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Crack Identification and Localization In Structural Beams Using Numerical and Experimental Modal Analysis- A Review

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Abstract: *This article presents a critical review of recent research done on crack identification and localization in structural beams using numerical and experimental modal analysis. Crack identification and localization in beams are very crucial in various engineering applications such as ship propeller shafts, aircraft wings, gantry cranes, and Turbo machinery blades. It is necessary to identify the damage in time; otherwise, there may be serious consequences like a catastrophic failure of the engineering structures. Experimental modal analysis is used to study the vibration characteristics of structures like natural frequency, damping and mode shapes. The modal parameters like natural frequency and mode shapes of undamaged and damaged beams are different. Based on this reason, structural damage can be detected, especially in beams. From the review of various research papers, it is identified that a lot of the research done on beams with open transverse crack. Crack location is identified by tracking variation in natural frequencies of a healthy and cracked beam*

Keywords*: Crack location; Damage identification; Experimental modal analysis; natural frequency; Structural health monitoring; and FFT analyzer.*

I. Introduction

During the last two decades, a lot of attention was given on structural health monitoring to prevent premature failure of the engineering structures. All engineering structures are prone to damage due to overstressing while in operation, or due to extreme environmental conditions. The Presence of damage alters the dynamic response of the structure. Specifically, the presence of cracks increases a local flexibility with a notable reduction in the natural frequency and a change in mode shapes. Earlier crack detection plays a vital role to prevent sudden or unexpected breakdowns. There are different Non-destructive testing methods (NDTs) such as ultrasonic testing, X-ray, magnetic particle, liquid penetrants, eddy current, and acoustic emission are available for earlier damage detection in structures. But they are very expensive, time-consuming and some of them are difficult to implement for complex structures such as air craft's, railway tracks, long columns, long pipelines in power plants.

Vibration testing has become a standard procedure for fault diagnosis in many industries. Experimental modal analysis is used to study the vibration characteristics of structures like natural frequency, damping and mode shapes. The modal parameters of undamaged and damaged components are different. Based on this reason, structural damage can be detected, especially in beams. Crack formation due to repetitive loads leads to fatigue of the structure. Hence crack detection plays a vital role in structural health monitoring applications.

II. Review of Literature

Prashant (2015) et al. [1] performed an experimental modal analysis on rectangular cantilever beam to obtain natural frequencies, mode shapes, and modal damping. Initial excitation is given by impact hammer as connected with FFT analyzer.NI LabVIEW software was utilized to extract modal data. Good conformity was observed between theoretical results and experimental results. Modal testing was done on mild steel and aluminum beams and the percentage of error between experimental and analytical method was found less than 20%. It is also discovered from modal testing that the modal damping in mild steel beam is less than aluminum. Modal testing is more reliable and accurate as compared to other non-destructive techniques to study the dynamic attributes of machines.

Karandikar (2016) et al. [2] performed an experimental modal analysis on cracked and un-cracked beam. Fast Fourier Transformer (FFT) set up was utilized to perform modal analysis on the cantilever beam with a single crack. These cracks were situated at different locations and having varying sizes. The results from a modal analysis performed in ANSYS were contrasted with experimental results. Modal testing is more reliable as the percentage of error between among these methods within the acceptable level.

Nahvi (2005) et al. [3] designed an experimental setup, in which a cracked cantilever beam is energized by an impact hammer and an accelerometer placed on the beam to receive the response. A crack in a structural member reduces a local stiffness that would influence the vibration attributes of the structure. This property can be utilized to estimate the presence of a crack along with its location and depth in the structure.

Agarwalla (2013) et al. [4] analyzed the influence of an open crack on the vibration attributes of the cantilever subjected to free vibrations. The dynamic response of an entire structure is influenced because of the presence of a crack. The cracks present in the structure altered the natural frequencies, mode shapes of the free vibration. The results obtained from the numerical method (ANSYS) are compared with experimental results.

Swamidas (2002) et al. [5] performed an experimental study on the impacts of cracks on the integrity of structures, to identify, measure, and determine their extents and locations. Two sets of aluminum beams were used for the experimental study. Each set comprised of seven beams, the main set had fixed ends, and the subsequent set was simply supported. The vibration characteristics of the beams are shown to be very sensitive to the crack location, crack depth and mode number.

More (2016) et al. [6] studied various vibration based crack identification methods for detection of damage in a fiber reinforced composite. Presence of cracks in the structure influence the static as well as dynamic response attributes. Cracks in a beam modify the natural frequency, mode shape and stiffness. It is discovered that detection of crack size, crack location in cantilever beam depends on natural frequencies and mode shapes.

Chandan Kumar (2017) et al. [7] determined natural frequency of different modes of a cantilever beam analytically and experimentally. Both theoretical and experimental results are contrasted for two materials (Aluminum and Mild Steel). It is found that results found by theoretical and experimental methods are nearly the same.

Vikram (2016) et al. [8] monitored vibration response of beams both experimentally and using ANSYS. Vibration analysis on different cantilever beams with open transverse crack and with various boundary conditions is performed. The results of modal frequencies are determined by FEM software ANSYS and then it is compared with experimental results utilizing FFT Analyzer.

Vader (2017) et al. [9] evaluated variation in natural frequencies of cantilever composite fabricated with glass epoxy. The effect of crack location and depth on the natural frequency of a beam with a transverse open crack is analyzed. The numerical results from ANSYS were found in good concurrence with the experimental results. The result of the study concludes that the presence of crack reduces the natural frequencies and alters the mode shapes of vibration.

Maksimoc (2018) et al. [10] developed an effective and reliable computational technique for residual life estimation of cracked aircraft structural components using fracture mechanics and fatigue analysis. A finite element model is made for numerical validation, fracture mechanics parameters of structural components such as stress intensity factors of aircraft cracked skins and lugs are determined.

Nikil (2014) [11] performed a vibration analysis on a portable crane to avoid failure of the crane due to resonance. This paper mainly concentrated on the vibration analysis of the beam of portable crane due to the motion of the load at its end. As resonance occurs, when the excitation frequency of a beam is equal to the natural frequency, also derived some mathematical equations to avoid the resonance.

Asilturk (2017) et al. [12] explained various vibration analysis fault diagnosis techniques for a gearbox. Most effective techniques are identified and experimentally verified. This study explained the importance of vibration based methods in fault diagnosis.

Ramachandran (2017) et al. [13] presented a technique for determination of first mode frequency of a healthy beam in bending mode. A static analysis performed on cracked beam in ANSYS workbench to obtain zero frequency deflection. Modal analysis is performed in ANSYS workbench to get modal frequencies. Finally, there is a good conformity between the modal frequencies calculated from proposed technique and ANSYS workbench.

Bhaduri (2016) et al. [14] performed finite element analysis of a cantilever beam to get modal frequencies using MATLAB code and ANSYS APDL and the results compared with experimental results. The mass of the accelerometer is considered for this analysis and there is good conformity between experimental and ANSYS results. It is observed that modal frequencies are decreased when mass at the tip of beam is increased.

Dipal Patel (2014) et al. [15] calculated the natural frequencies of a beam made of various materials such as aluminum and steel using experimental modal analysis. The beams were energized by an impact hammer and the modal spectrums are obtained by lab view software.

Puneet Sharma (2017) et al. [16] established a mathematical model of a beam using Euler's -Bernoulli's equation and simulated in ANSYS. Experimental modal analysis was performed using OROS software. Results from mathematical modal were compared with ANSYS and experimental results.

Nirmal (2016) et al. [17] studied the natural frequency of brass, aluminum, and steel using analytical and experimental methods. The modal frequency of the beams calculated from theoretical and experimental methods will be validated with harmonic analysis using FEA software ANSYS.

Subhash (2015) et al. [18] studied the transverse vibrations of a fixed-free beam using experimental and numerical analysis. ANSYS and experimental modal analysis utilized to determine modal frequencies. It was discovered that there is good conformity between results.

Furukawa (2004) et al. [19] proposed a technique for locating the damage present in the structure by using frequency response function (FRF) data. It depends on the principle that damage present in the structure reduces the structural stiffness and there by variations in vibration characteristics. These variations in frequency response function give useful data regarding location and severity of damage.

Vipinkumar (2015) et al. [20] determined the modal frequencies for different beams made from different materials having similar T and I cross-sections. Using FEM software ANSYS cantilever beam is modeled and simulated. it was discovered that the deflection of T section is more as compared to I section.

Sreekanth 17et al. [21] performed dynamic analysis on the cantilever beam to get modal frequencies and mode shapes. To find the maximum deformation at each modal frequency harmonic analysis is performed by using ANSYS software. Experimental modal analysis was performed by FFT setup and Lab View software to find the acceleration, velocity and displacement plots with respect to time.

Chandradeep Kumar (2014) et al. [22] performed a finite element analysis on cantilever beam having a tip mass at its free end. Stiffness and mass matrices are derived analytically. To determine modal frequencies of a cantilever beam, a MATLAB code was developed and validated with ANSYS and analytical results. There is a good agreement between the natural frequency calculated from MATLAB, ANSYS results and theoretical results.

Irshad A Khan (2013) et al. [23] reviewed the effect of crack depth on modal frequencies and mode shape of a beam. For entire analysis, a beam with one end fixed and both the ends fixed is used. Presence of transverse cracks greatly affects the mode shapes and modal frequencies. In this work, two transverse cracks are made from the fixed end of the beam, modeled and analyzed in FEM software ANSYS. It was concluded that modal frequencies increase and mode shape decreases when the crack depth increases.

Salawu (1997) [24] reviewed the various techniques for structural damage assessment through change in modal frequency. This paper also explained the various methods for locating geometric location of the damage using modal frequencies.

Behera 2014et al. [25] designed and analyzed a cantilever beam with a slanted open edge crack using FEM software ANSYS as well as experimental analysis. The impact of crack location and crack depth on modal attributes of a cantilever beam also examined. It has been discovered that the natural frequencies decline as crack depth increases and natural frequencies increases as the crack location increases from the fixed end.

Sonawane (2017) et al. [26] performed both experimental and numerical analysis on a rectangular cantilever plate to determine the modal frequencies and mode shapes. The results obtained from the experimental method were validated with the numerical results.

Vaishali (2013) et al. [27] used a modal curvature technique and modal flexibility technique for detecting damage in reinforced concrete beams. A discontinuing element model method is used for simulating crack damage. It was found that these methods can find the location of the crack damage.

VinayakFegade (2014) et al. [28] performed a theoretical analysis of transverse vibrations of a cantilever beam. Dynamic analysis was performed on a cantilever beam with open transverse crack using ANSYS software. Variations of natural frequencies with and without crack were observed. Establishment of the surface cracks on the

beams effectively influence the dynamic attributes of the structures. The greater variation observed in modal properties of the beams when the crack closer to the fixed end.
Kulkarni (2015) [29] studied the vibration damping attributes of aluminum, brass and mild steel. It was concluded that vibration damping is more for steel when compared with aluminum and brass.
Elshamy M. (2018) et al. [30] performed an investigation of a crack in a cantilever beam by monitoring natural frequency of the cantilever beam. In this work, experimental modal analysis performed on different beam materials and specimen dimensional and material effect on natural frequencies is also studied. Finally, results obtained from the experimental modal analysis are compared with FEA results.

III. Methodology of Experimental Modal Analysis

Experimental modal analysis is used to study the vibration characteristics of the structures like natural frequency, damping and mode shapes. Most of the researchers performed experimental modal analysis on structural beams to track the changing in vibration characteristics using FFT analyzer (fast Fourier transformer) as shown in Fig.1.

Fig.1 FFT analyzer

A Coco80 vibration analyzer consists following components.

1. Data Acquisition System (A 4-channel FFT analyzer).

2. Accelerometer (sensitivity -107 mv/g).

3. Impact Hammer (sensitivity- 10 mv/lbf).

4. A computer with Engineering Data Management Software (EDM).

5. Connecting Cables.

6. A Power Supply Unit.

7. IS 2062 Mild steel Cantilever beam.

The flow diagram of an experimental modal analysis using FFT Analyzer is shown in figure.

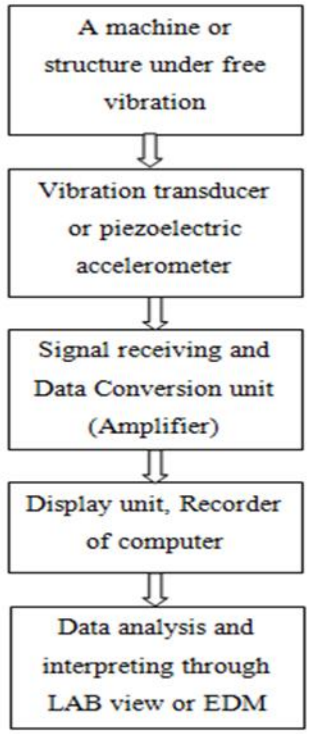

Fig.2 Block diagram of experimental modal analysis

IV. Discussion for Result

From the study of various researchers work, it is observed that change in vibration characteristics can be used as a tool to detect the damage present in the structures. Most of the work performed on transverse open cracks and very few works done on inclined cracks. Many researchers have studied the effect of crack location, depth, and crack orientation on the natural frequency of beams. Most of the researchers used the first three natural frequencies of the beam, fuzzy logic and artificial neural networks to track the crack location. From the last decade, a lot of research performed to predict the residual life of cracked beams through experimental modal analysis

V.Conclusion

From the review of literature following conclusion is made:

- Presence of damage in a structure alters the vibration characteristics such as modal frequencies and mode shapes.
- Structure damage can be identified by performing an experimental modal analysis on a cracked and healthy one.
- Effect crack parameters such as crack location, crack depth, and orientation on natural frequencies are also studied. Crack near the fixed end of the beam more effective in reducing the natural frequency as compared to far away one. Because crack near the fixed end is greatly reduces the stiffness of the beam.
- Crack location and depth are very important factors in crack investigation.
- Many researchers are used first three natural frequencies to track crack location and crack depth.
- Very little work is done on beams with inclined cracks.
- Results obtained from experimental modal analysis are compared with numerical results.

VI. Future Scope

Further studies should be done on

- The effect of multiple cracks on the specimen.

➢ Calculating the residual life of a cracked beam from experimental modal analysis.

References

1. Walunj Prashant S, V.N.Chouguleb, Anirban C. Mitrac, "Investigation on modal parameters of rectangular cantilever beam using Experimental modal analysis", Materials Today: Proceedings, 2015, vol.2, pp.2121-2130.
2. Pratibha M Karandikar, VaishnavVivek, and Dabhade Ganesh, "Experimental investigation of crack detection of cantilever beam-FFT analyzer", IOSR Journal of Mechanical and Civil Engineering, 2016, vol.13, pp. 12-17.
3. H. Nahvi and M. Jabbari, "Crack detection in beams using experimental modal data and finite element modal", International Journal of Mechanical Sciences, 2005, vol.47, pp. 1477-1497.
4. D.K. Agarwallaa and D.R. Parhi, "Effect of crack on modal parameters of a cantilever beam subjected to vibration", Procedia Engineering, 2013, vol.51, pp. 665-659.
5. G.M. Owolabi, A.S.J. Swamidas, and R. Seshadri, "Crack detection in beams using changes in frequencies and amplitudes of frequency response functions", Journal of Sound and Vibration, 2002, vol.265, pp. 1-22.
6. Ashish S. Apate and Nitin N. More, "Vibration analysis of cracked cantilever beam'', International Research Journal of Engineering and Technology, 2016, vol.3, pp. 1177-1181.
7. D.P. Kamble, Chandan Kumar, Shivprasad R. Sontakke, and Ratnadip T. Gaikwad, "Analytical and experimental analysis of cantilever beam under forced vibration", International Journal of Engineering Science and Computing, 2017, vol.6, pp. 2168-2171.
8. Vikram S. Yendhe, Prof.V.L. Kadlag, and Prof.R.SShelke, "Vibration analysis of cracked cantilever beam for varying crack size and location'', International Research Journal of Engineering and Technology , 2016 , vol.3, pp. 1913-1919.
9. Soham S. Vader and V. A. Raikar, "Crack detection in composite cantilever beam by vibration analysis and numerical method", International Research Journal of Engineering and Technology, 2017, vol.4, pp. 1776-1784.
10. Mirko S. Maksimovic, IvanaV.Vasovic, Katarina S.Maksimovic, NatasaTrisovic, and StevanM.Maksimovic, "Residual life estimation of cracked aircraft structural components", FME Transactions , 2018, vol.46, pp. 124-128.
11. Nikil j Patil, "Vibrational analysis of portable crane", International Journal of Engineering Research and Technology, 2014, vol.3, pp. 471-473.
12. IlhanAsilturk, HalitAslanci, and UgurOzmen, "Machinery Monitoring Using Vibration Signal Analysis",International Journal of Mechanical and Production Engineering, 2017, vol.5, pp.21-25.
13. V. Khalkar and S. Ramachandran, "Paradigm for Natural Frequency of an Un-Cracked Cantilever Beam and its Application to Cracked Beam", ARPN Journal of Engineering and Applied Sciences, 2017, vol.12, pp.1714-1729.
14. P. Kumar, S.Bhaduri , and A. Kumar , "Vibration Analysis of Cantilever Beam: An Experimental Study",International Journal for Research in Applied Science & Engineering Technology (IJRASET),2016, vol.4, pp.361-369.
15. Pragnesh K. Chaudhari,DipalPatel,Vipul Patel, "Theoretical and Software Based Comparison of Cantilever beam: Modal Analysis",International Journal of Innovative Research in Advanced Engineering (IJIRAE),2014, vol.1, pp.75-79.
16. Puneet Sharma, AshishGupta, Anuj Kumar Jain, VikasRastogi, "Dynamic Modelling and Validation of Continuous Beam with Free-Free Boundary Conditions",International Advanced Research Journal in Science, Engineering and Technology, 2017, vol.4, pp.47-53.
17. Nirmall. T and Dr. Vimala. S, "Free Vibration Analysis of Cantilever Beam of Different Materials", International Journal of Science and Research (IJSR), 2016, vol.5, pp.612-615.
18. S. P. Chaphalkar, Subhash. N. Khetre, and Arun M. Meshram, "Modal analysis of cantilever beam Structure Using Finite Element analysis and Experimental Analysis", American Journal of Engineering Research (AJER), 2015, vol.4, pp.178-185.
19. Aiko Furukawa and JunjiKiyono, "Identification of structural damage based on vibration responses",13th World Conference on Earthquake Engineering Canada, 2004, paper 134.
20. Vipin Kumar, Kapil Kumar Singh, and ShwetanshuGaurav, "Analysis of Natural Frequencies for Cantilever Beam with I- and T-Section Using Ansys",International Research Journal of Engineering and Technology (IRJET),2015, vol.2, pp.1013-1020.
21. SreekanthSura, AlkaSawale, and M Satyanarayana, "Dynamic Analysis of Cantilever Beam", International Journal of Mechanical Engineering and Technology (IJMET),2017, vol.8, pp. 1167–1173.
22. Chandradeep Kumar, Anjani Kumar Singh, Nitesh Kumar, andAjitKumar,"Model Analysis and Harmonic Analysis of Cantilever Beam by ANSYS",Global Journal for Research Analysis, 2014, vol.3, pp.51-55.
23. Irshad A Khan and Dayal R parhi, "finite element analysis of double cracked beam and its experimental validation", Procedia Engineering, 2013, vol.51, pp.703-708.
24. O. S. Salawu, "Detectionof structuraldamage through changes: a review", Engineering Structures, 1997,vol.19, pp.718-723.
25. Ranjan K. Beheraa, AnishPandeyb, and Dayal R. Parhic, "Numerical and Experimental Verification of a Method for Prognosis of Inclined Edge Crack in Cantilever Beam Based on Synthesis of Mode Shapes",Procedia Technology, 2014, vol.14, pp.67 – 74.
26. Ashish R. Sonawane and Poonam S. Talmale, "Modal Analysis of Single Rectangular Cantilever Plate by Mathematically, FEA and Experimental",International Research Journal of Engineering and Technology (IRJET), 2017, vol.4, pp.264-269.
27. Vaishali Dawari and GaurangVesmawala,"Identification of Crack Damage in Reinforced Concrete BeamsUsing Mode Shape Based Methods",Civil and Environmental Research, 2013, vol.3, pp.24-29.

28. PushkarVinayakFegade, Jayesh Ashok Mahajan, and GirishPrakashBhole "Study on Vibration Analysis of an Un-Crack and Cracked Cantilever Beam", International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS), 2014, vol.10, pp.340-343.
29. Prof. Vyankatesh S.Kulkarni**, "**A Review of Vibration of a Cantilever Beam",International Journal of Innovations in Engineering Research and Technology [IJIERT], 2015, vol.2, pp.1-7.
30. M. Elshamy, W.A. Crosby, M. Elhadary, Crack detection of cantilever beam by natural frequency tracking using experimental and finite element analysis, Alexandria Engineering Journal. (AEJ), 2018, Vol.57, pp.3755-3766.