results showed that the natural frequency data for three lowest mode of vibration from the present study were slightly nearer to the data of three lowest mode of vibration from the experimental study of Ruotolo and Surace (1997) and simulation study of Lee (2009b). The percentage error between the present study and both previous study was less than one percent as shown in Table 4 and Table 5. It proved that the model of cantilever beam having two cracks developed using ANSYS in the present study were acceptable and reliable indicate it could be used for further study.

Table 4: Percentage error between current research and results from earlier experiments

Natural Frequency (Hz)	Ruotolo & Surace, 1997	Present Study	%Error
Undamaged			
f_1	24.175	24.215	0.165
f_2	152.103	151.320	0.515
f_3	424.455	421.680	0.654
Cracked			
f_1	24.044	24.028	0.067
f_2	149.268	148.630	0.427
f_3	409.287	407.640	0.402

Table 5: Percentage error between current study and earlier simulation results

Natural Frequency (Hz)	Lee, 2009b	Present Study	%Error
Undamaged			
f_1	24.108	24.028	0.332
f_2	149.090	148.630	0.309
f_3	408.730	407.640	0.267

Generally, the crack size had given influence on the dynamic characteristic of the engineering structure. In this sub topic, the influences of the different crack size on natural frequency of the cracked cantilever beam were studied. The simulation was started by setting the both cracks in cantilever beam would had similar crack size. The model then was simulated using ANSYS and the three lowest modes of natural frequencies were collected. The simulation was repeated with another five set of different crack size and the three lowest modes of natural frequencies data were collected. The results of these simulations were shown in Table 6.

Table 6: Result of natural frequencies under various sets of crack sizes

Crack Size (m)		Dimensionless Crack Size	Natural Frequencies (Hz)		
a_1	a_2	a/h	f_1	f_2	f_3
0.002	0.002	0.1	24.171	150.950	419.530
0.004	0.004	0.2	24.043	149.910	413.440
0.006	0.006	0.3	23.819	148.110	403.170
0.008	0.008	0.4	23.456	145.310	387.700
0.010	0.010	0.5	22.869	141.010	365.240
0.012	0.012	0.6	21.885	134.310	333.210

Based on the data from above table, the variation of natural frequencies upon the cracks size were studies. The crack size was illustrated into dimensionless crack size (a/h) where a_1 was a size for crack one (near to the fixed end), a_2 was a size for crack two and h was a thickness of cantilever beam.

The three lowest modes of natural frequencies and the dimensionless crack sizes were plotted in the graph as shown in Figure 4.

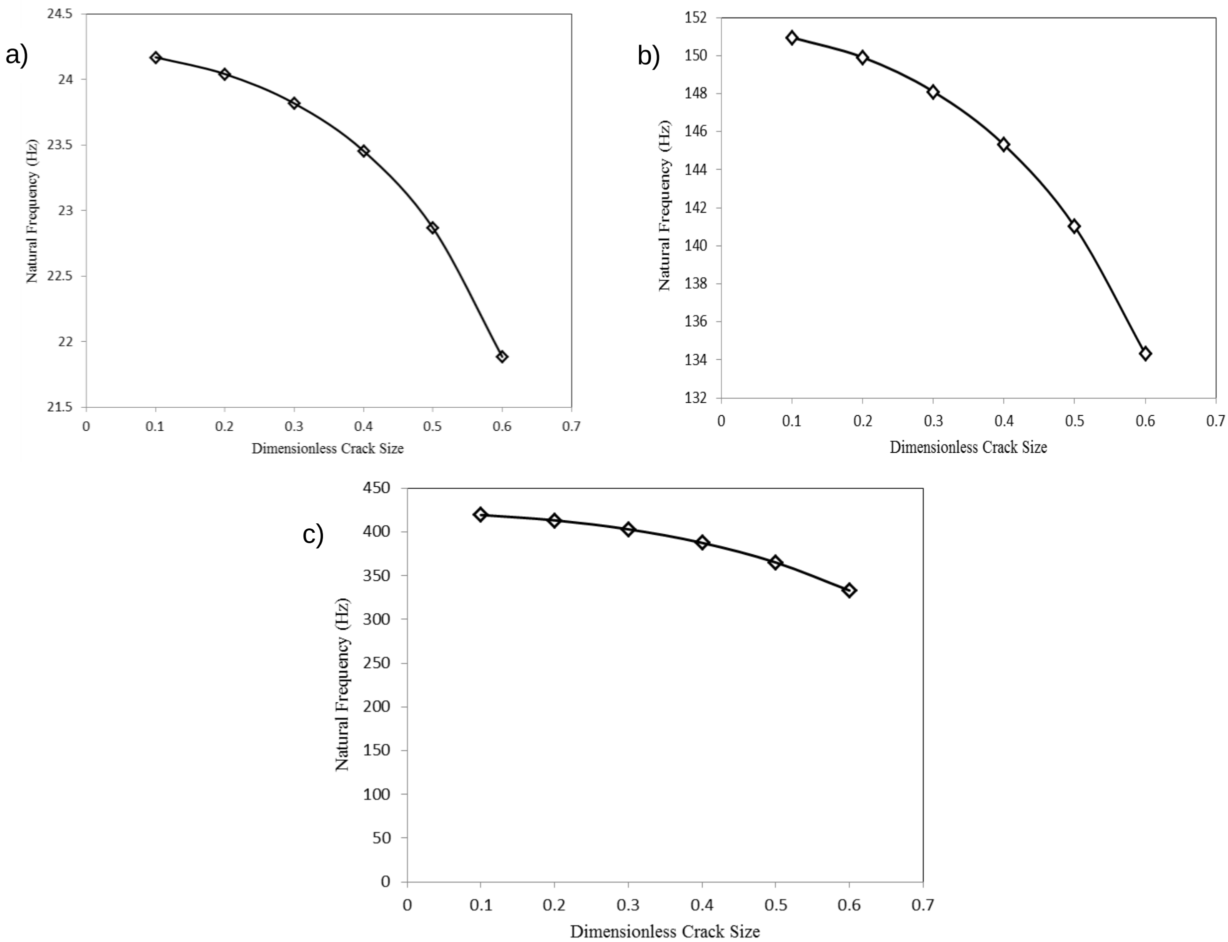

Figure 4: Graph of natural frequencies in different dimensionless crack size for a) mode one b) mode two and c) mode three

Based on the Table 6 and Figure 4, they showed that the natural frequencies of three lowest mode of vibration were dropped as the size on both cracks in cantilever beam increased. The natural frequency was slightly dropped in small amount when the crack size is small but it became dropped obviously in large amount when the cracks size was large. These situations occurred as the reduction of natural frequency in cracked cantilever beam was expected due to crack flexibility.

The influences of different crack location on the natural frequency were studied. The both cracks size were fixed and the cracks locations were changed from near to the fixed end until became more far from the fixed end of cantilever beam. The first crack, a_1 was fixed at 0.004 m while the second crack, a_2 was fixed at 0.006 m. The first set of location for both cracks were established and the model was simulated to find the natural frequency. The simulation was repeated with another five set of crack location. The results of these simulations were shown in Table 7.

Table 7: Result of natural frequencies under various sets of crack location

Crack Loc (m)		Dimensionless Crack Loc		Natural Frequencies (Hz)		
s_1	s_2	s_1/L	s_2/L	f_1	f_2	f_3
0.20	0.50	0.250	0.625	23.952	148.230	411.570
0.25	0.55	0.313	0.688	24.025	148.760	407.450
0.30	0.60	0.375	0.750	24.082	149.200	408.820

0.35	0.65	0.438	0.813	24.125	149.480	414.400
0.40	0.70	0.500	0.875	24.156	149.620	419.500
0.45	0.75	0.563	0.938	24.178	149.750	420.390

Based on the Table 7, the variations of natural frequencies upon the cracks locations were studied. The crack location was illustrated into dimensionless crack location (*s/L*) where s_1 was a location for crack a_1, s_2 was a location for crack a_2 and *L* was a thickness of cantilever beam. The three lowest modes of natural frequencies and the dimensionless crack location for crack a_1 and crack a_2 were plotted in the graph as shown in Figure 5.

Based on the Figure 5, the graph showed the natural frequencies were affected by the location of both cracks in cantilever beam. For the mode one and mode two of vibration, it was clearly showed that the natural frequencies were increased as the crack location of cracks a_1 and a_2 increased (far away from the fixed end). Only for mode three of vibration, the natural frequency had slightly decreased from first to second set of crack location and then start increased at the third set of crack location when the crack location increased.

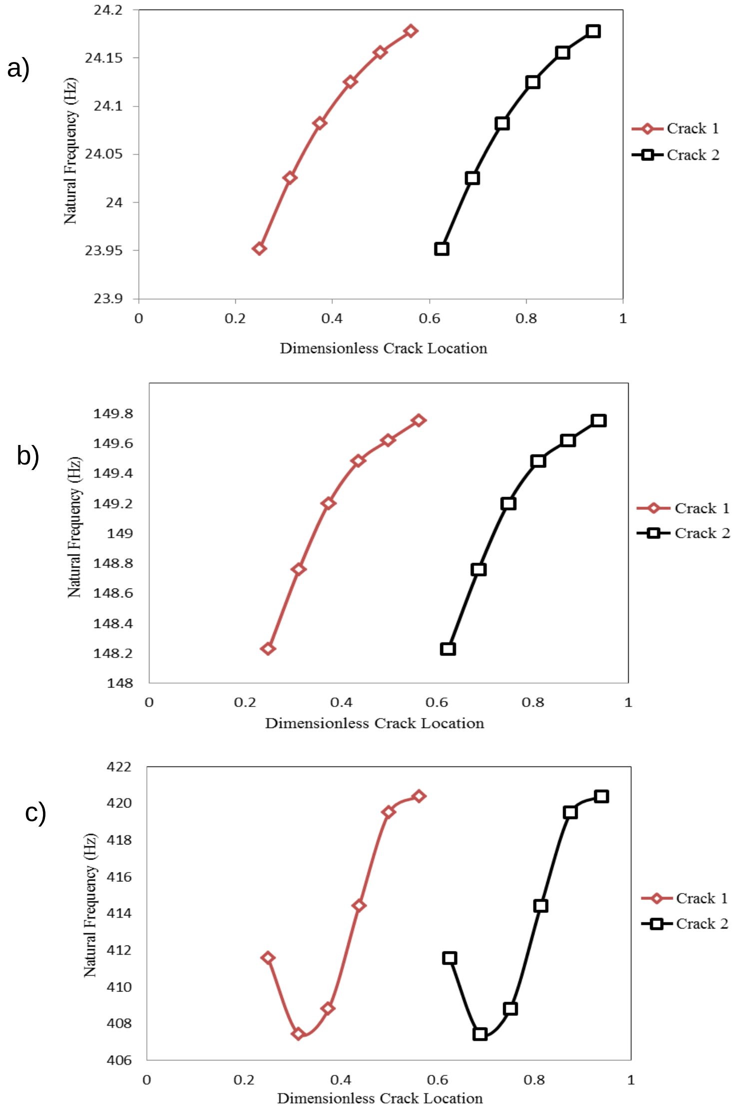

Figure 5: Graph of natural frequencies in different dimensionless crack location for a) mode one, b) mode two and c) mode three

From the observation based on the Table 7 and Figure 5, it was clearly showed that the natural frequency was lower when the cracks were nearer to the fixed end of cantilever beam while when the cracks became far away from the fixed end, the natural frequency was high. The reason for this situation was the damage to the stiffness of cantilever beam structure was bigger when the cracks were nearer to the fixed end of model compare to when the cracks were far away from the fixed end.

5 CONCLUSION

In this study, the natural frequencies of the multiple cracks in cantilever beam was established and investigates through numerical simulation using finite element software. From the verification process, it’s proved that the model developed by using ANSYS was trusted and reliable to use in further study. The percentage error calculated was below 1% indicated that the model developed correctly. The influence of cracks on natural frequency is studied. The further study was carried out under different cracks size and cracks location. The results showed that as the crack size increased, the natural frequency dropped obviously. The natural frequency was lower when the cracks exist nearer to the fixed end while the natural frequency was high when the cracks exist far away from the fixed end. This information can be used to develop more effective methods for cracks detection in cantilever beam in the future.

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