DAMAGE DETECTION IN 4-STORY STEEL BRACED FRAMES USING RESIDUAL FORCES BASED ON WAVELET TRANSFORM

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ABSTRACT

Wavelet transform, which was first introduced in 1980, is operating on a modified basis functions and makes them a new function. Wavelet analysis capability using a new method to analysis the signals and time-frequency signal processing offers. By replacing the wavelet network rather than rigorous analysis, accurate operation will not reduce the computational time is reduced dramatically.(Roland, 2000). Wavelet analysis is an efficient tool to detect structural damages like cracks and stiffness degradation (Kim and Melhem, 2004).

In this study, residual forces and damage detection procedure by wavelet transform of residual forces were described. A four story space frame with diagonal braces with several damage states was considered. For every state of damage mass and stiffness matrices, mode shapes and natural frequencies were evaluated. Finally dynamic responses of structure were conducted under wavelet analysis and for all cases, damages were successfully detected.

After wavelet analysis on responses, wavelet analysis curves of residual forces showed peak points on degree of freedoms of damaged members.

The damage locations, when damage occurs, are easily determined simultaneously by the ridges in the residual forces based on wavelet transform. The degrees-of-freedom that have large magnitudes in residual wavelet force (RWF) are associated with the potential damage members within the structure.

INTRODUCTION

During last decades ways of detection mechanical and structural structures damage has got a lot of attention. Wavelet analysing, a relatively new mathematical relation and a mean of signal processing, is one of the ways which is studied recently. Analysing time–frequency give more detailed information regarding unstable signals which February series can’t do. This has been used in various fields like Civil engineering, Mechanic and Aerospace, for recognizing diminishing and controlling the structure health (Kim and Melhem, 2004). Hasang Kim and Hani Melhem (2004), categorized the ways of collapse recognizing through using wavelet into three levels: 1- wavelet amounts variations 2- local disturbance of wavelet amount in a short time. 3-reflections wave created by local collapse. The first level is usually used if there is any collapse and the intensity of that; the second level is used to determine the place of collapse, and the third level is used to determine the intensity and exact place (Kim and Melhem, 2004). Fan and Qiao used the continuous to dimensional wavelet of mode shapes to determine the damage in planer structures. The suggested algorithm, is a response which is based on collapse recognizing method and only needs the mode shapes of damaged plate. This algorithm is applied in cantilever mono plate vibratory mode shape with different types of collapse to show its efficiently and durability (Fan and Qiao, 2009). Ovanesoa and Suarez (2004) studied the ability of wavelets in recognizing collapse in a structural member and a simple frame (Ovanesovaand Sua,2004). Wu and Wang has down laboratory studies to recognize collapse through wavelet conversion to achieve this fact and to recognize crack, they analysed a cantilever aluminium beam which has been under stoical change-plate through using Gabor wavelet. Beam damage and cracks different depth were recognized wavelet conversion was efficient in recognizing collapse area in a situation that the crack depth is 26% beam thickness. Yan and et al (2007) could determine the collapse of a braced 5 story steel structure by using residual wavelet force. The structure they considered had spans with small dimensions which wasmodelled in MATLAB software (Yan G. et al, 2010). This study aims to recognize damage in structure. In this study the damages of structures will be recognized through using residual wavelet force analysis. The method of this research is a little different with other activities done in this regard. In this article the aim is recognizing damage and determining the place of damage occurrence in the structures. The mentioned residual force is because of the mass and stiffens changes.

WAVELET TRANSFORM

Continuous wavelet transform, is a transform which takes time continuous function to time-frequency space. The new space bases of time frequency are wavelet functions. In mathematic term, continuous wavelet transform for continuous function$x(t)$which its square isintegrablein $a > 0$ scale and $b \epsilon R$ place is define as fallow:

(1)

Here x(t) is main signal and b is transition parameter. $\psi(t)$is a frequency and time continues function and is known as mother wavelet. (ψ^* is the complex conjugate of wavelet function), a is scale parameter and is as the compaction or strain of the were.

RESIDUAL FORCE

In this part residual forces will be defined first. Then the ways of damage detection by using residual forces will be given. For the i-est mode of damaged structure, specific amount equation is written as follow:

$$(K_d-\omega_{di}M_d)\varphi_{di}=0 \quad (2)$$

In the above equation K_d and $M_d$are stiffness and mass matrix of the structure in damaged statues. ω_{di}andφ_{di} are specific amount and i-est mode shape. With the assumption that the relation between stiffens matrix and mass matrix of both damaged and safe structure are as the following relations:

$$M_d=M_u+\Delta M \quad , \quad K_d=K_u+\Delta K \quad (3)$$

Here M_u and $K_u$are mass and stiffens matrix of structure is the safe status. ΔMandΔK also mass matrix and stiffens matrix changes which are caused by damage. Now by putting relations (3) in equation (2):

$$-(\Delta K-\omega_{di}\Delta M)\varphi_{di}=(K_u-\omega_{di}M_u)\varphi_{di} \quad (4)$$

The left side of equation (4) is defined as residual force vector for thei-est mode of damaged structure which can be determined as follow:

$$R_i=-(\Delta K-\omega_{di}\Delta M)\varphi_{di} \quad (5)$$

From the right side of equation (4), it can be seen that R_i is the error of placing i-est mode data in damaged status in the structural specific amount equation in safe status. $R_i$vectordimensions are equal to the structure freedom degree. A member in which$R_i$is nonzero, is the place of damage in structure (Yan G. et al, 2010).

RESIDUALFORCES WAVELET TRANSFORM

In this part residual forces will be defined based on wavelet transform which are knew as residual wavelet forces. Then damage detection based on residual wavelet forces will be given. The equation of motion of a multi-degree of freedom is undamping as follows:

$$M_u\ddot{x}(t)+K_u x(t)=0 \quad (6)$$

Here $\ddot{x}(t)$and $x(t)$ are acceleration and translation vector of moment t. M_u and K_u are the same as relation (3) equation (6) has the same role of equation (2). Converted equation can be achieved by having continuous wavelet transform in the both sides of equation (6)and selecting appropriate basic wavelet $\psi_{a,b}(t)$, The transformed equation can be obtained:

$$M_u W_{\psi}^{\ddot{x}}(a,b)+K_u W_{\psi}^{x}(a,b)=0 \quad (7)$$

That $\ddot{\psi}_{a,b}(t)$is second derivative than t at $\psi_{a,b}(t)$, $W_{\psi}^{\ddot{x}}(a,b)$ and $W_{\psi}^{x}(a,b)$are responsibilitycoefficients CWT from $\ddot{x}(t)$ and $x(t)$as shown below:

$$W_{\psi}^{x}(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} x(t)\ddot{\psi}\left(\frac{t-b}{a}\right)dt \quad (8)$$

In which a and b are scale and translate parameters. The relation between slips response of continuous wavelet transform coefficients, acceleration and speed are given bellow:

$$W_{\ddot{\psi}}^{x}(a,b)=-aW_{\dot{\psi}}^{\dot{x}}(a,b)=a^2W_{\psi}^{\ddot{x}}(a,b) \quad (10)$$

By putting equation (10) in relation (7) we have:

$$\frac{1}{a^2}M_u W_{\ddot{\psi}}^{x}(a,b)+K_u W_{\psi}^{x}(a,b)=0 \quad (11)$$

In addition translated equation for damaged structures is obtained as follow:

Here $\bar{W}_{\ddot{\psi}}^{\ddot{x}}(a,b)$ and $\bar{W}_{\psi}^{x}(a,b)$are coefficient of continuous wavelet transform of acceleration and replacement of damaged structures responses. With the assumption that the variations of mass matrix and stiffens matrix in damaged structure in relation to safe status is as relation (3), and by putting relation (3) in relation (12):

The left side of relation (13) is defined as residual wavelet force (RWF). It is clear that, any changing in mass and stiffness matrix leads to any amount other than zero in RWF, which shows damage in the related member. As calculating RWF from the left side of relation (13) is difficult but the right side can be used so:

$$RWF(a,b)=\frac{1}{a^2}M_u\bar{W}_{\ddot{\psi}}^{x}(a,b)+K_u\bar{W}_{\psi}^{\ddot{x}}(a,b) \quad (14)$$

So the calculations can be completed by using relation (14) and mass matrix and stiffness matrix of the structure before damage and the response which are calculated after damade (Yan G. et al, 2010).

STRUCTURAL MODELS

In this study a four story structure with diagonal bracing came into modal analysis. The length of each span is 6 meters and the height of story is three meters. The lateral bracing system is considered as diagonal bracing. The used software are MATLAB and SAP 2000. SAP 2000 was used to analyze the structure and taking the needed outputs like mass matrix and stiffness was used. MATLAB software was also used for wavelet analysis. The structure was analyzed in different status and the wavelet Bior3.3, residual wavelet force analysis was done.

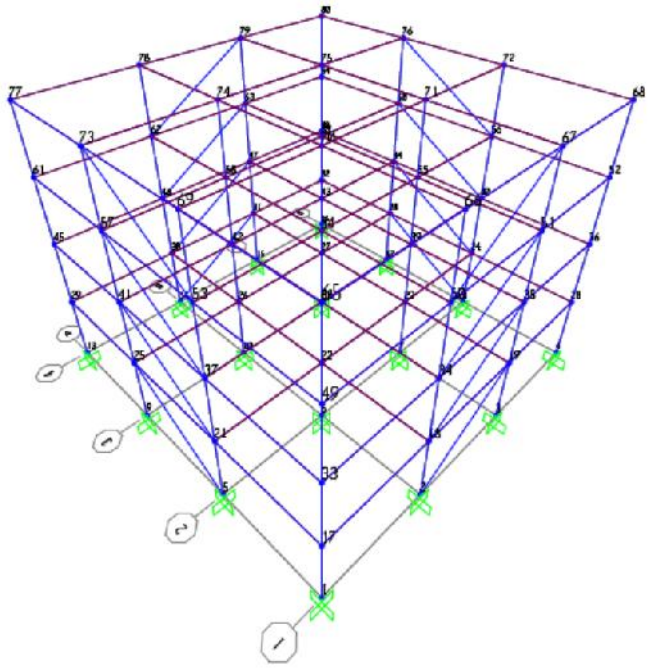

Figure1. structure model

Table 1.Characteristics of materials

materials	Elasticity modules (kg/cm^2)	Yield stress (kg/cm^2)	Poison ratio
steel	2.1x10^6	2400	0.3
concrete	2.1x10^5	210	0.2

Table 2.Sections of the structure

sections	Beam	column	brace
Story 1-4	IPE240	2IPE18+PL20x0.8	2UPN20

DAMAGE STATES

In this different damage states of the structural models of this study are considered and their responses were studied.

FIRST STATE: REMOVING BEAM ELEMENT AS A DAMSGE

In this state beam element 31-32 is defined as damage (Figure 1). For this purpose, the related element was removed and wavelet analysis was done through using the obtained responses and residual force concept. It is expected that the result of damage be appeared in the wavelet analysis out put graph in the form of a disturbance (peak point) in the freedom degree of the removed element joint place. As it can be seen in graphs 2 and 3, in the first mode the degree of freedom 32 and in the second mode the degree of freedom 31 are presented as the highest point which it represent the damage in these degrees of freedom.

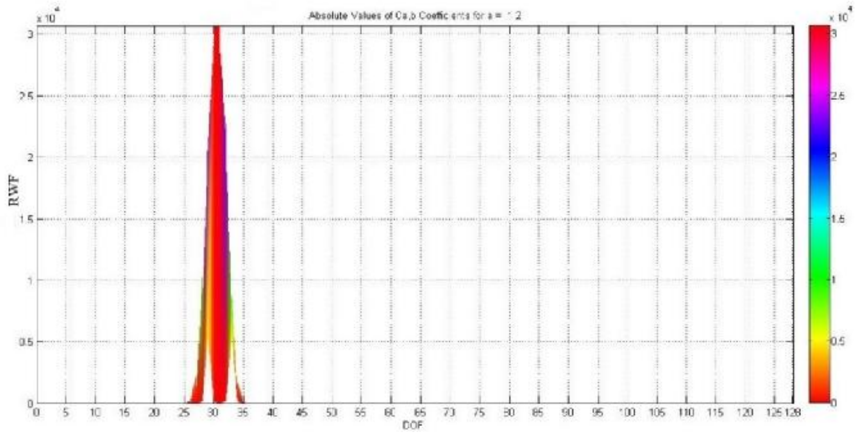

Figure 2. Wavelet plot of the residual force in the first mode from the first case of damage

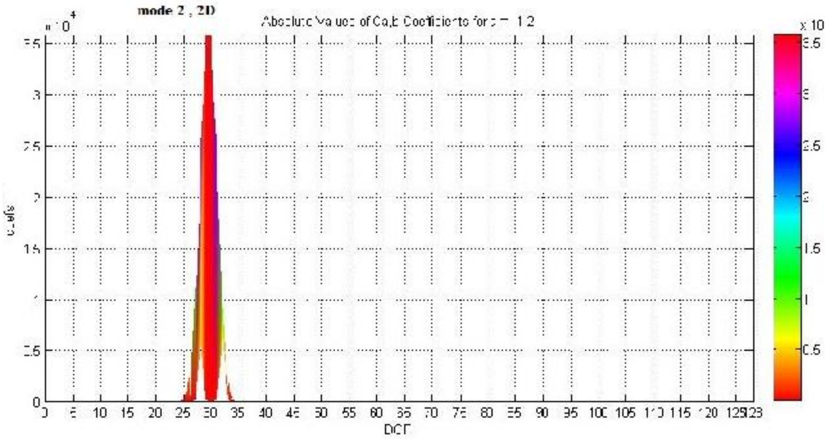

Figure 3. Wavelet plot of the residual force in the second mode from the first case of damage

SECOND STATE OF DAMAGE: REMOVING COLUMN ELEMENT AS DAMAGE

In this state column element 6-22 was introduced as damage. Based on the figures 4 and 5, the damage is the first mode was seen in degree of freedom 12 and in the second mode was seen in degree of freedom 11.

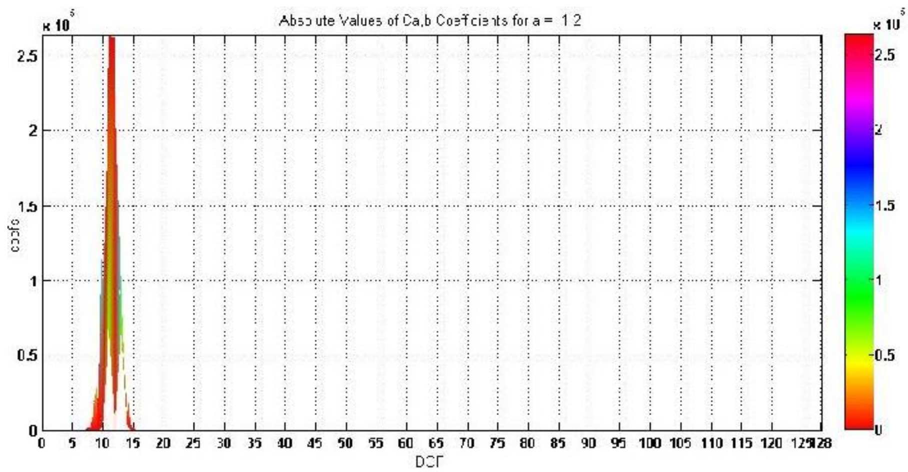

Figure 4. Wavelet plot of the residual force in the first mode from the second case of damage

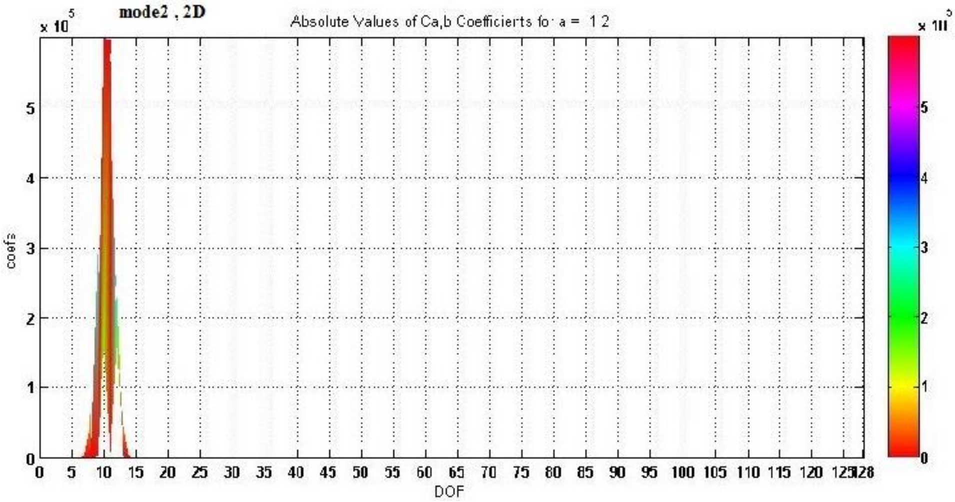

Figure 5. Wavelet plot of the residual force in the second mode from the second case of damage

THIRD STATE OF DAMAGE: REMOVING BRACING ELEMENT AS DAMAGE

In this state wind-brace element 2-19 was introduced as damage.infigure.6 ofresidual wavelet forces transform in degree of freedom 6, and in figure.7 in the degree of freedom 5 peak point was seen. Which are related to joint 19 and shows damage in this joint?

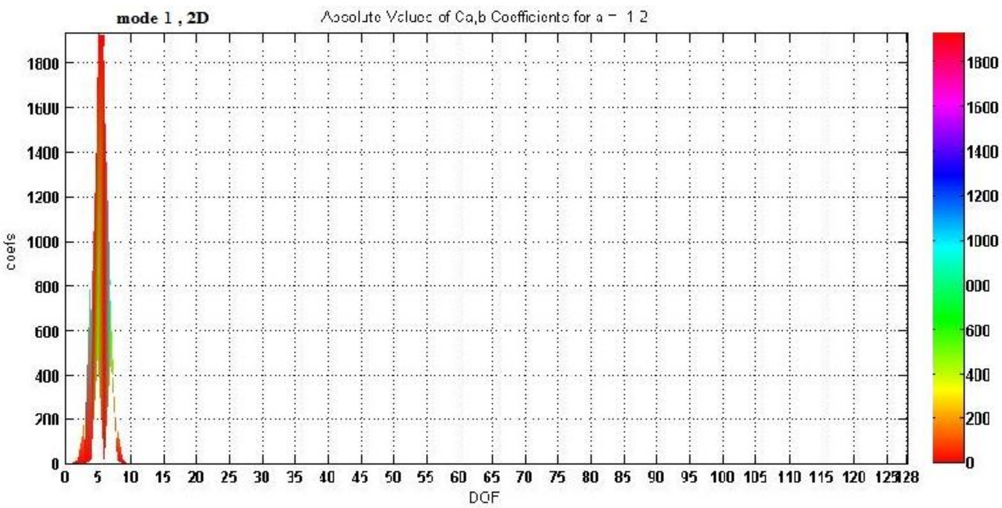

Figure 6. Wavelet plot of the residual force in the first mode from the third case of damage

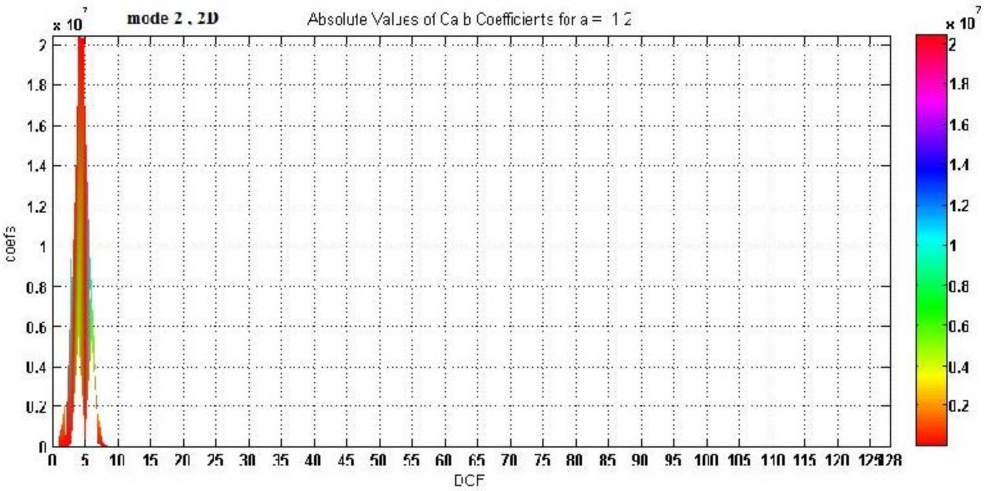

Figure 7. Wavelet plot of the residual force in the second mode from the third case of damage

SIMULTANEOUS DAMAGES

In this state, with providing the first, second and third states of damage simultaneously in the studied structure the expected for calculating residual force was obtained in this state, the graph has disturbance in degrees of freedom5, 12 and 31 which represent the damage in the their related joint.(Figure 8)

CONCLUSION

This study began with defining wavelet conversion and identified as an efficient and andestroying mean for determining damage the structures. The importance of damage detection before leading to critical state is clear. Residual force in structure was defined and damage detection method was explained through using residual wavelet forces conversion. Then a 4 story braced with diagonal bracing was studied. In the next step several damage states was defined for the studied structure. Mass matrix and stiffness matrix, mode shapes and natural frequencies for each state were extracted. Finally the results were analyzed through wavelet analysis, and the damage for each state was defined and detection

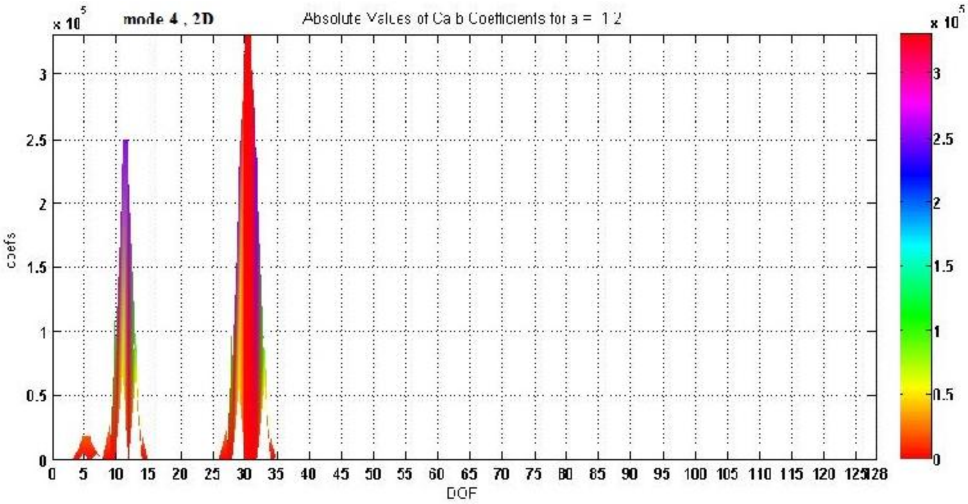

Figure 8. Wavelet plot of the residual force in the forth mode from Simultaneous damages

RESULTS

The result show that wavelet conversion is an appropriate method for determining the structure damages. In each state of damage in the graph of residual wavelet forces analysis, peak point were found in the damage places. In this study different amounts of residual wavelet forces conversation for different damage states and damaged element were obtained. In additional, wavelet conversation method for damagesdetection simultaneously was used which leads to acceptable results.

Results of the study can be presented briefly as follow:

- Wavelet conversation is able to detection several damages simultaneously
- The amount of residual wavelet forces is different for the different damage state.
- Considering the amount of residual wavelet forces in different elements, we can found the role of each of the mentioned elements in the structure total behavior.

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