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Crack Detection in Structural Beams by using Curvature Mode Shapes

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Abstract

In recent years, the use of Aluminium structures in engineering application has increased. This is mainly due high structural performance, high corrosion resistance, tolerance of temperature; extreme fatigue resistance and high strength/weight ratio. However, some disorders like matrix cracking and delaminating could be caused by operational loading, aging, chemical attack, mechanical vibration, changing of ambient conditions and shock etc. during the service. The aim of paper is to develop a Vibration-based Structural Health Monitoring (SHM) method for cantilever beam specimens with the embedded artificial delamination. In the present work, the modal analysis has been carried out on cantilever with and without crack and observed the influence of crack on the beam by using vibration and mode shapes analysis, in this transverse open crack as considered as damage in the beam. Evaluation the natural frequencies and their corresponding mode shapes for different crack parameters (depths and locations) of the cantilever beam has been done by commercially available ANSYS software. Also, the experimental work is done by using Universal Vibration Machine with different crack depth; obtained experimental results are validated with simulation results, which give satisfactory results. Later, curvature mode shapes were calculated by using a central difference approximation to identify the crack location and quantification of the cracked beam. The location and depth corresponding to any peak on this curve becomes a possible crack location and depth. The identification procedure presented in this study is believed to provide a useful tool for detection of medium size crack in a cantilever beam applications.

Keywords: Structural Health Monitoring, Finite Element Method, Modal Parameters, Universal Vibration Machine, Central Difference Approximation

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I. INTRODUCTION

Major engineering structures such as crane hooks, aeroplane blades, connecting rods, etc. constitute a significant portion of the national wealth. The maintenance costs of these structures is substantially high, and even a small percentage reduction in the maintenance cost amounts to significant saving. Also damage occurred during service because of the operational loading, aging, chemical attack, mechanical vibration, changing of ambient conditions and shocks. Hence, early detection of damage and its severity and location is a key point. The initial way of damage detection is to remove the structure from a service and check for its damage zones, however this is time consuming and expensive. Therefore online detection of damage which means checking the structure while it is in-service is preferred. Thus the online damage detection of a structure called "Structural Health Monitoring (SHM)" has become a major issue in various fields and industries. Generally, structural health monitoring has 3 steps: exciting the structure, gathering responses of the structure to excitation and establishing the relationship between these responses and damage status (location and severity).Once damage is detected in the structure, the mechanical and dynamic properties of the structure change. Therefore responses of the intact and damaged structures to the excitations are different. These differences can be used to extract the damage status according to the method used for structural health monitoring such as vibration-based method can help in prevention of catastrophic failure and structural deterioration beyond repair. Structural health monitoring has great potential for enhancing the functionality, serviceability and increased life span of structures and, as a result, could contribute significantly to the economy of the nation.

II. LITERATURE REVIEW

The location of crack is determined by the sudden changes in the spatial variation of the transformed response. The results in the simulation mode and experiments show that HHT appears to be a more effective tool for the analysis [1].The location and depth corresponding to any peak on this curve becomes a possible notch location and depth. The identification procedure presented in this study is believed to provide a useful tool for detection of medium size crack in a cantilever and simply supported beam applications [2].Vibration data obtained from the perturbed system is processed for mode shapes which are converted into mode shape curvatures and subsequently fed to the wavelet transform. It is observed that the decomposition of the spatial signal into wavelet details can identify the damage position in beam like structure by showing relatively larger peaks at the position of the damage [3].Damage is considered as localized reduction in structural stiffness. From the numerical simulations, it is observed that the absolute changes in modal curvature are localized in the region of damage and hence can be used to detect damage in a structure [4].A new scheme of damage detection and localization is presented by implementing frequency response functions (FRFs) of damaged structure only [5].Model for free vibration analysis of a beam with an open edge crack has been presented. Variations of natural frequencies due to crack at various locations and with varying crack depths have been implemented [6].Cantilevered beam model is investigated numerically by use of finite element method. Slope and curvature of displacement mode shapes differences were calculated using a central difference approximation. Changes in the mode shape characteristics are good indicator of damage location and severity, and hence can be used to detect damage in a structure [7].Illustrating significant refinements concerning the use of wavelets, when these latter are used in the guise of continuous wavelet transforms (CWT) for identifying damage on transversally vibrating structural components [8].The estimated mode shapes of the beam are analyzed by the one-dimensional continuous wavelet transform. The formulation of the two dimensional continuous wavelet transform for plate damage detection is presented [9].The spatial wavelet based approach can provide an alternative to classical approaches in damage detection because it is not necessary that detecting damage from variation in natural frequencies and structure stiffness relative to an undamaged structure [10].The damage reduces the stiffness of the structure and increases its damping value, at the same time it will decrease the natural frequency and the corresponding mode shape changes. The present thesis work aims at detecting the cracks of a propped cantilever beam and to study the effects of cracks in its dynamic characteristics [11].The curvature response function, function of crack location and size, are approximated by means of polynomial surface fitting. The numerical data obtained is meshed using B-spline. The algorithm based on curvature, Wavelet Transform and surface fitting technique is proposed for damage detection [12]**.**An experimental program was undertaken to test the feasibility to detect the occurrence of structural damage using a modified mode shape difference technique. Modal analysis was performed to extract the frequencies and mode shapes. The method shows a good potential in detection of occurrence and location of damage [13]. A technique for structure damage detection based on spatial wavelet analysis by using only needs the spatially distributed signals (e.g. the displacements or mode shapes) of the rectangular plate after damage [14].The premise of the technique is that damage in a structure will cause structural response perturbations at damage sites. Such local perturbations, although they may not be apparent from the measured total response data are often discernible from component wavelets [15].

III. MODAL ANALYSIS USING FEM

To create numerical model of the cantilever beam, commercial finite element analysis package ANSYS 12 is used. The dimensions of this beam are 0.8m X 0.01m X 0.025m, cross section. To solve this problem beam is converted as plane stress condition and SOLID PLANE 183 element is chosen, this is best suitable for irregular meshes. Simulation work is done on both crack and un-cracked beams. According to the manufactures specification of aluminium beam, modulus of elasticity is set to be 70GPa, poissions ratio 0.3 and material density 2700 kg/m^3. Simulation is done in on the beam at different crack depth (10%, 20%, 30% of beam height) and different crack location (20%, 40%, 60%, 80% of beam length) to observe the crack influences on the beam and change in modal parameters like mode shapes and natural frequencies. The beam was discretized into 400 elements. Cantilever boundary conditions can also be modelled by constraining all degrees of freedoms of the nodes located on the left end of the beam. The Blocklencoz mode extraction method was used to calculate the natural frequencies of the beam.

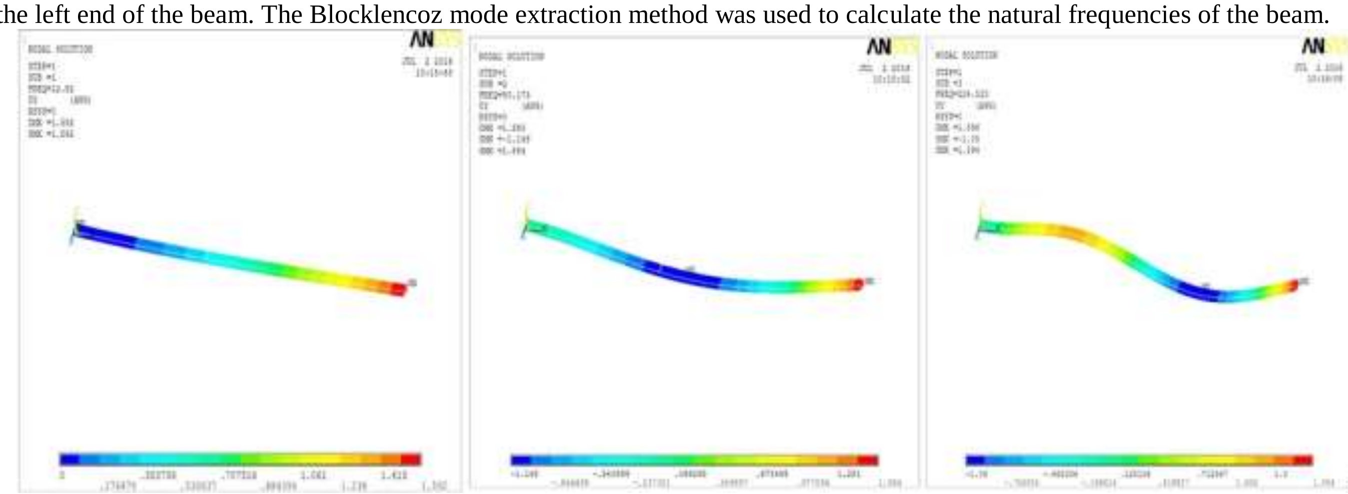


Fig. 1: first three mode shapes of cracked beam obtained from Ansys

IV. EXPERIMENTAL ANALYSIS

To validate the Finite element analysis result, an experiment on aluminium beam has been performed. Aluminium cantilever beam and fixed-fixed beam of length 800 mm and cross-section 25 x 10 mm^2 was clamped at a vibrating table. Before the experimental study the beams surface has been cleaned and organized for straightness. Subsequently, transverse cracks are created manually, which varies from 1mm to 3mm at the interval of 1 mm. During the experiment the cracked and undamaged beams have been vibrated at their 1st, 2nd and 3rd mode of vibration by using an exciter and a function generator. The vibrations characteristics such as natural frequencies and mode shape of the beams correspond to 1st, 2nd and 3rd mode of vibration have been recorded by placing the accelerometer along the length of the beams and displayed on the frequency analyser. The surface specimens were cut manually and measured crack depth with depth micrometre to ensure high accuracy of cracked model. The experimental results are in close justification with Finite Element Analysis results.

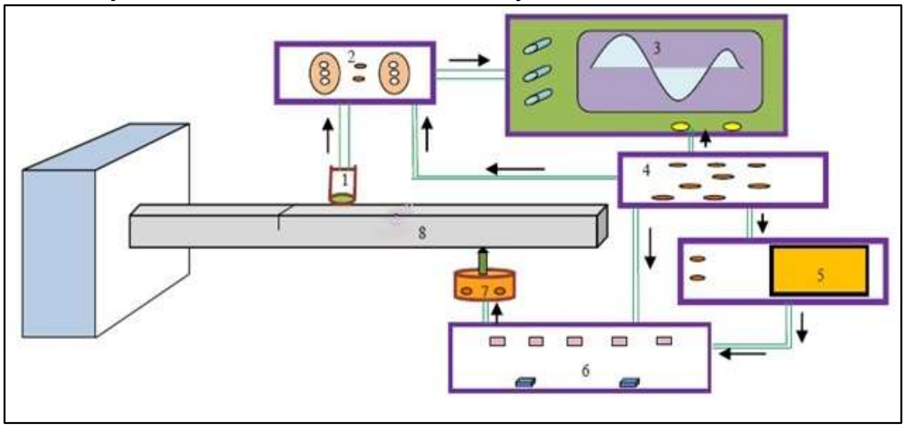


Fig. 2: Block diagram of experimental setup

1) Accelerometer
2) Vibration analyzer
3) pulse lab shop
4) Power distribution
5) Function generator
6) Power amplifier
7) Vibration exciter
8) Cracked cantilever beam.

V. RESULTS AND DISCUSSIONS

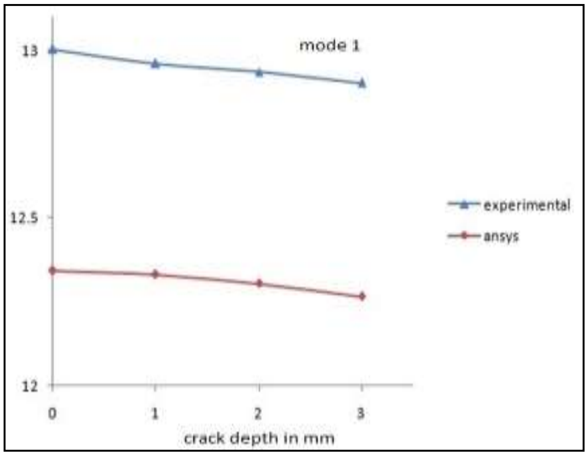
In this analysis, transverse open crack is assumed as damage in the cantilever beam. The depth (d) and location (x) of the damage are normalized to the height and length of the beam respectively. The first three mode shapes of the beam were calculated by using ANSYS software.

A. Change in natural frequency:

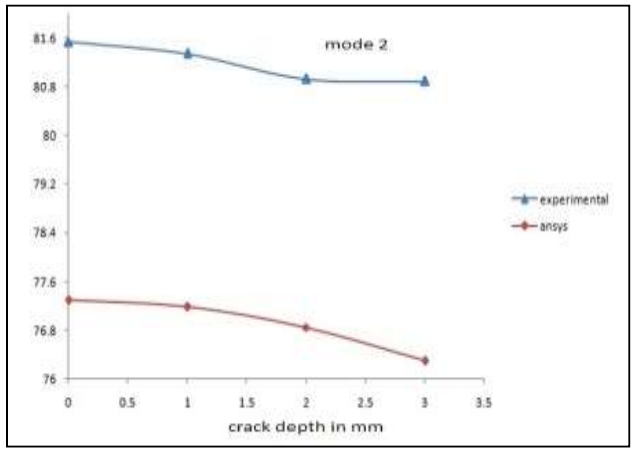
Crack is located at the distance of 20% of beam length and depth is varies from 10% to 30% of beam height that means 1mm, 2mm, 3mm. The change in natural frequencies of first three modes are given in below table.

Table – 1
First three Natural Frequencies of Aluminium Beam with different crack depth

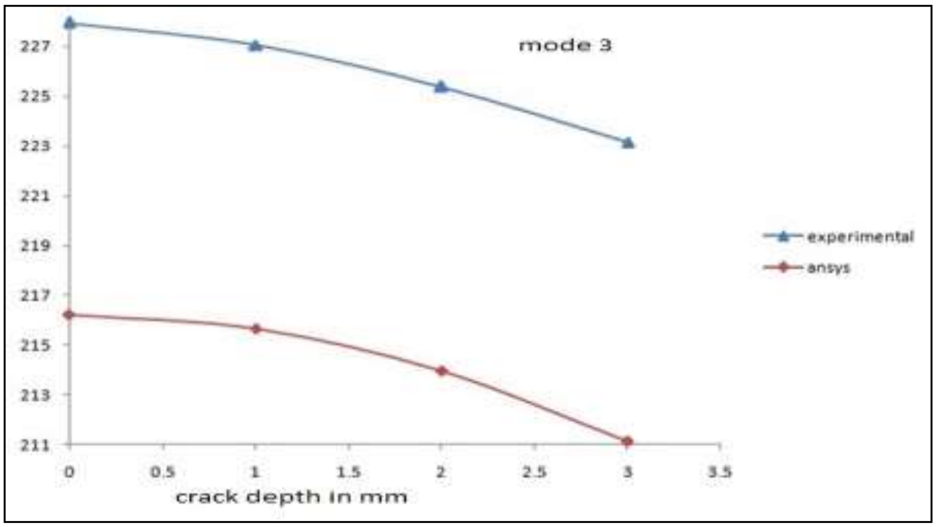
Crack depth (w/d)	*MODE 1*		*MODE 2*		*MODE 3*	
	Exp	*Ansys*	*Exp*	*Ansys*	*Exp*	*Ansys*
No-crack	*13.004*	*12.343*	*81.542*	*77.299*	*227.94*	*216.22*
10%	*12.962*	*12.323*	*81.349*	*77.183*	*227.06*	*215.66*
20%	*12.936*	*12.305*	*80.933*	*76.853*	*225.39*	*213.95*
30%	*12.904*	*12.267*	*80.895*	*76.302*	*223.157*	*211.3*



(a) mode 1



(b) mode 2

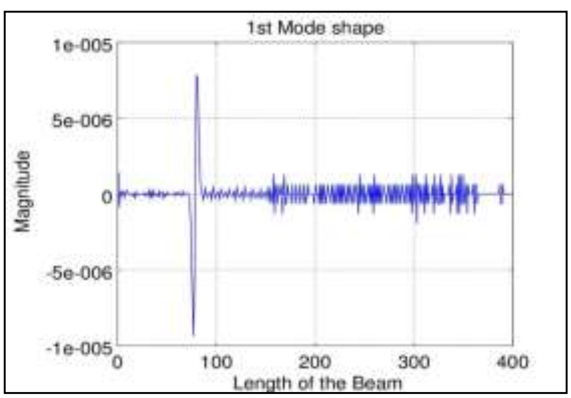


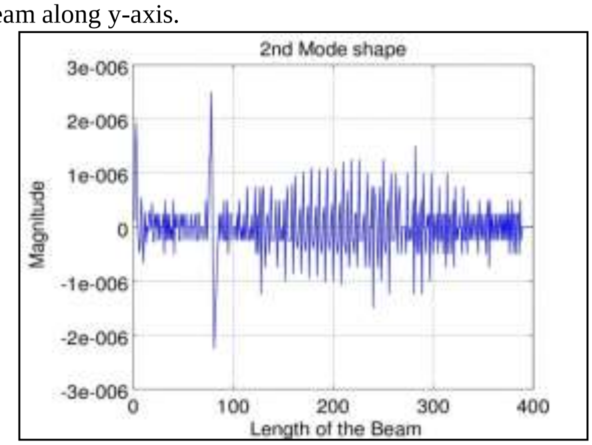
(c) mode 3

Fig. 3: comparison of natural frequencies at different crack depth

B. Mode Shapes:

In this simulation first eight mode shapes are plotted at crack location is 20% of crack length and 2mm of crack depth. Length of the beam is consider as one unit along x-axis, amplitude of the beam along y-axis.





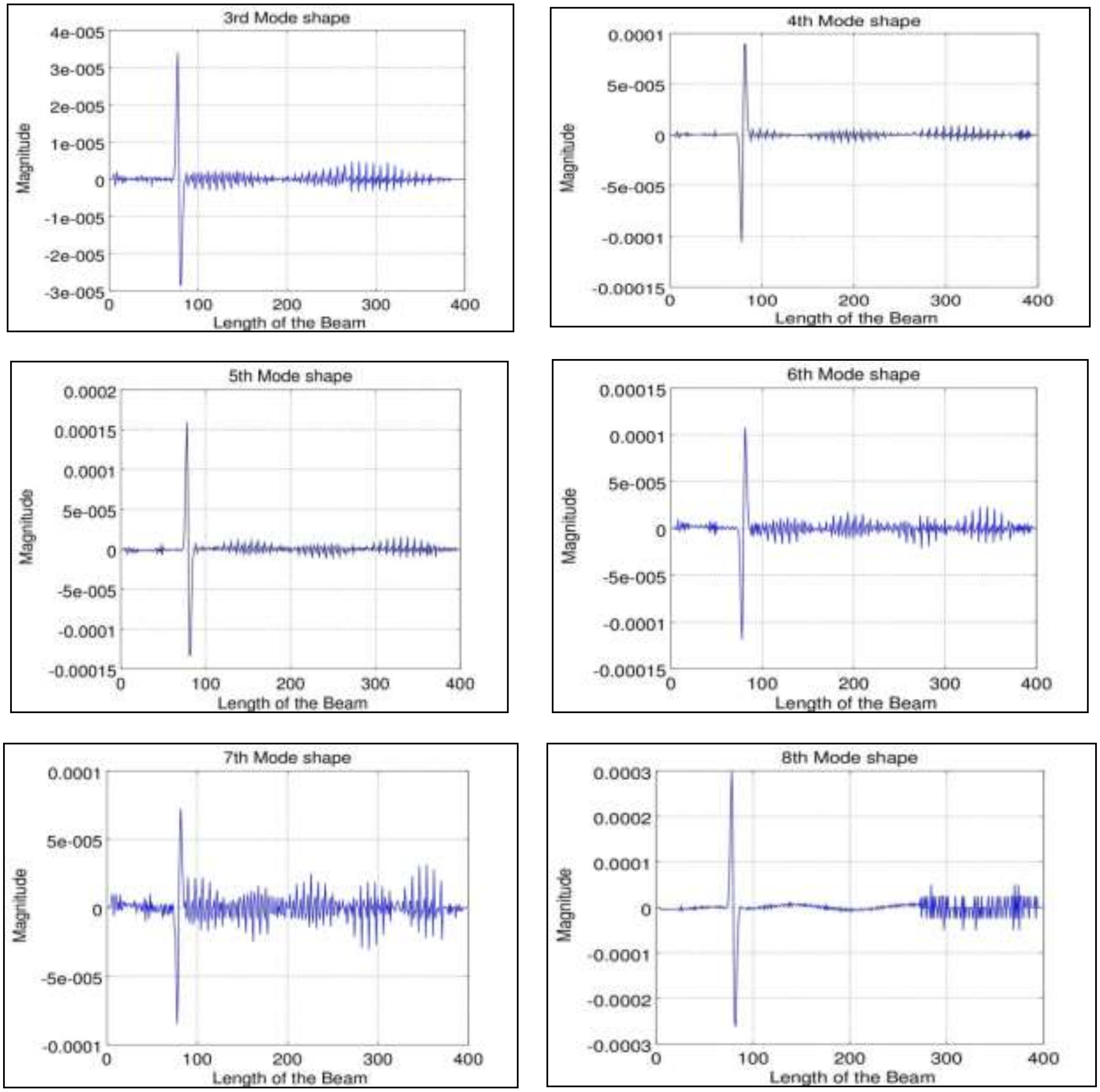


Fig. 4: Eight mode shapes of the cantilever beam

C. *Central Difference Approximation:*

Damage in the beam effects on the local change in stiffness its results on mode shape, that has localized change in slope of the mode shape. Therefore, this feature is will be helpful as a possible parameter for damage detection purpose. The curvature (K) of beam in bending is approximated by the second derivate of the deflection:

$$K = d^2y/dx^2 \qquad (1)$$

In addition, numerical data mode shape is discrete in space, thus the change in slope at each node can be calculated by using central difference approximations. In this paper, the central difference equation was used to calculated the second derivate of the displacements U along the X - direction at node i:

$$K = \frac{x_{i-1} - 2x_i + x_{i+1}}{L^2} \qquad (2)$$

The term $L = x_i - x_{i-1}$is the element length. In this process meshing and node numbering is very important if the descritization is fine it is very sensitive to identify the damage. Equation (2) require careful observation about the displacements at node i, node i -1 and node i+1 in order to calculated the curvature at node i. After obtaining the curvature mode shapes the absolute difference between the un-cracked and cracked state is determined to obtain the non-zero values at the damage in the beam.

$$\Delta K = \left|K\right|_{NoCrack} - \left|K\right|_{withcrack} \tag{3}$$

From this result of analysis, a set of non-zero values are obtained at the position of damage in the beam.
Crack at different depth (d):

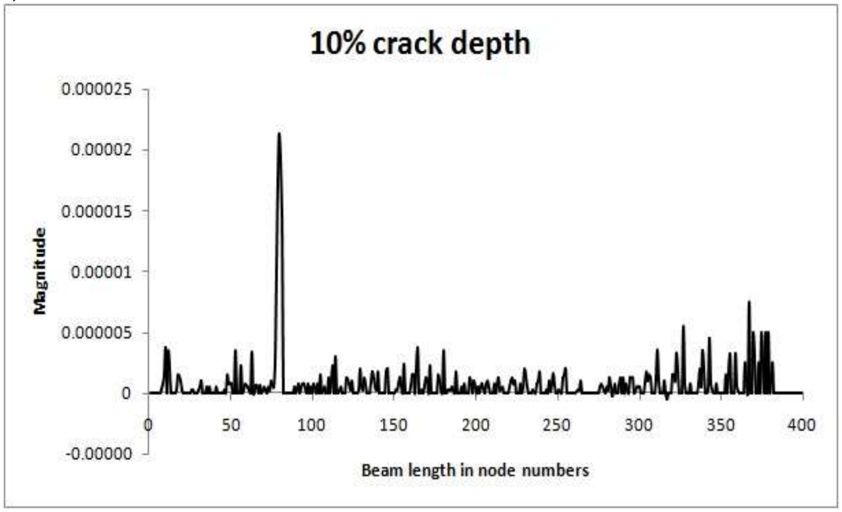


Fig 5: curvature mode shape of 1st mode crack depth d=1mm

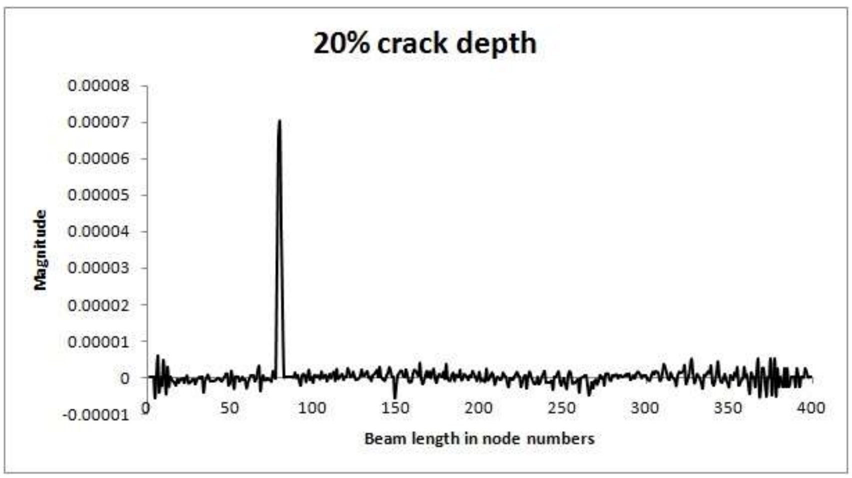


Fig. 6: curvature mode shape of 1st mode crack depth d=2mm

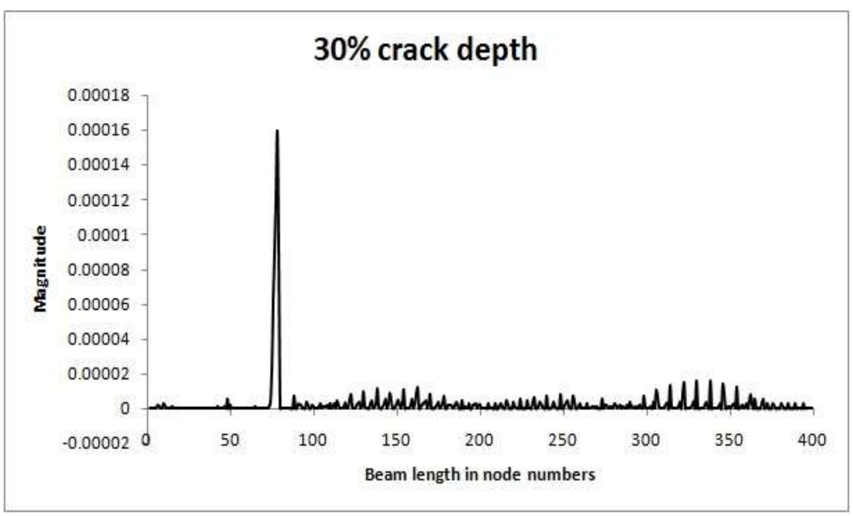


Fig. 7: curvature mode shape of 1st mode crack depth d=3mm.

D. *Crack at different location (x):*

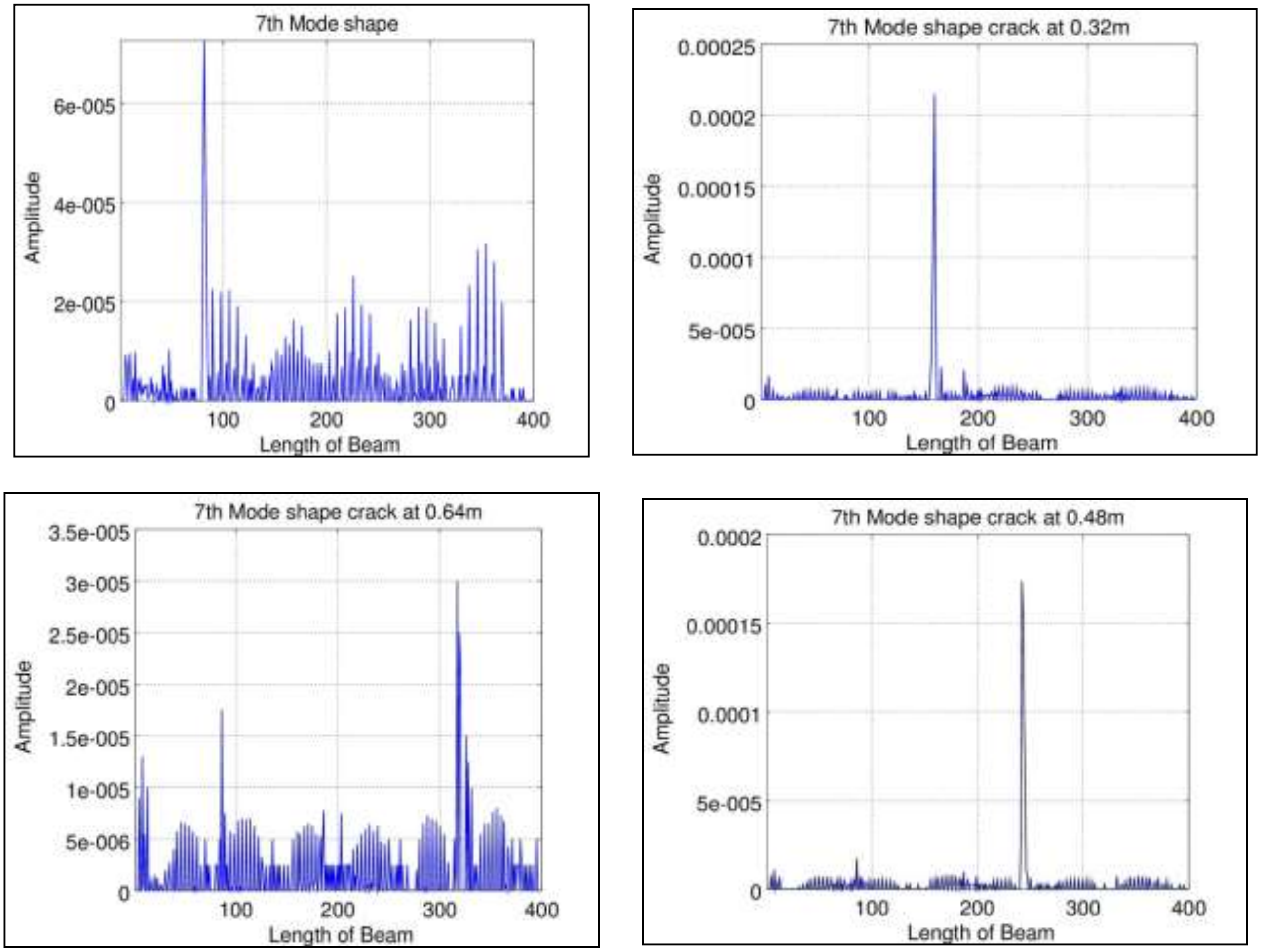


Fig 8: curvature mode shape of 1st mode crack at different location

VI. CONCLUSION

In this paper, the curvature damage detection technique was investigated both experimentally and numerically on an example of the cantilever beam with damage in the form of the notch of depth 10%, 20% and 30% of the beam height. The analysis was performed on the first eight mode shapes. Results of the research on the effectiveness of the damage detection technique applied to higher vibration modes lead to the following conclusions: For the established curvature function, if the mode is higher, the value of the curvature modulus is also higher, what indicates that higher modes are more sensitive to the presence of the defect. For the established mode shape, it contains a large number of zero values, what facilitates damage identification. In this case, strong non-zero values are observed only in places where the damage occurs.

VII. FUTURE SCOPE OF WORK

- In this research project, delamination as one of the more important type of damage is studied. The possible future work would be generalizing the invented technique for other types of damage such as impact, thermally loaded cracks and layer misaligned cracks.
- The cracked cantilever can be analyzed under the influence of external forces.
- The dynamic response of the cracked beams can be analyzed for different crack orientations.
- Stability study of the cracked beams can be done. Use hybrid neuro genetic technique for crack detection

REFERENCES

[1] Mangesh dilip ratolikar, m chandra sekhar reddy, t ravi theja, chintapatla siddhartha, “crack detection for various loading conditions in beam usinghilbert – huang transform”, iosr journal of mechanical and civil engineering (iosr-jmce), e-issn: 2278-1684,p-issn: 2320-334x, volume 12, issue 1 ver. ii (jan- feb. 2015), pp 22-29.

[2] K. ravi prakash babu1, b. raghu kumar2, k. l.narayana2 and k. mallikarjuna rao, "multiple crack detection in beams from the differences in curvature mode shapes", asian research publishing network (arpn), vol. 10, no. 4, march 2015 issn 1819-6608.
[3] N. g. jaiswal, d. w. pande, "sensitizing the mode shapes of beam towards damage detection using curvature and wavelet transform", international journal of scientific & technology research volume 4, issue 04, april 2015 issn 2277-8616.
[4] V. B. Dawari, G. R. Vesmawala "Structural Damage Identification Using Modal Curvature Differences" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN: 2278-1684, PP: 33-38 may 2015.
[5] M. Makki Alamdari, J. Li , B. Samali "Damage identification using 2-D discrete wavelet transform on extended operational mode shapes", archives of civil and mechanical engineering 15 (2015) 698 – 710.
[6] Malay quila, prof. samar ch. mondal, prof. susenjit sarkar, " free vibration analysis of an un-cracked & cracked fixed beam", iosr journal of mechanical and civil engineering (iosr-jmce) e-issn: 2278-1684,p-issn: 2320-334x, volume 11, issue 3 ver. iii (may- jun. 2014), pp 76-83
[7] Reshmi revi, indu. v.s "crack detection of propped cantilever beam using dynamic analysis", international journal of technical research and applications e-issn: 2320-8163, www.ijtra.com volume 3, issue4 (July-august 2015), pp. 274-278.
[8] YanfengWang, MingLiang, JiaweiXiang, "Damage detection method for wind turbine blades based on dynamics analysis and mode shape difference curvature information", Mechanical Systems and Signal Processing 48 (2014)351–367.
[9] Maosen Cao , Maciej Radzieński , WeiXua, Wiesław Ostachowicz, "Identification of multiple damage in beams based on robust curvature mode shapes", Mechanical Systems and Signal Processing 46 (2014) 468–480.
[10] Kaushar H. Barada, D. S. Sharmaa, Vishal Vyas, "Crack detection in cantilever beam by frequency based method".,Procedia Engineering 51 (2013) 770 – 775.
[11] Elma Ekinovic, Sabahudin Ekinovic, Raza Sunulahpašic "a glance to a mode shape based damage detection technique" 17th International Research/Expert Conference" Trends in the Development of Machinery and Associated Technology" TMT 2013, Istanbul, Turkey, 10-11 September 2013.
[12] Lonkar A.A, Srivastava R.K. Modeling Curvature Damage Surface for Damage Detection in Cantilever Beam. AMAE International Journal on Production and Industrial Engineering, 2011, 2 (1), pp.4. Hal-00935152
[13] Ahmed A. Elshafey, H. Marzouk and M. R. Haddara, "Experimental Damage IdentificationUsing Modified Mode Shape Difference", J. Marine Sci. Appl. (2011) 10: 150-155 DOI: 10.1007/s11804-011-1054-5.
[14] Arcangelo Messina, "Refinements of damage detection methods based on wavelet analysis of dynamical shapes" International Journal of Solids and Structures 45 (2008) 4068–4097.
[15] E. Castro M.T. Garc-Hernandez, A. Gallego, "Defect identification in rods subject to forced vibrations using the spatial wavelet transform", Applied Acoustics 68 (2007) 699–715