Utilizing Dynamical Loading Nondestructive Identification of Structural Damages via Wavelet Transform

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Abstract: Different methods are represented in order to investigate and identification of damages that each one has some advantages and disadvantages. For example, Fourier Transform which represents related information over frequencies of a signal while no information is in access about the time of a frequency's creation. For identifying the place of damage, knowing the time of frequency creation is of high importance. On this base Fourier Transform encounters problem. Modern and efficient methods which are placed in signal analyses field and are in favor of researchers are wavelet transforms. The most important advantage of using wavelet is its ability in analyzing a signal place in every time or place domain. In this paper, a method for identification of damage in a beam via wavelet transform is represented. In this method beam identification is possible without dynamic parameters of healthy structure. At first, the structure is put under harmonic analyses through Finite Element Software (ANSYS5.4) and then it is put under wavelet analyses in wavelet box by (MATLAB7.1) Software and at the end the results are observable on two dimensional coefficient-location graphs which indicate high ability of wavelet theory in response analyses of a structure and disharmonic identifications in structural systems.

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1. Introduction

In recent years, many attempts are done on developing reliable systems and structural health monitoring [SHM]. The aim is to find a process in order to response the place of damage and its strength. Two main aims of this study are to represent a method for monitoring structures that firstly; do not need any response of healthy structure and secondly; its sensitivity toward measurement and other errors be less. Wavelet Transform is a method that in the case of having two mentioned characteristic can be a suitable response to this demand. In this method instead of investigating natural frequencies and their changes, vibration or static response of structure in different spots of structure in a definite time is demanded which in fact is a place-domain signal. After WT analyses the place of any kind of damage on wavelet coefficient graph in the shape of summit and disordered spots are detected.

It seems that along static loading and structure displacement measurement, compulsory vibration implement can be a suitable method for gaining the response of damaged structure. According to carried out researches, static transformation and structural modal shapes are considered as the response functions of defective structure. In current study; for the first time, harmonic loading is utilized in order to gain the response functions of defective structure.

Damage causes stiff local changes which affects significantly structure dynamic action. This matter is observable in the change of natural frequency and vibration mode-shapes also, this change analyses makes the identification of these damages possible. In the aim of damage characteristic identification, first Dimargutas modeled the damage as local flexibility and gained the equal hardness through some experiments (Dimorogonas. 1976). Chandras made use of this method for studying dynamic response of damage beam (Chondros. 1977). Cowly and Adams represented experimental method for calculating situation and damage depth of changes in natural frequencies (Cawely. Adams. 1979). Goodmanson used disorder method for predicating changes in structure natural frequencies resulted from damages, cracks and some other geometric changes (Gudmaunson. 1982). Since then much more works are done over identifying damages on the bases of natural frequency changes. But in some cases because of damage smallness and measurements' errors the ability of damage identification decreased. In order to solve this problem utilizing mode-shapes are considered important. Rizas proposed a method for utilizing measured width in two spots far from beam that vibrates in one of its natural modes (Rizos at all. 1990). Shancog Zhong and Olutunde Oyadiji presented a new approach for crack detection in beam-like structures when crack is relatively small. This approach is based on finding the difference between two sets of detail coefficients obtained by the use of the stationary wavelet transform (SWT) of two sets of mode shape data of the beam-like structure (Zhong. Oyadiji. 2007). Yan and his colleagues suggested intelligent damage diagnosis and its application prospects in structural damage detection. And also the development trends of structural damage detection are also put forward (Yan at al. 2006). Xiang and his colleagues studied the model-based forward and inverse problems in the diagnosis of structural crack location and size by using the finite element method of a B-spline wavelet on the interval (FEM BSWI) (Xiang at al. 2006). Zhu and Law presented a new method for crack identification of bridge beam structures under a moving load based on wavelet analysis (Zhu at al. 2005). Maosen Cao and Pizhong Qiao proposed a new technique (so-called 'integrated wavelet transform (IWT)') of taking synergistic advantages of the stationary wavelet transform (SWT) and the continuous wavelet transform (CWT) that this technique improved the robustness of abnormality analysis of mode shapes in damage detection (Maosen at al. 2008). M. Rucka and Wilde presented a method for estimating the damage location in beam and plate structures. A Plexiglas cantilever beam and a steel plate with four fixed boundary conditions tested experimentally. And also, the proposed wavelet analysis can effectively identify the defect position without knowledge of neither the structure characteristics nor its mathematical model (Rucka at al. 2006). Zheng Li and colleagues suggested a damage detection method based on a continuous wavelet transform and applied to analyze flexural wave in a cracked beam (Zheng at al. 2006). Later an exact comparison between two methods of frequency- base, mode-shaped-base was spread for damage identification in structural beams by Kim et al (Kitada. 1998).

2. The Background of Continues Wavelet Transform Theory

Wavelet transform is a useful and modern method for analyzing signals. Wavelet functions are mixtures of a number of basic functions which are capable of separating a signal at a time (or place) and frequency (or scale). Therefore, wavelet conversions are capable to explore many unknown aspects of information that cannot be distinguished through other methods of signal analyses. These characteristics are especially very useful in detecting damage. A number of researchers (Wong, Dang and Curly) make use of wavelet transform in damage detecting in structural frames. But one disadvantages of wavelet transform is weak decomposition of signal in areas with high frequency (Ang, Wang, Wang, Dimarogonas et al 1975, 1999 ,1996,1986).

According to high capability of wavelet transform in vibration or static response signal analyses of a structure that facilitates detecting any kind of discontinuity or disharmony (e.g. sudden flexibility and resistance decrease) and through wavelet coefficient graph are detectable in one or several spots near together with disorder or disharmonic numbers in comparison to other spots. Wavelet transform of a signal is defined as:

$$W_x(b,a) = |a|^{-1/2}\int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-b}{a}\right)dt \qquad (1)$$

Therefore, wavelet transform is gained through internal multiplication X(t), transformed and scaled version of single function $\psi(t)$ which is called wavelet (ψ^* is mixed binary of wavelet function).

When a transform is used in order to have a better view of signal it should be guaranteed that the signal can be completely restructured from restructured form. On the other side, restructuring can be completely or partly meaningless. In order to wavelet transform the condition of restructuring consists:

$$C_\psi = \int_{-\infty}^{+\infty}\frac{|\Psi(\omega)|^2}{|a|}d\omega < \infty \qquad (2)$$

That $\Psi(\omega)$ is wavelet Transform. This condition is considered as admissibility condition for wavelet. Clearly for having this condition of wavelet:

$$\Psi(0) = \int_{-\infty}^{+\infty}\psi(t)dt = 0 \qquad (3)$$

It means that wavelet is oscillatory function with average amount of $\Psi(\omega)$ should decrease as $|a| \to \infty$ and $|a| \to 0$. So, $\psi(t)$ should be the response of cross-pass impact. Because a response of cross-pass impact is similar to a small wave this transform is called Wavelet Transform.

3. Modeling Structure

For this purpose, a direct beam of 6m mouth with simple supports and square section 40cm for damage sample is shown in Fig.1. Mass and structure elasticity are respectively 7850 kg/m^3 and 2.11×10^{11} pa. Area and inertia of shear section equals 0.16m^2 and 2.13×10^{-3} m^4 (Gudmaunson, Rizos. 1982,1990).

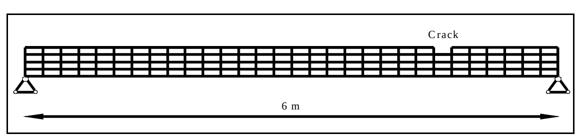

Figure 1. Characteristics of modeled structure

4. Harmonic Analyses and Damage Identification Process Continues Wavelet Transform

A healthy sample and six damage samples with mentioned characteristics are shown in table 1. These samples in frequency band of 0-100 were put under modal analyses. The 1st to 4^{th} natural frequencies are shown in table 2 for all 7 samples.

Table 1. Characteristics of place and depth of damage in modeled samples

Sample	Damage Position	Damage Depth
1	Safe	
2	4.6 (m) from left support	10%
3	4.6 (m) from left support	25%
4	4.6 (m) from left support	35%
5	4.6 (m) from left support	50%
6	4.6 (m) from left support	60%

Table 2. Results from the first 4 natural samples' frequencies

Sample	1^{st} Frequency	2^{nd} Frequency	3^{rd} Frequency	4^{th} Freque ncy
1	10.413	24.588	42.279	63.309
2	10.411	24.477	41.932	62.855
3	9.630	24.531	39.644	59.644
4	9.420	24.251	38.562	58.635
5	8.925	24.120	37.856	56.635
6	7.564	23.532	35.229	53.470

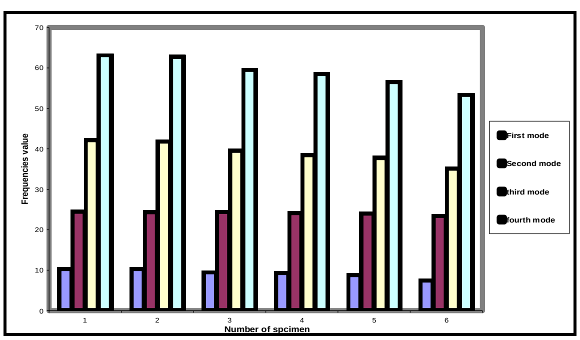

Figure 2. Samples frequency changes in first 4 frequencies

Also, each mode's frequency changes in all samples are investigated in Fig.2. As figure shows, as damage depth increases the amount of frequencies decrease. These decreases are very tangible after 3^{rd} mode and they are shown as disorder in graph.

Supposed force should be implemented in distance of 1m on the structure and the results of frequency displacement for 3 spots of 0.5m, 2m and 3m from left support in every 2 healthy samples (1) and damage sample (2) are shown.

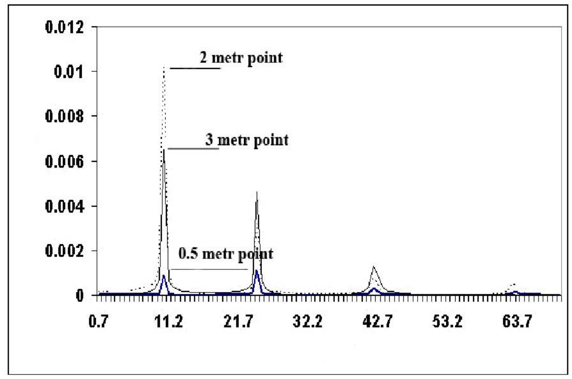

Figure 3. Displacement frequency graph of 3 spots of healthy samples

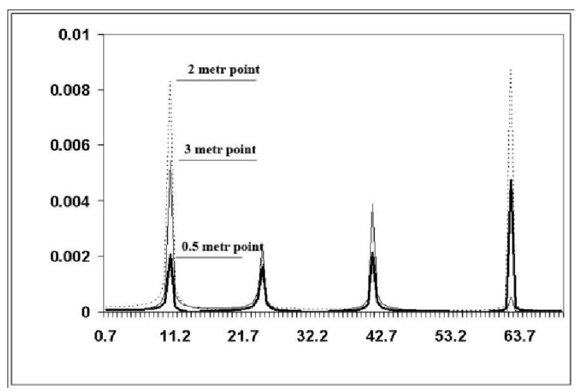

Figure 4. Displacement frequency graph of 3 spots of damage samples

The result from above figures is that the structure in frequency band of 0-70 is of 4 peak of displacements. The significant point is that the maximum amount of displacement is exactly created in principle frequency places. As figures show maximum amounts are in frequencies of 10.431 and 24.588 which are exactly equal to principle frequencies amounts from modal analyses and it is a reason for accuracy of modal analyses.

The results from harmonic analyses will be investigate later and frequency of 11 (HZ) for primary investigation is chosen for healthy and damaged samples response in data 207 in equal distances (maximum displacement in each spot). Above data are analyzed through wavelet analyses and the results from Db5 analyzer are shown in figures 5 to 10.

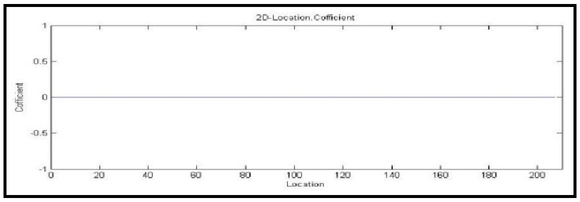

Figure 5. Location-coefficient graph of health sample 1

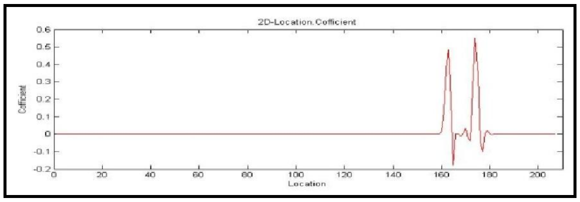

Figure 6. Location -coefficient graph of health sample 2

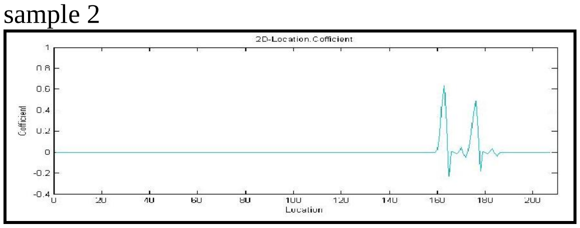

Figure 7. Location -coefficient graph of health sample 3

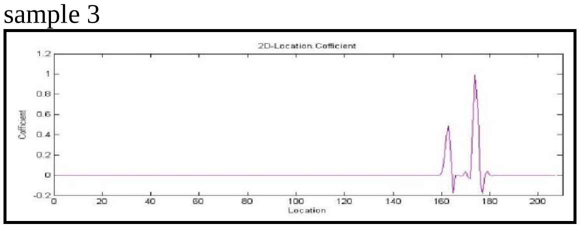

Figure 8. Location -coefficient graph of health sample 4

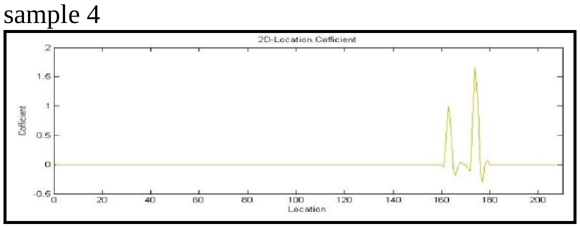

Figure 9. Location -coefficient graph of health sample 5

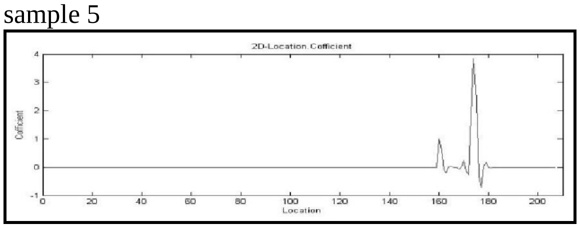

Figure 10. Location-coefficient graph of health sample 6

As it is observed in Fig.5, there is no disorder or disharmony in the length of beam which proves that the structure has no damage or destruction in its length. Also, in Fig.6 to 10, Disorders related to 160-180 spots are the exact damages of destructive structure. Through this method the exact location of damage can be identified. The length of disorders correspond the length of damage in structure.

5. Conclution

1. Continues Wavelet Transform is of high ability in vibrate or static response signal analyses. This ability is clear in identifying all kinds of disorders or disharmonies like stiffness sudden decrease and can be detected through continues wavelet coefficient graph in one or several near spots with disorder or disharmony toward other spots. On these bases wavelet method is one of efficient methods of damage detecting.

2. In this way, force implement in the length of beam produces some disorders on wavelet coefficient graph and the identification of damage will be difficult. The end spots will affect the wavelet coefficient graph (as disorders) even without the presence of force. Therefore, spots near to support can be the most suitable spots for harmonic force implement in structure.

3. Since in the continuous wavelet transform method extraction of 207 data is an easy and very cheap task, therefore this method can be a practical and functional one.

4. Increase in the depth of the damage raises the coefficient based on the wavelet, but does not have a linear relationship with high damage in the structure.

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