Prediction of Crack Locations using Non Destructive Tests

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Abstract

Objectives: In this paper non destructive tests are used to find the location of multiple cracks in the cantilever beam. Methods/Analysis: The impact echo test along with Ultrasonic Pulse Velocity (UPV) test is used to find the crack locations. These tests are conducted on cantilever beam having two cracks at different positions. The frequency spectrum is recorded from the impact echo test. While the ultrasonic pulse time is recorded from ultrasonic pulse velocity test. A MATLAB based code is used to find out the dominant frequency of the sound signals corresponding to each impact echo test. The ultrasonic pulse velocities are calculated from the travel time and the distance between the transducers. Findings: It was found that the frequency values are increasing when the cracks move away from the fixed end of the cantilever beam since the frequency ratio increases when the distance of the crack increases from fixed end (based on Equation 3). Ultrasonic pulse velocity also increases since the distance between the transducers of the UPV equipment decreases when the location of crack changes. Applications/Improvements: From the values of frequency and ultrasonic pulse velocity, mathematical expressions of crack location are developed. The developed expressions are tested on the cantilever beam to find the crack locations in a laboratory model.

Keywords: Crack Location, Impact Echo Test, MATLAB, Multiple Cracks, Non Destructive Tests, Ultrasonic Pulse Velocity Test

1. Introduction

Vibration based methods are commonly used to predict the presence and location of the cracks in structures. In majority of the vibration based methods, crack location and crack depth of a structure are determined by using the modal parameters such as frequency. The values of frequency depend on the crack size, crack depth and crack position in any structure. So the variation these parameter will give considerable change in the frequency response. For conducting the vibration based experiments to find the location and depth of the crack beam structures are commonly used. Metal beams are more suitable for this because of the homogeneity and isotropic properties. In this paper, a frequency based test and ultrasonic based test are described. That are impact echo test and ultrasonic pulse velocity test respectively. This paper mainly focuses on the determination of location of two transverse cracks on a cantilever beam using the above tests.

Presented[1] the vibration analysis on a cantilever beam having single crack. They have performed experiments to get the frequency change with respect to crack location and crack depth on cantilever beam. They concluded that, under no load the frequency decreases with crack depth increases. While frequency increases when the crack location moves away from the fixed end. From the study of vibration analysis conducted on simply supported beam by[2], it can be seen that when crack moves from the support to the midspan of the simply supported beam the lowest fundamental frequencies decrease. The cracks which are at symmetric positions of the beam, the lowest fundamental frequencies are almost equal. Demonstrated[3] theoretical and software analysis of structures. They are concluded that the natural frequency varies with both crack depth and crack location. These changes are observed at the area of crack location. Other than the experiment analysis, software analysis also significant to compare the result with theoretical or experimental
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Presented\(^1\) the analysis of a cracked cantilever beam using finite element method. In their study, they obtained that when crack depth increases the value of natural frequency of the beam decreases. Presented\(^2\) an experimental study of the crack detection for cantilever beams. Their study reveals that, when the position of crack location moves from the fixed end of the cantilever the vibration amplitude at higher natural frequency will increase but amplitude at lower natural frequency will decrease. Studied\(^3\) the significant benefits of vibration based method for the crack prediction over other regular non destructive tests. They presented modeling of the crack as a torsional spring and the crack location was predicted successfully. In their method an error of 4% was occurred in finding crack location and crack size. Used\(^7\) the finite element based analysis to detect the crack in cantilever beam. They presented the effects of crack on the first three modes of vibrating cantilever beams. At the end of their work, they have demonstrated crack identification technique by using frequency contours.

Ultrasound method is an NDT method for concrete and other materials. In this paper, Ultrasonic Pulse Velocity (UPV) is conducted on aluminium beams. The variation of ultrasonic waves depends on the type of material, homogeneity, presence of defect etc. Mentioned\(^8\) that ultrasound won’t transmit through the concrete linearly. Because of the presence of uneven rough stones and mortar in concrete, the ultrasonic waves will undergo for reflection and refraction. But in the homogeneous materials like metals, this many disturbances for sound wave will not be there. If the material is stressed or cracked those will affect the speed of sound waves. Used\(^9\) the ultrasonic signal characteristics for the yield detection in steel structures. They have plotted the relative change in the sound wave speed with strain and stress. Presented\(^10\) the ultrasonic surface wave characterization using Rayleigh waves.

He could detect and predict the surface crack in different metal component structures. Presented\(^11\) a pulsed laser ultrasound method to detect the crack in aluminium sheets and concluded that the laser generated lamb waves can clearly propagate around the cracks. Proposed\(^12\) method based on the application of Hilbert transform to detect flaw characteristics from the ultrasonic testing. Stainless steel and carbon steel are considered for the method.

2. Theoretical Study of Frequency and Crack Location

The crack on the cantilever beam can be modeled by a spring of stiffness \(K_x\) (Figure 1). Have\(^13\) mentioned the mathematical expression for finding the change in frequency at any fundamental mode. That is given by,

\[
\frac{\Delta f}{f} = \sin^2 \left(\frac{nl}{2L}\right) \frac{EI}{K_x L} = \text{(1)}
\]

Stiffness of spring can be calculated as,

\[K_x = \frac{EI}{5.346 h f(a/h)}\text{ (2)}
\]

Now the change in frequency becomes,

\[
\frac{\Delta f}{f} = \sin^2 \left(\frac{nl}{2L}\right) \frac{5.346 h f(a/h)}{L}\text{ (3)}
\]

Where \(EI = \) Flexural stiffness

\(l = \) Distance of crack from the fixed end of the cantilever

\(L = \) Length of the cantilever

\(a = \) Size of crack

\(h = \) Height of crack

Value of the function \(f(a/h)\) depends on the crack size and crack height.

3. Experimental Setup

The experiment consists of impact echo test and ultrasonic pulse velocity test. Both these tests are conducted on cantilever beam of aluminium having two cracks at its surface. Aluminum beams of 250 x 100 mm cross section and 500 mm length are used. Transverse cracks of 2mm size and 3mm depth at first location and 2mm size and 2mm depth at second location are made on the beam surface from the fixed end of the cantilever. For impact echo test, a transducer is attached on the beam surface at first
crack location and the frequency spectrum is recorded. Then, the transducer kept at second crack location and the frequency spectrum is recorded. All Impacts are given at the free end of the cantilever using a rebound hammer. For ultrasonic pulse velocity test, the transmitter of the UPV apparatus is placed at the free end of the cantilever and receiver is placed at the different crack locations. The ultrasonic pulse times are recorded. The above procedure is repeated for the cantilever beams having two cracks at different locations. The experimental arrangements are shown in Figures 2 and 3.

Figure 2. Impact echo test on cantilever beam having two cracks

Figure 3. Ultrasonic pulse velocity test on cantilever beam having two cracks

4. Result and Discussion

From the values got from the experiment, graphs are plotted between frequency and crack location, ultrasonic pulse velocity and crack location. Those plots are shown in Figure 4 and 5. Finally mathematical expressions were developed to find the locations of the two cracks in the cantilever beam using frequency and ultrasonic pulse velocity.

Figure 4. Typical frequency vs. crack location diagrams for two cracks on the cantilever beam
The frequency and ultrasonic velocity can predict the locations of the cracks on the cantilever beam. Equation 4 and 5 show the expressions for calculating the first and second crack location on the cantilever beam respectively. Tables 1 and 2 show the actual and predicted values of crack locations on the cantilever beam using the Equation 4 and 5. The bar diagrams of the same are shown in Figure 6.

\[ y_1 = 8.38f + 179.74v - 2.77 \]  
\[ y_2 = 10.22f + 216.3v - 1.51 \]

Where \( y_1 \) = Location of First Crack from the fixed end in mm  
\( y_2 \) = Location of First Crack from the fixed end in mm  
\( f \) = Frequency in Hz  
\( v \) = Ultrasonic Pulse Velocity in km/sec

**Table 1.** Actual and predicted location of the first crack on the cantilever beam

| Actual First Crack Location (mm) | Frequency (Hz) | UPV (km/sec) | Predicted First Crack Location (mm) | % error |
|---------------------------------|----------------|--------------|-------------------------------------|---------|
| 50                              | 128            | 5.67         | 50.74                               | 1.49    |
| 100                             | 136            | 5.75         | 103.41                              | 3.40    |
| 150                             | 144            | 5.89         | 145.28                              | 3.15    |
| 200                             | 156            | 6.07         | 213.49                              | 6.74    |
| 250                             | 164            | 6.16         | 264.35                              | 5.74    |
| 300                             | 168            | 6.24         | 283.49                              | 5.50    |
| 350                             | 180            | 6.35         | 364.28                              | 4.08    |

**Table 2.** Actual and predicted location of the second crack on the cantilever beam

| Actual Second Crack Location (mm) | Frequency (Hz) | UPV (km/sec) | Predicted Second Crack Location (mm) | % error |
|-----------------------------------|----------------|--------------|--------------------------------------|---------|
| 85                                | 128            | 5.68         | 78.07                                | 8.16    |
| 135                               | 136            | 5.79         | 136.03                               | 0.77    |
| 185                               | 144            | 5.9          | 194                                  | 4.86    |
| 235                               | 156            | 6.26         | 238.77                               | 1.61    |
| 285                               | 164            | 6.34         | 303.23                               | 6.40    |
| 335                               | 168            | 6.45         | 320.32                               | 4.38    |
| 385                               | 180            | 6.75         | 378.07                               | 1.80    |
5. Summary and Conclusion

The crack location algorithms are proposed based on frequency and ultrasonic pulse velocity values from the linear regression analysis. By knowing the values of frequency and ultrasonic pulse velocity, it is possible to determine the unknown crack locations in the cantilever beam. In this paper, two different cracks at certain intervals were predicted with their locations. The predicted crack locations were compared to the actual crack locations on cantilever beam model. The crack locations were found to be very close to the actual crack locations.

6. References

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