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FRACTURE ANALYSIS OF REINFORCED CONCRETE (RC) BEAM

Akshay Gund.*, Dr. Ajit Pati**

* M.Tech Student, G.H. Raisoni College of Engineering and Management, Pune.
** Professor, G.H. Raisoni College of Engineering and Management, Pune.

Abstract- Crack is important consideration in limit state of serviceability and analytical determination of crack formation and crack propagation in reinforced concrete material was difficult task and engineers had to rely on empirical formulas because concrete consists of heterogeneous material and which is affected by creep and shrinkage. Due to these complexities engineers in past had been facing difficulties in coping such problems, but with the advancement of digital computerization and modern numerical methods for analysis such as finite element method, these problems can be addressed in a very efficient way.

Beams are made of brittle materials like concrete or cement, show increasing crack development during their service life due to static and dynamic loadings on it of different categories. This partial damage can be translated into a reduction of the bending stiffness and strength. This change in stiffness can be observed by monitoring the vibration behavior of the beam. In this paper the modal parameters of an undamaged beam and damaged beams were compared to monitor the reduction in modal parameters and hence stiffness modification by creating artificial notches based on Rankine principal stress theory.

Index Terms- Crack Identification, Reinforced Concrete Beams, ANSYS Software, CATIA software.

1. INTRODUCTION

Crack width and depth calculation is one of the serviceability requirements in the structural members. The occurrence of cracks in RC structures is unavoidable because of the low tensile strength of concrete. Cracks form when the tensile stress in concrete exceeds its tensile strength. Cracks in a RC member will always be a threat for the satisfactory performance and serviceability of the structure; it has significant influence on serviceability, durability, aesthetic and force transfer.

Hence, an accurate estimation of the crack widths and its predictions are essential in structural design.

The dynamic response of structures can offer unique in-formation 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 in-formation. 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 vibra-tion 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.

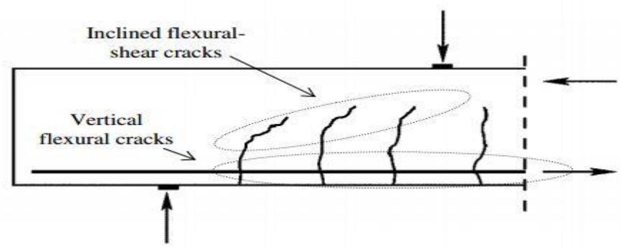

Figure 1: Cracks in concrete beam due to flexural and shear

Formation of crack can modifies the stiffness parameters like mode shapes, modal frequency and moment of inertia .As crack tends to propagate the mass reduction is there and hence material is displaced outside which in turn reduce moment of inertia and hence reduce the stiffness of beam .hence propagation of crack ultimately alter the load carrying capacity of beam.

2 .THEORETICAL BACKGROUNDS

2.1 Modal Analysis Using FEM

The modal analysis is used to obtain the natural frequencies and the corresponding mode shapes of a structure during free vibration and forced vibration. As modal parameters are commonly based on stiffness modification and which is related to energy release rate during crack formation and crack propagation. The finite element method (FEM) is generally used to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are near to practical results. The Eigen values and Eigen vectors which come from solving the Eigen system represent the frequencies and corresponding mode shapes. The required mode is the lower frequency mode at which structure will vibrate first.

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 as per law is given as:

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

Where

[M] - mass matrix,

[Ü] - 2nd time derivative of the displacement

[Ú] -velocity,

[C] -damping matrix,

[K] - stiffness matrix,

[F] -force vector.

Generally, the problem with nonzero damping is a quadratic Eigen value problem and damping in the system is ignored.

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

After solving above equation with limited constrains and by condition of free and forced vibration we get the mode shapes and modal frequency respectively

3. FINITE ELEMENT ANALYSIS

3.1 General

The most accurate numerical technique to analyze structure is finite element analysis. Here, all the cases of the problems, like varying shape, boundary condition and loads are maintained and the less absolute error solution is obtained. 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.

3.2 ANSYS

ANSYS is commonly used engineering simulating software. ANSYS Parametric Design Language (APDL) is one of widely used FEA package which is capable of simulating all general engineering problems. Modeling is facilitated by means of various geometric and Boolean operations. ANSYS solve the constrained governing differential equation.

4. MODELLING OF REINFORCED CONCRETE BEAM USING ANSYS AND CATIA

The reinforced concrete beams with Flexural symmetric crack are modelled in ANSYS 18. Different boundary conditions, different crack inclination, crack depth is applied to the beam and free vibrational analysis is done. Also the beam is modelled with without stirrups and free vibrational analysis is done. The crack is symmetric and at effective depth distance from the supports.

4.1. Reinforced Concrete.-An eight-node solid element (SOLID65) was used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing.

4.2. Steel Reinforcement - To model concrete reinforcing, LINK180 is used. These elements can be directly generated from the nodes in the model. This method of discretization is useful in simple concrete models.

4.3Material Property

Concrete	M25 Density-2500 Kg/Cubic metre Poisson ratio-0.2
Steel	Fe-415 Density-7850 Kg/Cubic metre Poisson ratio-0.3

4.4 Geometry and modeling of beam

Beam is modeled in CATIA with solid geometry having M25 grade concrete

Design -Balanced section, Crack formation and its propagation is based on Rankine theory of failure, Crack of width 0.3mm and depth 10mm formed which behaves like artificial notch.

Beam 250* 300mm

By keeping Ast constant and by varying bar size 4 beams were modeled and analyse in ANSYS

1. 2#18mm diameter bar-2#10mm hanger

2. 4#16mm diameter bar-2#10mm hanger

3. 6#14mm diameter bar-2#10mm hanger

4. 8#12mm diameter bar-2#10mm hanger

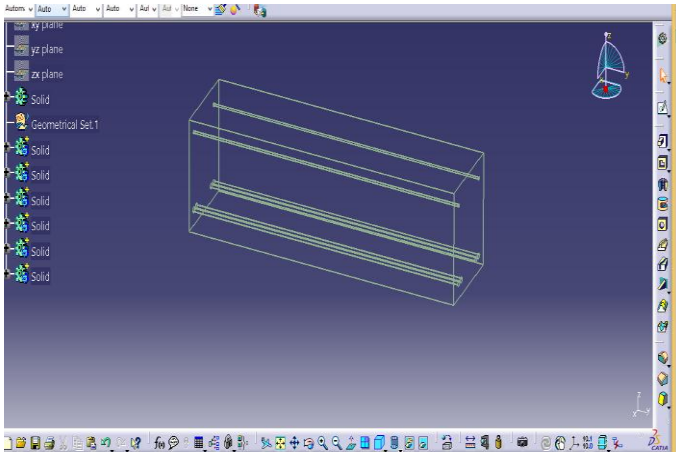

Figure 2: Geometry of RC un-cracked beam in CATIA

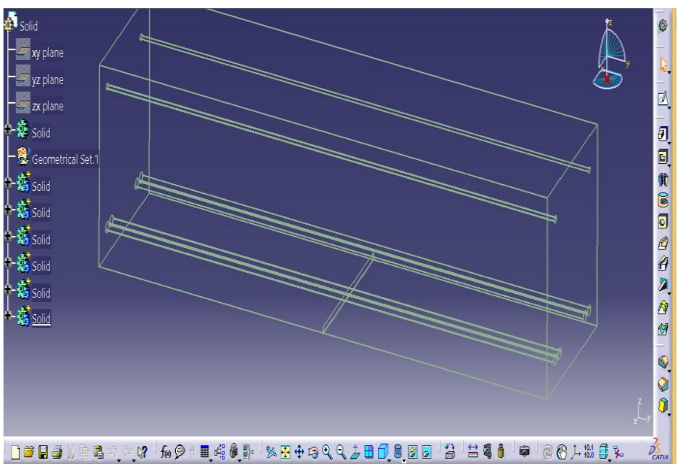

Figure 3: Geometry of RC cracked beam in CATIA

Modal analysis is done in ANSYS for cracked and un-cracked beam with free vibration analysis. Beam is simply supported and medium meshing is used for finite element analysis. For accurate analysis the refinement is done at cracked edge and at a reinforcement and concrete bond. As natural frequency is a inherent property of structure and independent on loading is main reason for free vibration analysis over forced vibration analysis .Corresponding mode shapes and natural frequency is obtained from ANSYS as beam is flexural member so our focus is primarily on flexural mode only.

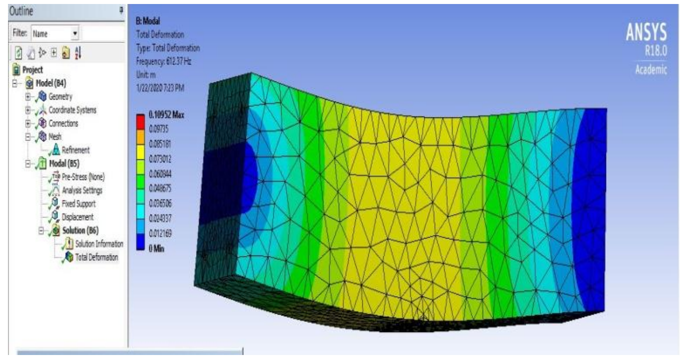

Figure 4: MODAL analysis in ANSYS

5. RESULTS AND DISCUSSION

5.1 Modification in natural frequency of 250*300mm plain concrete beam doe to change in area parameters

5.1.1 Reduction in natural frequency due to change in width of beam

Beam width (mm) Beam depth 300	Natural frequency (Hz)
250	267.91
300	267.98
350	269.59
400	271.34

As beam depth and beam width increase hence the more mass is displaced outside from centre hence resistance to rotation i.e. moment of inertia increase and which increase the stiffness and increase the natural frequency

5.1.1 Reduction in natural frequency due to change in depth of beam

Beam depth (mm) Beam width 250	Natural frequency (Hz)
250	256.5
300	267.91
350	270.3
400	272.52

As beam depth and beam width increase hence the more mass is displaced outside from centre hence resistance to rotation i.e. moment of inertia increase and which increase the stiffness and increase the natural frequency.

5.2 Modification in natural frequency of 250*300mm RC concrete beam doe to change in Rebar size by keeping Ast as constant parameters

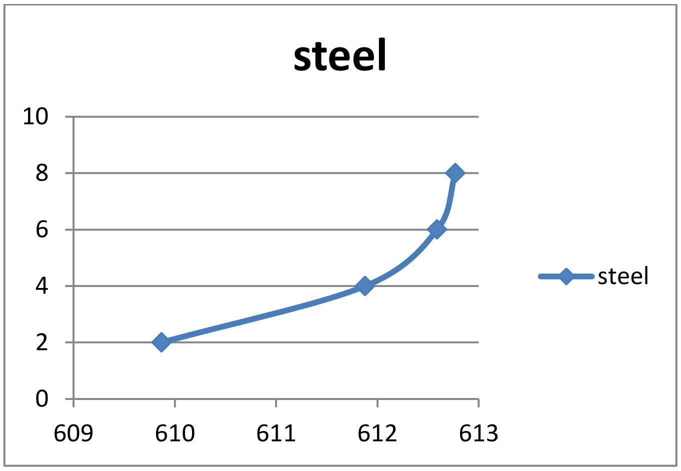

Figure 4: Natural frequency vs. No of rebar's

Three reasons to increase in natural frequency as no of rebar increases – as more steel is placed outside results increase in moment of inertia and hence bending stiffness and natural frequency

1. Mass displaced outside the centre of symmetry is more so increase in moment of inertia and hence bending stiffness

2. Displacement of crack getting arrested by reducing energy release rate

3. Propagation of crack is alter due to reduction in propagating path

Beam Simply supported Dim 250*300 (mm)	Area of steel Asti (mm^2)	Un-cracked damped Natural frequency	Cracked natural frequency Crack depth 10mm@500mm
B1	Main steel 2#18mm diameter Hanger bar 2#10mm	609.87	609.65
B2	Main steel 4#16mm diameter Hanger bar 2#10mm	611.88	611.54
B3	Main steel 6#14mm diameter Hanger bar 2#10mm	612.59	611.69
B4	Main steel 8#12mm diameter Hanger bar 2#10mm	612.77	611.74

5.2 Modification in natural frequency of 250*300mm RC concrete beam doe to propagation of flexural and shear crack with 4#16mm diameter rebar and 2#10mm diameter hanger bar

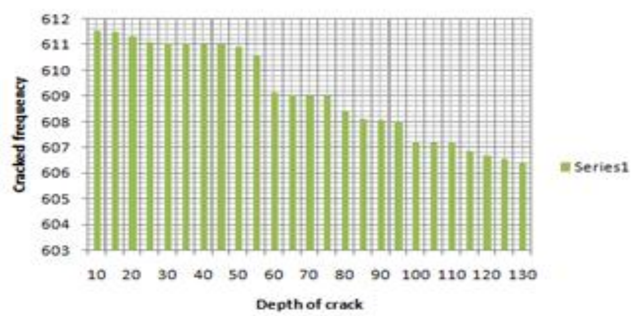

Figure 5: Reduction in natural frequency vs. Crack propagation

As due to large energy release rate crack propagates and follow a tip opening and due to reduction in stiffness natural frequency is reduces.

6. CONCLUSION AND FURURE SCOPE

1. As crack occurs in structure can reduce the natural frequency of structure and alter stiffness parameter.
2. Concrete beam subjected to number of mode displacement –opening mode, sliding mode, tearing mode
3. Flexural crack is opening mode –dangerous
   1. Existing crack grows provided that total energy of system is lower by growth of crack 2.crack branches out if more energy it posses and on order to dissipate it branches out
4. Flexural –shear crack
   1. Opening of crack is further altered due to shear
   2. Due to shear stress crack inclined and which dissipated energy of opening due to compression
5. Shear crack –sliding mode
   1.crack is inclined at 45 degree which thus reduce the principal stress opening path but energy posses by crack is more in such a case-cause due to

formation of crack reduction in natural frequency is more.

6. Natural frequency is important term by which we can easily predict performance of a structure. Modal study can be used to study propagation path of crack with respect to time.

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