

The Case Examination of Detection of Structural Damages on a Plate using Wavelet Transform

Ali Mohammad Rousta

Department of Civil Engineering,
Yasouj University, Yasouj, Iran
E-mail: arousta@yu.ac.ir

Peyman Beiranvand*

Department of Civil Engineering,
Lorestan University, Khorramabad, Iran
E-mail: peyman51471366@gmail.com

*Corresponding author

Farzad Akbarinia

Department of Civil Engineering,
Imam Khomeini International University, Qazvin, Iran
E-mail: farzadakbarinia@gmail.com

Mehdi Hooshmand

Department of Civil Engineering,
Khorasgan Branch, Islamic Azad University, Isfahan, Iran
E-mail: mehdihooshmand61@gmail.com

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Abstract: Sometimes, suddenly or gradually structural or nonstructural damages are created in structure's members due to natural or unnatural reasons like earthquake or corrosion. One of the methods used from the early in last decade to recognize damage is wavelet transform method. In this method, instead of examination of natural frequencies and the rate of its changes, vibration response or static response of a structure in various points of a structure is recorded at the same time, which in fact is a place-domain signal. In this paper, some factors have been investigated on a plate such as the effect of crack depth reduction, effect of changing support conditions, and the effect of approaching two rectangular cracks; and the responses obtained from finite element analysis, have been studied and the following results are gained: the ability of wavelet method to recognize the locality and severity of cracks, identification of tiny cracks up to 0.5mm depth and increasing the intensification of cracks' effect on plate by reducing their distance from each other.

Keywords: Crack, Damage, Plate, Wavelet Transform

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Biographical notes: **Ali Mohammad Rousta** is an Assistant Professor in Civil Engineering Department at Yasouj University, Iran. He received his PhD in Civil Engineering from Tehran University. **Peyman Beiranvand** is a Lecturer in Civil Engineering at Lorestan University. He received his PhD in Civil Engineering from Razi University of Iran. **Farzad Akbarinia** is now a PhD candidate from the Imam Khomeini International University, Qazvin, Iran. **Mehdi Hooshmand** is now a PhD candidate from the Islamic Azad University, Khorasgan Branch.

1 INTRODUCTION

During recent decades, wavelet analysis has been an useful tool in detecting damage in structures. However, most researches have focused on the damage identification in basic structures such as beams, plates and bearings. In practical application, the basic structures do not exist alone. Instead, they are usually accompanied with one another, and these composite structures are commonly used in ships. Wavelet transform can resolve time domain-frequency domain problems more effectively and has a great capability in reconstructing the decomposed signal. In this study, a method for crack identification in stiffened plates based on two-dimensional wavelet analysis was investigated.

French physicist Morlet determined that the Fourier transform was unable to analyze seismic waves during short time periods [1], so Goupillaud, Grossmann and Morlet later applied the wavelet concept on this signal analysis technique [2]. Afterwards, Meyer and Mallat introduced the multi-resolution concept into wavelet analysis to form discrete wavelet transform [3-4].

Cawley and Adams combined measurements of natural frequencies from the experimental results and the finite element analysis to detect damage locations in structures [5]. Daubechies constructed the orthogonal and compact support wavelet, which had local resolution in both time and frequency domains [6]. Surace and Ruotolo simulated the vibration signal of a cracked beam by wavelet transform [7]. Furthermore, Wang and Mcfadden handled the vibration signal of a gear box with wavelet transform [8]. Rucka and Wilde analyzed the modal shape of a cracked cantilever beam and plate by utilizing continuous wavelet transform to identify the damaged area [9]. Yang and Hwang carried out a method involving both wavelet packet node norm and two-Dimensional Discrete Wavelet Transform (DWT2) which, in return, measured the first mode shape of aluminum alloy plates and found the location of cracks [10]. In this paper, the first modal shape for an aluminum rectangular plate with stiffeners was obtained by using wavelet packet node norm initially, and then the damage locations were detected by two-dimensional discrete wavelet transform.

Sometimes, suddenly or gradually and owing to natural or unnatural reasons including earthquake, firing, corrosion, destruction and etc. structural or nonstructural damages in members of structure are created. Among these damages are rupture of all members or some members, steel submission/yield, concrete crunch, strength reduction, elasticity modulus, plastic joint formation, fraction and similar cases. These damages generally lead to the following short term and long term structural effects: strength reduction, stiffness reduction, ductility reduction, destroy of structure's stability and so on. If these damages can be recognized in the member

itself by some methods, then the member can be repaired or replaced by recognition based on analysis of structural failure conditions and therefore, it can prevent the general damages or greater damages of structure and yet useful life of structure servicing including technical, functional or economical, can be increased.

One of the methods used from the early in last decade to recognize damage is wavelet transform method. In this method instead of examination of natural frequencies and the rate of its changes, vibration response or static response of a structure in various points of a structure is recorded at the same time, which in fact is a place-domain signal. After analysis by WT, the place of each destruction of defect can be distinguished on the graph of wavelet coefficients in form of points of climax and turbulence.[11] In this article, items like the effect of crack depth reduction, effect of changing support conditions and the effect of approaching two rectangular cracks have been investigated, and the responses obtained from finite element analysis are studied by wavelet transform. For modelling the plate and gaining responses, ANSYS software is used and for analysis results, a toolbox Wavelet of MATLAB is being used. It must be noted that for analysis of concluded results, two dimensional discrete wavelet transform has been used that its mathematical definition is given in the following.

2 CONTINUOUS WAVELET TRANSFORM

Wavelet transform is widely used to resolve time domain-frequency domain problems. The basis of a wavelet transform is composed of translation and dilation functions. These functions are orthogonal functions and are formulated by shifting and expanding a basic wavelet function according to high or low frequency signals, which are to be analyzed. With the above features, the wavelet transform has great capability to display high time domain resolution at high frequencies and high frequency domain resolution at low frequencies.

In this part, wavelet function is introduced in summary, for more details refer to mentioned sources. In reality, the purpose of applying a mathematical transform on a signal is obtaining hidden and additional information which are not accessible in crude signal. One of the most important tools to analyze a signal is Fourier transform in which a signal is decomposed into alternative sinusoidal signals with various frequencies. In fact, Fourier transform changes a signal from time mode into frequency mode [12]. However, Fourier transform has this weakness that by converting signal into frequency domain destroys time information. Actually, by looking at the Fourier transform of a signal, it cannot be understood that when a definite event has happened [9],[13]. Now, if the properties of a signal does not

change so much over time, it is not an important weakness, but many signals have various unstable modes and sudden changes, that these features are the most important part of signal and Fourier transform is not appropriate for their recognition [15]. Wavelet transform is a new and efficient method to analyze signals, which transforms a signal into a series of small waves and it removes the defects of Fourier transform for signal analysis. Wavelet, means small wave and wavelet is a suitable equivalent.

Wavelet function is a function with two characteristics: being fluctuant and being short-term. $\Psi(x)$ is the function of wavelet, if and only if its Fourier transform $\Psi(\omega)$ satisfies the following term [14-15]:

$$\int_{-\infty}^{+\infty} \frac{|\Psi(\omega)|^2}{|\omega|^2} d\omega < +\infty \quad (1)$$

$\Psi(x)$ is the mother wavelet function. According to the following relation, the size and location of wavelet functions used in analysis will get changed by two mathematical operations of transfer and scale during the analyzed signal [16]:

$$\Psi_{a,b}(x) = \frac{1}{\sqrt{a}} \Psi\left(\frac{x-b}{a}\right) \quad (2)$$

$\Psi_{a,b}(x)$ is continuous wavelet function, b is transfer parameter and a is scale parameter. Finally, continuous wavelet transform of function $f(x)$ is obtained by the following relation [14-17]:

$$CWT(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(x) \Psi\left(\frac{x-b}{a}\right) dx = \int_{-\infty}^{+\infty} f(x) \Psi_{a,b}(x) dx \quad (3)$$

In signal analysis, another form of wavelet transform named discrete wavelet transform is used. In discrete wavelet transform, transfer and scale parameters are chosen non-continuously, such that:

$$a = 2^{-j}, b = 2^{-j}k \quad (4)$$

Where, j and k are integers. In conclusion, by replacing with a and b we have:

$$\Psi_{j,k}(x) = 2^{\frac{j}{2}} \Psi(2^j x - k) \quad (5)$$

Construction of two dimensional wavelets is the direct generalization of one dimension mode. As it was said, in this paper two dimensional discrete wavelet transform is used to obtain wavelet coefficients. Knitter et al. studied on concerned with defect detection in plate structures while considering the influence of external loads [18]. In another research, Knitter et al. investigated the defect detection using Discrete Wavelet Transform in rectangular plate structures [19-20].

3 NUMERICAL SIMULATION BY ANSYS

In this paper, A square plate with dimensions of (1000x1000) mm and thickness of 10mm subjected to clamped-clamped boundary conditions at all four edges is considered for this study. The plate is modelled with a commercial finite element program ANSYS. The characteristics of this plate has been assumed as follows: 1-dimensions: 1000x1000x10mm (distances and sizes all are in millimeter), 2-mechanical features: in whole test, the elasticity modulus has been considered as 2×10^9 Kg/mm², Poisson's ratio as 0.2, and density as 2.4×10^7 Kg/mm². 3-type of loading: fixed wide load, 4-supporting conditions: all considered plates are 4 sides clamped (of course it should be noted that in examination of crack depth effect, supporting conditions and the amount of wide load applied on plate, will change in order to compare with previous modes).

The considered damage is like 1 or 2 rectangular cracks with dimensions of 40mmx10mm and nearly in the middle of plate. For modelling plate, ANSYS 12 software has been used, that by conducting a static analysis on a plate, the response was obtained in considered modes. In this paper, crack depth effects and approaching of two rectangular cracks to each other on the considered plate are investigated.

3.1. Crack Depth Effect

If there is a crack in a structure or a structural member, this crack grows with time due to repetition of alternative loads or due to combination of load and effects of environment. By increase in crack length, more stress concentration will be made in it. By increasing stress concentration, the rate of crack extension speed will increase over time. In this section, by reducing the initial depth of crack which has been considered 9 millimeter, in addition to examination of crack depth effect on plate, the minimum depth that which wavelet can distinguish, can be obtained too. In "Fig. 1", the considered plate and also the location and shape of assumed crack on it has been shown.

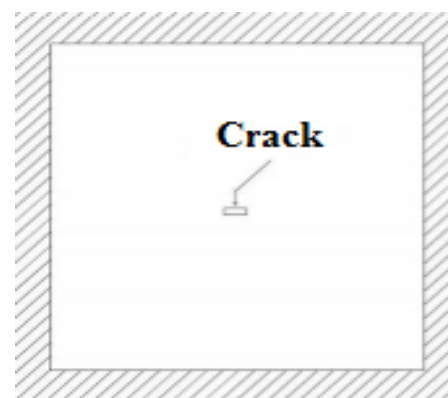


Fig. 1 Square 4 sides clamped plate and rectangular location of crack.

To investigate the crack depth effect on considered plate, 4 different depths are considered and with change in the condition of plate definition, two more modes are spotted too. In the following, the results are shown in form of graphs of wavelet coefficients (“Figs. 2 to 7”).

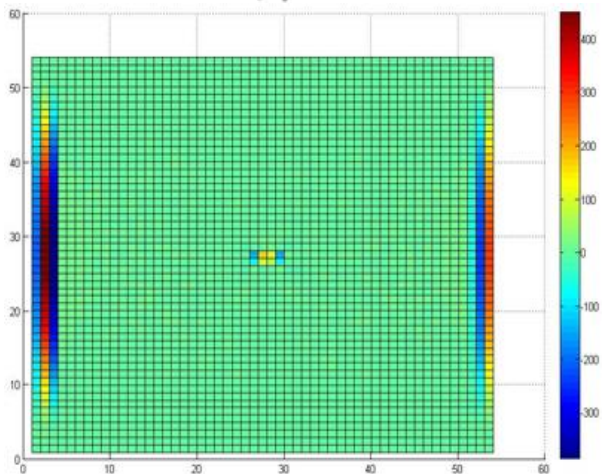
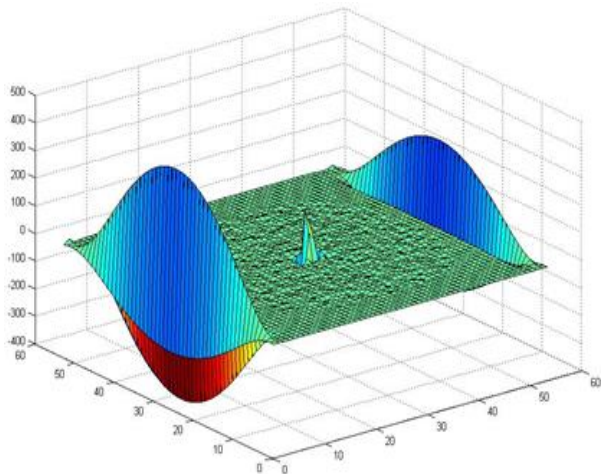


Fig. 2 Two and three dimensional demonstration of wavelet coefficients’ graph of given plate with crack of 9mm depth.

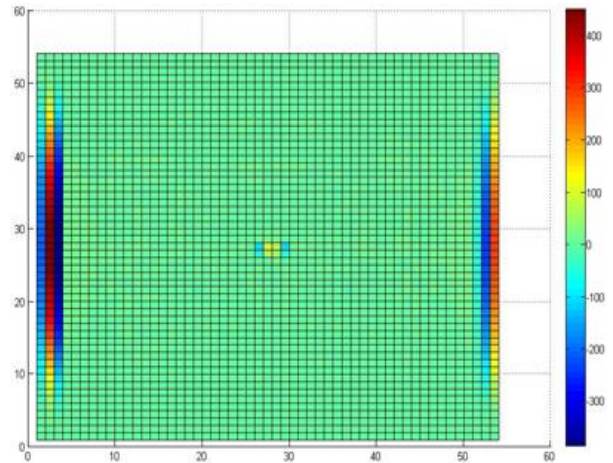
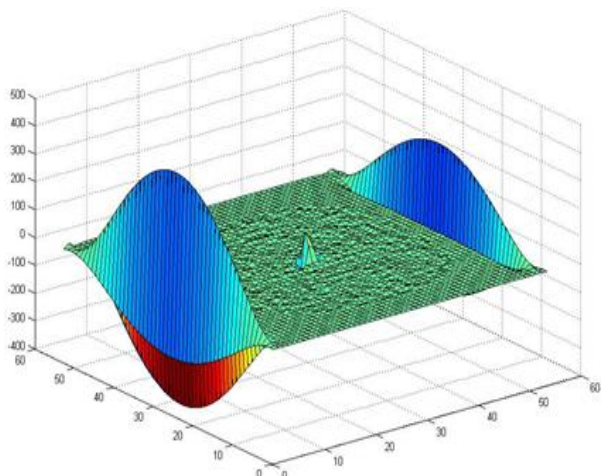


Fig. 3 Two and three dimensional demonstration of wavelet coefficients’ graph of given plate with crack of 5mm depth.

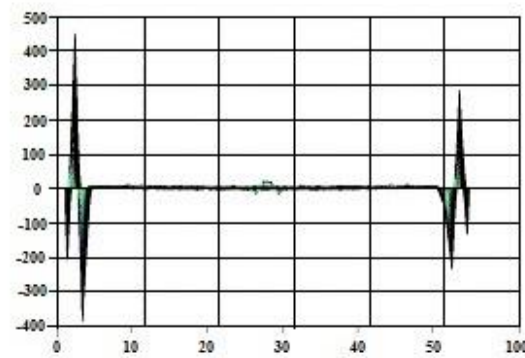


Fig. 4 Wavelet coefficients’ graph of given plate with crack of 1mm depth (the location of graph is clear as a ness in graph).

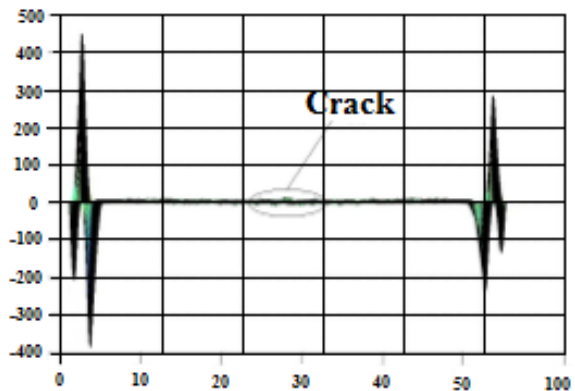


Fig. 5 Wavelet coefficients’ graph of given plate with crack of 0.5mm depth (the location of crack is evident as ness in graph).

The above results were obtained for 4 sides clamped plate, now for a plate of 4 sides joint and with wide loading of half of the last loading, 2 modes of the following modes is investigated for rectangular crack which is at the same condition.

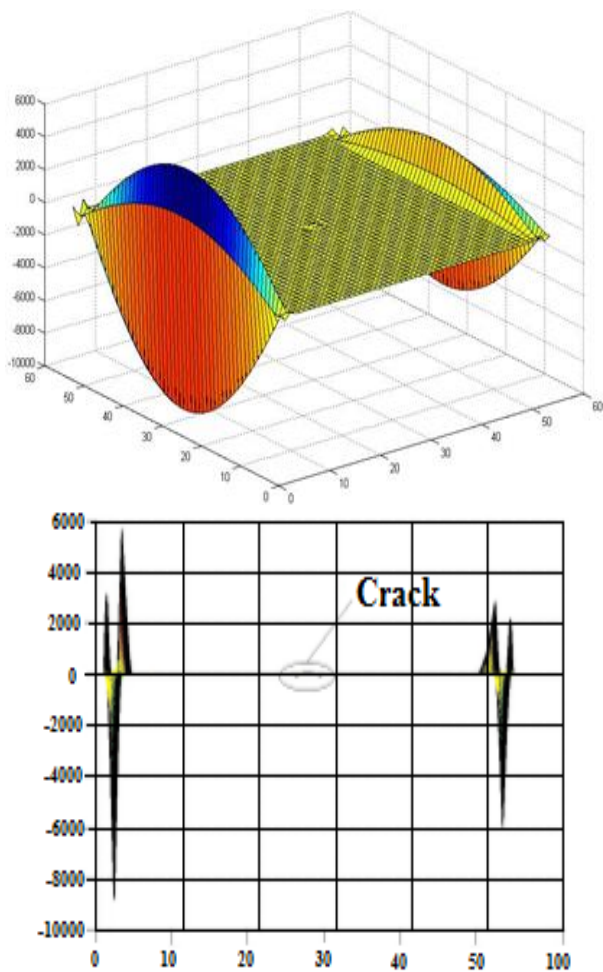


Fig. 6 Two and three dimensional demonstration of wavelet coefficients' graph of 4 side joint plate and with crack of 9mm.

3.2. Effect of Two Rectangular Crack Vicinity

In this part, as it has been shown in figure 7, two rectangular cracks have been considered which were attached to two supports opposite each other and the distance between cracks will be reduced during 4 phases. The dimension of each crack has been considered 40mm×10mm in this part. In the following, the results are shown in the form of graphs of wavelet coefficients.

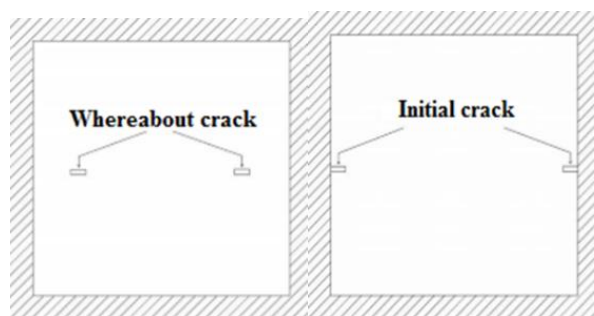


Fig. 7 Square 4 side clamped plate and reduction of rectangular cracks' distance on it.

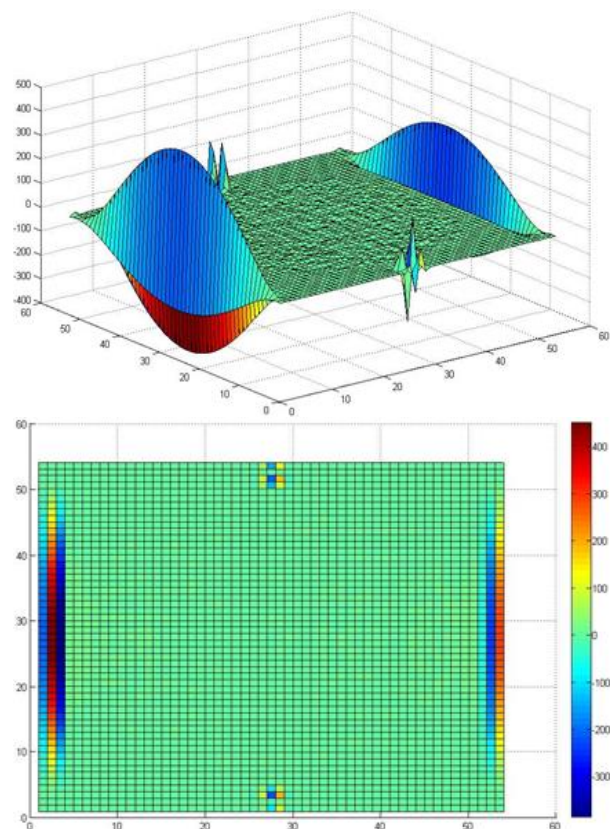


Fig. 8 Two and three dimensional representation of wavelet coefficients graph of given plate, with two rectangular cracks with depth of 8mm and attached to two opposite supports.

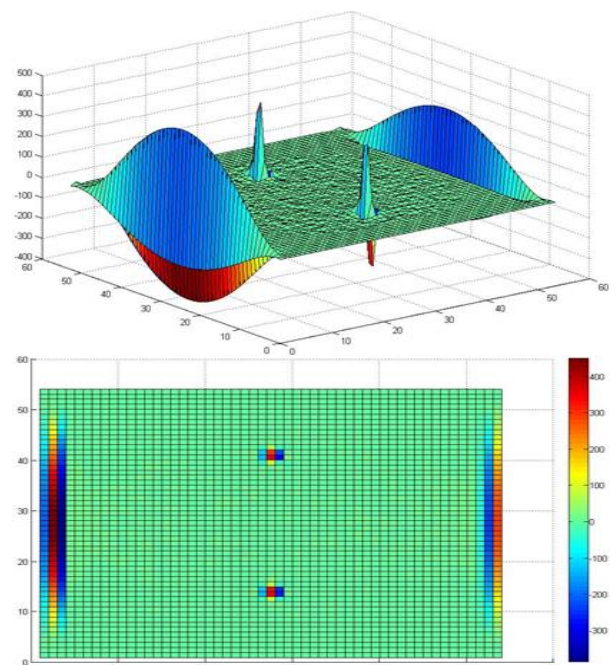


Fig. 9 Two and three dimensional representation of wavelet coefficients graph of given plate, with two rectangular cracks with depth of 8mm and distance of 500mm from each other.

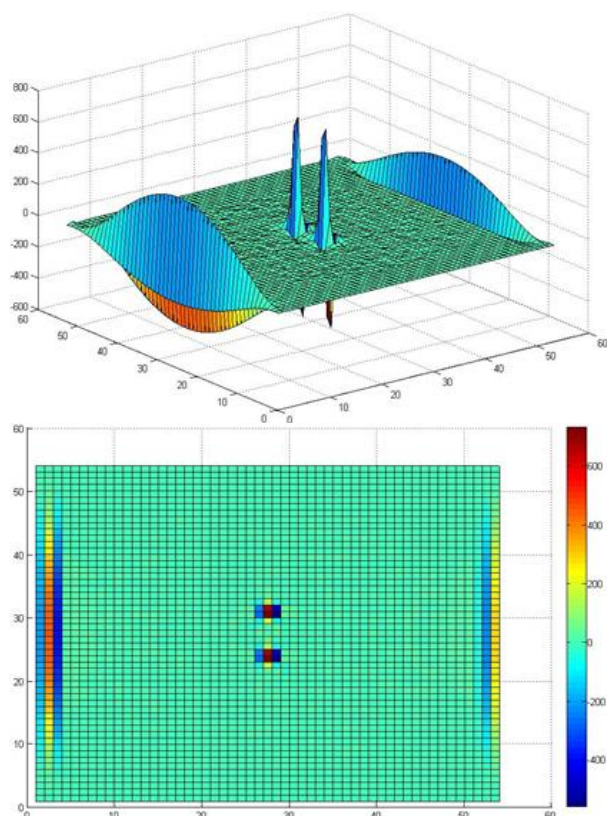


Fig. 10 Two and three dimensional representation of wavelet coefficients graph of given plate, with two rectangular cracks with depth of 8mm and distance of 100mm from each other.

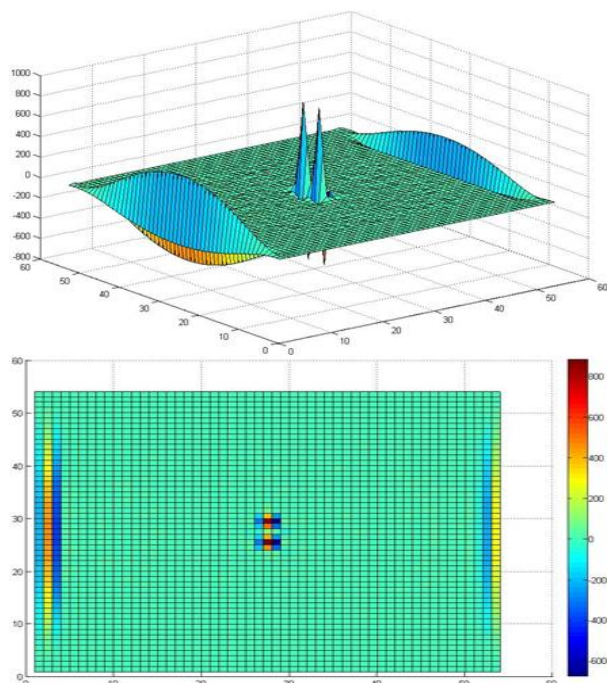


Fig. 11 Two and three dimensional representation of wavelet coefficients graph of given plate, with two rectangular cracks with depth of 8mm and distance of 40mm from each other.

4 CONCLUSIONS

By examination of obtained results from surveying crack depth effect, it can be concluded that:

-Wavelet transform not only distinguish the crack location very well, but also it can identify the increase or decrease in its depth.

-As the figures suggest, the severity of crack effect on a plate decreases by reducing crack depth.

-It seems that wavelet transform does not have the capability to recognize cracks with less than 0.5 millimeter depth.

-Among wavelet transform problems, one is the effect of end points on coefficients graph.

-In plates with supports of 4 side joints, crack location is recognizable too, but it seems that increase or reduction of crack depth cannot be identified.

-Turbulences and noises around crack location will be removed totally in plates with supports of 4 side joints in comparison to plate with supports of 4 side clamped (which is significant and may cause problems).

By investigation of obtained results from studying the effect of two rectangular crack vicinity, it can be concluded that:

-Wavelet transform, not only recognize the location of two cracks very well, but also it shows the reduction of their distance compared to previous mode and also the effect of this reduction on plate.

-It can be concluded that the reduction of two cracks distance will increase the severity of their effect on plate.

-For cracks near to supports or attached to them, the effect of endpoints and crack effect will interfere with each other and may bring about some problems in distinguishing crack.

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