Vibrational Analysis of Cracked Reinforced Concrete Beam

Nimisha K P, K Subha

Abstract— Structural Health Monitoring has gained attention from the scientific community since unpredicted major hazards, most with human losses, have been reported. Development of an early damage detection method for structural failure is one of the most important keys in maintaining the integrity and safety of structures. Among many Structural Health Monitoring techniques, the dynamic response-based damage detection method attracts most attention due to its simplicity for implementation. This technique makes use of the dynamic response of structures which offers unique information on the defects contained with these structures. Changes in the physical properties of the structures due to damage can alter the dynamic response, such as the natural frequency and mode shape. These parameter changes can be extracted to predict damage detection information, such as the presence, location, and severity of damage in a structure. The damage tends to reduce the stiffness of the structure. Thus natural frequency provides the simplest damage detection method. Therefore, a reduction of natural frequency may indicate the existence of damage in the structure. However, the natural frequency is a global feature of the structure, from which the location of the damage is difficult to determine. The modal parameters (e.g., the mode shape and flexibility), which can capture the local perturbation due to damage are used in order to locate damage. In this project, the free vibrational analysis is done for Reinforced Concrete beam with inclined crack by varying the crack depth and boundary conditions. This can be done for various L/D ratio and also forced vibration analysis can be performed in the future.

Index Terms— Crack depth, inclined crack, mode shape**,** natural frequency, reinforced concrete beam, structural health monitoring, free vibrational analysis

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1 INTRODUCTION

THE dynamic response of structures can offer unique information on defects that may be contained within the structures. Changes in the physical properties of the structures due to damage will alter the dynamic responses such as natural frequencies, damping and mode shapes. These physical parameter changes can be extracted to estimate damage information. In the past 20 years a lot of work has been published in the area of damage detection, where various methods have been proposed. The modal parameters can be used to detect the initiation and development of cracks.

The fundamental idea for vibration-based damage identification is that the damage-induced changes in the physical properties (mass, damping, and stiffness) will cause detectable changes in modal properties (natural frequencies, modal damping, and mode shapes). Therefore, it is intuitive that damage can be identified by analyzing the changes in vibration features of the structure. Although in vibration test, the excitation and response are always measured and recorded in the form of time history, it is usually difficult to examine the time domain data for damage identification.

A more popular method is to examine the modal domain data through modal analysis technique, in which the time domain data is transformed into the frequency domain, and then the modal domain data can be further extracted from the frequency domain data. During the past three decades, great effort has been made in the researches within all three domains (i.e., time, frequency, and modal domains). It seems that this effort will continue since no single existing method can solve all the damage identification problems from various types of damages and structures. The modal domain methods play a dominant role in the state-of-the-art of structural damage identification. The modal domain methods evolve along with the rapid development of experimental modal analysis technique, and they gain their popularity because the modal properties have their physical meanings and are thus easier to be interpreted than those abstract mathematical features extracted from the time or frequency domain. During the last three decades, extensive research has been conducted in vibration-based damage identification, and significant progress has been achieved in this highlighted area. Thus, the main objective of this work is to contribute for a better understanding of the dynamic behaviour of a reinforced concrete beam with inclined symmetric crack. The influence of depth of crack on the dynamic parameters (natural frequency and mode shapes) of RC beam with different boundary conditions is studied.

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2 THEORETICAL BACKGROUND

2.1 Modal Analysis Using FEM

The modal analysis is done to obtain the natural frequencies and the corresponding mode shapes of an object or structure during free vibration. It is common to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analysed can have arbitrary shape and the results of the calculations are acceptable. The eigen values and eigen vectors which come from solving the eigen system represent the frequencies and corresponding mode shapes. The only desired modes are the lowest frequencies because they can be the most prominent modes at which the object will vibrate, dominating all the higher frequency modes. We can test a physical object to determine its natural frequencies and mode shapes. This is called an Experimental Modal Analysis.

2.2 FEA Eigen Systems

The matrix equations take the form of a dynamic three-dimensional spring mass system for a linear elastic material which obeys Hooke's Law. The generalized equation of motion is given as:

$$[M][\ddot{U}] + [C][\acute{U}] + [K][U] = [F]$$

where [M] is the mass matrix, $[\ddot{U}]$ is the 2nd time derivative of the displacement [U] (i.e., the acceleration), $[\acute{U}]$ is the velocity, [C] is a damping matrix, [K] is the stiffness matrix, and [F] is the force vector. Generally, the problem with nonzero damping, is a quadratic eigenvalue problem. However, for vibrational modal analysis, the damping is generally ignored, leaving only the 1st and 3rd terms on the left-hand side:

$$[M][\ddot{U}] + [K][U] = [0]$$

The above equation is the general form of the eigen system encountered in structural engineering using the FEM.

3 FINITE ELEMENT ANALYSIS

3.1 General

The finite analysis is a numerical technique. Here, all the cases of the problems, like varying shape, boundary condition and loads are maintained as they are but the solutions obtained are approximate. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering. Many popular brand of finite element analysis package are now available commercially. Some of the popular packages are STAAD-PRO, GT-STRUDEL, NASTRAN, NISA and ANSYS. Using these packages one can analyse several complex structures.

3.2 ANSYS

ANSYS is commonly used engineering simulating software developed at south of Pittsburgh in South Pointe business park. ANSYS Parametric Design Language (APDL) is one of widely used FEA package which is capable of simulating all general engineering problems. Modelling is facilitated by means of various geometric and Boolean operations. APDL is equipped with an element library which ensures wide applicability of the package. Element assignment is made through simplified selection and numbering methods. ANSYS is commercial finite element software with capability to analyse a wide range of different problems. As any finite element software, ANSYS also solves governing differential equations by breaking the problem into small elements. The FEA software ANSYS includes time-tested, industrial leading applications for structural, thermal, mechanical, computational fluid dynamics and electromagnetic analysis.

The ANSYS has many features of the FORTRAN programming language. In addition to this, ANSYS has several built-in functions for further manipulation of ANSYS results or geometry parameters. There are two primary ways to use ANSYS interactively through the graphical user interface and through the use of batch files and ANSYS commands. It is very easy to learn the ANSYS interactively, especially when compared to the daunting task of learning all of the relevant ANSYS commands. Thus Interactive ANSYS has disadvantages such as it requires the user to save the model geometry, mesh, and results in a *.db file, which can get as large as 50MB or more and the second one is Interactive use is slow if you need to repeat operations. Sub Batch processing is highly modular. If you spend time creating batch files, changing dimensions and mesh densities is a snap.

4 MODELLING OF REINFORCED CONCRETE BEAM USING ANSYS

The reinforced concrete beams with inclined symmetric crack are modelled in ANSYS 17. Different boundary conditions, different crack inclination, crack depth are applied to the beam and free vibrational analysis is done. Also the beam is modelled with and without stirrups and free vibrational analysis is done. The crack is symmetric and at effective depth distance from the supports. The concrete used is of M30 mix and steel bar Fe 415.The ANSYS finite element program was used for free vibration of the cracked beams. For this purpose, the key points were first created and then line segments were formed. The lines were combined to create an area. Finally, this area was extruded and a three-dimensional inclined cracked beam model was obtained. The crack is modelled with a 0.005m width on the bottom surface of the beam near the supports going through the depth of the beam. An 8-node three-dimensional structural solid element under SOLID 65 was selected to model the beam. Fixed boundary conditions can also be modelled by constraining all degrees of freedoms of the nodes located on both ends of the beam. Simply supported beam is modelled by providing hinges at both the ends. LINK 180 element is used for modelling reinforcement bars.

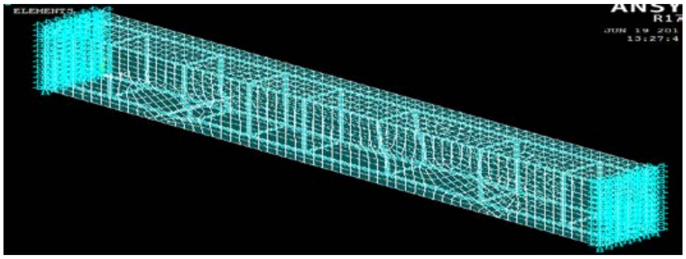

Fig. 1. Model of the fixed RC beam

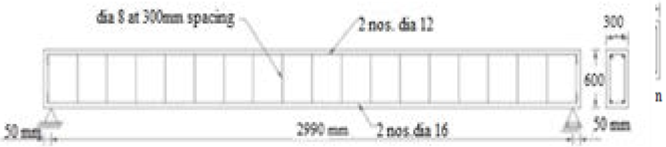

Fig.2. Dimensions of the beam

TABLE 1
Properties of material

Properties	Concrete	Steel
Young's modulus	27.38 GPa	200 GPa
Poisson's ratio	0.15	0.3
Density	2435 kg/m^3	7905 kg/m^3

5 RESULT AND DISCUSSION

5.1 Fixed RC Beam with Inclined Crack

Reinforced concrete beams with fixed ends are modelled with symmetric inclined crack with different angle of inclination for various crack depth to beam depth ratio and the following results were obtained.

TABLE 2
Natural Frequency For Fixed Beam With Various Crack Angle

Crack inclination (degree)	a/D ratio	Natural frequency (Hz)		
		Mode 1	Mode 2	Mode 3
Intact		61.93	143.68	241.52
35	0.2	60.065	131.35	221.35
	0.3	59.463	118.05	213.38
	0.35	58.459	108.91	208.49
	0.4	57.515	100.99	206.58
	0.45	56.288	91.627	203.88
	0.5	54.922	83.488	202.26

Crack inclination (degree)	a/D ratio	Natural frequency (Hz)		
		Mode 1	Mode 2	Mode 3
Intact		61.93	143.68	241.52
40	0.2	60.122	132.40	221.97
	0.3	59.6	120.21	214
	0.35	59	111.71	208.61
	0.4	58.411	104.69	207.93
	0.45	57.92	99.61	205.43
	0.5	56.14	87.681	204.53

Crack inclination (degree)	a/D ratio	Natural frequency (Hz)		
		Mode 1	Mode 2	Mode 3
Intact		61.93	143.68	241.52
45	0.2	60.3	132.9	222.10
	0.3	59.8	122.5	215.4
	0.35	59.3	115.66	209.77
	0.4	58.74	106.86	208.1
	0.45	57.985	99.9	206.32
	0.5	56.946	91.197	205.10

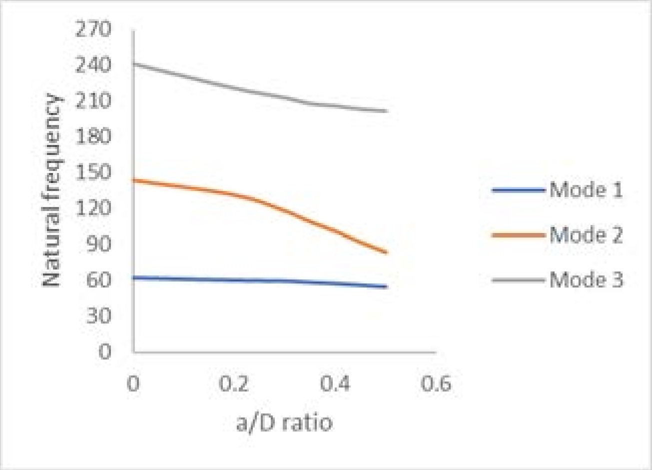

Fig. 3. Natural frequency v/s a/D ratio for angle of inclination 35°

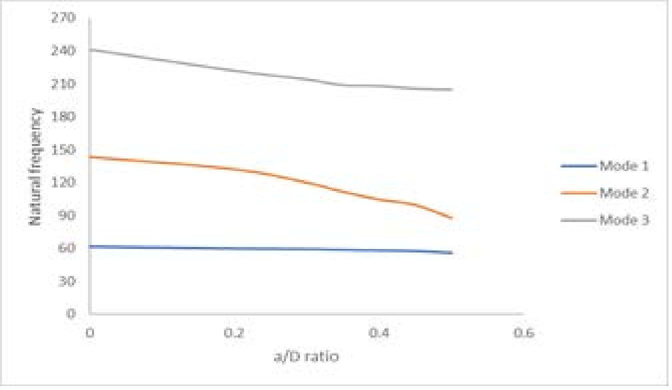

Fig. 4. Natural frequency v/s a/D ratio for angle of inclination 40°

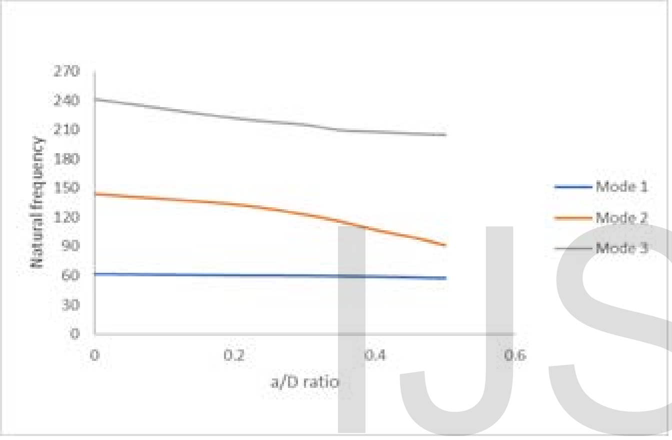

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Fig. 5. Natural frequency v/s a/D ratio for angle of inclination 45°

5.2 Simply Supported RC Beam with Inclined Crack

Reinforced concrete beams with simply supported ends are modelled with symmetric inclined crack with different angle of inclination for various crack depth to beam depth ratio. The table below shows the results obtained.

TABLE 3
Natural Frequency for S.S Beam with Various Crack Angle

Crack inclination	a/D ratio	Natural frequency (Hz)		
		Mode 1	Mode 2	Mode 3
Intact		25.712	96.273	152
35	0.2	24.063	91.606	149.85
	0.3	21.979	86.947	141.99
	0.35	20.55	83.802	139.2
	0.4	19.245	81.16	138.97
	0.45	17.528	77.927	136.23
	0.5	16.082	75.249	135.87

Crack inclination	a/D ratio	Natural frequency (Hz)		
		Mode 1	Mode 2	Mode 3
Intact		25.712	96.273	152
40	0.2	24.2	92.1	150.10
	0.3	22.205	87.6	142.3
	0.35	20.76	84.10	141.9
	0.4	19.538	81.79	141.21
	0.45	18.422	79.069	140.86
	0.5	16.5	76.1	140.10

Crack inclination	a/D ratio	Natural frequency (Hz)		
		Mode 1	Mode 2	Mode 3
Intact		25.712	96.273	152
45	0.2	24.317	93.21	151.73
	0.3	23.12	88.9	147.1
	0.35	19.83	85.6	146.7
	0.4	19.7	82	145.8
	0.45	18.46	79.48	144.1
	0.5	17.1	76.93	143.79

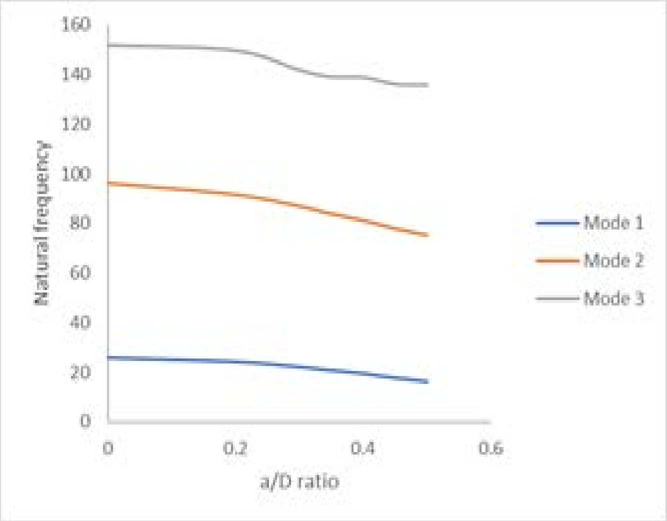

Fig. 6. Natural frequency v/s a/D ratio for angle of inclination 35°

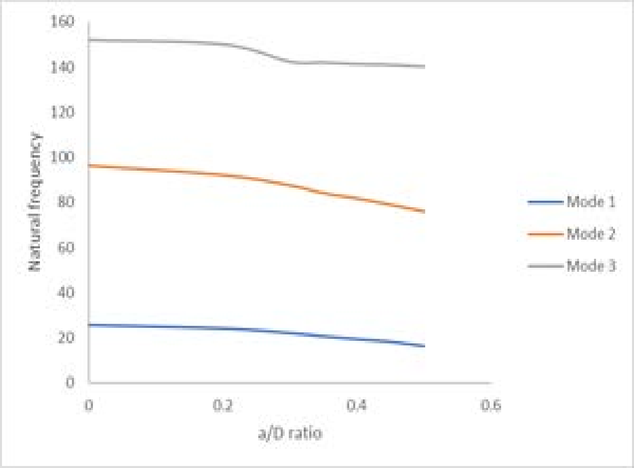

Fig. 7. Natural frequency v/s a/D ratio for angle of inclination 40°

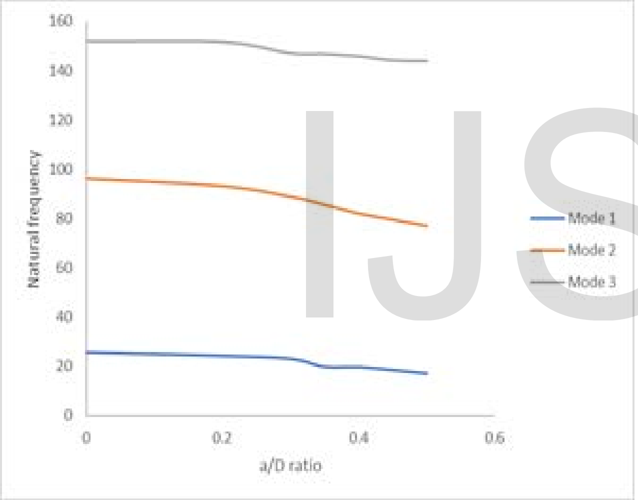

Fig. 8. Natural frequency v/s a/D ratio for angle of inclination 45°

6 CONCLUSION

Vibrational analysis of cracked RC beam results into following conclusion:

- As the crack depth increases, natural frequency decreases due to the reduction in stiffness, for a fixed reinforced concrete beam with inclined symmetric crack.
- As the crack depth increases, natural frequency decreases due to the reduction in stiffness, for a simply supported reinforced concrete beam with inclined symmetric crack.
- The variation in natural frequency is more observed in cracked fixed beam when compared to cracked simply supported beam.
- The natural frequency of the fixed cracked beam is more compared to the simply supported beam, since fixity increases the stiffness of the beam.

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