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Damage Localization in a Beam by Lifting Wavelet Scheme and Photographic based Experimentation

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Abstract

The structures under fatigue loading are fault prone. The damage reduces the local stiffness. This local stiffness leads to a slope discontinuity in the structure's elastic line. Localizing the local discontinuity reveals the location of the damage. Wavelet transform is a powerful tool to localize a local slope discontinuity in a signal. The major challenges in the localization of damage in a beam are obtaining the high spatial resolution beam deflection and eliminating the border distortion. The high spatial resolution shrinks the border distortion as well as gives more localized crack detection. The reduced border distortion leads to the detection of cracks very close to the ends of the beam. In the present work, finite element analysis is used for getting the simulated beam deflection. The lifting wavelet is used for the localization of cracks in the beam. The lifting wavelet has certain advantages over the classical wavelet. The lifting wavelet possesses perfect reconstruction and a narrower border distortion zone. A comparative study is presented between the discrete wavelet transform and the lifting wavelet transform for localizing the crack. The ability of lifting wavelet is tested for different noise conditions and multiple crack localization. A photographic method is used to get the high-resolution of experimental beam deflection of stainless-steel material.

Keywords: *Crack Detection, Discrete Wavelet Transform, Image Edge Detection, Lifting Wavelet, Stainless Steel Beam (SS-304)*

1.0 Introduction

Cracks are unavoidable in structures under fluctuating loading. The presence of cracks changes the dynamics of the structures. These changes in the dynamics are utilized for crack identification. The presence of a crack in beam-like structures leads to changes in modal parameters such as natural frequencies, modal damping, and mode shapes[3-9]. A good amount of literature survey is presented on crack localization techniques[10-12]. The major challenge in the crack localization is to get the high spatial resolution of beam deflection measurement. Measuring the high resolution of beam deflection with mounting traditional sensors is a tedious task[13-15]. In the present work the photographic measurement is used to obtain the high measurement spatial resolution beam deflection. The procedure for obtaining the experimental beam deflection by using photographic method is presented in author previous work[1].

Detecting the slope discontinuity from the beam deflection uses wavelet transform as the most convincing tool[16-20]. The wavelet transform has several representations the new representation or second-generation representation is the lifting scheme. The lifting

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scheme has certain advantage over the classical wavelet. It has perfect reconstruction properties, and it works well with the signal of any size.

For the experimental verification, a high-resolution beam deflection is obtained using the photographic method. Then, a bandpass filter is used to smooth the experimentally obtained deflection data. A moving window variance is applied to the filtered data[21]. Visualization of the results is improved by applying the variance twice on the beam deflection. The proposed algorithm is also tested for multiple crack localization and localization of cracks near the ends of the beam.

2.0 Lifting Wavelet

The block diagram of lifting scheme is shown in Figure 1. There are three steps in lifting scheme. The first step is split step in which the input signal is split into even and odd components. The second step is predicting step is similar to high pass filtering and leads the detailed coefficients (D). The third step is updating step it calculates the scaling function and results the approximate coefficients (A).

The lifting scheme can be employed to any orthogonal and biorthogonal wavelet by using the polyphase matric factorization[22]. The lifting scheme reveals the discontinuity present in a signal. The beam deflection of a crack beam consists local slope discontinuity at the crack location. Locating the slope discontinuity present in the signal reveals the crack location. The numerical simulation for obtaining the beam deflection is presented in the next section.

3.0 Numerical Simulation

The simulated beam deflection is obtained by using the Timoshenko beam theory. The finite element code is developed in MATLAB. The details of the procedure to obtain the simulated beam deflection is presented in the author's previous work[1]. In real practice the beam deflection must be contaimated with measurement noise. To mimic the measurement noise the white gaussian noise is added to the simulated beam deflection. The beam deflection of a cantilever beam is plotted in Figure 2. A noise of 85 dB SNR is added in it. The crack detection using the lifting sceme is attempted, the lifting detailed coefficients are plotted in Figure 3(a). A clear spikes corrosponfding to the crack location is seen. Further for comparision purpose the crack localization using the DWT is attempted, the DWT detailed coefficients for numerical simulation is presented in Figure 3 (b). It is found that the crack localization using both techniques is comparable. The crack localization using lifting is identical by DWT. For testing the noise robusteness of the lifting and DWT scheme, noise of 75 SNR is added to the simulated beam deflection. The Wavelet detailed coefficients through the lifting and DWT sceme is plotted in Figure 3 (c) and Figure 3(d), respectively. Both the techniques gives a comparble and likely dominat spikes corrosdponding to the crack location.

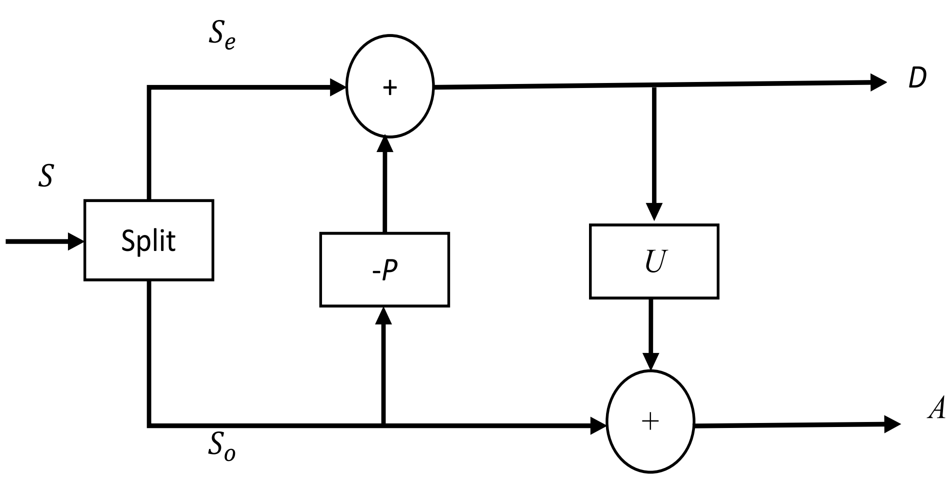

Figure 1. Block diagram of lifting steps.

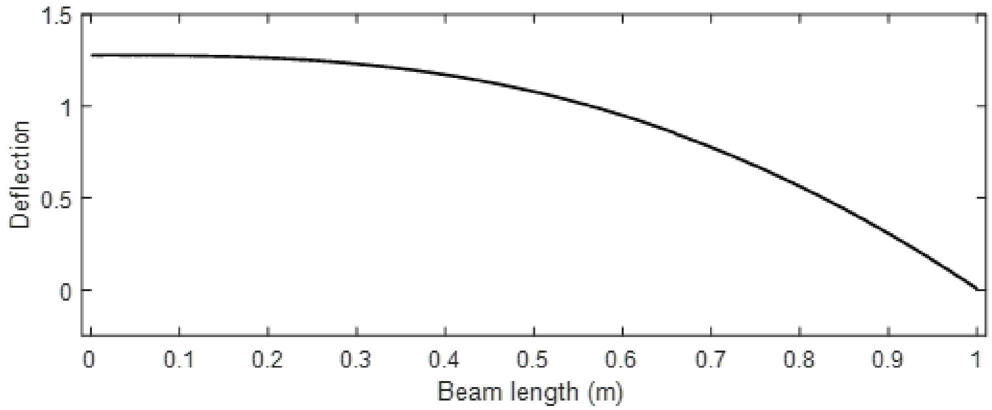

Figure 2. Beam deflection shape at an excitation frequency of 40 rad/s.

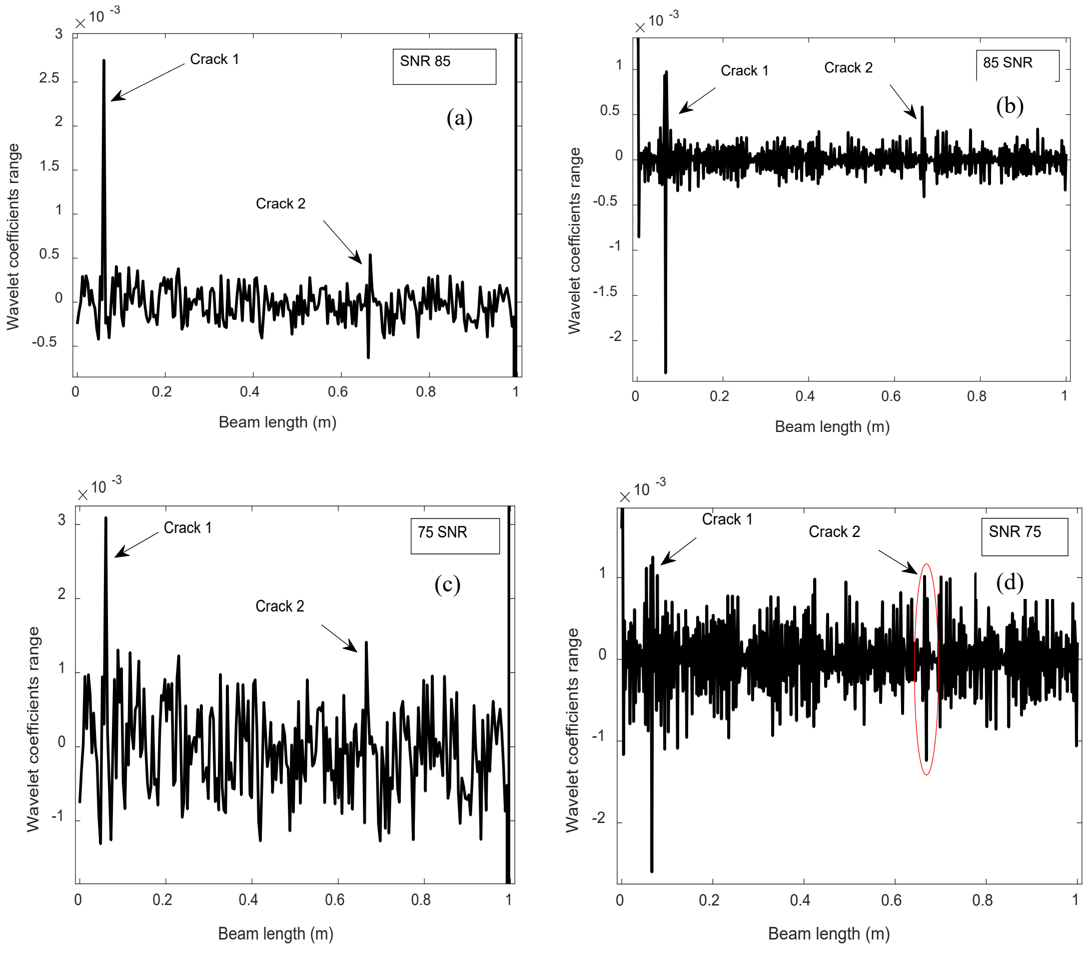

Figure 3. Crack localization by using: **(a)** Lifting scheme at 85 SNR, **(b)** DWT at 85 SNR, **(c)** Lifting at 75 SNR, and **(d)** DWT at 75 SNR.

3.1 Effects of Measurement Resolution

To study the effects of measurement resolution, the number of data points along the beam length is varied. The beam deflection with 20 and 40 data points are taken. Responses at FE nodes are considered to be the measurement data for the beam deflection. The beam

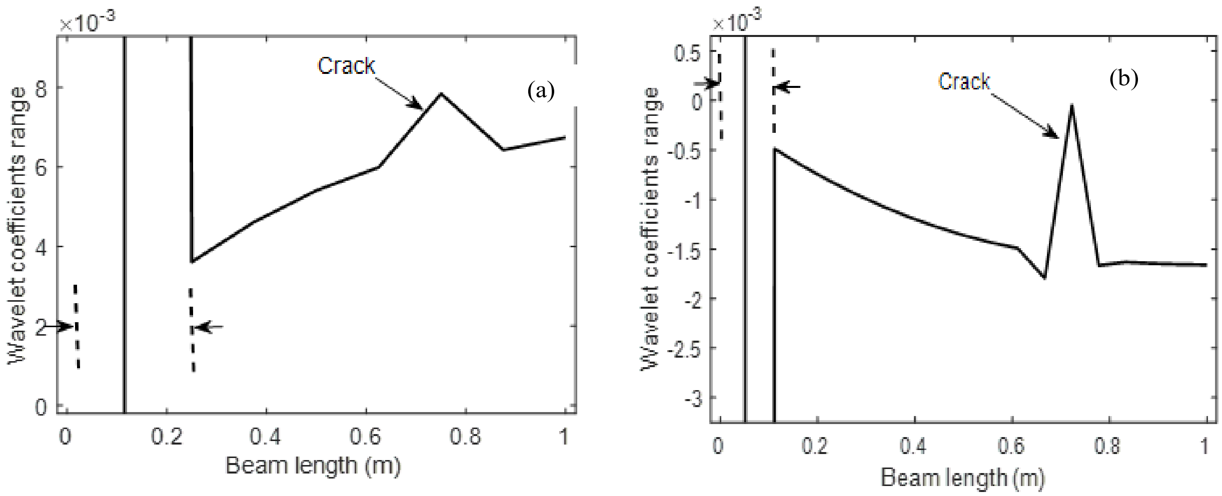

Figure 4. Effects of measurement resolution on crack localization: **(a)** With 20 data points, **(b)** With 40 data points.

deflection with different data points is taken as the input signal for the lifting wavelet transform. The lifting wavelet coefficients with 20 and 40 data points are plotted in Figure 4. A spike is obtained at the location of the crack in the beam. However, the spike gets localized with an increase in measurement resolution. The border distortion zone shrinks with the increase in the number of data points. Hence, it can be concluded that high measurement resolution gives more localized crack detection.

4.0 Experimentation

For obtaining the high spatial resolution beam deflection, photographic-based measurement is used. The detail discription for getting the high spatial aresolution beam deflection by using photogfraphic method is given in the author's previous work[20]. The details of experimental parameter fro the present work are presented in Table 1. The DWT coefficients for the experiment I are plotted in Figure 5. Also, the lifting wavelet coefficients for the experiment I is plotted in Figure 6. A dominant spikes corresponding to the crack location is seen. The arrowhead marking shows the edge distortion zone. The edge distortion zone covers 0.055 m from both ends.

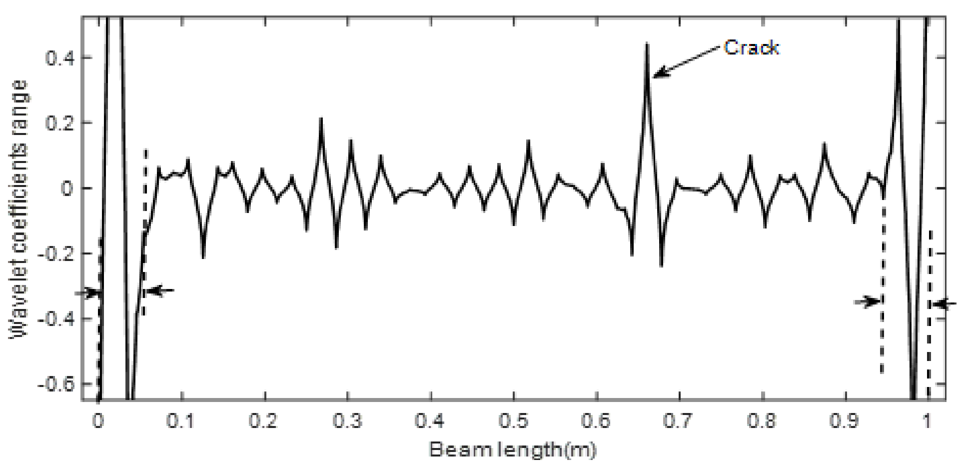

Figure 5. DWT coefficients for experiment I.

Table 1. Parameters for experimentation

	Experiment I	Experiment II	Experiment III
Crack size (mm)	4	2	3
Crack location from fixed support (m)	0.66	0.1	0.065 and 0.66

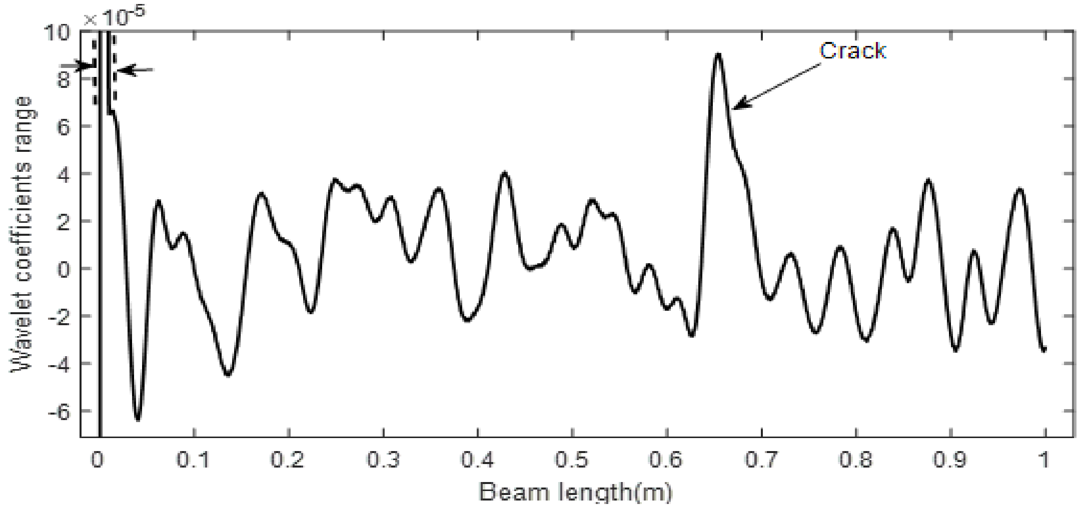

Figure 6. Lifting wavelet coefficients for experiment I.

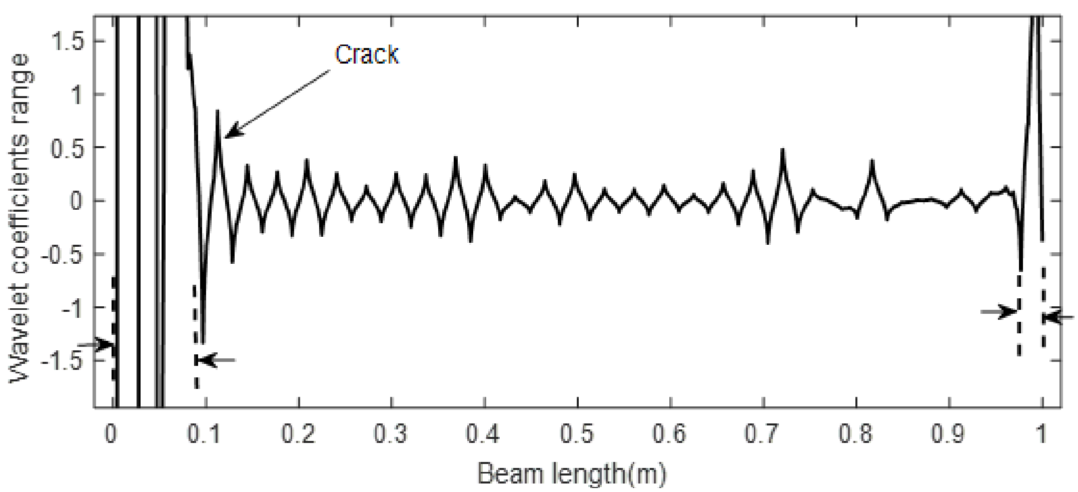

Figure 7. DWT coefficients for experiment II.

Similarly, the DWT coefficients and the lifting wavelet coefficients for the experiment II are plotted in in Figure 7 and Figure 8, respectively. Finally, for experiment III, the lifting wavelet coefficients are represented in Figure 9.

5.0 Conclusions

In the present work, finite element analysis is used for getting the simulated beam deflection. The lifting wavelet

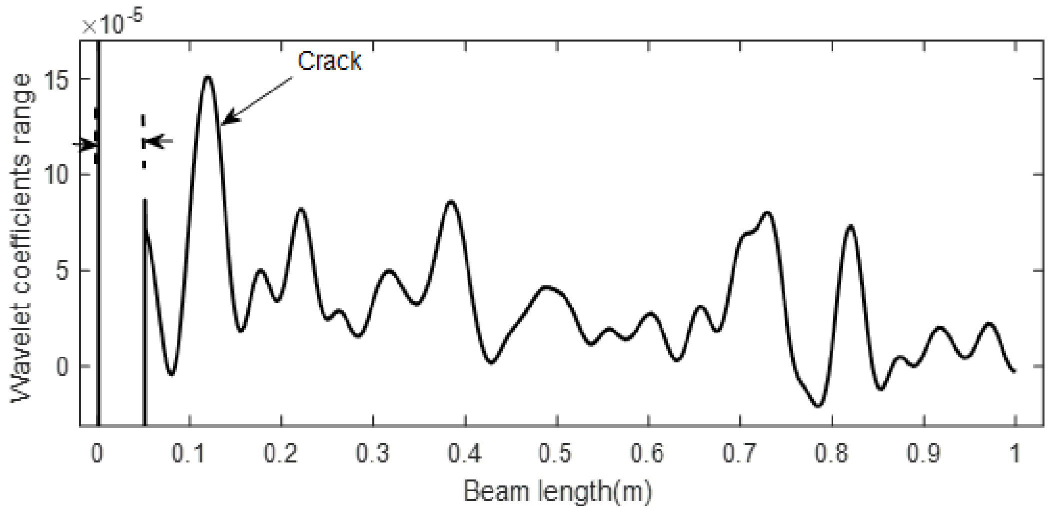

Figure 8. Lifting wavelet coefficients for experiment II.

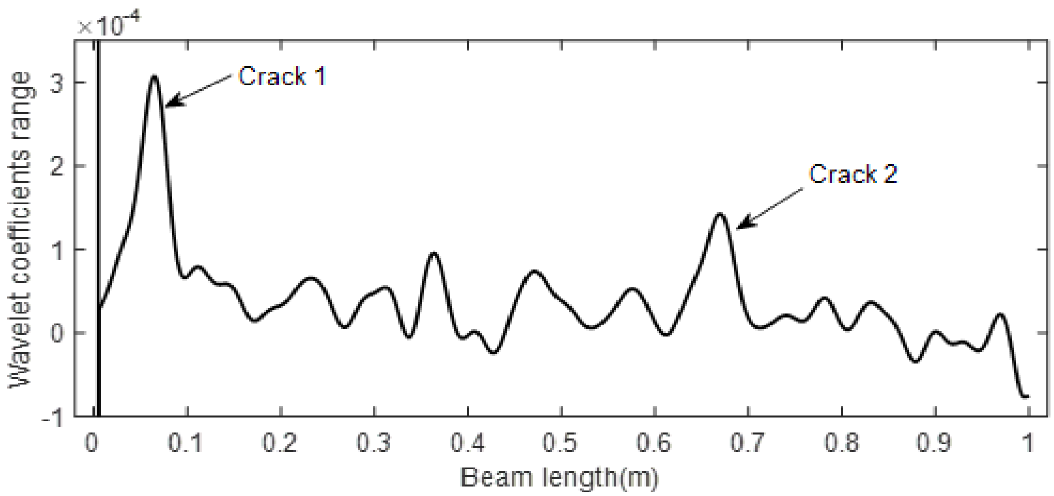

Figure 9. Lifting wavelet coefficients for Experiment III.

is used for the localization of cracks in the beam. The lifting wavelet has certain advantages over the classical wavelet. The lifting wavelet possesses perfect reconstruction and a narrower border distortion zone. A comparative study is presented between the discrete wavelet transform and the lifting wavelet transform for localizing the crack. The ability of lifting wavelet is tested for different noise conditions and multiple crack localization. For experimental testing, low-cost photographic-based experimentation is used to get the high spatial resolution of beam deflection. The high-resolution measurement of beam deflection results in localized crack detection and a shorter edge distortion zone. The numerical simulation and the experimentation show that the proposed lifting scheme wavelet-based algorithm can detect the crack location correctly. Further, the algorithm is also tested for multiple crack detection.

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