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Damage Assessement of Structure's Based on Wavelet Technique

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ABSTRACT

The paper presents the application of Wavelet analysis technique for crack identification in a reinforced concrete beam with transverse loading. Damage is assumed to occur due to the loss of stiffness in the member. Damage was simulated in the finite element model of the beam by reducing the flexural rigidity (EI) in some selected elements at different locations. The beam was analyzed for different loading conditions and open crack was introduced in the beam at different locations to assess the damage. The beam was analyzed using two dimensional and three dimensional models in FEM to obtain the deflection and curvature profiles under various loading conditions. Displacement and moment curvature obtained from the finite element analysis under undamaged and damaged conditions were analyzed using wavelet analysis technique to identify the damaged elements. Different types of wavelets were studied for their usefulness and efficiency in identifying the damage, Based on the studies, it is observed that the wavelet analysis technique is very effective in identifying the damage even using the static response measurements.

KEYWORDS:

INTRODUCTION

Detection and identification of structural damage is a vital part of the monitoring and maintenance of structural systems during their lifetime. Structural damage in normal lifetime may include corrosion, fatigue, ageing or even impact of natural forces. Future intelligent structures would demand high strength performance, structural safety, integrity and low maintenance cost. To meet these challenges, structural health monitoring has emerged as a reliable, efficient and economical approach to make a diagnosis to the structural health conditions and to make maintenance decision. The objective of the detection and identification of structural damage is to construct a qualitative or quantitative description of the deterioration in the system. Cracks in the structural elements cause some local variation in the stiffness that affect the static behavior of the structure considerably. Methods allowing an early detection and identification of cracks have been the subject of intensive investigation for the past two decades.

Many methods were proposed by several researchers by which the damage could be detected by finding the changes in the structural parameters. Some of the recent tools and trends for the damage detection include wavelet theory, simulation verification using modal data, spatial wavelet packet signature analysis and single input – single output measurements. In this paper, effort has been made to identify damage on structural damage in structural elements such as beams using the discrete wavelet transforms.

They studied Bridge Integrity assessment. The continuous wavelets were used for detecting the damage of existing bridges. A simply supported beam and a three-span concrete bridge were used for analysis. This paper underlines the high sensitivity of the wavelet analysis to damage intensity and its ability to apply directly to the

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damaged data [4]. They moving load and pre-stress identification using wavelet. Based on finite element and wavelet based method, they developed a method for identification of moving force and pre-stress, using the strain or acceleration. Identification of crack in a rotor system using wavelet element method was presented by B-spline wavelets used to find out the crack through local stiffness change. Crack identification was solved by surface fitting technique and contour plotting method[5]. Wavelet transformation of mode shape difference function for structural damage location identification. Structural damage was detected using mode shape difference between the reference and damage states [4].

The wavelet based sensitivity analysis of the impulse response function for damage detection. Wavelet based impulse response function was extracted from the acceleration response using the discrete wavelet transform[5]. A 31-bar plane truss structure was used to verify the method with different damages with or without model error and noise effect studied the damage detection of high rise building using pseudospectra, music, and dynamic wavelet neural network[9]. A large structure is divided in to a series of substructures around a few preselected floors where sensors are made. This new model balances the global and local influences of the training data and incorporates the imprecision existing in the sensor data effectively. This methodology was used in 38-storey concrete test model. The wavelet based structural health monitoring of earthquake excited structures. The mode shape information was first extracted from the vibration response data collected during an earthquake by using wavelet packet sifting process. The effectiveness of the approach was illustrated for sudden stiffness loss and progressive stiffness degradation and different base excitation including three real earthquake signals and a random signal Structural damage detection. They used the Wavelet Kurtosis technique. A detailed numerical study was performed for a beam element with an open crack. The first natural mode shape of the beam with an open crack was simulated and static deflected shape was also simulated using vertical static loading. In that Gaussian white noise of different intensities introduced to both mode shape and static deflected shape for locating damage[8]. They studied identification of vehicle axles from bridge measurements using wavelet analysis. Bridge weigh-in-motion was used to determine the weight of vehicles traveling at highway speeds. The transformed signals were used to identify the axle passage and vehicle velocity and axle spacing. The numerically generated strain signals were analyzed by the wavelet transformation to extract axle position information[9].

Wavelet analysis and enhanced damage indicators were studied [10]. A small perturbation in a static or dynamic displacement profile could be captured using multi-resolution wavelet technique. Curvature mode shapes are found to be the improved indicators of damage and these are coupled with wavelet[10]. They studied the experimental wavelet analysis of flexural waves in beams. Wavelets were used for the time frequency analysis. Gabor wavelet is used to decompose a dispersive wave in to each frequency component in the time domain. It determines the traveling time of a wave along the beam at each frequency [11].

II. Wavelet Transform -An Overview:

The basis for the wavelets is Fourier transforms, which breaks down a signal into constituents of different frequencies. The Fourier transforms (Fig-1) convert the signal from a time-based or space-based domain to a frequency-based domain. Unfortunately, in the transformation to the frequency domain, the time or space information is lost and it is impossible to determine when or where a particular event took place. Fourier transforms should thus be used for non-stationary signals, when the interest lies in what spectral components exist in the signal, and not at which locations these occur.

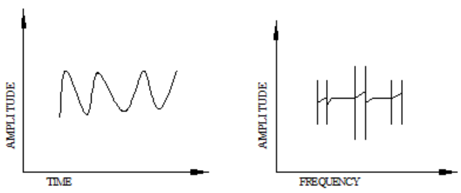

Fig. 1: Fourier Analysis.

To overcome these difficulties, the short-time Fourier transform (STFT) proposed windowing technique which analyzes only a small portion of the signal at a time or space. In the STFT (Fig.2), the signal is divided into small-enough segments, so that these segments of the signals can be assumed to be stationary. For this purpose, a window function, w, is chosen in such a way that its width is equal to the stationary segments of the signal.

The disadvantage of this procedure is that the precision of the time or space and frequency is governed by a unique window size for the entire signal. Therefore, a more flexible method making use of multiple window sizes would be required to determine, with greater precision, any particular features of a signal in time or space as a function of frequency.

The wavelet transform others this flexibility and is therefore perceived as a new way to analyze signals that overcome the drawbacks that other signal processing techniques exhibit. The wavelet analysis is done in a similar way to the STFT analysis, in the sense that the signal is multiplied by a function similar to the window function defined in the STFT, and the transform is computed separately for different segments of the time domain signal.

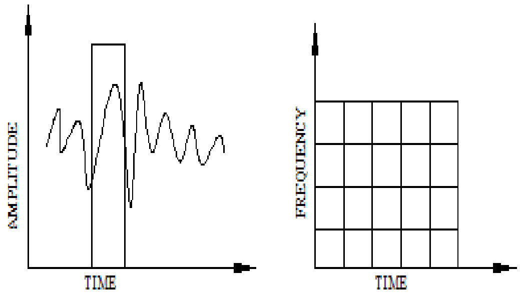

Fig. 2: Short – time Fourier analysis.

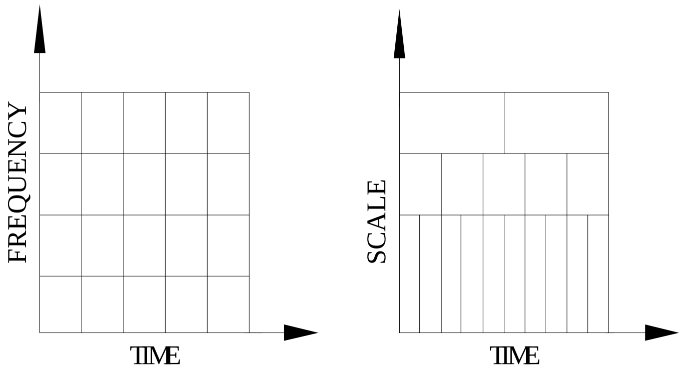

Fig. 3: Wavelet analysis.

The wavelet transform is a mathematical tool which is able to examine a signal simultaneously in time and frequency. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information. Wavelet analysis does not use a time-frequency region, but rather a time-scale region as shown in Fig.3. Based on that, we can find out the location of damage and when it occurred.

A. Concept Of Damage Identification Using Dwts:

The main idea supporting the use of wavelets for structural assessment is based on the fact that structural modifications introduce discontinuities in a structure response. The measured mode shape or deflection of a structure can be treated as a spatially distributed signal. Once a signal or its derivatives is available, it can be analyzed through the wavelet transforms. A sudden change or peak in the analyzed wavelet coefficient may indicate the location of the damage or possible structural medications.

Application Of Wavelets For Damage Assessment Of Structural Components:

The feasibility and performance of the DWTs in damage assessment are examined via a numerical example representing the structure of a simply supported beam .The details of the beam are as given below. All elements were assumed to be made of the same material, with the following characteristics.

Table 1: Max. Deflection for undamaged condition for various load increments.

Sl.No	Load in (Tonne)	Deflection in (mm)
1	1	0.345
2	2	0.689
3	3	1.034
4	4	1.379
5	5	1.724
6	6	2.086
7	7	2.413
8	8	2.758
9	9	3.102
10	10	3.447
11	11	3.792
12	12	4.137
13	13	4.481

Details of Specimen:

Beam length = 3300 mm
C/s of Beam = 300x300 mm
Modulus of elasticity = 28350 N/mm2
Density = 2500e-9 kg/mm3
Poisson ratio = 0.3
Reinforcement used
Bottom : 1 nos of 25 mm dia bar
: 2 nos of 16 mm dia bar
Top : 2 nos of 10 mm dia bar
Stirrups : 8 mm dia bar @ 190 mm c/c
Ultimate load (P) = 13 Tonne

The beam was analyzed to get the deflection and curvature profiles for undamaged and damaged conditions under incremental loads. Their response profiles were analyzed using wavelet analysis tool available in MATLAB

The beam was modeled in a finite element analysis package (ANSYS) to get the response profiles.

The Beam was equally divided into 66 elements (Fig-4)in two-dimensional plane in the ANSYS Environment.:

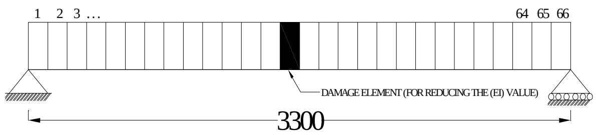

Fig. 4: Finite element model with damage location.

The beam was subjected to a static two point load in increments of 1 KN to ultimate load. The load is applied incrementally in 1 tonne increments. .For each load increment, maximum deflection and deflected shape has been obtained at mid span

A. Damage Simulation in 2-D:

Damage is assumed to occur in 2D due to the loss of stiffness in the member. Damage was simulated in the finite element model of the beam by reducing the flexural rigidity (EI) in some selected elements at different locations. Different damage cases were considered by reducing the flexural rigidity (EI) by 10%, 20%, 30%, 40%, 50%....

For each damage case, the maximum deflection, deflected shape and curvature was obtained.

The maximum deflection obtained is shown in Table – 2

The deflection profile is obtained for different loading conditions and damage parameters. Here, damaged element is at mid-span portion (34^{th} element) and quarter portion (17^{th} element). The deflection values obtained for different percentages of damages are given in Table-3 and 4.The finite element model of the beam and the deflected profile for 50% damaged conditions are shown in Fig. 5-7

Table 2: Deflection for Damaged Condition.

Sl.No	Load in (Tonne)	% Reduction in "I"	Deflection in (mm)
1	1	10	1.732
2	2	20	1.741
3	3	30	1.751
4	4	40	1.766
5	5	50	1.786

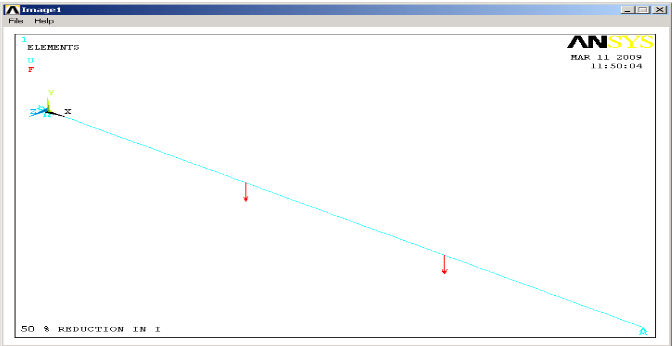

Fig. 5: Modeling of the beam.

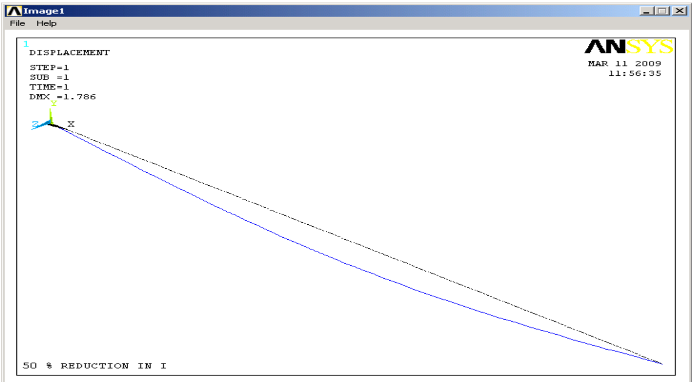

Fig. 6: Deflected shape of the beam.

Table 3: Deflection values along beam length for different % of damage at element -17.

Sl. No.	Load In {T}	% reduce In "I"	Deflection in (mm) for different loading location					
			Center Point	1/3 Distance From Left	1/3 Distance From Right	1/4 Distance From Left	1/4 Distance From Right	Two Point Load 1/3
1	5	10	2.028	1.746	1.744	1.419	1.416	1.728
2	5	20	2.031	1.751	1.746	1.424	1.418	1.731
3	5	30	2.035	1.757	1.749	1.43	1.42	1.735
4	5	40	2.041	1.765	1.752	1.439	1.422	1.741
5	5	50	2.049	1.776	1.756	1.451	1.425	1.748
6	5	60	2.06	1.793	1.765	1.469		
7	5	70	2.079		1.775			
8	5	80						

Table 4: Deflection values along beam length for different % of damage at element-34.

Sl. No.	Load In (T)	% reduce In "I"	Deflection in (mm) for different loading location						
			Center Point	1/3 From Left	1/3 From Right	1/4 From Left	1/4 From Right	Two Point Load at 1/3	Two Point Load 1/4
1	5	10	2.03	1.74	1.74	1.42	1.42	1.73	1.394
2	5	20	2.04	1.75	1.75	1.42	1.42	1.74	1.404
3	5	30	2.06	1.76	1.76	1.43	1.43	1.75	1.412
4	5	40	2.08	1.77	1.78	1.44	1.43	1.76	1.422
5	5	50	2.11	1.79	1.8	1.45	1.45	1.78	2.875
6	5	60	2.15	1.82	1.83	1.47	1.47		1.46
7	5	70	2.23	1.87		1.51	1.51		
8	5	80	2.38			1.58			

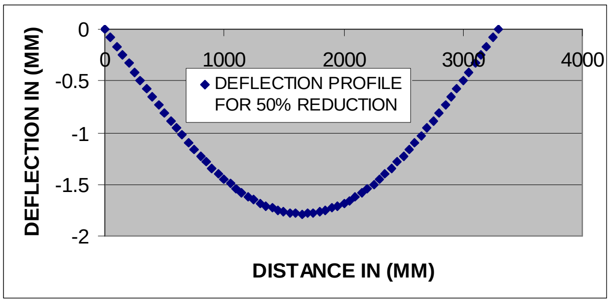

Fig. 7: Deflection profile of the beam.

B. Damage Simulation in 3 –D:

The beam is modeled using 3-D elements are shown in Fig. 9 and crack is introduced in the body of beam to assess the damage by wavelet analysis using displacement curvature.

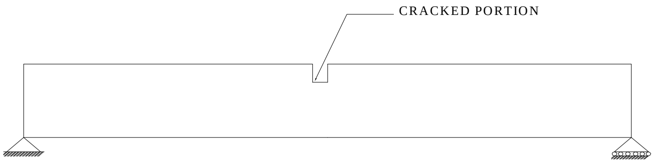

Fig. 8: Damage assessment by making crack.

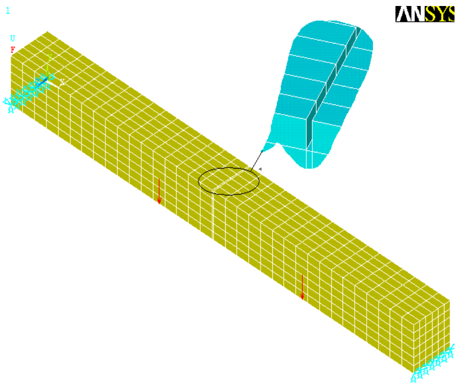

Fig. 9: Modeling of Damaged beam.

The crack is introduced at center of the span. The width and depth of the crack are 50 mm and 150 mm respectively. The deflection profiles are obtained from finite element analysis. The deflection profile is considered for wavelet analysis. The deflected change in shown in Fig. 10 and 11.

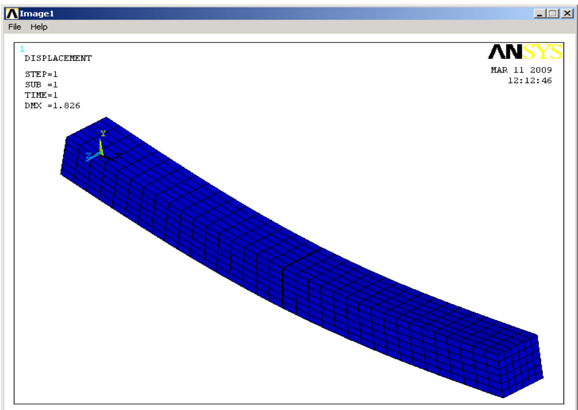

Fig. 10: Deflected shape of the beam.

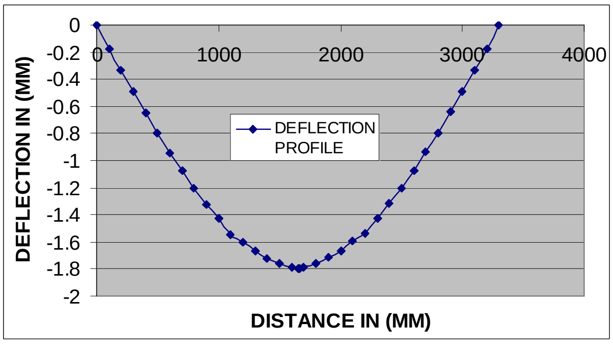

Fig. 11: Deflection profile at center of the cracked beam.

C. Damage assessment using static curvature:

The static curvature is more sensitive to local faults than static displacement. Static curvatures obtained from the deformation of neutral surface which is dependent an bending rigidity (EI) of the member. Fault or cracking in the element, reduces EI which will result in increase of curvature. That is, fault location can be detected by curvature. Basically curvature is constructed by central difference technique using displacement mode shapes as follow

$$V_i'' = (V_{i+1} - 2V_i + V_{i-1}) / h^2$$

Here V_i'' is a curvature of the section, h is the length of the elements, V_i is a displacement of the particular node V_{i-1} is a displacement of the previous node, V_{i+1} is a displacement of next node.

Simply supported beam of uniform cross-section is used in this study. The dimensions of the beam are same as that of used in displacement curvature analysis.

The finite element model for each of the beam consisted of 66 equal length two-dimensional beam elements. Three degrees of freedom, translations along the X and Y axes and rotation about the Z axis, are used at each node in the finite element analysis.

The change in the stiffness due to damage was modeled by reduction in the flexural rigidity (EI) of the section. The degree of damage is then related to the reduction in the moment of inertia, I.

A study was conducted with different percentage reduction like 10%,20%,30%,40%,50%,70%,90% in the moment of inertia in the particular element assess the damage of the structure. The displacement profile and static curvature for 40% reduction in EI at mid span is shown in Fig. 12 and 13 respectively, Fig. 13 clearly shown the damage location. But for small magnitude of damaged it is observed that the damage identification in difficult using curvature.

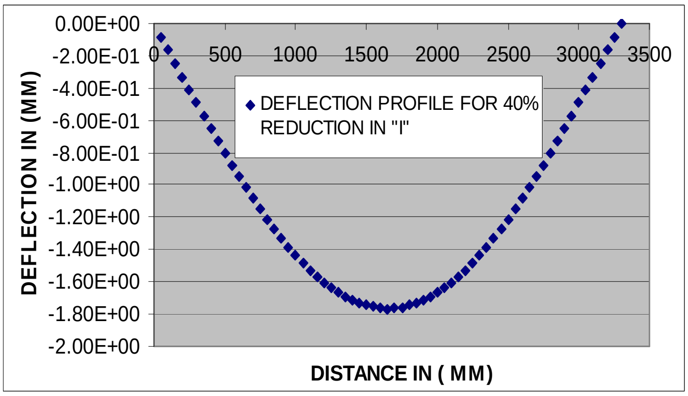

Fig. 12: Displacement profile of the beam.

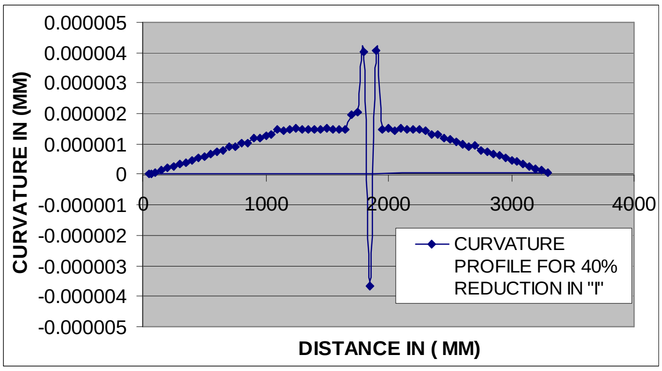

Fig. 13: Static Curvature of the beam.

D. Damage Assessment using Moment Curvature:

Curvature and nodal displacements are related to the flexural stiffness of beam cross-section. Curvature at a point is given by

V" = M/ (EI)

In which v" is the curvature at a section M is the bending moment at a section, E is the modulus of elasticity and I is the second moment of the cross-sectional area.

If a crack or other damage is introduced in structure, it reduces the (EI) of the structure at the cracked section or in the damaged region, which increases the magnitude of curvature at that section of the structure. The changes in the curvature increases with reduction in the value of (EI) and also local in nature and hence can be used to detect and locate a crack or damage in the structure.

The change in the curvature increases with reduction in the value of (EI), therefore the amount of damage can be obtained from the change in curvature. The moment curvature is obtained for 50% damage case and the deflection and curvature profile is shown in Fig. 14 and 15 respectively. This information is found to be not effective in damage identification.

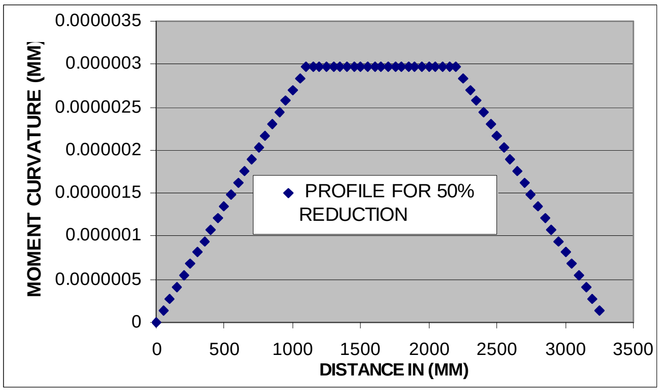

Fig. 14: Displacement Curvature of the beam.

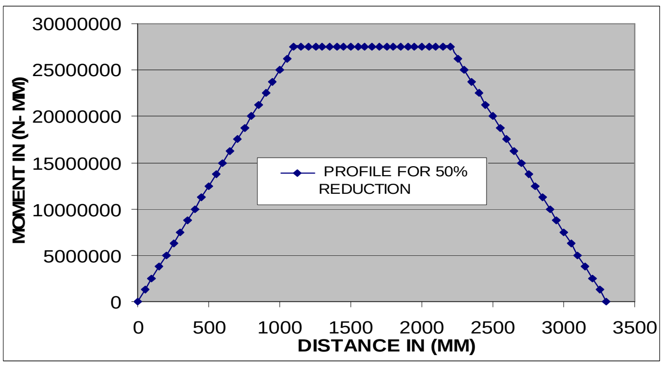

Fig. 15: Moment Curvature of the beam.

E. Damage Assessment using Wavelets:

The wavelet transforms play a major role in identifying the change in simulated curvature results. The displacement curvatures obtained for different damage cases and moment curvatures are analyzed by wavelets. Daubechis and Coiflet family of wavelets, available in MATLAB wavelet tool-box suite are used for the computation of the approximation and details functions. Multiresolution analysis is found to be sufficient to capture the disturbances in the deformation profile. A sudden change or peak in the analyzed wavelet decomposition may indicate the location of the damage or possible structural medications.

Fig – 16 shows the wavelet analysis of deflection profile for 40 percentage reduction in flexural rigidity at the center of the span. In this figure, different levels of decomposition are shown. At midspan shows the clear location of disturbance (crack). In the Figure 'S' is the synthesized signal, 'a' is approximation, and'd' is the details of the wavelet function.

Fig – 17 shows the wavelet analysis of moment curvature for 50 percentage reduction in flexural rigidity. Fig.17 shows disturbance at two locations. Similarly, it is proposed to carry out wavelet analysis of moment curvature profiles for different levels of damage.

Conclusion:

This paper presents the wavelet-based approach for structural health assessment and damage detection. It shows that structural damage or a change in system stiffness can be detected by wavelet analysis of curvature profiles.

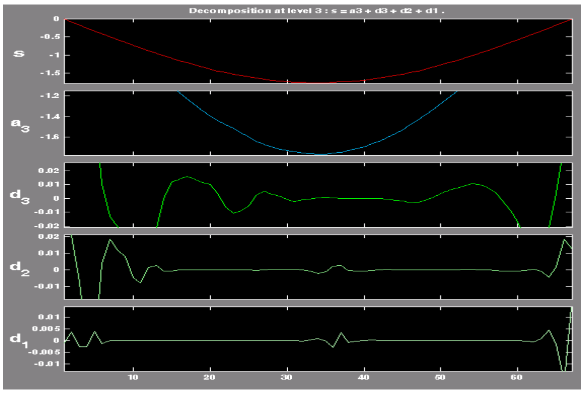

Fig. 16: Wavelet Analysis for 40% percentage reduction in "I".

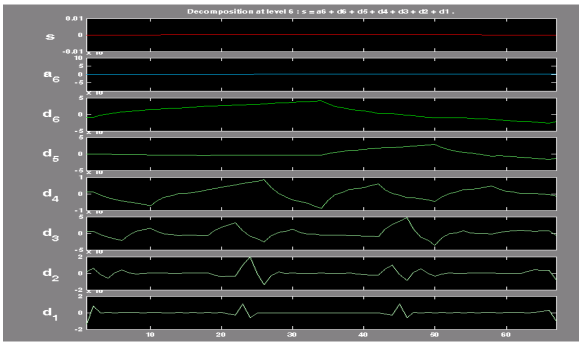

Fig. 17: Wavelet Analysis for Moment curvature in 40% percentage reduction in "I".

The numerical results for the simply supported beam model demonstrate the usefulness of curvatures in detecting and locating a state of damage. It has been shown that changes in the curvature shapes are localized in the region of damage. On the other hand, changes in the displacement curvatures are not localized and, hence, they do not give any indication of the location of the damage. This is a very useful feature of the method since it is much easier and more inexpensive to measure the static response compared to the dynamic one. Another fact that makes the wavelet-based methodology easy to implement in practice is that it can be used for structural monitoring at the expected areas of damage only. All these properties make the method a potentially reliable and cost-effective assessment technique that can be applied to the maintenance of the built infrastructure (bridges, water and gas distribution pipelines, electrical and transmission towers, dams and other hydraulic structures).

The present wavelet analysis has shown that it can detect disturbances and crack positions in structure

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