Jr. of Industrial Pollution Control 33(S3)(2017) pp 1437-1441
www.icontrolpollution.com
Research Article

DAMAGE ASSESSMENT OF RC BEAM IN TERMS OF ITS STIFFNESS AND MODAL CHARACTERISTICS

MOHAMMAD FAIZAN[1*] AND KRITHIKA P[2]

[1]Student, M.Tech, Structural Engineering, S.R.M. University, Kattankulathur, Tamil Nadu, India

[2]Assistant Professor, Civil Engineering Department, S.R.M. University, Kattankulathur, Tamil Nadu, India

(Received 17 June, 2017; accepted 24 November, 2017)

Key words: Natural frequency, Stiffness, Modal analysis, Steel fibers

ABSTRACT

A crack in a structure introduces a local flexibility which can change the dynamic behavior of the structure, and from this change the crack location and size can be determined. Damage identification in reinforced concrete flexural member using the change in natural frequency and in turn change in flexural stiffness has been the subject of forensic structural engineering. This paper presents experimental results on damage severity of beams in terms of their dynamic parameters. The flexure and modal performance of plain reinforced concrete beam and SFRC beam was compared. As a part of the research, beams were subjected to flexure and modal tests in order to assess and compare their damage state. The results obtained showed changes in stiffness and natural frequencies. The trend in the measured stiffness and frequencies showed more deterioration in Plain RC beam as compared to SFRC beam.

INTRODUCTION

One of the most cost effective maintenance methods is structural health monitoring. Early detection of problems, such as, cracks at critical locations, delaminations, corrosion, spalling of concrete etc., can help in prevention of catastrophic failure and structural deterioration beyond repair. The most common dynamic parameters used in damage detection are the natural frequencies and the mode shapes (Prasad and Seshu, 2010; Lee and Barr, 2004). But changes in natural frequencies alone cannot provide spatial information about structural damage. Therefore mode shape information is additionally needed to uniquely localize the damage (Salawu, 1997).

When a reinforced concrete beam suffers from cracking due to various reasons, its dynamic properties change. The damage causes loss of stiffness which can lead to a decrease in natural frequencies. Most of the dynamic tests conducted for health monitoring on actual structures utilize natural frequency to be the most convenient parameter to identify and quantify the damage. The crack present in the component reduces the effective flexural stiffness. Using this concept the flexural rigidity and hence these damage location of the systems are detected by using vibration based index. The method for detecting damage can be done by observing the change in mode shape also. Modal analysis is used to locate the crack damage in a RC beam by many researchers. The determination of damage location and quantification can be done using vibration data. There will be a change in the flexural rigidity in the cracked area which in turn reflects in the natural frequency of the beam. It is now well established that one of the important properties of steel fiber reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fiber composites possess

***Corresponding authors email: khanfaizan007@gmail.com; krithika.p@ktr.srmuniv.ac.in**

increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading (Van, 2004). Therefore this investigation provides a comparison of flexural and dynamic behavior between plain concrete and SFRC. The main objective of this research is to identify the changes occurred in the modal parameters due to damage induced to the beams by static loading.

There has been several significant studies carried out to determine the existence and the severity of defects in structures using one or more of their modal properties. Examples are work by (Prasad and Seshu, 2010) who presented results obtained within the framework of the development of a health monitoring system for civil engineering structures, based on the changes of dynamic characteristics. As a part of this research, Reinforced concrete beams were subjected to cyclic loading to introduce damage. After each loading phase, an experimental modal analysis was performed on the beams with the impact hammer to obtain dynamic characteristics. (Lee and Barr, 2004; Prasad and Seshu, 2008) compared fatigue behavior of plain concrete and FRC under the framework of structural health monitoring advancements. They used S-N curves in order to represent true behavior of concrete under fatigue loading. They concluded that the presence of fibres cannot display their true effectiveness under compressive loading, as the mode of failure is different. (Abdul and Choi, 2001) studied the effect of corrosion on the natural frequency and modal damping of reinforced concrete beams mode shapes of the beams. This investigation provided insight on the use of modal parameters to detect damage in structural concrete elements. (Salawu, 1997) used change in frequencies to quantify structural damage. The relationships between frequency changes and structural damage were discussed and various methods proposed for detecting damage using natural frequencies were reviewed. Similarly various authors like (Pandey, *et al.*, 1991; Khazali and Askari, 2011; Ismail, *et al.*, 2011; Lab View version, 2015) researched on damage assessment of structures using various analytical and experimental approaches.

METHODOLOGY

This investigation focuses on the evaluation of stiffness degradation and in turn flexural rigidity of the beam at various load stages using both static load deflection as well as modal analysis techniques.

In order to assess the mechanical properties of concrete, compressive strength and split tensile strength tests were carried out on cube (150 mm × 150 mm × 150 mm) and cylinder specimen (150 × 300 mm) of M50 grade concrete as per (ACI 211 4R_08, 2008) which included hooked end steel fibers of 0%, 0.5%, 1%, 1.5% by weight of concrete.

It was found out that inclusion of 1.5% of steel fibers by weight of concrete increased the 28th day compressive strength and split tensile strength by 18.39% and 10.82% respectively with respect to 0.5%, 1% and conventional M50 grade concrete. The respective results are tabulated in Tables 1 and 2.

To quantify and compare the rate of degradation in addition to normal reinforced concrete beam, one more beam was casted of same dimensions with steel fibers of 1.5% by weight of concrete in the matrix. The stages of pre-crack were identified based on various stages of loading. The formation of cracks reduces the effective stiffness of the beam (Salawu, 1997; Kam and Lee, 1992; Ismail, *et al.*, 2011). At each of these stages, the load deflection behavior and its dynamic characteristics were found from experiment. The natural frequencies so found were used to compute the corresponding stiffness.

Two beams of length 1.6 m, depth 0.23 m and breadth 0.15 m were casted out of which one consisted of conventional M50 concrete and other included hooked end steel fibers of 1.5% proportion. The detailing of RC beam is shown in (Fig. 1).

EXPERIMENTAL INVESTIGATION

An experimental program was carried out to establish

Table 1. Compressive strength values

Particulars	Compressive strength (N/mm^2) @ 28 days
Conventional	46.88
SF0.5	49.33
SF1	45.32
SF1.5	57.45

Table 2. Split tensile strength values

Particulars	Split Tensile strength (N/mm^2) @ 28 days
Conventional	3.79
SF0.5	4.06
SF1	3.98
SF1.5	4.25

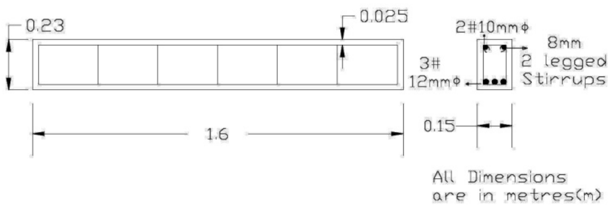

Fig. 1 Reinforcement detailing of R.C. beam.

the relation between damage due to static loads and change of structural dynamic characteristics due to induced damage.

A. Static flexure tests

One-point static flexure test was performed on both two beams; one plain RC beam and other included hooked end steel fibers (1.5% by weight of concrete). The loading was applied at the centre of the beam. The effective span of beam was 1200mm with simply supported end conditions. The beam was mounted on the loading frame and gradual loads were applied using hydraulic jack of 500KN range. Deflections were recorded using deflectometer at every 4KN interval (Fig. 2).

B. Dynamic tests

Modal test were carried out by using transfer function technique on RC beam, which was simply supported. The dynamic measurement was first performed on an undamaged state of the test beams. Excitation points at the distance of 200 mm from the supports at both ends were marked on the top surface of the beams. After every 20 KN load, the loading was stopped and dynamic tests were carried out by striking Impact hammer at the excitation points of the beam. An accelerometer was attached on the top surface of beam which records the free vibrations due to impact. The excitation from the input force was recorded using DAQ analyzer. NI Lab View software package was used to interpret the data in the form of graphical plot (Fig. 3).

The instruments used in the study were an Impact hammer used for exciting the beam, an accelerometer of weight 10 g (DYTRON model 3055B2) and NI DAQ for obtaining amplitude due to vibration. It performs operations like filtering the signals and converting analog signals to digital signals. The obtained data was interpreted using (Lab View, 2015).

RESULTS AND DISCUSSION

The results obtained from the two beams were evaluated. Based on the investigation through load test and modal test conducted on both the beams, the results were compared.

During the static load test, both loading and mid span deflection were recorded. The results obtained such as ultimate strength (Pult in KN) and its corresponding deflection (δ in mm) in static tests are shown in Table 3.

Fig. 2 Load test setup.

Table 3. Static load test values

Beam desg.	Frequency of Loading	Pult (KN)	δ (mm)
NB	4	112	7.24
SFRB	4	120	5.29

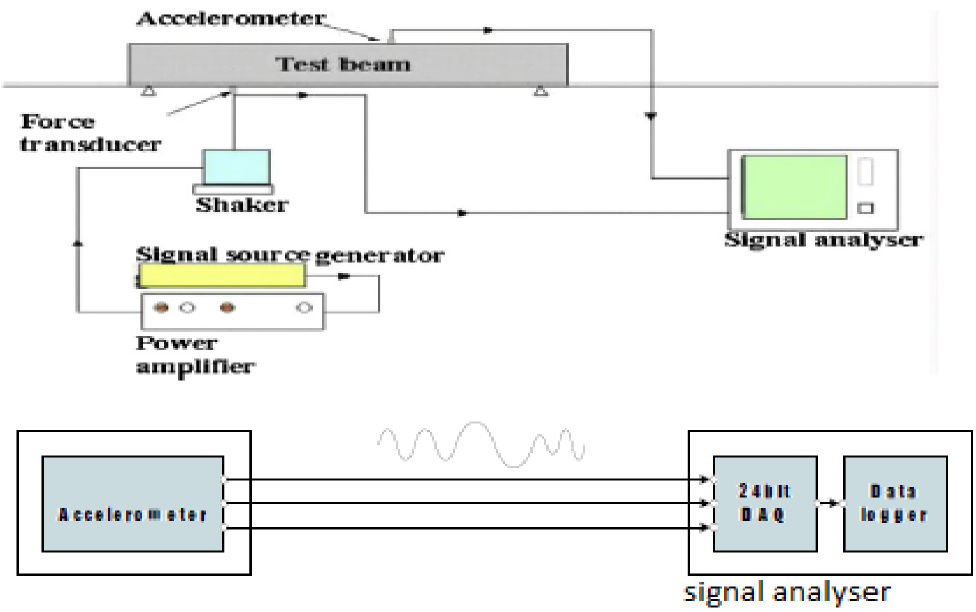

Fig. 3 Modal test set up.

For the record, Plain reinforced concrete beam was designated as NB while Steel fiber reinforced beam was designated as SFRB.

Graphical representation of Deflection vs Load curve is shown in (Fig. 4).

When a system is subjected to certain degree of damage or deterioration, it experiences a change in stiffness (Salawu, 1997; Kam and Lee, 1992; Van, 2004; Ismail, *et al*., 2011). 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 (undamaged beams). The values of natural frequencies for the test beams are tabulated in Table 4 and corresponding graph is plotted in (Fig. 5).

There is a higher decrement in normal reinforced beam as compared to steel fiber reinforced beam. Maximum decrease in natural frequency 16.4% and 10.54% was observed respectively in NB and SFRB from undamaged state to final damaged state.

Assuming the motion in beams as a single degree of freedom (SDOF), the stiffness variable can be calculated using the formula.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Where

f_n = Natural frequency in hertz (cycles/second)
k = Stiffness of the beam (Newtons/meter or N/m)
m = Mass (kg)

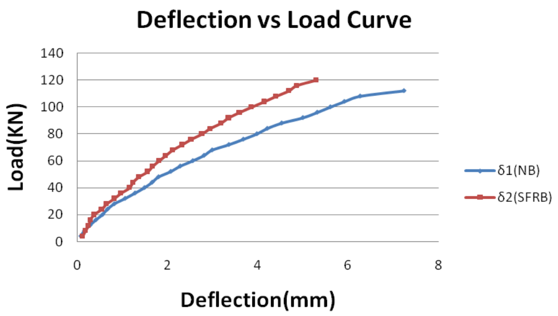

Fig. 4 Deflection vs. load graph.

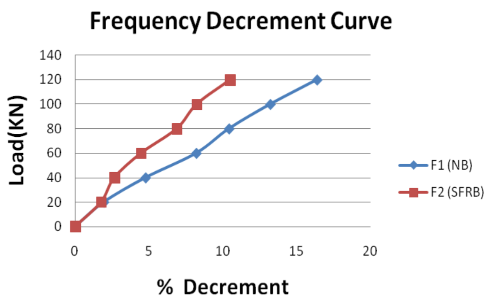

Fig. 5 Load vs. frequency decrement graph.

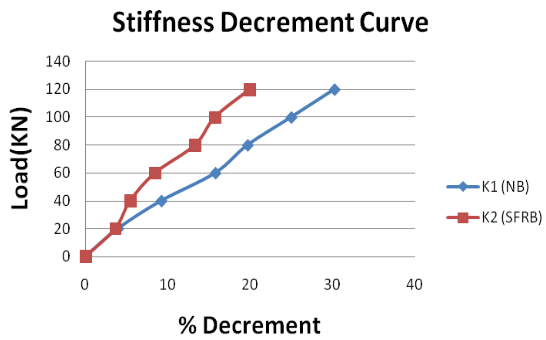

Fig. 6 Load vs. stiffness decrement graph.

Table 4. Modal test values

Load (KN)	Frequency NB (Hz)	Decrease (%)	Frequency SFRB (Hz)	Decrease (%)
0	166	0	173.09	0
20	162.78	1.94	170.03	1.76
40	158.08	4.77	168.47	2.67
60	152.37	8.21	165.32	4.48
80	148.67	10.43	161.09	6.9
100	144.03	13.23	158.78	8.26
120	138.78	16.4	154.83	10.54

Table 5. Stiffness degradation values

Load (KN)	Stiffness NB (N/mm) x10^4	Decrease (%)	Stiffness SFRB (N/mm) x10^4	Decrease (%)
0	15.2	0	16.5	0
20	14.6	3.94	15.9	3.63
40	13.8	9.21	15.6	5.45
60	12.8	15.78	15.1	8.48
80	12.2	19.7	14.3	13.33
100	11.4	25	13.9	15.75
120	10.6	30.26	13.2	20

The changes in the stiffness of the beams can be evaluated by their respective changes in frequencies. The degradation values of stiffness are tabulated in Table 5 and corresponding graphical interpretation is shown in (Fig. 6) (Thomas and Ramaswamy, 2007; Al-Ta, *et al*., 2010).

Maximum stiffness degradation of 30.26% and 20% was observed in NB and SFRB respectively at the failure load. As the effect of damage was more severe in beam NB as compared to beam SFRB, it might be concluded that NB experienced a greater loss in bending stiffness and hence bigger drop in natural frequencies.

CONCLUSION

Based on the experimental investigation, it can be concluded that, with the increase in the damage level on the beams, the natural frequency decreases and subsequently the stiffness factor of the beams also deteriorates. In successive damage states the percentage decrease in Natural frequency and stiffness is higher in plain reinforced concrete beam as compared to Steel fiber reinforced beam. Maximum decrease in natural frequency, 16.4% and 10.54% was observed respectively in NB and SFRB from undamaged state to final damaged state. Similarly, stiffness degradation of 30.26% and 20% was observed in NB and SFRB respectively.

ACKNOWLEDGMENTS

First author would like to extend their sincere thanks to SRMU for providing the platform to facilitate the work. Also to Dr. K.S. Satyanarayanan (HOD Civil Engg. Department,SRMU), and Dr. P. Kannan rajan (Professor, Civil Engg. Dept., SRMU) for their constant support and cooperation.

REFERENCES

Abdul, R.H. and Choi, F.C. (2001). The effect of corrosion on the natural frequency and modal damping of reinforced concrete beams. *Engineering Structures*. 23 : 1126-1233.

ACI 211 4R_08. (2008). Guide for selecting proportions for high strength concrete using Portland cement and other cementitious materials. American Concrete Institute.

Al-Khazali, H.A.H. and Askari, M.R. (2011). Experimental technique to investigate vibration monitoring in revolving structures using oscilloscopic/modal testing. *International Journal of Engineering Science and Technology (IJEST)*. 3 : 7799- 7814.

Al-Ta, S.A., Abdalkader, Mohammed A.A.S. and Majid, A. (2010). Nonlinear three-dimensional finite element analysis of steel fiber reinforced concrete deep beam. *The Iraqi Journal for Mechanical – and Materials Engineering*.

Ismail, Z. (2011). Crack damage detection of reinforced concrete beams using local stiffness indicator. *Scientific Research and Essays*. 6(34) : 6798-6803.

Kam, T.Y. and Lee, T.Y. (1992). Detection of cracks in structures using modal test data. *Eng.Fract. Mech*. 42(2) : 381-387.

Lab View version. (2015). Software Package 1. National Instruments.

Lee, M.K. and Barr, B.I.G. (2004). An overview of the fatigue behaviour of plain and fibre reinforced concrete. *Cement and Concrete Composites*. 26 : 299-305.

Pandey, A.K., Biswas, M. and Suman, M.M. (1991). Damage detection from changes in curvature mode shapes. *Journal of Sound and Vibration*. 2 : 321-32.

Prasad, D.R. and Seshu, D.R. (2008). A study on dynamic characteristics of structural materials using modal analysis. *Asian Journal of Civil Engineering (Building and Housing)*. 9 : 141-152.

Prasad, D.R. and Seshu, D.R. (2010). Study on change in modal parameters of R.C. beams due to fatigue type damage. *Asian Journal of Civil Engineering (Building and Housing)*. 11 : 521-532.

Salawu, O. (1997). Detection of structural damage through changes in frequency: A review. *Engineering Structures*. 19 : 718-723.

Thomas, J. and Ramaswamy, A. (2007). Mechanical properties of steel fiber-reinforced concrete. *Journal of Materials in Civil Engineering © ASCE*. 392.

Van, C.N. (2004). Steel fiber reinforced concrete. Faculty of Civil Engineering, Ho Chi Minh City University of Technology. Seminar Material. 108-116.