



Influence of pretension in Identification of Cracks in Rebars Using Mode Shape Techniques

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Abstract: *Structural Health Monitoring is the need of the hour with the increase in adulteration of the construction materials, atmospheric pollution etc. apart from the structural distress the structures undergo due natural calamities like earth quakes, cyclones accompanied with high velocity winds Etc. As a result Condition assessment technique plays a vital role in the damage detection, assessment of the life of the structure, to ensure the durability of the structures, retrofitting to be implemented. Poor structural design, Effect of natural calamities lead to unequal settlements of structures which induces, High stress concentrations, Linear Strains especially in the tension members in the concrete structures (Rebar's). In this paper crack damage detection using, Damage Index method, modal flexibility and modal curvature methods on pretension Rebar's are discussed and the difference in the modal frequency between Intact and cracked pretension Rebar's is discussed. The location of the crack and its damage are presented through experimental modal analysis and computational analysis software. It can be concluded that these methods effectively correlating with in determining existence of damage and also are able to locate the position of damage for highly tensioned Bars.*

Keywords: *crack damage; Damage Index method, modal curvature; modal flexibility; pretension Rebar's*

I. Introduction

Structural health monitoring is a great potential for augmenting the functionality, serviceability and increased life span of structures .it could contribute ominously to the economy of the nation. The perception of long-term monitoring of civil engineering structures is evolving and it is the need of the hour for cost-effective maintenance of complex structures and the development of new era in structural safety and security

The goal of Structural health monitoring is to diagnose structural damage at the primary possible stage so that human life can be protected. All structures are prone to damage during their service lifetime as a result of normal operations, accidents, deterioration or severe natural events such as earthquakes and storms. Damage assessment attempts to determine whether structural damage has occurred as well as the location and extent of the damage. The information produced by a damage assessment process can play a vital role in the development of economical repair and retrofit programme. Structural health monitoring is gaining high importance in conjunction with damage assessment and safety assessment of structures.

Frequent structural condition monitoring of structures is necessary to ensure that they provide a continued protection. Accurate Condition Assessment of civil engineering structures has become increasingly important. The need for reckonable global damage detection methods that can be applied to complex structures, has led to the development of methods that examine changes in vibration and long term stress characteristics of the structure. Doebling et al (1996) provided an extensive overview of vibration-based detection methods. Those are nondestructive methods based on the fact that structural damage usually causes a decrease in the structural stiffness, which produces changes in the vibration characteristics of the structure. Several methods had been used to determine the location and severity of defects in structures using one or more of their modal properties [Lim , Penny et al. , and Maeck et al.2000]

Conventional assessment procedures usually rely on visual inspection and location-dependent methods. Natural frequencies had been utilized and found to be the most convenient parameter to be used. A method of surveillance of structures through monitoring the characteristics of the natural frequencies and mode shapes as mentioned by [Cowley Javor and Konig and Giegerich 2001]. It was found that the most easily observable change was the reduction in natural frequencies, and most investigators use this feature in one way or Damage is determined through the comparison between the undamaged and the damaged states of the

structure

In recent years, advancement in damage detection techniques based on modal parameters has attracted momentous attention with regards to civil engineering applications. Damage in a structure alters its dynamic characteristics. The change is characterized by changes in the eigen parameters such as natural frequency, damping values and the mode shapes associated with each natural frequency. Damage is identified by comparing the typical dynamic properties of the damaged and undamaged structure. Many algorithms for damage detection have been developed as the outcome of all-encompassing research over the three decades in the field of vibration based damage detection (Doebbling, 1998).

In reinforced concrete structures Rebar's are main structural element apart from concrete which play vital role in taking the major tensile force, cracks on main structural elements can be a major cause of concern since it can lead to structural failure. Thus early crack detection is crucial in order to avoid sudden failure especially when there is the likelihood of overloading on the structure. In general, cracks will cause a reduction in stiffness and correspondingly cause a change in the dynamic parameters like mode shape and its derivatives. Therefore, it is possible to detect the damage location by measuring the change in the mode shape derivatives. There have been significant efforts to detect the location of defects in reinforced concrete structures using one or more modal properties (Maek et al. 2000, Ndambi et al. 2002, Owobami et al. 2003, Ismail et al. 2001, 2006, Perera et al. 2008, Baghiee et al. 2009 and Fayyadh et al. 2011a, 2011b).

II. Methods Of Damage Detection And Location

1. Damage index method[based on strain energy]

The damage index method was developed by Stubbs and Kim (1994) to locate damage in structures given their characteristic mode shapes before and after damage. For a structure that can be represented as a beam, a damage index, β , is developed based on the change in strain energy stored in the structure when it deforms in its particular mode shape. For location j^{th} on the beam this change in the i^{th} mode the damage index β_{ij} was defined as

$$\text{Where } \beta_{ij} = \frac{\left(\int_a^b [\phi_i^{*''}(x)]^2 dx + \int_0^L [\phi_i^{*''}(x)]^2 dx \right) \int_0^L [\phi_i''(x)]^2 dx}{\left(\int_a^b [\phi_i''(x)]^2 dx + \int_0^L [\phi_i''(x)]^2 dx \right) \int_0^L [\phi_i^{*''}(x)]^2 dx}$$

Where $\phi_i''(x)$ and $\phi_i^{*''}(x)$ are the second derivatives of the i^{th} mode corresponding to the undamaged and the damaged structures, respectively. Here, 'a' and 'b' are the limits of a segment of the beam where the damage is being evaluated. L is the length of the beam.

For mode shapes obtained from ambient data, the modes are normalized such that

$$\{\psi_n\}^T \{M\} \{\psi_n\} = 1$$

2. Modal flexibility based method

The pre and post-damage eigenvectors are the basis for damage detection. With the normalized modes to unit mass, Flexibility matrix [F] of the model can be expressed as

$$[F] = [\Omega] \left[\frac{1}{\omega^2} \right] [\Omega^T]$$

Where, $[\Omega]$ = mass normalized modal vectors, $[1/\omega^2]$ = diagonal matrix with reciprocal of the square of natural frequencies. The flexibility matrix is affected by the mode shapes and the natural frequencies. The localized damage reduces the stiffness and increases the flexibility of the structure.

The modal contribution to the flexibility matrix decreases as the frequency increases, so the flexibility matrix converges rapidly with lower modes. Therefore, a good estimate of the flexibility matrix can be approximated with lower modes (Pandey and Biswas, 1994).

The change in flexibility matrix $\Delta[F]$ can be approximated as

$$[\delta F] = [F^*] - [F] = \Delta_{ij}$$

where [F] and [F*] are the flexibility matrices of the intact and the corresponding damaged structure, respectively. $\Delta_{i,j}$ is the i^{th} row and j^{th} column element of matrix $[\delta F]$. The damages result in stiffness reduction and the flexibility increment in the corresponding elements near the damages, especially in the corresponding diagonal elements. The flexibility change vector is defined as (A) can be used to detect and locate damages in structure (Pandey and Biswas, 1994). The location of damage is considered to be at maximum value of Δ .

$$\Delta = [\Delta_{1,1}, \dots, \Delta_{2,2}, \dots, \Delta_{n,n}]^T \quad (A)$$

3.Modal curvature based method

Mode shape curvature (κ) for beam can be estimated numerically from the displacement mode shapes, using central difference approximation (Pandey et al. 1991).

$$\kappa = \varphi_{ji} = \frac{\varphi_{(j+1)i} - 2\varphi_{ji} + \varphi_{(j-1)i}}{l^2}$$

With i being mode shape number, j the node number and l the distance between the nodes. Thus, φ_{ji} is the modal displacement of the coordinate j at mode i .

For a beam with given moment applied to the damaged (shown with *) and undamaged structure, a reduction of stiffness associated with damage will lead to an increase in curvature. Thus the existence and extent of damage can be estimated by measuring the amount of change in the mode shape curvature.

The mode shape curvature criterion may be defined as the difference in absolute curvatures (Δ) of the healthy and damaged structures, for each mode, and may be represented as

$$\Delta = [\kappa^* (x) - \kappa(x)]$$

The value of mode shape curvature is significantly higher at a certain damage location than the ones at other locations. Based on the curvature difference values of measured data of damaged and healthy structures, the location of damage in the structure can be identified. The effect of prestressing force on the tensile member, on above mentioned methods are studies with reference to finite element model of Rebar of $\phi 12\text{mm}$, length 500mm {Link8(Ansys Nomenclature) element is used to model steel reinforcement. It is developed using ANSYS 15. as shown in Figure 1(a). The Rebar is divided into 200 elements along the length and rebar was cracked at 75mm from fixed end to increase the accuracy and decrease computation time, as shown in figure below

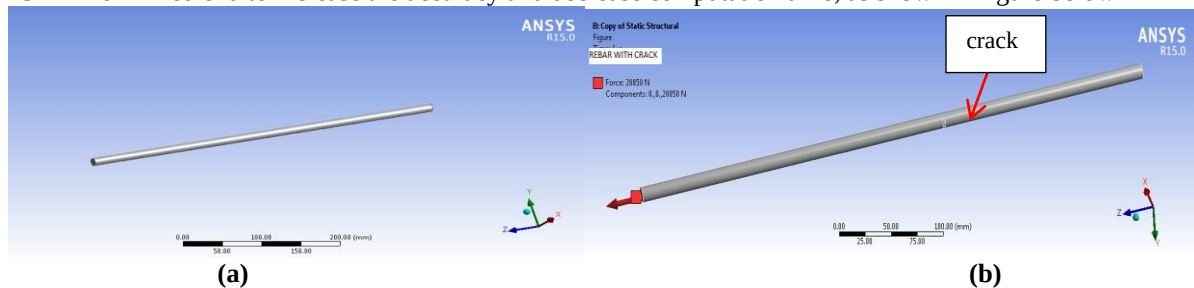
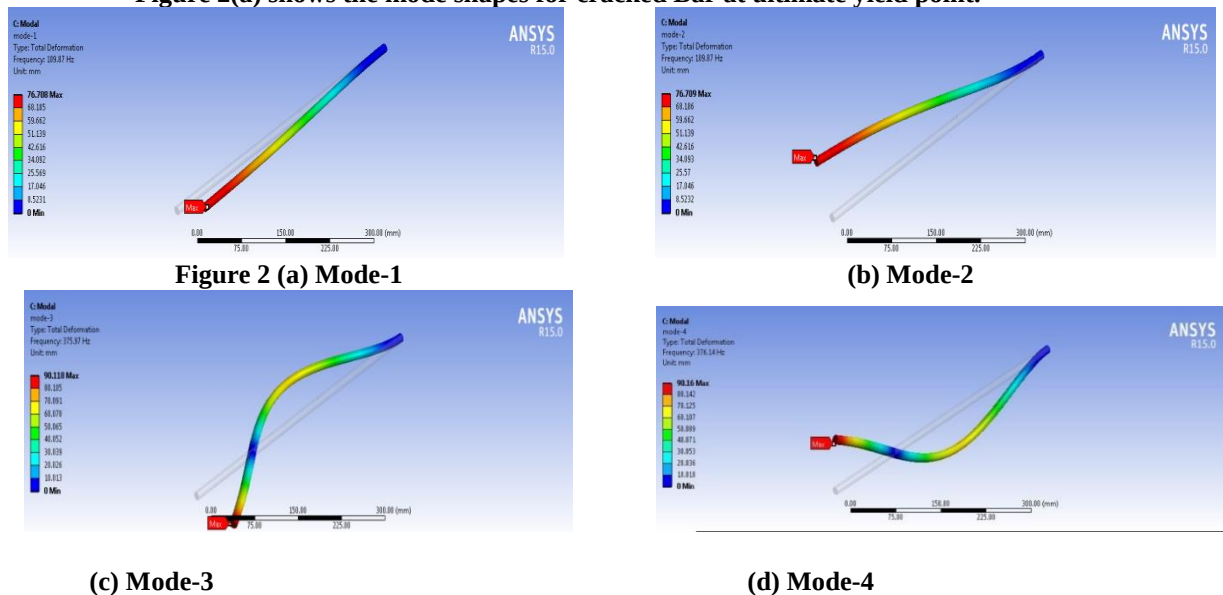
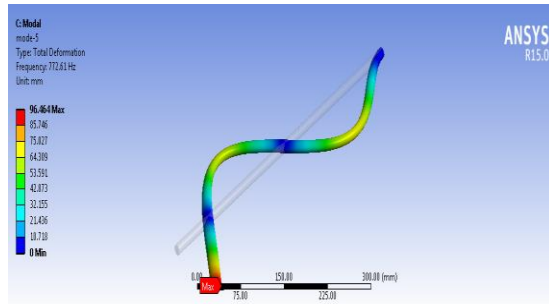


Figure 1 (a) Ansys model of Rebar [$\phi 12\text{mm}$, length 500mm]
Figure 1 (b) Ansys model of Rebar [with 2x2mm crack at 75 mm from fixed end]

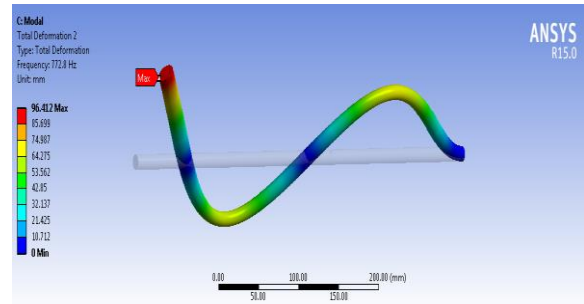
The material properties for the steel, yield strength considered as 410 MPa and density 7850 kg/m^3 , Modulus of elasticity as 205 GPa. The fixed boundary condition has been considered at the first bottom node.

Figure 2(a) shows the mode shapes for cracked Bar at ultimate yield point.





(e) Mode-5



(f) Mode-6

Table 1. Showing the undamaged and Damaged rebar Natural Frequencies considered in the present study

12mm dia bar Intact(undamaged)								
pretension force (N)	max tensile stress(Mpa)	Location in the Stress strain graph	Natural Frequencies obtained(Hz)					
			Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
17000	202.6	Yeild zone	89.737	89.738	322.63	322.63	706.08	706.10
18000	214.16	Yeild zone	91.677	91.677	327.66	327.66	712.13	712.14
19000	226.06	Yeild zone	93.562	93.563	332.58	332.58	718.13	718.13
20000	237.96	Yeild zone	95.399	95.4	337.41	337.41	724.06	724.06
21000	249.85	yeild point	97.19	97.191	342.15	342.15	729.94	729.96
22000	261.75	plastic region	98.939	98.94	346.8	346.8	735.75	735.77
25000	297.45	plastic region	103.96	103.96	360.26	360.27	752.88	752.88
34500	410.25	utimate yeild point	118.15	118.16	399.01	399.02	804.2	804.2
12mm dia bar with crack at 75mm from fixed end(cracked Bar)								
pretension force (N)	max tensile stress (Mpa)	Location in the Stress strain graph	Natural Frequencies obtained(Hz)					
			Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
17000	241.73	Yeild zone	89.678	89.679	322.19	322.37	705.02	705.36
18000	255.94	Yeild zone	91.613	91.614	327.2	327.38	711.03	711.10
19000	270.14	plastic region	93.495	93.495	332.11	332.29	716.98	717.08
20000	284.35	plastic region	95.327	95.327	336.92	337.1	722.87	722.99
21000	298.55	plastic region	97.114	97.114	341.64	341.82	728.7	728.96
22000	312.75	plastic region	98.858	98.859	346.27	346.45	734.48	734.49
25000	355.36	plastic region	103.87	103.87	359.69	359.86	751.48	751.48
28850	410.02	utimate yeild point	109.87	109.87	375.97	376.14	772.61	772.61

III. Results and Discussions

Modal analysis is repeated for intact and damage location with pretension force as per the Table-1 and six natural frequencies and corresponding flexural mode shapes are obtained for the intact and cracked Rebar. Simulated crack damage scenarios represent the study at locations of 75mm from the fixed end of the beam. The modal flexibility change, change in the strain energy and modal curvature difference between the damaged and intact case are obtained by Specific MATLAB based code “DIAMOND” with modal data obtained from finite element analysis using ANSYS 15.0 as input. The Damage index method [based on strain energy], curvature difference and modal flexibility change methods are used to locate the damage.

The natural frequencies obtained from the intact case and typical damaged case with pretension force considered in the present study are listed in Table 1, The natural frequencies have slightly decreased with increase in the pretension as compared to the undamaged case. However, from the changes in the natural frequencies existence of damage can be identified and its location can be predicted. The changes in the flexibility for all modes for typical damage location are plotted in Figure 3 and location of the severe damage can be clearly seen at 425mm (75mm from fixed end); The changes in the modal curvature for all modes for typical damage locations are plotted in Figure 4 and at the location of the severe damage there is differences in the curvature mode shapes and are localized near the damaged zone (15th element from fixed end)

Use of the The Damage index method [based on strain energy] in figure5 (Notice that the pink area (highest indicator level) is around the point of the damage (Node 20, x=0, y=425) also showed the evidence of crack and predicted severe damage case. Change in the flexibility matrix is zero at the supports and increases linearly towards the crack zone of the Rebar. For each damage location, the change in flexibility reaches its maximum at the damaged element. Hence, for the Rebar, the region in which the change in the flexibility matrix is maximum is the damaged region. The change in the flexibility, strain energy and modal curvature matrix is larger for the damages located at 75mm from the fixed end of the beam than near the supports. Figure-6 gives the modal assurance criteria (MAC) between the undamaged and damaged data sets. This plot gives insight as to which modes exhibit the largest change as a result of damage. This knowledge is helpful in selecting which modes to

use for the damage identification techniques. Figure-7 gives the COMAC which is similar to the MAC, but is spatially referenced to each degree of freedom. A lower COMAC indicates areas of discrepancy between the undamaged and damaged mode sets. In this case, the lowest values of COMAC appear at the 100mm, which is near the damage location. COMAC Location of the damage Using Strain energy method. The modal assurance criteria (MAC). Indicating areas of discrepancy

IV. Conclusions

Use of Damage index method, modal curvature and flexibility difference are reliable methods to detect crack damage in pretension Rebar models. The numerical results demonstrate the effectiveness of methods and use of the Tool “DIAMOND” in locating damage in Pretension Rebar’s which is real time scenario of the rebar in the concrete. The Damage index method, modal curvature and flexibility difference, can detect the location of crack even when the rebar are in pretension condition. Hence these methods can be effectively applied in the pretension condition.

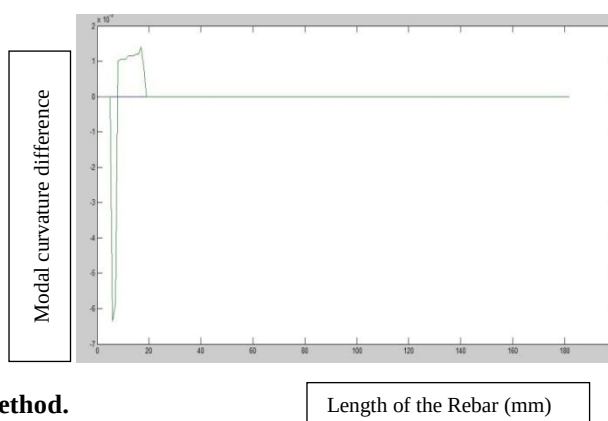
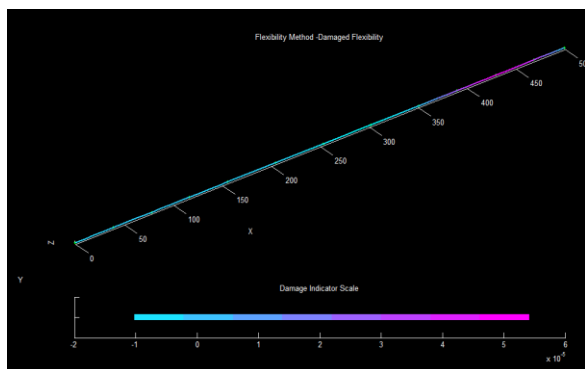


Figure 3 Location of damaged Part using flexibility method.

Figure 4 Location of damaged Node using Modal Curvature Difference method

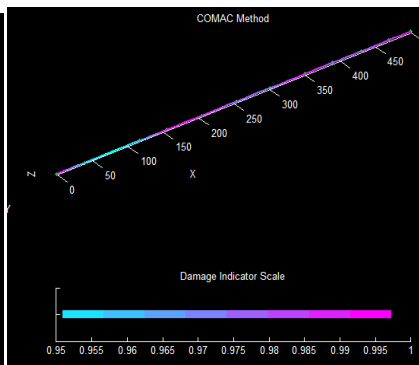
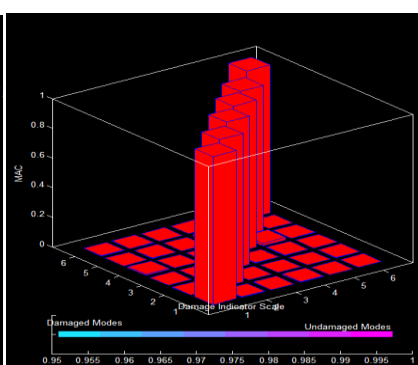
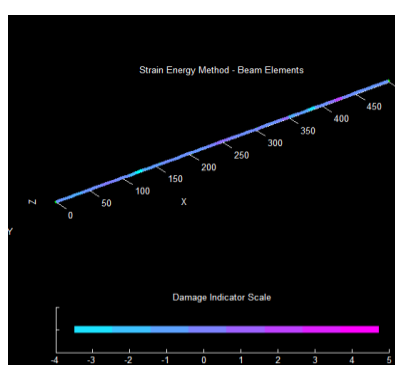


Figure 5

Figure 6
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Figure 7

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