Effect of Cracks on Natural Frequency Cantilever Beam Structures with T, I and H Cross-sections

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ABSTRACT

All structures such as cantilever beams are susceptible to defects such as cracks which can affect the strength of the structure. Over time, these defects can cause complete damage to the structure. One of the things that is affected by cracking is the value of the natural frequency.

The analysis was carried out to determine the natural frequency for the 3 modes of initial bending that occurred in the structure. The structure used is a cantilver beam with cross sections H, I and T. The finite element method (FEA) is carried out with the help of software MSC.Nastran. Comparison of analytical calculations with FEA results shows nearly the same results. The study also shows that the natural frequency value decreases with the presence of cracks, where the value depends on the crack location, depth of the crack and the shape of the cross-sectional structure used.

Keywords : Natural Frequency, Crack, Cantilever Beam, FEA

1. Introduction

All structures are susceptible to degenerative effects due to the manufacturing process as well as due to the operating load they receive. These effects can result in structural defects such as cracks which can lead to structural failure over time. The dynamic behavior of structural elements is affected by cracks or imperfections, which alter their stiffness and damping qualities. One of the things that is affected is the natural frequency of the structure. Cantilever beam structures made of mild steel are widely used in aircraft, ships and offshore platforms. These structures are also used to construct stadiums, bridges, buildings, towers, and many other constructions. Cracks in the cantilever beam structure can cause damage to the structure as a whole, so an analysis is needed to study the effects of these cracks. One of the analyzes carried out is a modal analysis, but there are difficulties in conducting a modal analysis on a limited cantilever beam using an analytical approach..

One approach that is considered effective and widely used in previous studies is to use the finite element method [1]. Previous research conducted by Yendhe et al. [2] regarding the comparison between theoretical results, experimental FFT Analyzer and computational ANSYS15 for the case of cantilever beam with cracks and without cracks shows that the natural frequency values of the three methods have very small differences. Similar results were obtained in the study conducted by Lanka Ramesh et al [3] for the case of multiple cracks. Experiments using a universal vibration apparatus give results that are close to the results of modeling using ANSYS. The shape of the crack has a different influence on the calculation results. Research conducted by Khalkar, et al [4] showed a higher natural frequency value for V-shaped cracks compared to rectangular ones. The use of element types from finite element modeling also has an influence on the results of crack case analysis. The study conducted by Mia, et al [5] using Abaqus showed that wedge and hexahedral elements gave the best results compared to the theoretical results. Variations in the depth and length of the crack also affect the natural frequency that occurs. Research conducted by Ramachandran, et al [6] and Patil, et al. [7] shows that the natural frequency value decreases with the increasing length and depth of the cracks that occur. This occurs both in variations into cracks at different and fixed positions. Variations in crack position also affect the natural frequency value. Ahiwale et al. [8] study showed that the natural frequency value was reduced when cracks occurred at the top and bottom of the beam, while in the middle it was relatively stable.

The constituent material of the cantilever beam also gives different results as seen in the research of Ghodke, et al. [9] which used Aluminum and Steel, Elshamy, et al. [10] which used Copper and Kahya, et al. [11] which used Composite.

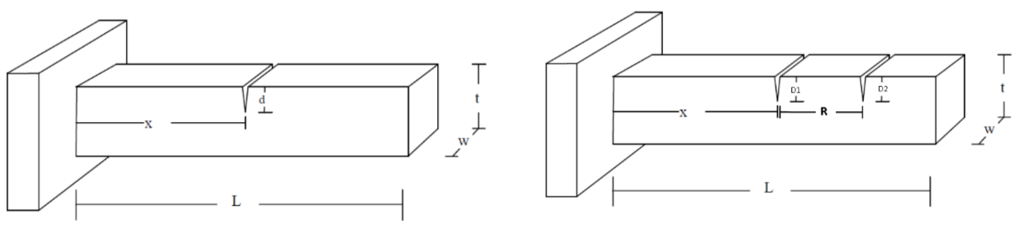
Previous studies have generally focused on cantilever beam structures with a square cross section. However, there has been no research that has focused on discussing the effect of cracks on the nature of the frequency for cantilever beams with cross sections H,I and T. Therefore, this study focuses on knowing the effect of cracks on natural frequencies in cantilever beams with cross sections in the shape of H, I and T. The study was also conducted with vary the position and depth of the crack.

2. Methodology

2.1 Geometry

Natural frequency is the frequency possessed by a system or structure that vibrates when it is initially excited without damping or excitation. The study of natural frequencies is important because it affects the overall structure. When the frequency of the load received by the structure is the same as its natural frequency, it causes the structure to vibrate until the structure finally fails. Therefore, knowledge is needed to be able to know the natural frequency value of a system in order to avoid massive damage.

Fig. 1. Single and Double Cantilever Beam Models



In this study, modal analysis was carried out to determine the vibration frequency for different shapes. Between one system with another system has a different frequency value for each form of vibration that occurs. As research material, a cantilever beam with a length of 3 meters and made of steel is used with details as shown in Fig.1. Details of material properties can be seen in table 1. The cross section of the cantilever beam used is section H, I and T. Cracks are assumed to be at the top of the cantilever beam surface. The crack is assumed to be perpendicular to the longitudinal axis of the cantilever beam and has a triangular shape. The study was carried out using single crack and double crack models. As a first step, an analysis of the effect of crack opening sizes was carried out with sizes of 0.002 meters, 0.006 meters, 0.008 meters and 0.01 meters. The results of the analysis are then used as the basis for the next modeling. The cracks were positioned at a distance of 0.2 meters, 0.5 meters, 1 meter and 1.3 meters. The crack depth is modeled with sizes of 0.03 meters, 0.05 meters and 0.08 meters. The final result of the modeling, the value of the 3 modes of initial bending that occurs is taken.

Table 1. Material Properties

Property	Value
Material	Mild Steel
Elastic Modulus (E)	210 x 10^9 N/m^2
Poisson's Ratio	0.3
Density	7860 kg/m^3

2.2 Validation

Initial validation was carried out theoretically for the model without cracks. The same model was then analyzed using the MSC Patran Nastran software. For theoretical calculations, equation (1) is used from Pilkey[12]

$$\omega_n = \frac{\lambda^2}{L^2}\sqrt{\frac{EI}{\rho}} \tag{1}$$

By using this equation, the natural frequency value from modes shape 1, 2 and 3 is obtained from the initial bending for all cross-sections of the cantilever beam. Almost the same results were also obtained from MSC Patran Nastran modeling. Details of the calculation and modeling results can be seen in table 2.

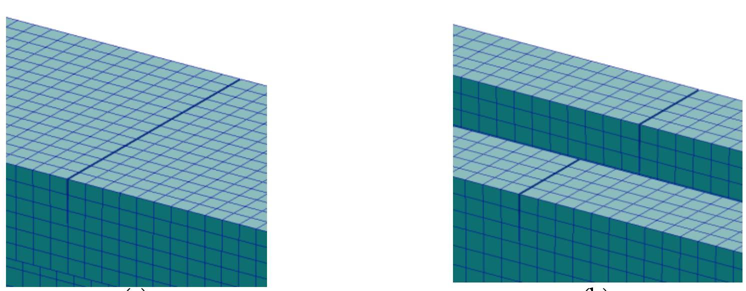
Table 2. Natural Frequencies of un-cracked beam

		Model H	Model I	Model T
Modal (Cyc/sec)	Mode 1	25.905	30.728	27.135
	Mode 2	156	174.84	160.15
	Mode 3	412.86	434.96	413.46
		Model H	Model I	Model T
Theoritical (Cyc/sec)	Mode 1	25.863	30.657	27.085
	Mode 2	157.04	175.77	161.24
	Mode 3	419.53	438.96	419.9

2.3 Crack Modelling

To analyze the structure with cracks on its surface, it is necessary to use finite element software, namely MSC. Patran Nastran. Fixed boundary conditions are applied to one end of the cantilever beam model, while the other end is left free. The crack is modeled as a triangle with different openings, positions and depths. Cracks are located on the upper surface of the cantilever beam. Especially for the H section, the cracks are placed on the two top surfaces as shown in Fig 2. The cantilever beam modeling uses hexahedral 8 isomesh solid elements with a size of 0.02 meters. By using the solution type Normal Modes on the default solver from MSC Patran Nastran, the frequency value of each mode shape is obtained..

Fig. 2. (a) I and T . sectional model cracks ; (b) H sectional model crack



(a) (b)

3. Result and discussion

3.1 Effect of Crack Opening Size

Table 3 shows the natural frequency values for several crack opening sizes. From the results obtained, it is shown that there is no significant change in value with the increasing size of the crack openings for both single and double cracks in each cross section of the cantilever beam..

Table 3. Frequency for different crack opening size

Single					Double		
Size	Mode Shapes	Model H	Model I	Model T	Model H	Model I	Model T
Uncracked	Mode 1	25.905	30.728	27.135	25.905	30.728	27.135
	Mode 2	156	174.84	160.15	156	174.84	160.15
	Mode 3	412.86	434.96	413.46	412.86	434.96	413.46
0.002m	Mode 1	25.765	30.531	26.974	25.515	30.178	26.686
	Mode 2	152.58	170.49	156.3	152.47	170.32	156.18
	Mode 3	412.78	434.8	413.27	397.65	417.66	396.81
0.006m	Mode 1	25.74	30.532	26.975	25.489	30.18	26.688
	Mode 2	152.14	170.5	156.33	152.03	170.34	156.21
	Mode 3	410.36	434.81	413.28	395.61	417.75	396.94
0.008m	Mode 1	25.74	30.532	26.975	25.49	30.181	26.69
	Mode 2	152.15	170.51	156.35	152.04	170.35	156.22
	Mode 3	410.36	434.81	413.28	395.64	417.8	397.01
0.01m	Mode 1	25.741	30.532	26.976	25.49	30.182	26.691
	Mode 2	152.16	170.52	156.36	152.05	170.36	156.23
	Mode 3	410.36	434.82	413.28	395.67	417.84	397.08

3.2 Effect of Crack Depth

A study of the depth effect of cracks was carried out for the crack position of 1 meter from the end of the cantilever beam support, while for multiple cracks, the distance between the cracks was 1 meter. From the results obtained in table 4, it shows that the natural frequency value decreases with the depth of the crack size.

Table 4. Frequency for different crack depth

Size		Single			Double		
	Mode Shape	Model H	Model I	Model T	Model H	Model I	Model T
uncracked	Mode 1	25.905	30.728	27.135	25.905	30.728	27.135
	Mode 2	156	174.84	160.15	156	174.84	160.15
	Mode 3	412.86	434.96	413.46	412.86	434.96	413.46
0.03m	Mode 1	25.836	30.668	27.085	25.769	30.558	26.992
	Mode 2	154.42	173.46	158.91	154.74	173.4	158.86
	Mode 3	410.94	434.95	413.45	407.41	430.23	408.01
0.05m	Mode 1	25.765	30.531	26.974	25.515	30.178	26.686
	Mode 2	152.58	170.49	156.3	152.47	170.32	156.18

	Mode 3	412.78	434.8	413.27	397.65	417.66	396.81
0.08m	Mode 1	25.544	30.092	26.632	24.923	29.023	25.781
	Mode 2	147.66	162.08	149.08	147.49	161.83	148.87
	Mode 3	412.59	434.68	411.37	376.59	412.72	367.02

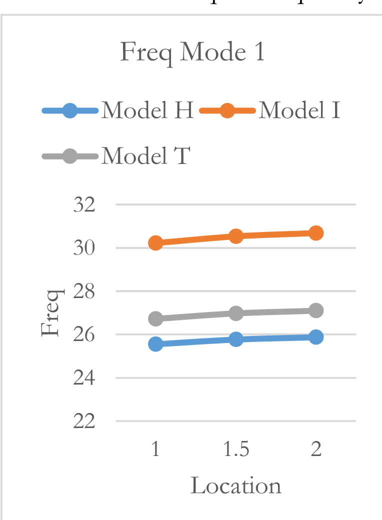
3.3 Effect of Crack Location for Single Crack

Table 5 and Figures 3(a), 3(b) and 3(c) show the natural frequency values for a single crack with a depth of 0.05 meters and an opening of 0.002 meters. From these data, it is known that the natural frequency value changes with the change in the location of the crack. The pattern of changes in natural frequency values also differs between mode shapes and cantilever beam cross-sections.

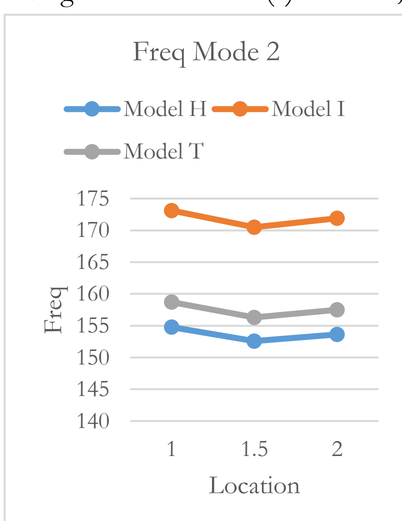
Table 5. Frequency for single crack position

Location	Mode Shapes	Cross Section		
		Model H	Model I	Model T
1m	Mode 1	25.548	30.222	26.721
	Mode 2	154.77	173.12	158.71
	Mode 3	405.95	433.4	404.9
1.5m	Mode 1	25.765	30.531	26.974
	Mode 2	152.58	170.49	156.3
	Mode 3	412.78	434.8	413.27
2m	Mode 1	25.872	30.683	27.098
	Mode 2	153.62	171.89	157.5
	Mode 3	403.83	432.35	402.84

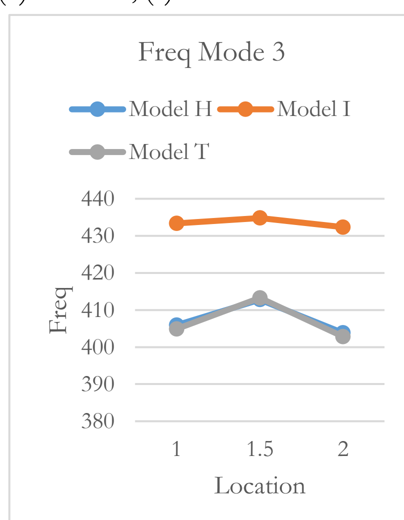
Fiq.3. Frequency for single crack location (a) Mode 1 ; (b) Mode 2 ; (c) Mode 3



(a)



(b)



(c)

For mode 1, it can be seen that the value of the natural frequency increases with the distance of the crack position from the end of the cantilever beam. For mode 2, it can be seen that the natural frequency value decreases to a position of 1.5 meters and then enlarges with the further location of the crack. In mode 3, it is seen that the natural frequency value decreases at a location of 1 meter, then enlarges at a location of 1.5 meters before decreasing again at a location of 2 meters..

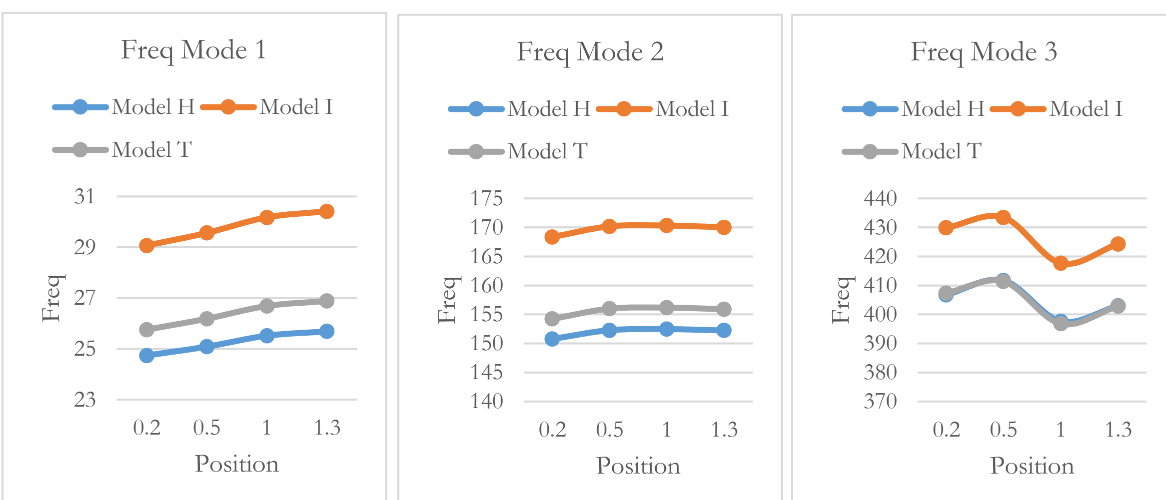
3.4 Effect of Crack Position for Double Crack

Table 6 and Figures 4(a), 4(b) and 4(c) show the natural frequency values for double cracks with a depth of 0.05 meters, an opening of 0.002 meters and a distance between cracks of 1 meter..

Table 6. Frequency for double crack position

Position	Mode Shapes	Cross Section		
		Model H	Model I	Model T
0.2	Mode 1	24.737	29.069	25.754
	Mode 2	150.78	168.35	154.23
	Mode 3	406.79	429.86	407.37
0.5	Mode 1	25.083	29.565	26.183
	Mode 2	152.29	170.19	156
	Mode 3	411.71	433.47	411.38
1	Mode 1	25.515	30.178	26.686
	Mode 2	152.47	170.32	156.18
	Mode 3	397.65	417.66	396.81
1.3	Mode 1	25.685	30.418	26.882
	Mode 2	152.24	170.03	155.91
	Mode 3	403	424.31	402.93

Fiq.4. Frequency for double crack location (a) Mode 1 ; (b) Mode 2 ; (c) Mode 3



(a) (b) (c)

As is the case for single cracks, the natural frequency values for multiple cracks have a different pattern for each mode shape. For mode 1, the frequency value increases as the distance of the crack position increases. For mode 2, the frequency value increases to a position of 1 meter and then decreases to a position of 1.3 meters. In mode 3, the frequency value increases to a position of 0.5 meters, then decreases to a position of 1 meter, then rises again to a position of 1.3 meters.

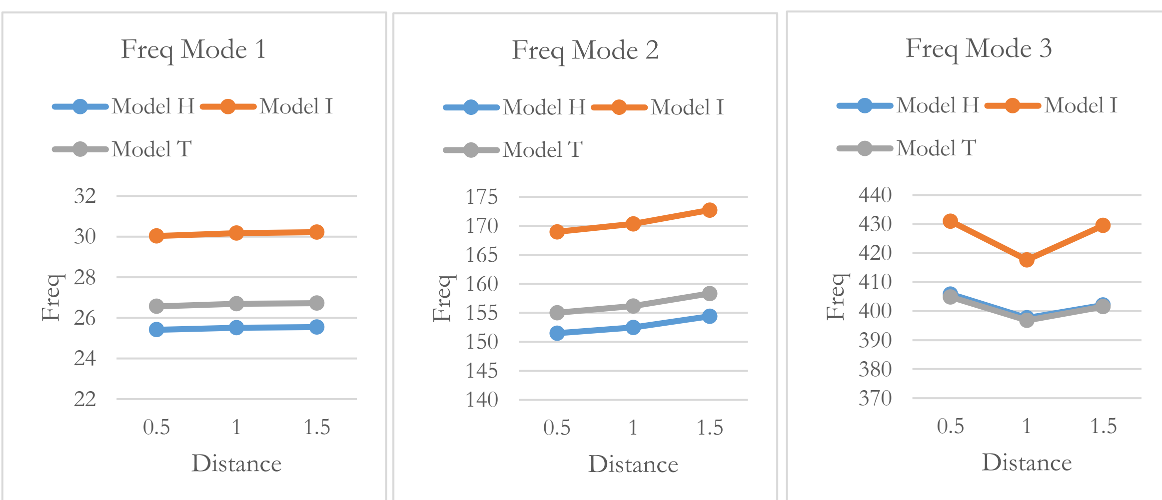
3.5 Effect of Crack Distance for Double Crack

The study was conducted to determine the effect of the distance between cracks on the natural frequency value. The model used has a distance to the pedestal of 1 meter with a crack opening of 0.002 meters and a crack depth of 0.05 meters.

Table 7. Frequency for double crack distance

Distance	Mode Shapes	Cross Section		
		Model H	Model I	Model T
0.5m	Mode 1	25.412	30.03	26.565
	Mode 2	151.49	168.97	155.02
	Mode 3	405.88	431	404.87
1.0m	Mode 1	25.515	30.178	26.686
	Mode 2	152.47	170.32	156.18
	Mode 3	397.65	417.66	396.81
1.5m	Mode 1	25.545	30.221	26.722
	Mode 2	154.41	172.72	158.34
	Mode 3	402.1	429.57	401.57

Fiq.5. Frequency for double crack distance (a) Mode 1 ; (b) Mode 2 ; (c) Mode 3



(a) (b) (c)

As shown in table 7, Fig 5 (a), (b) and (c) show the different patterns of natural frequency values for each shape modes. For modes 1 and 2, it is seen that the frequency value increases with increasing distance between cracks. Different things are shown in mode 3, where the frequency value decreases to a distance of 1 meter and then increases at a distance of 1.5 meters.

4. Conclusion

From the studies that have been carried out, several conclusions can be drawn, including:

- The natural frequency value decreases with the appearance of the crack where the magnitude of the decrease depends on the position of the crack, the depth of the crack and the shape of the cross section of the cantilever beam.
- The effect of the crack is different in each shape mode. Each mode shape has a different pattern.
- In the case of multiple cracks, the distance between cracks has an effect on changes in the natural frequency value

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