LITERATURE ANALYSIS OF STATIC AND DYNAMIC BEHAVIOR OF STRUCTURE: A STUDY

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Abstract- In the design of concrete structures, an adequate margin of safety must be provided against any mode of failure that might occur under the forces that act on the structure during its lifetime. In a well-designed system, a localized failure should not cause immediate or even progressive collapse of an entire structure. A deficient structure have to be evaluated at Micro and Macro level Dynamic characteristics (frequencies, mode shapes and damping) have to be exactly evaluated from the vibration measurements and should be used for assessment of deficient and engineered RC structural components.

Keywords- Concrete Structure, Deficient Members, Static and Dynamic Behavior, Vibration Characteristics

I. INTRODUCTION

Reinforced concrete structures are often leads to failure because of loss of structural capacity of the members. Structural failure refers to the loss of structural integrity, which is the loss of the load-carrying capacity of a component or member within a structure, or of the structure itself. Structural failure is initiated when the material is stressed to its strength limit, thus causing fracture or excessive deformations. In a well-designed system, a localized failure should not cause immediate or even progressive collapse of the entire structure. Ultimate failure strength is one of the limit states that must be accounted for in structural engineering and structural design. A structure may be shear deficient, flexural deficient or torsional deficient. Accordingly, suitable retrofitting and up-gradation techniques have to be applied in order to strengthen them. Various factors affect the deterioration of structural member, depending on the type of loading and other conditions to which it is subjected. The behavior of structural members subjected to static loading, for instance will be very different from that subjected to fatigue or dynamic loading. While members subjected to static loading exhibit gradual deterioration, those subjected to fatigue loading indicate three definite stages of deterioration, namely, an initial damage phase, a steady-state damage accumulation state and a final damage phase.

The aim of the present study is to investigate and improve the understanding of the static and dynamic behavior of structurally deficient reinforced concrete structural components by doing vibration NDT (Non Destructive Tests).

II. VIBRATION CHARACTERISTICS

The vibrations have two categories linear and non linear.

Linear:

The vibration measurements to detect damage were proposed by Cawley and Adams (1979) [1]. It indicates that damage will reduce the local stiffness of the structure, which in turn reduces the natural frequencies of the whole structure. To detect damage changes, most studies use vibration measurements in modal properties and assume that these properties were linear, and were not related to the amplitude of oscillation. The types of indicators can be split into several main groups, each of which is briefly described below with some examples of their application. Idea of few more vibration damage detection methods were given by Doebling et al. (1998) [2] and Salawu (1976)[3],[4].

Maguire and Severn (1987)[5] conducted tests on four simply-supported pre-cast post-tensioned concrete bridge beams with a span of 27.6 m. When the cover concrete was removed, exposing the pre-stressing tendons, they reported a drop in frequency, but the changes were very small (in the order of 2%) and comparable to their frequency resolution. So, proper results cannot be derived with small changes.

Salawu (1997) [6],[7] conducted tests on a concrete bridge before and after the support bearings had been replaced and reported an average change in frequency of only 1.7% for the first six modes of vibration. which is also small. Thus, number of experiment has to be increased in order to achieve perfect co- relation.

Most of the work on mode shapes has concentrated on looking at the Modal Assurance Criterion (MAC) or Co-Ordinate Modal Assurance Criterion (COMAC). This compares the damaged mode shape for mode j against the undamaged reference mode shape for mode k, for all the modes j and k measured, and produces a correlation value between each damaged mode shape and each reference mode shape. For an undamaged structure, it would be expected that for all j

= k the MAC is 1 and for all $j \neq k$, it is 0. COMAC is an extension to the MAC. It is intended to identify the location where two sets of mode shape data disagree and hence to find the location of the damage.

V. Srinivas et. al. (2007) [8] formulated functions using the changes in frequencies and mode shapes and damage detection process has been carried out using genetic search algorithm. Stiffness reduction factors have been used as the parameters for identification of the damage and its localization. It was observed that the methodology of damage detection based on genetic search procedure using frequency and MAC values was capable of identifying the damage with good accuracy.

Salawu and Williams (1997) [6],[7] reported some success when using mode shape data taken before and after repairs to a reinforced concrete bridge. They reported that the MAC values indicated some damage and the COMAC indicated four locations for damage, of which two were correct and two incorrect once a suitable threshold value for damage had been selected, although nothing could be concluded from inspection of the mode shapes directly. Also, third actual damage site was not detected.

On the contrary, Das et al. (1997) [9] found that for lower modes the change in MAC number was extremely small, the greatest difference being when the damage was very localised, i.e. at first cracking and at the point where the steel first yielded by conducting tests on reinforced concrete beams damaged by static four-point loading and. They also found that when the damage became more uniform the mode shape returned to a similar one to its undamaged state.

This method of detecting damage was extended by Ratcliffe (1997) [10], who proposed a method of studying the curvature of only the damaged beam rather than those of both the damaged and undamaged beams. The method uses the Laplace operator to estimate the change in slope of the beam from the mode shape. The presence of severe damage was detectable in the form of a noticeable step in the Laplacian. For less severe damage, the effect on the Laplacian was less obvious and a comparison between the Laplacian at each point and a cubic fit to the Laplacian using the two points either side of the point in question was suggested. The method was reasonably successful in predicting damage location in a steel beam.

Maeck et al. (1999) [11] extended the use of curvature to detect damage by using it to calculate the local beam Stiffness. A smoothed version of the curvature was calculated from the mode shape data then the stiffness was calculated using the curvature and the moment distribution along the beam (which may be derived using the mode shapes). Maeck et al. (2000) looked at using this method along with changes in natural frequency firstly to establish the state of a concrete beam and then to locate any damage that was present. The method was reasonably successful for a distributed damage region. It does, however, require a dense measurement grid and an accurate undamaged stiffness profile. Raghavendrachar and Aktan (1992) [12] also calculated Flexibility using the mode shapes and concluded that it was a superior indicator to examining the raw mode shape data. They noted that higher modes would reveal local damage but that these higher modes would be difficult to identify experimentally on an aged bridge.

As per Farrar CR (2007), Most of the techniques that have been developed for the analysis of both linear and nonlinear systems pre-suppose that the acquired data were observations of a stationary random process. This assumption was useful to invoke because it can greatly simplify the estimation of quantities relevant to system identification. The difficulty, of course, was identifying when it was appropriate to treat the data as stationary. Additionally, the practitioner must also discern whether the data were produced by a linear or nonlinear system. Distinguishing among these categories (linear/nonlinear, stationary/ non-stationary) was a challenging problem that does not admit a simple nonparametric (data driven) solution.

Thus, looking for changes in Natural Frequency is a very insensitive method of detecting damage is clear from the above literature.

Nonlinear:
Little has been done to investigate nonlinear time dependent vibration properties of civil engineering structures in contrast to the vast quantity of work reported on linear damage detection techniques.

Potential use of the non-linear behaviour of a breathing crack in detecting the existence of the crack was demonstrated by the Sundermeyer and Weaver (1995) [14]. They used a model with a bilinear spring representing the crack to show that, in theory, for a beam that is excited at two frequencies simultaneously the steady state signal consists not only of the two driving frequencies, as expected, but also of a component at a frequency equal to the difference between the two driving frequencies. This was thought to be due to the bilinear stiffness properties of the spring. They concluded that this additional frequency component could be a useful indicator of bilinear behaviour that resulted from damage.

Pugno et al. (2000) [15] developed a method of calculating the response of a beam with several breathing fatigue cracks to periodic excitation. The method used harmonic balancing to calculate the

frequency components of the response. They concluded that the non-linear dynamic behaviour leads to the presence of super-harmonics in the response spectrum which could in theory be used to detect damage. A super-harmonic is a harmonic which is at a frequency that is an integer multiple of one of the modal frequencies and results from the motion not being perfectly sinusoidal but taking the form of a distorted sinusoid at the same frequency. This was demonstrated by Bovsunovsky and Matveev (2000) who conducted experiments on and modelled a steel beam with a fatigue crack. They presented experimental data comparing the sinusoidal vibration of the uncracked beam to the periodic vibration at a slightly lower frequency of the cracked beam, which takes the shape of a distorted sinusoid. They then investigated how the amplitudes of the super-harmonics changed with damage. Tsyfansky and Beresnevich (2000) also made use of super-harmonics to detect cracks. They conducted forced vibration tests on aircraft wings. To ensure that any cracks present opened and closed during the test the wing was supported close to its tip to counteract the effects of self weight. Without this support cracks on the upper surface would act as notches remaining open throughout the vibration tests and cracks in the lower surface would remain closed unless the vibration test was of very high amplitude. They concluded that, with this support condition, fatigue cracks lead to excitation of super-harmonics. Their work stressed the important point that nonlinearities due to fatigue cracks will only be present if the fatigue crack is opening and closing during the excitation.

Rivola and White (1998) [16] investigated the possibility of using the auto bispectrum to detect non-linearities in a bilinear system using a simple model. The auto bispectrum detects coherence between the phases of the signal at different resonant frequencies. If a non-linearity is present there will be some relationship between the phases causing a peak in the auto-bispectrum (see, for example, Nikias and Petropulu 1990 [17] or Collis et al. 1998). They concluded that the auto-bispectrum was more sensitive to changes in behaviour than the power spectral density, but it was far more difficult to interpret. Worden and Tomlinson (2001) also used the auto-bispectrum to analyse a non-linear three degree of freedom model.

Neild SA (2002) [18] presented the possibility of using changes in the nonlinear vibration characteristics to detect damage in reinforced concrete elements. The nonlinearities were detected by examining the changes in the fundamental frequency during the decay of an impulse response with time and hence, with amplitude of vibration. The tests demonstrated that there is a change in nonlinear vibration behavior with damage. The change is greatest at low levels of damage. After the beam has been loaded to 27% of the failure load in three-point bending there is a reversal in the trend and a slight reduction in nonlinearity with further damage. These results indicate that the method is unlikely to be useful in detecting high levels of damage in reinforced concrete bridges, however, it is capable of detecting low levels of damage not visible to the naked eye, and so has potential for assessment of special structures where very high levels of structural integrity were required.

Chen G, Yang X, Ying X, et al. (2009) [19] proposed new indicator to detect induced damage in reinforced concrete (RC) beams, based on the transient characteristics of nonlinear vibration. Numerical results and test data showed that the indicator rapidly increases with the severity of damage and were very sensitive to cracking even under service loads. Experimental test results also showed that the fundamental natural frequency of the strengthened beam suddenly decreases at the initiation of cracking and then remains nearly constant while natural frequency of the unstrengthened beam decreases continuously as the beam experiences concrete cracking and reinforcement yielding.

V. Srinivas et. al. (2009) [20] carried out on damage identification methods using model-and nonmodel-based approaches have been presented describing their effectiveness in identification, localisation and quantification of damage. Usefulness of different parameters such as change in frequency, mode shape, modal curvature and strain energy for detection of damage has been studied. Their efforts were appreciable but results did not show proper quantification of damage.

The effect of random variation in composite material properties on the reliability of structural damage detection was addressed by P. Gayathri and R. Ganguli (2011) [21]. Matrix crack induced delamination was emphasized, thresholds for the damage accumulation were found using finite element simulations so that the structure can be subjected to inspections and removed from service safely. Uncertainty effects of composite material properties on the response of the structure were quantified using Monte Carlo simulations. Vibration modes which were robust damage indicators for fixed and simply supported plates were identified.

Damage assessment studies have been carried out by V. Srinivas et. al. (2012) [22] on a reinforced concrete beam by evaluating the changes in vibration characteristics with the changes in damage levels. Structural damage is introduced by static load applied through a hydraulic jack. After each stage of damage, vibration testing was performed and system parameters were evaluated from the measured acceleration and displacement responses. Reduction in fundamental frequencies in first three modes was observed for different levels of damage. It was found

that a consistent decrease in fundamental frequency with increase in damage magnitude.

M. Peeters et. al. (2011) [23] realized that nonlinearity is a frequent occurrence in engineering structures and that linear Experimental Modal Analysis (EMA) is of limited usefulness in this context; an attempt to develop nonlinear EMA by targeting the extraction of Nonlinear Normal Modes (NNMs) from time series of nonlinear mechanical systems. Based on a nonlinear extension of phase resonance testing, the proposed methodology excites the structure to isolate a single NNM during the experiments. Because of the invariance principle, the energy dependence of that nonlinearmode (i.e., the NNM modal curves and their oscillation frequencies) can be extracted from the resulting free decay response using time–frequency analysis. Rand RH (2005) [24] also suggested phase plane theory and K. K. F. WONG (2011) [25] suggested applications in the same regards.

Wei Fan and Pizhong Qiao (2011) [26] presented damage identification algorithms in terms of signal processing. They classified damage identification methods into four major categories: natural frequency-based methods, mode shape-based methods, curvature mode shape-based methods, and methods using both mode shapes and frequencies, and their merits and drawbacks were discussed. They observed that most mode shape-based and curvature mode shape-based methods only focus on damage localization. In order to precisely locate the damage, the mode shape-based methods have to rely on optimization algorithms or signal processing techniques; while the curvature mode shape-based methods were in general a very effective type of damage localization algorithms. As an implementation, a comparative study of five extensively-used damage detection algorithms for beam-type structures is conducted to evaluate and demonstrate the validity and effectiveness of the signal processing algorithms. V. Srinivas et al. (2013) [27], found that resolution of modal responses in the case of burst random is much better when compared to true random excitation. The excitation type and force levels were found to have considerable influence on vibration characteristics. It is opined that judicious selection in using the type of excitation, level of excitation force plays important role especially when evaluating the vibration characteristics of reinforced concrete structures for damage assessment. P. Reynolds (2008) [28] also tried field testing models and was successful in some areas. A one-dimensional second gradient damage continuum theory was presented within the framework of the variational approach by Luca Placidi (2013) [29]. The action was intended to depend not only with respect to the first gradient of the displacement field and to a scalar damage field, but also to the field of the second gradient of the displacement. Constitutive prescriptions of the stiffness (the constitutive function in front of the squared first gradient term in the action functional) and of the microstructural material length (i.e., the square of the constitutive function in front of the squared second gradient term in the action functional) were prescribed in terms of the scalar damage parameter. At a given value of the damage parameter, the behavior was referred to second gradient linear elastic material. However, the damage evolution makes the model not only nonlinear but also inelastic. The damage identification studies were carried out based on the dynamic properties of the structure such as frequencies, mode shapes and their derivatives and also using advanced techniques such as neural networks and genetic algorithms. The effectiveness of these methods and usefulness of different parameters such as change in frequency, mode shape, modal curvature and strain energy for identification, localisation and quantification of damage were presented by K. Ramanjaneyulu, V. Srinivas and Saptarshi Sasmal (2013) [30].

V. Srinivas et. al. (2014) [31] carried investigations out on the phenomena associated with non-linear vibration, which were observed during the vibration tests on damaged reinforced concrete structures. Damage indicators based on basic signal statistics and non-linearity in vibration responses were evaluated. Using the phase-plane information obtained from various damage scenarios, non-linear damage indices have been formulated. Another significant non-linear damage feature has been identified by the occurrence of higher harmonics observed by analysing the spectral density functions obtained from the frequency domain decomposition.

CONCLUSION

There has been much work published in recent years on the use of vibration characteristics to evaluate and assess the performance of RC structures. It is observed that, development of an efficient procedure for non-destructive structural performance evaluation is of utmost importance in order to assess the integrity and serviceability of existing structures. here, it is aimed to develop experimental modal analysis procedures for assessment of structurally deficient RC structural components by investigating the vibration characteristics at different levels of structural deficiencies. Dynamic characteristics (frequencies, mode shapes and damping) have to be exactly evaluated from the vibration measurements and should be used for assessment of deficient and engineered RC structural components at Micro and Macro level co relations. Further, numerical investigations are also being carried out by simulating the structurally deficient RC members using nonlinear finite element analysis with appropriate constitutive material properties. For this purpose, a finite element analysis software, Abaqus is being used to carry out nonlinear

analysis up to the ultimate load level. Correlation studies between analytical and experimental results and parameter studies havebeen conducted with the objective to establish the validity of the proposed strengthening strategies and identify the significance of various effects on the local and global static and vibration response of reinforced concrete members. The aimed work is on the verge of completion. Author thanks Dr. Pradeep Ramancharala, IIIT Hyderabad, India and Dr. V Srinivas, SERC-CSIR, Chennai, India; for continues support in research field.

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