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Detection and Prediction of Cracks in Structures: A Review

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Abstract - ***The main aim of this survey paper is to collect different research papers published by different researchers for crack/damage detection of beams through various techniques. There are so many techniques for detection of crack /damage and can be classified as destructive and non destructive techniques. Some frequently used techniques are taking natural frequency as basic criteria and through vibration analysis of the structure the damage of the structure is detected. Application of Finite element method and ANSYS software are observed frequently by different authors to detect and predict of crack in the structures. The various modern intelligent techniques like Artificial Neural Network (ANN), fuzzy logic techniques are also used by different authors for prediction of crack location and depth and size of the cracks.***

Key Words: *Finite Element Method, Beam, Crack, Natural Frequency.*

Introduction: Beams of different materials like aluminium, iron, steel, and fiber reinforced composite material are widely used in structural purposes in civil, mechanical and other engineering applications. Crack/damage is such an important phenomenon which needs to be studied closely for the safety of structure. The presence of the crack in the structure reduces the stiffness of the structure which in turn reduces the natural frequency of it. Thus dynamic characteristics of the structures are changed. The number of cracks present in the structure, the positions of those cracks and depths of the cracks are important parameters to change the natural frequencies of it. Detection of crack is necessary to ensure that the structure is free from any defect or not.Various techniques are adapted by different authors for the prediction of the crack location and the depth and size of crack. The finite element method is considered as a mathematical tool for the analysis of complicated structures. It is observed in this study that many authors used this method for the modeling of the structure for the analysis. The commercial software package ANSYS is used frequently for the analysis. ANN and fuzzy logic are used also for the prediction of the crack location and size, depth of the crack. In this study, an attempt has been taken to discuss different research papers on the detection and prediction of cracks in different structures by non destructive methods. This study will help any scholar to collect information of some research papers related with cracks in structures.

Research of different researchers on crack detection/prediction on structural beams is as follows.

As the presence of cracks changes the dynamic characteristic of the structures therefore many attempts have been taken to detect the crack using vibration monitoring technique. Kumar and Mahto [1] analysed the crack in aluminium cantilever beam using such vibration monitoring technique. The concept of experiment was based on changes in natural frequencies of structure due to the presence of crack. Such phenomenon was very useful for fault diagnostic and detection of crack in structure. In this aluminium cantilever beam with crack was exited by a power exciter and accelerometer attached to the beam provide the response. The specimens with edge cracks of different lengths were analyzed experimentally. The experimental result of frequency was obtained by Digital Storage Oscilloscope (DSO).The first three natural frequencies were considered as basic criteria of crack detection. For crack location 3D graph of normalized frequency in terms of crack depth and location were plotted. The intersection of these three contours gave the desire location of crack and crack depth.

Deokar and Wakchaure [2] also used natural frequency as basic criteria for crack analysis on a cantilever beam. In this experiment modal analysis was carried out with and without crack. The first three natural frequencies

obtained from the above experimental modal analysis. 3D graph of normalized frequency in terms of crack depth and location of crack was plotted to detect the desired crack location with depth.

Revi et al. [3] analysed the crack in propped cantilever beam using dynamic analysis. The dynamic response properties of structures are used for damage detection with Finite Element Discretisation method applied for evaluating stiffness and modal property of the structure. Reinforced concrete propped cantilever beam was used in experiment and crack was induced in beam by applying incremental load at different stages. Curvature Damage Factor (CDF) with curvature mode shape was used to find cracked position in beam.

Yamuna and Sambasivarao [4] analysed the varying crack location of beam with vibration analysis. In this natural frequency of a simply supported beam with triangular crack on it was analysed numerically by FEM using Finite Element Analysis software ANSYS. The different position of crack effects results were compared with without crack result of the beam. The comparison showed that the fundamental frequency of beam without crack is greater than that of with crack.

ANSYS software is used frequently by different authors for the modeling of the finite element model of the structure. Fegade et al. [5] used ANSYS software to detect the natural frequencies of a cantilever beam with and without the presence of crack. They analyzed the change in natural frequencies of the beam due to the crack at various locations and with variable depth. In this study the authors used linear fracture mechanics theory to find the crack location and crack depth. It was also found that decrease in natural frequency is more for a crack which is located at higher bending moment region.

Amit V. et al. [6] analyzed a cracked and an un-cracked beam by solving Euler's equation. CATIA software was used to model the beam whereas ANSYS software was used to analyze the beam in finite element method.

Different other softwares were used for the analysis of cracked structures. Mihir Kumar Sutar [7] used ALGOR software for the finite element analysis of the Aluminium cantilever beam. In this study, the author developed a relationship between modal frequency with crack location and its depth. Only single crack at different location with different depth was analysed. As a result the dynamic property like stiffness, modal frequency reduces as the depth and crack location increases from the fix end of cantilever beam.

The crack in the rotating structure is also a very important field of study because the cracked components are failed without any prior indication. Therefore the detection or prediction of crack in rotating structure is very important for the safety purpose. Satpute et al. [8] proposed the detection of multiple cracks in a rotating shaft. The vibration analysis of shaft was done through Experimental Modal Analysis and Finite Element Analysis. The first three natural frequencies of transverse vibration were evaluated and the mode shapes were extracted and plotted using ANSYS 14.5. The comparison of results between Experimental Modal Analysis and Finite Element Analysis holds good. The result shows that natural frequency of vibration of all three transverse modes of vibration decreases with increase in depth of crack.

Bhinge et al. [9] used cantilever beam with single crack and they considered only normal edge crack. The theoretical analysis of the crack was done by spring which connected the two segment of beam. The beam model was generated using FEM. First of all, the natural frequencies of beam obtained using FEM and the result was compared with experimental output. Now crack was developed in beam whose dimensions and location were known. As a result of crack natural frequency reduced. The plot between spring stiffness versus crack location was obtained for the three lowest transverse modes. Their common intersection point gave the location of crack and corresponding stiffness.

In their study, Dimitrina Kindova-Petrova [10] modeled the crack by a rotational spring. Using vibration based method they predicted crack depth and location in a simply supported beam which were compared with the actual data obtained from the Finite Element Models.

Kamble and Chavan [11] identified the crack in cantilever beam by using experiment and wavelet analysis. In this study crack was modeled by rotational spring and equation was developed for non-dimensional spring stiffness. Now by taking first three natural frequencies by vibration measurement, curves of crack equivalent stiffness were plotted and the intersection of the three curves indicated the crack location and size. The experiment on cantilever was done with single crack

at different position and different depth size by FFT Analyzer and the natural frequency obtained was compared with ANSYS package. The time-amplitude data obtained was further used in the wavelet analysis to obtain time-frequency data. The above data played vital role to find the small crack parameters which affect the dynamic properties of the system.

Ghadami et al. [12] developed a new algorithm to detect multiple cracks in beam like structures. In this study natural frequency was used for detection, localization and quantization of multiple cracks in beams. Crack was modeled as rotational spring, and author demonstrates a relationship between natural frequencies, crack depth and crack location. An algorithm was developed know the exact number of cracks available.

The smart materials were also used for the analysis of crack in beam. Djidrov et al.[13] analyzed a cracked aluminium cantilever beam along with bonded piezoelectric transducer near the fixed end. The piezoelectric transducer was playing the role of sensor in modal analysis and the role of actuator in transient analysis. The Finite Element Analysis of the piezo bonded aluminium cantilever beam was performed in ANSYS. Experimentation of the above mentioned cantilever beam was performed to know natural frequency. The results of vibration analysis of undamaged beam model were compared with damaged beam. The technique of this experiment is based on theory that cracks changes the physical properties of beam which results in change of modal properties of beam.

Dawari and Vesmawala [14] proposed the damage detection in reinforced concrete beams by using mode shape based methods. In this modal flexibility method and modal curvature method was used to detect the crack in finite element model of reinforced beams. To implement algorithm, Eigen value analysis was carried out for finite element models of concrete beams and the Eigen vectors were considered for different damages. Finally it was analysed that this method was very effective to detect the damage and also to locate the position of damage for single as well as for multiple.

Now a day, different intelligent methods are used to analyze the dynamic behavior of structures. Artificial Neural Networks (ANN) method and Fuzzy logic method are frequently used by different authors for many vibration engineering problems. Similarly in the field of crack detection it is observed that these methods are used to predict the location size and depth of crack. Baviskar and Tungikar [15] applied Artificial Neural Networks (ANN) method to predict the location of crack with depth in beams by using the data of natural frequencies .The finite element analysis was performed in ANSYS software to calculate the natural frequencies of the beam. They performed the experimentation with a simply supported beam having a single crack and cantilever beam with two cracks. The result of FFT analyzer is validated with ANSYS result. The natural frequencies obtained from the above two analysis were further used for prediction of crack location with depth of crack by ANN. Some of the predictions obtained by ANN again were validated with FEM and it holds well for single as well as for multiple cracks.

Nazari and Baghalian [16] described a new method for damage detection in symmetric beams using ANN and FEM. As natural frequency is frequently used for detection of crack and crack depth in structures but due to symmetric structure it was not possible with only natural frequency to detect the required damage. In this experiment a structure of rectangular beam was fixed at both of its end was used and FEM was used to obtain natural frequency of beam with different crack conditions. Then in analysis it was assumed that crack was located at right side of the structure, the data obtained from FEM is verified by two distinct ANN process applied for crack location and depth detection for some different conditions. Finally an algorithm was used based on first vibration mode shape of structure to verify the original location of crack and crack depth.

Ramadas C. et al. [17] analysed the transverse cracks in a composite beam by combination of Lamb wave and Artificial Neural Network (ANN). In this study authors used four damage features of beam in which time of flight and amplitude ratio concerned with Lamb wave and the first and second natural frequencies concerned with vibration based technique. These four damage features are used as input of ANN. The result obtained by ANN gave crack location and depth.

Andhale and Wankhade [18] applied Fuzzy Logic technique to study the cracks in structures. In this study, authors applied crack location and crack depth as input for FEA and FFT and took natural frequency as output. The comparison of results among theoretical analysis, ANSYS and FFT holds good agreement. Now fuzzy

controller with triangular membership function was applied and the system predicted crack location and crack depth within nano second. The result verified by theoretical calculation.

Kim and Song [19] analysed the crack in ceramic material by using Fuzzy Logic based stretching and ART2 learning algorithm. In this study first of all Fuzzy stretching is used to enhance brightness contrast from the input image. Now by application of the Fuzzy binarization and upper/lower level search algorithms the interval range of defects existence are located. Introduction of ART2 learning algorithms detects the different types of defects.

Parhi and Choudhry [20] discussed detection of crack in a Cantilever beam using Fuzzy Logic technology with hybrid membership function. In this study Cantilever beam was analysed by authors with transverse surface crack by Fuzzy Logic system and Finite Element Method. Fuzzy Controller was used in which hybrid membership functions used as input and triangular membership function as output. Authors used first three natural frequencies as the input parameter for Fuzzy Controller whereas relative crack depth and relative crack location as the output parameters. Beam model was generated in FEM. The results of relative crack depth and location are obtained by trained several Fuzzy rules and are compared with FEM results. The comparisons of results holds good.

Material and Methodology

The authors are analyzing the vibration of aluminium and iron cantilever beam by finite element programming developed in MATLAB language. The results coming out from the programming are compared with the analysis in ANSYS software. The experimental analysis of those beams is done in laboratory and the results are compared with the analytical results.

Conclusion

The fault detection in structures is considered as an important engineering problem because of safety. In this paper a review is conducted on the prediction and detection of crack in structures. Different methods of crack analysis are discussed in this paper. Both the experimental and theoretical methods are applied to predict and detect the presence of the crack in the structure. This survey will give an introduction to a new researcher in this field to different published papers at a single glance.

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