

Numerical and experimental investigation of crack in beams using frequency contour method

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Abstract

Health monitoring of Structures is a vital tool for engineers to ensure the life of important structures like Dams and bridges, Stadiums and buildings and, Platforms and vessels, Wind turbines Airframes, and large machinery and equipments. SHM helps to detect damage at earlier stage before failure occurs by sensing systems. Various damage detection methods are available in accordance with vibrational characteristics of the structure. In this paper Frequency contour method which consumes less time is employed to detect, locate, and characterize damage in structural and mechanical systems.

Experimental and Numerical modal analysis were carried out on cracked and healthy beams of steel with cantilever support conditions of size 20mmx20mm and of length 300mm using ABAQUS. Three natural frequencies are obtained as a basic criterion for crack detection. To locate the damage of the normalized frequency in terms of location and depth of the crack were designed using MATLAB. The intersection of three contour lines represents crack location and crack depth. Prediction of damage using frequency contour method gives good result.

Keywords: Damage Detection; Frequency Contour Method; Surface Plot; Normalized Frequency.

1. Introduction

Health Monitoring is an improved way to make Non-Destructive Evaluation in the civil Engineering domain. It involves the integration of sensors, smart materials, computational power, data transmission, and processing capacity inside the structures. The existence of damage in a structure alters the vibrational characteristics of a structure. The dynamic characteristics of a structure are mode shapes, modal damping and natural frequencies. The Knowledge on these variations had driven way to the location, detection and characterization of the damage. The essential key principle is to carry a comparative study on the structural behaviour in the undamaged and damaged conditions. Such studies have become a core research in the field of Structural Health Monitoring.

There are various methods to predict the existence of damage in a structure. In this paper Frequency contour method is used which is less time consuming and efficiency the advantage of this method is frequency can be found out at any point in a beam without disturbing the structure.

Deokar et al. [1] discussed a detailed methodology for detection of open transverse crack in a steel cantilever beam. Experimental Modal Analysis (EMA) was carried out on healthy and cracked beams. The results of the experimental investigation to find the location and the depth of the crack was similar to the actual crack size and location on the corresponding specimen. Kumar A. & Mahto, J. N. [2] investigated the crack in aluminum cantilever beam using digital storage oscilloscope (DSO). Siebel et al. [3] studied the application of health monitoring techniques in wind turbines. The study shows that the damages are located by the proposed algorithms with the strain and acceleration data's. How-

ever, there is a high sensitivity to noise in curvatures calculated from the acceleration data. Cawley and Adams et al.[4] proposed a methodology down to the element level in which the incomplete and noise measured modal data are utilized to locate and to estimate the magnitude of damage in a structures. In the laboratory, damage cases of the European Space Agency structures and a single bay two-story portal steel frame structures are investigated. The proposed approach results in effective location and quantification of damage in real life structures. Salehi et al. [5] suggested a damage technique based on the real and imaginary parts of measured FRFs. The analytical modeling is eliminated because this method uses the intact and damaged state information of structure. Park et al. [6] delivered a damage detecting GA algorithm which includes natural frequency, mode shape, and modal strain energy. On free-free beams the experimental studies were carried out and the proposed algorithm was good in locating the damages. Pandey et al. [7] employment a new method based on the modal strain energy for determining the damage locations and estimation of their severities, requiring only the information about the changes of a few lower natural frequencies.

The objective is to perform comparative studies based on numerical and experimental works. Using Frequency Contour method the crack location and depth of steel beam were studied.

2. Theoretical background

2.1. Equation for cantilever beam

The natural frequencies for first three modes of a cantilever beam is derived as follows. The equation governing the transverse vibra-

tion of a beam subjected to external force is used for deriving the Natural vibration frequencies. The general solution obtained is

$$\frac{d^4Y}{dx^4} - \beta^4 Y(x) = 0 \tag{1}$$

$$\beta^4 = \frac{\omega^2 m}{EI} \tag{2}$$

$$n = 1,2,3 \dots \infty \text{ and } \beta_n L = n\pi$$

$$\omega_n = \alpha_n^2 \sqrt{\frac{EI}{mL^4}} \tag{3}$$

Where

$$\alpha_n = 1.875, 4.694, 7.885$$

3. Numerical studies

3.1. Model description of steel beam with cantilever support condition

Change in natural frequencies, damping and stiffness can be observed due to the presence of crack in structures Free vibration analysis is carried out in a cantilever steel beam using ABAQUS FEA Software. The cross-sectional dimension and the span of the beam is 20mm x 20mm and 300 mm. Young's modulus, mass density and poisons ratio are $2.06 \times 10^5 \text{MPa}$, 7850kg/m^3 and 0.35 respectively. The beam was modeled as an eight noded brick element (C3D8I). Cantilever Boundary Conditions was applied. First three natural frequencies for the undamaged beam were obtained by free Vibration Analysis. Then a single crack has been modeled and the free vibration analysis was performed considering the geometric and material non linearity. 49 damaged beams were used for the analysis, in which the cracks provided were modeled as open cracks along the top of the beam with various depths (d) of 2mm, 4.5mm, 6mm, 7.5mm, 10mm, 12mm, 14mm with various crack location(x). The frequency of the damaged beam is lesser when compared to the undamaged beam which confirms the presence of damage in the beam. Table 1 shows the first three natural frequencies of an undamaged beam.

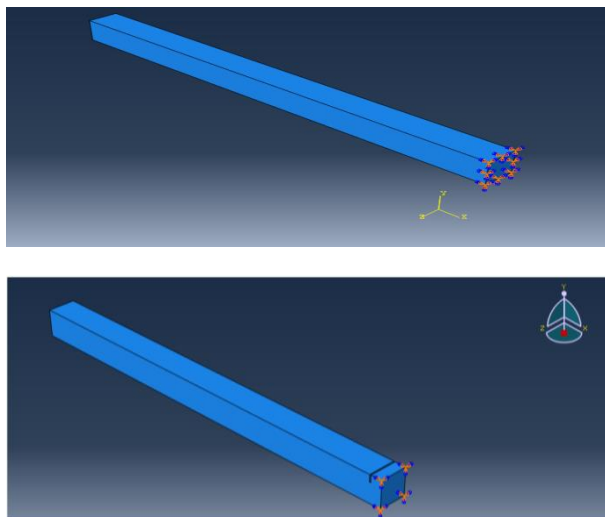


Fig. 1, 2: Undamaged and Damaged Beam Modeled in ABAQUS.

Table 1: Natural Frequencies of Undamaged Steel Beam

S. No	Natural Frequency (ω) Hz
1	183.94
2	1129.6
3	3068.8

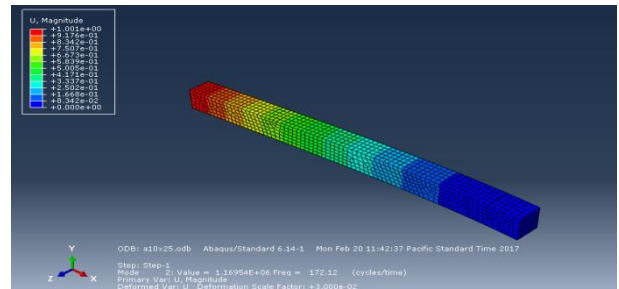
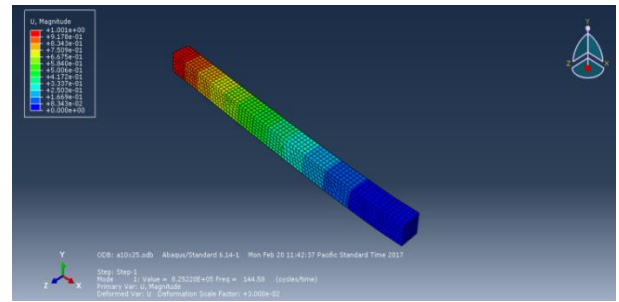


Fig. 3&4: First and Second Mode Shape of A Damaged Steel Beam (D = 10mm, X = 25 Mm).

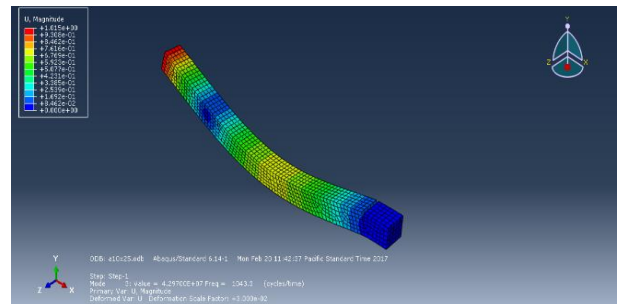


Fig. 5: Third Mode Shape of A Damaged Steel Beam (D = 10 Mm, X = 25 Mm).

4. Experimental studies

4.1. Experimental setup

Free vibration analysis is carried out in a cantilever steel beam using digital storage oscilloscope. The cross-sectional dimension and the span of the beam is 20mm x 20mm and 300 mm Young's modulus, mass density and poisons ratio are $2.06 \times 10^5 \text{MPa}$, 7850kg/m^3 and 0.35 respectively. The setup consists of 49 damaged beams and 1 undamaged beam. Fig-6 shows the experimental setup of cantilever beam with oscilloscope.



Fig. 6: Vibration Test.

4.2. Methodology

The modelled steel beam was placed between the two thick steel plates and the vibration exciter was connected at the free end of the steel beam. In un-cracked beam, the first three natural frequen-

Normalized Natural Frequencies of Experimental Studies

Table-5, 6, 7 shows the first three normalized natural frequencies of cantilever beam using digital storage oscilloscope (DSO).

5.3. Contour plot

Damage detections are based on the changes in the natural frequencies. The first three normalized natural frequencies are used to plot the contours in MATLAB. Contour line resulting from a combination of different crack depths and crack locations (for a particular mode) are plotted in MATLAB with location and depth of the crack as its axes. The plotted contour lines intersect at the crack location of 150mm and at the crack depth of 7.5 mm of cantilever beam for the numerical studies as shown in Fig.10. The position detected is the actual location of the crack detected in simply cantilever beam. The same procedure is followed for experimental studies of a cantilever steel beam. The contour lines plotted intersect at the crack location of 150 mm and at the crack depth of 7.5 mm as shown in Fig.11. The position detected is the actual location of the crack detected in cantilever beam.

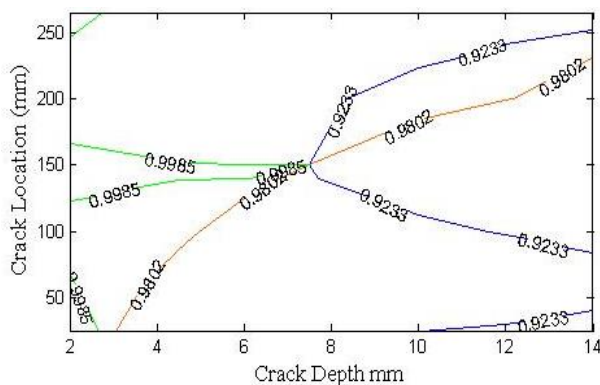


Fig. 10: Frequency Contour Plot of First Three Normalized Frequencies in Case of Cantilever Beam for Numerical Studies ($X = 150$ Mm, $D = 7.5$ Mm).

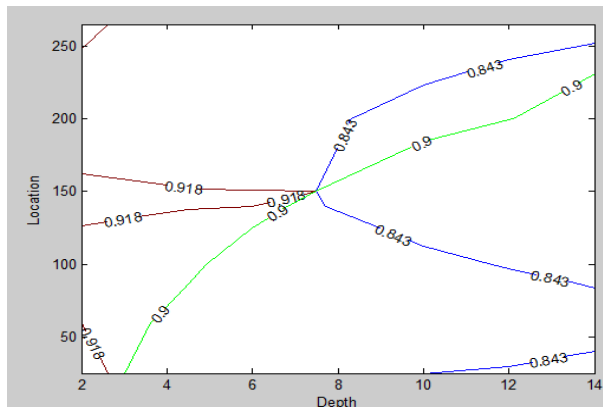


Fig. 11: Frequency Contour Plot of First Three Normalized Frequencies in Case of Cantilever Beam for Experimental Studies ($X = 150$ Mm, $D = 7.5$ Mm).

6. Conclusion

In this paper a numerical study and experimental study has been undergone to detect the cracks in a steel beam with cantilever support conditions by taking natural frequency as the basic criteria. Beam frequency reduces due to the presence of damage in the structure. When the crack depth is more than 75% of its total depth, the decrease in frequencies is identified to be higher. The variation of natural frequency is very less when the damage is far away from the support. It is concluded the in case of cantilever beam the variation in natural frequency is found to be more if the crack depth is large when located near the support.

The important conclusions arrived from this study are presented

- The stiffness of the beam decreases as more materials get removed and hence the natural frequency of the beam is decreased.
- The crack location is represented by the intersection of the three contours of Normalized natural frequencies.
- The natural frequencies of the undamaged beam were found to be higher than the natural frequencies of the damaged beam.

Frequency contour method is one of the best methods suited to detect damage in civil, mechanical & aerospace elements.

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