International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 3, Issue4 (July-August 2015), PP. 274-278

CRACK DETECTION OF PROPPED CANTILEVER BEAM USING DYNAMIC ANALYSIS

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***Abstract*— This paper deals with a methodology for the use of dynamic response as an inspection and surveillance tool for the damage in a structure. The method is based on finite element discretisation to identify the stiffness characteristics (related to cracking) starting from modal dynamic parameters (natural frequency and mode shape) derived from dynamic tests. Any damage in the structure alters its dynamic characters. 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. The beam used here is a Reinforced Concrete Propped cantilever Beam. Crack is induced by applying incremental load at different stages. Curvature Damage Factor (CDF) using curvature mode shape was used to locate the damaged positions.**

Index Terms*— Crack Detection, Propped cantilever Beam, Dynamic Analysis, Curvature mode shape, Curvature Damage Factor, Ansys.

I. INTRODUCTION

Engineering structures under repeating loading conditions undergoes damage or crack in overstressed zones. The presence of cracks in a structural member such as beam causes the reduction in stiffness of the structure which in turn mainly depends on the location and depth of the cracks. These variations in turn have a significant effect on the vibrational behaviour of the entire structure. To ensure the safety of the structures, it is important to know whether their members are free of cracks and should any be present, to detect their location and provide safety measures.

Any damage in a structure alters its dynamic characteristics or the modal parameters such as natural frequency, associated mode shapes and damping values. The damage reduces the stiffness of the structure and increases the damping value. The reduction in stiffness is associated with decrease in natural frequencies and changes in corresponding mode shapes. The mode shape of the damaged structure may seem to be similar as the mode shape of the undamaged structure. But the derivatives of the mode shapes show a discontinuity at the damaged location. This hidden feature of the mode shape gives the motivation to use it as a damage detection tool. Cracks occurring in structural elements are responsible for local stiffness variations, which in consequence affect their dynamic characteristics. This problem has been a subject of interest for the past few years.

Curvature mode shape method is used as a damage detection tool in this thesis work. Finite element analysis of the Reinforced concrete propped cantilever beam was done in Ansys to obtain the displacement mode shapes of the models. The dynamic properties of a damaged structure and an undamaged structure are compared.

II. FINITE ELEMENT MODELLING

A. Modelling of Beam

The selection of finite element model to simulate the response of a structure is very important task in any analysis. The Finite Elemental Method (FEM) discretize the structure into a discrete number of elements from which an approximate numerical solution is obtained. With the easy of simulating the mathematical model in FEM on personal computer, this approach provides an accurate solution for many structural analysis problems. The accuracy of result depends on the selection of suitable elements with the appropriate material characteristics modelling. In this paper propped cantilever beam was modelled using the FEM with the commercial software package ANSYS. The material property assigned for the propped cantilever beam is given in Table 1.

TABLE I. MEMBER PROPERTY OF THE MATHEMATICAL MODEL

Member	**Beam**	
Material	Reinforced concrete	
Length	6.4m	
Width	0.25m	
Depth	0.6m	
	Concrete	***Reinforcement bar***
Element type	Concrete 65	Link 180
Poisson's ratio	0.2	0.3
Mass density	2500kg/m^3	7850 kg/m^3
Modulus of elasticity	2738.6 GPa	200 GPa

B. Modelling of Damages

There are a number of approaches to model damage in a mathematical model. Although the geometry of the damage can be very complicated, the condition is that for lower frequency vibration only an effective reduction in stiffness is required. Thus for comparison, a simple model of a damage is required. Damage can be introduced into the finite element model by applying incremental load.

III. DYNAMIC ANALYSIS USING ANSYS

A dynamic analysis is first performed for beam with self weight only. The frequency and mode shapes are read from the analysis. This test results serves as a reference for later comparison of dynamic characteristics at the different damage stages. Then dynamic analysis is performed by applying incremental load. After each loading phase, the beam is unloaded, and the dynamic analysis is performed. Formation of crack can also be seen in this analysis.

I. LOCATING THE DAMAGES BY USING MODE SHAPE CURVATURE AND CURVATURE DAMAGE FACTOR

It is likely that damage indicators based on derivatives of the mode shape will amplify the localized damages in a structure .The curvature mode shape has emerged as one of the best way to amplify the effect of the damage on the mode shape. The curvature mode shapes are based on flexural stiffness of the beam cross section. Based on beam theory the curvature at a point in the beam is given by

$$V'' = M / (Ebxx\ Iyy)$$

Where M is the bending moment at the section and (Ebxx Iyy) is the flexural stiffness of the beam.

The presence of damage in a beam at a given location reduces the flexural stiffness of the beam and hence increases the magnitude of curvature at the damaged location. Typically damages occurred due to impact and are likely to be localized at some point in the structure. The changes in curvature are local in nature and can be used to find the damage location in the beam. To obtain curvature mode shape of a damaged beam finite element analysis is done to get the displacement mode shape. Then using displacement mode shape, curvature mode shapes are obtained numerically by a central difference approximation as:

$$V_{i,j} = \frac{\Phi_{(i+1),j} - 2\Phi_{i,j} + \Phi_{(i-1),j}}{he^2}$$

Where Vi,j represents curvature mode shape, subscript i represent the node number and subscript j represents the mode number. Also he represents the finite element length and □i,j represents the mass normalized displacement mode shape for the ith mode shape.

Absolute difference in curvature mode shape between damaged and undamaged structure is obtained as;

$$\Delta V_{i,j} = V_{i,j}^{(d)} - V_{i,j}^{(u)}$$

The Curvature Damage Factor (CDF) is obtained by averaging the first few curvature mode shape. In general CDF of ith node is obtained by considering the first n curvature mode shape and is given as;

$$CDF_i = \frac{1}{N}\sum_{j=1}^{N} \Delta v_{i,j}$$

The CDF at each node is obtained by considering the first five curvature mode shape. With increase in damage density, the peak magnitude of CDF at the damage location also increases and hence indicates the extent of damage.

IV. RESULTS AND DISCUSSIONS

The results obtained from the two beams were compared. The control beams (Un- damaged state) provides the reference readings which form the basis of the comparison of the modal parameters obtained in successive damage states as described below.

A. Natural Frequency

When a system is subjected to certain degree of damage or deterioration, it experiences a change in stiffness. Subsequently it causes the natural frequency to change. The magnitude of the changes is also an indicator of the severity or state of the damage experienced. This is apparent in the changes in the natural frequencies of the damaged beams as compared to the control beam. The values of natural frequencies for the test beams are tabulated in Table 2, Table 3 and in Table 4.

TABLE II. CHANGE IN NATURAL FREQUENCIES OF BEAM FOR MODE 1

Loading conditions		**Mode Number**	
		1	
		Frequency (Hz)	***Decrease (%)***
Dead Load only (N/mm^2)		1.5600	0
Dead load + Live load (N/mm^2)	0.056	1.1670	25.19
	0.064	1.1543	26
	0.072	1.1499	26.29
	0.08	1.1414	26.83
	0.088	1.1321	27.43
	0.096	1.1282	27.68
	0.104	1.1262	27.81

TABLE III. CHANGE IN NATURAL FREQUENCIES OF BEAM FOR MODE 2

Loading conditions		**Mode Number**	
		2	
		Frequency (Hz)	***Decrease (%)***
Dead Load only (N/mm^2)		7.3629	0
Dead load + Live load (N/mm^2)	0.056	6.3674	13.32
	0.064	6.3390	13.91
	0.072	6.3187	14.18
	0.08	6.3027	14.39
	0.088	6.2816	14.69
	0.096	6.2682	14.87
	0.104	6.2649	14.91

TABLE IV. CHANGE IN NATURAL FREQUENCIES OF BEAM FOR MODE 3

Loading conditions		**Mode Number**	
		3	
		Frequency (Hz)	***Decrease (%)***
Dead Load only (N/mm^2)		15.592	0
Dead load + Live load (N/mm^2)	0.056	13.344	14.42
	0.064	13.219	15.22
	0.072	13.053	16.28
	0.08	13.045	16.34
	0.088	13.008	16.57
	0.096	12.882	17.38
	0.104	12.876	17.42

B. Mode shapes

A mode shape is a specific pattern of vibration executed by a mechanical system at a specific frequency. Different modes will be associated with different frequencies. The mode shapes of test beams are shown below.

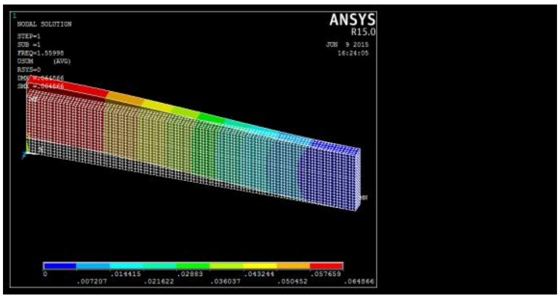

Fig. 1. Mode shape 1 of undamaged beam

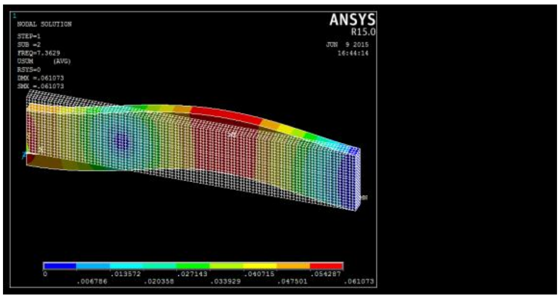

Fig. 2. Mode shape 2 of undamaged beam

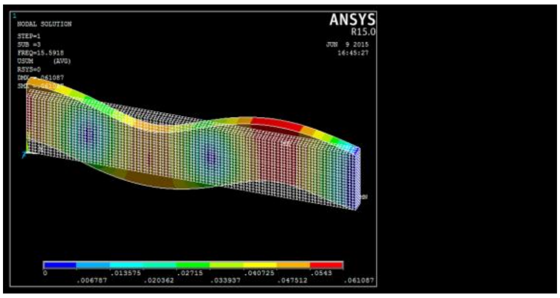

Fig. 3. Mode shape 3 of undamaged beam

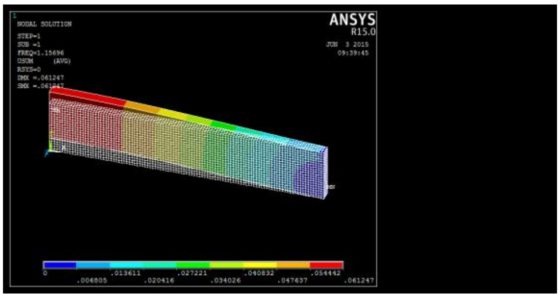

Fig. 4. Mode shape 1 of beam at last damage condition

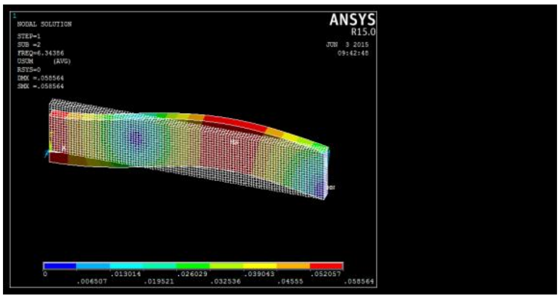

Fig. 5. Mode shape 2 of beam at last damage condition

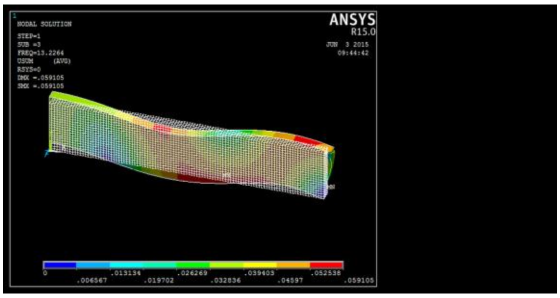

Fig. 6. Mode shape 3 of beam at last damage condition

C. Difference in Curvature Mode Shape

Locating the damaged positions using Difference in Curvature Mode Shape 1, 2, and 3 of last loading condition are shown in Figure. 7, 8, and 9.

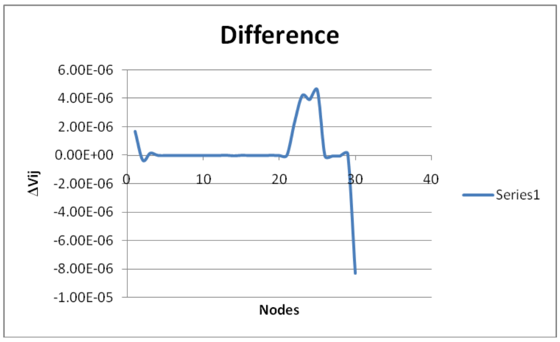

Fig. 7. Difference in curvature mode shape 1

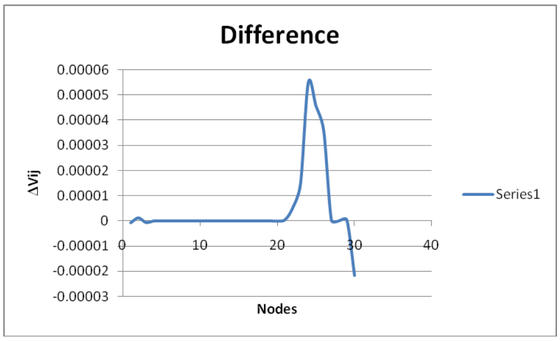

Fig. 8. Difference in curvature mode shape 2

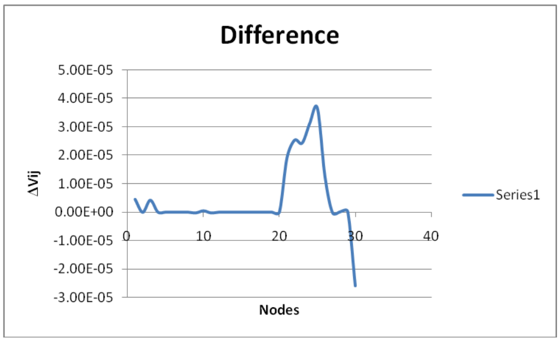

Fig. 9. Difference in curvature mode shape 3

D. Curvature Damage Factor

Locating the damaged positions using Curvature Damage Factor for last loading condition are shown in Figure. 10.

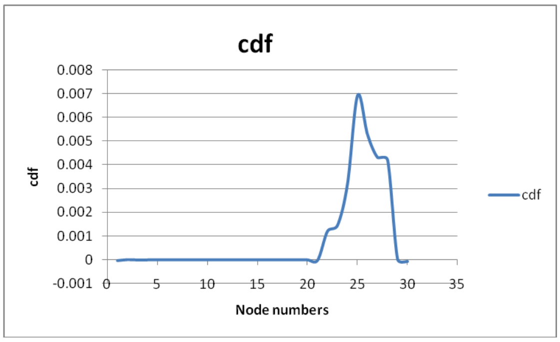

Fig**.** 10**.** Curvature damage factor for last loading condition

V. CONCLUSIONS

The purpose of the current study is to obtain the dynamic behaviour of Reinforced concrete beam under various damage conditions. Damages are introduced by applying incremental load and dynamic analysis is done. Mode shape curvature method is used for locating crack in the beam. Based on the results, the following conclusions can be derived:

As damage level on the beams increased, Natural frequency decreased. Mode shape curvature method using curvature damage factor is an effective method for locating cracks. The numerical results show the high efficiency of the proposed method for accurately locating structural damages.

Dynamic analysis is an economical and time saving method than experimental method for crack detection. Prediction of formation and location of crack can be done before casting.

VI. ACKNOWLEDGMENT

First and foremost, I would like to thank the Almighty god who blessed me to overcome all the obstacles I came across while proceeding with this thesis. I am deeply indebted to my thesis guide Mrs. Indu. V. S, Assistant Professor, Department of Civil Engineering, Sree Buddha College of Engineering for her sincere guidance, timely help and much appreciated correction during every step of this work. Finally, yet importantly, I would like to express my heartfelt thanks to my beloved parents for their blessings, and my friends for their help and wishes for successful completion of this thesis.

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