Damage detection in composite plate based on vibration Measurements using Genetic Algorithm

Rafal Taha Abdulhussein
Mechanical Eng. Dep.
Al-Nahrain University
rataha6914@gmail.com

Muhammad A.M.
Mechanical Eng. Dep
Al-Nahrain University
m1976sjnr@gmail.com

Abstract

The effect of defect on structures and machines has negative consequences on them and it always takes researchers concern and attention in order to find feasible solutions to trace and detect the location of the defect accurately.

In this research, the effect of a hole with different diameters on a square composite plate is studied as well as the effects of both the boundary condition and the plate thickness, furthermore, Vibration analysis of composite plate has been studied numerically and experimentally. The Numerical analysis has been carried out by using FEM by building MATLAB program **as well as (ANSYS 15).** The experimental part of this research is done by using vibration measuring instruments. The rate of error among the experimental tests and the numerical solution is less than 15%. These results have been used an inputs to the Genetic Algorithm model that the defect is located by, with a high percentage of success.

Keywords: Data management, experimentation.

1. Introduction

Composite laminated structures has been widely used in different fields of our life like aerospace, marine, mechanical and civil industries. The main causations for this trend are the prominent mechanical properties of composite, such as high strength to weight ratio, excellent corrosion resistance and very good fatigue characteristics however, laminated composites structures are susceptible to damage, which may external or internal These defect can observed by using nondestructive inspection (NDI) techniques. The main challenge in NDI applications is to design a structural health monitoring system that is capable of detecting the damage existing in the structure without prior information about the location of the damage. **Z. Zhang, K. Shankar, M. Tahtali 2010 [1]** The ultimate goal of this study is to improve a Structural Health Monitoring (SHM) system depending on vibration measurements and to identify, localize and evaluate the damage caused by delamination in composite structures by using Finite element modelling. Modal-analysis has been applied to the free FE model for the estimation of Eigen frequencies whereas transient-analysis is used to calculate natural frequencies from the constrained model. **M. I. Friswell 1998[2]** established a method that is depending on the combination of usage of Eigen-sensitivity and genetic algorithms (GA) to detect position and severity of damage by utilizing vibration measurements .The goal is to pinpoint the location of one or more damage, and to calculate the severity of the damage. The discrete damage variables are optimized by using GA. **Raich and Liszkai 2003 [3]** suggest a method to detect damage depend on frequency measurements that uses genetic algorithm. The damage is modeled and simulated by means of damage indices that are valued between 0 and 1. The detection of damage is expressed as an optimization issue representing the reductions of stiffness in elements. **M.-Taghi and V.-Baghmisheh et. al. 2008 [4]** delivered an identification formula concerning the position and depth of crack in a cantilever-beam as a matter of optimization, moreover binary and continuous genetic algorithms are used to optimize the location and severity by the variance of measured and calculated frequencies **Seyed A. Ravanfar, Hashim A., et. al.2015 [5]** express a detection of damage tactic by using two- step that are depend on multi-resolution wavelet analysis and genetic algorithm (GA). The crack location is recognized in (1st) step by outlining the damage-index that is called "relative packet of wavelet entropy". In the 2nd step, the severity of the damage at the detected locations is evaluated using GA**. Mares and Surace 1996[6]** used a Genetic Algorithm to detect damage in elastic structures.in this study the objective function to be minimized was an improved version of residual force vectors in terms of the stiffnessmatrix of the damaged structure whilestiffness decrease factors of all elements werechosen to be variables. **Aveen A., Nabil H. Hadi 2009 [7]** show that a genetic algorithm has been implemented to identify damage in curved-beam model, stiffness and mass-matrices for curved-beam elements is expressed by means of the principle of Hamilton. The damage identification is expressed as optimization trouble, (binary) and (continuous) genetic algorithms are implemented to identify and trace the damage by two objective-functions (natural frequencies changes and Modal Assurance-Criterion MAC). **Seth S. Kessler, S. Mark Spearing, et. al. 2002 [8]** express the assessment and detection of damages in composite structures using both experimental and analytical methods. Based on the Changes in mode shapes and natural frequencies which are estimated using laser vibrometer, in addition to that a 2 dimensional finite element model has been used for the reason of comparing with the experimental results. **Nabil H. Hadi, Basim J. Hamood 2015 [9]** show that the usage of composite materials is greatly increased recently. Non-destructive test method is used in damage detection of composites. Detecting and localizing of delamination have been done depending on the vibration measurements of frequency and by using modal analysis. The model is endorsed be using experiments. **Felipe S. Almedia and Armando M. Awruch, 2007 [10],** presented an optimization technique, using a genetic algorithm, applied to plates and shell of laminate composite materials, two cases are analyzed. In the first case weight and central deflection of a plate under atransverse pressure load are minimized using as optimization variables thickness andthe fiber angle of each layer. In the second case, the stiffness maximization of cylindrical shell, under a transverse pressure load, and with geometrically nonlinear behavior, is obtained using as optimization variable the fiber angle of each layer**. N. Navabian, M. Bozorgnasab, R. et. al. 2014 [11]** deliberates new, modal measurements-depend detector of defects and damages. Modal analysis method has been used by this detector to estimate the vibration measurements by using MATLAB. The location of the damage is estimated by a numerical example that is deliberated with and without presence of the "noise" **Marco A. Péreza, Lluís G., Sergio O. 2015 [12]** in this paper, an investigation has been conducted concerning the feasibility of the implementation of vibrational methods regarding the identification of low-velocity impact damages of composite structures. An assessment of the resistance of the impact damage and the tolerance of ASTM test methods are conducted through the experimental program. The identification of the damage comprised the localization andevaluation. Many methods of damage detection have been used by previous researchers. The main part of these studies was the change in the natural frequencies which is considered as the most suitable method in damage identification. This work is considered as a complement of the previous studies besides it used a plate with a very small thickness (0.8 mm) that is rarely studied previously. In addition, the experimental natural frequencies used as input to genetic algorithm.

2. Experimental Work

An important part in the dynamic analysis of composite structure is the calculation of their natural frequencies. The composite materials used in this work are fiber reinforced polymer (FRP). The polymer (matrix) is epoxy and reinforcement is glass fiber. The imported laminates sheets were manufactured from the ready-made prepreg which consists of a combination of a matrix (or resin) and fiber reinforcement the fiber and resin (epoxy) fraction were supplied by the manufacturer. They are as follows: (by volume): glass fiber reinforced polymer (GFRP): 54% Fiber Glass, 46% Epoxy. It is available to usage in the component manufacturing process. The process of manufacturing the final composites laminate sheets are done by applying high temperature and vacuum pressure, which is called Vacuum Bag Oven Process. The Pressing cycle begins by heating up the oven to about 120°C, then the sheets were put inside the oven and continuing to heat up to about 190°C at a rate of 3-5°C/min. The cure time is more than 60 min with a pressure of 35 bar, As a result, the laminated sheets had a constant thickness, completely flat; the fibers distributed equally, excellent surface finish, and voids free. All the laminates sheets were imported from China.

The laminated sheets used in this work are classified as follow:

1- Glass Fiber Reinforced Polymer (GFRP) sheet (30 cm x 30 cm) with 6 layers of fiber glass prepreg. All the layers are plane woven, and the total thickness of the sheet is 0.8 mm.

2- Glass Fiber Reinforced Polymer (GFRP) sheet (30 cm x 30 cm) with 16 layers of fiber glass prepreg. All the layers are plane woven, and the total thickness of the sheet is 3.2 mm.

Table (1): presents the detailed properties laminate for all the composites which are used as An input data for the numerical models [13]

	GFRP6	GFRP16
E_x (GPa)	27.03	31.25
E_y (GPa)	27.03	31.25
E_z (GPa)	14.925	17.271
υ_{xy}	0.137	0.1375
υ_{yz}	0.386	0.3875
υ_{xz}	0.386	0.3875
G_{xy} (GPa)	4.699	5.44
G_{yz} (GPa)	4.708	5.45
G_{xz} (GPa)	4.708	5.45

Structural natural frequencies in this research measured by applying steady state, in the steady state method the structures are excited by a sinusoidal load. As shown in the figure (1)

Figure (1): set up for modal testing of a laminated plate

The damage structures studied in this work are of simple plates. Damage was made by drilling a hole of diameter (5 mm, 10 mm, and 15 mm) which placed at position (x=21 cm, y=21 cm) at element number 17 as illustrated in figure 10 . The accelerometer was placed in one of the specimens' quartersto overcome the overlap point.

4. Result and Discussion

4.1. Computer Programming

In this study, it was focused on the vibration behavior of different boundary conditions of laminates plates by using a computer code which is written in (**MATLAB 2014**) for the free vibration of composite laminated with and without damage by using the first order laminated plate theory, And **ANSYS (Mechanical APDL 15.0)** in which SHELL281 is used as an modeling element the results for the first six frequencies are listed in Table (2) & (3) and for the undamaged plate of thickness 3.2mm (16 layer) and 0.8 mm thickness (6 layer) that are predicted from the finite element (FE) model and comparing with ANSYS results. Figures (3) and (4) show the first five modes for different boundary conditions, figures (5), (6) and (7) show the compression between the two analytical results and experimental results accordingly the comparison shows that the frequencies estimated from these two programs are vitally close.

4.2. Damage Effects on Natural Frequencies

In the present investigation, both the numerical computation and experimental study are carried out for sixteen layered and six layered (0/90) woven glass fiber composite plate. The geometrical dimensions of the woven composite plates are: length, a =300 mm width, b = 300 mm, and two thicknesses, h = 3.2 mm and h=0.8 mm. The material properties of the woven glass fiber composite plates are considered as given in **Table 1**. Hole with diameters (5 mm, 10 mm, and 15 mm) was introduced at one of the quarters. In this study, the effects of hole, boundary conditions, and plate thickness on the natural frequencies are investigated. Figures (5), (6) and (7) give a comparison of the first six frequencies which is between experimental work and numerical work of the laminated plate with different boundary conditions.

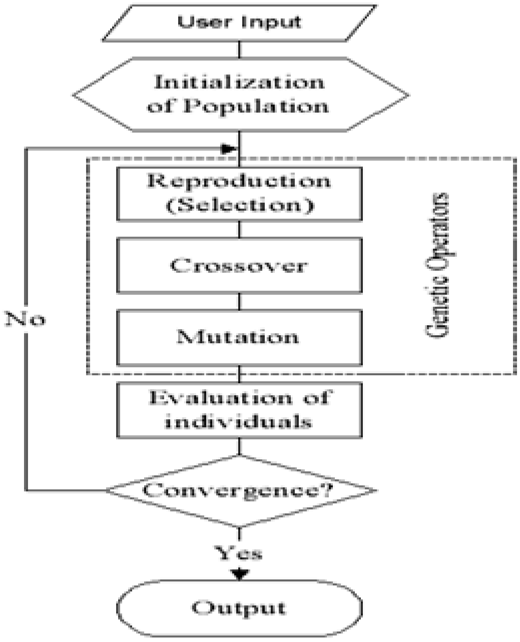


Figure (2) Schematic of genetic algorithm operators

These figures show good agreements between experimental and numerical works. The deviations for the numerical results and the experimental method are due to some doable measurement errors that can be indicated such as: measurement noise, different locations of the accelerometers and their mass, non-uniformity in specimens' properties (voids, variations in thickness, non-uniform surface finishing). Such factors are not taken into account throughout the numerical analysis, since the model considers the specimen perfect entirely with homogeneous properties, which seldom occurs in the practice. Also, the computational numerical programs differs in number of elements, the number of elements in ANSYS was 300 while in MATLAB was 25 element this lead to little difference between the two numerical results.

4.3. The effect of damage location on natural frequency

Also in this study we show the effect of damage position on natural frequency, it was found that the reduction in first mode for plate depends on the damage location from the fixed end figure (8).

4.4. The effect of plate thickness on natural frequency

Plate with two different thicknesses one 3.2 mm and other 0.8 mm was used in this work to study the effect of thickness on stiffness results shows that the thickness has greet effect on stiffness reduction because reducing in thickness will reduce the stiffness as shown in figure (9)

4.5. Damage Detection

The natural frequency used such as an indicative parameter in procedures of structural calculations using vibration monitoring. The benefit of use just eigenvalue in the damage detection because it is inexpensively acquired and the method can provide a cheap structural valuation technique. The objective function which is used to maximize is illustrated as follows.

$$\Delta\omega = \sum_{i}^{n}\left(\omega_i^m - \omega_i^a\right)^2 \quad \text{…. Equation (1)}$$

i :- Mode number (i=1,2,3,…..,n)

ω_i^m :-Test natural frequencies

ω_i^a :-Calculated natural frequencies

ωi the natural frequencies which are utilized to our damage detection system as inputs. The first natural frequencies are calculated experimentally and numerically using finite element model and ANSYS for the test damage element of the clamp for all side , clamp-free-clamp-free and clamp -free -free -free respectively for plate .Three hole cases (5mm ,10 mm,15 mm).The experimental frequencies were used as test input for GA. , A population of individuals is created arbitrarily after introducing the test natural frequencies which numerated for each chromosome, which coded the damage state, then the objective function equation (1) is evaluated for these chromosomes. Only best chromosomes are chosen to continue, and reproduction and mutation operator are applied on the chromosomes except the best chromosomes. Figure (2) show Schematic of genetic algorithm operators. The GA plot for clamp from all side, clamp-free-clamp-free and clamp-free-free-free boundary condition for 6 and 16 layer plates are shown in Figure (11), (12), (13), and (14) and, in figures the line graph shows the relation between number of generation and fitness function value. GA uses random values of damage location and magnitude until the fitness value became zero or near zero. The bar graph display two variables. The first bar represent the number of damaged element, while the second illustrate the damage magnitude. It was seen that there is good match between the damage location by genetic algorithm results table (4) and actual damage location which is located at element 17 figure (8).

Table (2): Natural Frequencies for the undamaged CCCC 16 layer plate using Matlab code and ANSYS APDL

Mode number	Natural frequency (Hz)		Error (%)
	ANSYS	MATLAB	
1	259.63	249.3819	3.94
2	532.64	519.0021	2.5
3	532.64	519.1952	2.5
4	749.94	730.9616	2.5
5	971.9	969.9096	0.2
6	975.37	973.2912	0.21

Table (3) Natural Frequencies for the undamaged CCCC 6 layer plate using Matlab code and ANSYS APDL

Mode number	Natural frequency (Hz)		Error
	ANSYS	MATLAB	
1	62.31	62.8528	0.86
2	129.56	131.8925	2
3	129.23	131.9386	2
4	203.39	186.0837	8.5
5	231.97	249.8464	7.7
6	238.27	250.6411	5.1

Table (4) the results of genetic algorithm for the damage location in 16 layer plate

	Diameter of hole (mm)								
	5			10			15		
Boundary condition	Actual Damage location	Location by GA	Error %	Actual Damage location	Location by GA	Error %	Actual Damage location	Location by GA	Error %
CCCC	17	17.5	0.02	17	17.5	0.02	17	19	0.1
CFCF	17	18	0.05	17	19	0.1	17	16.4	0.03
CFFF	17	17	0	17	17	0	17	17	0.02

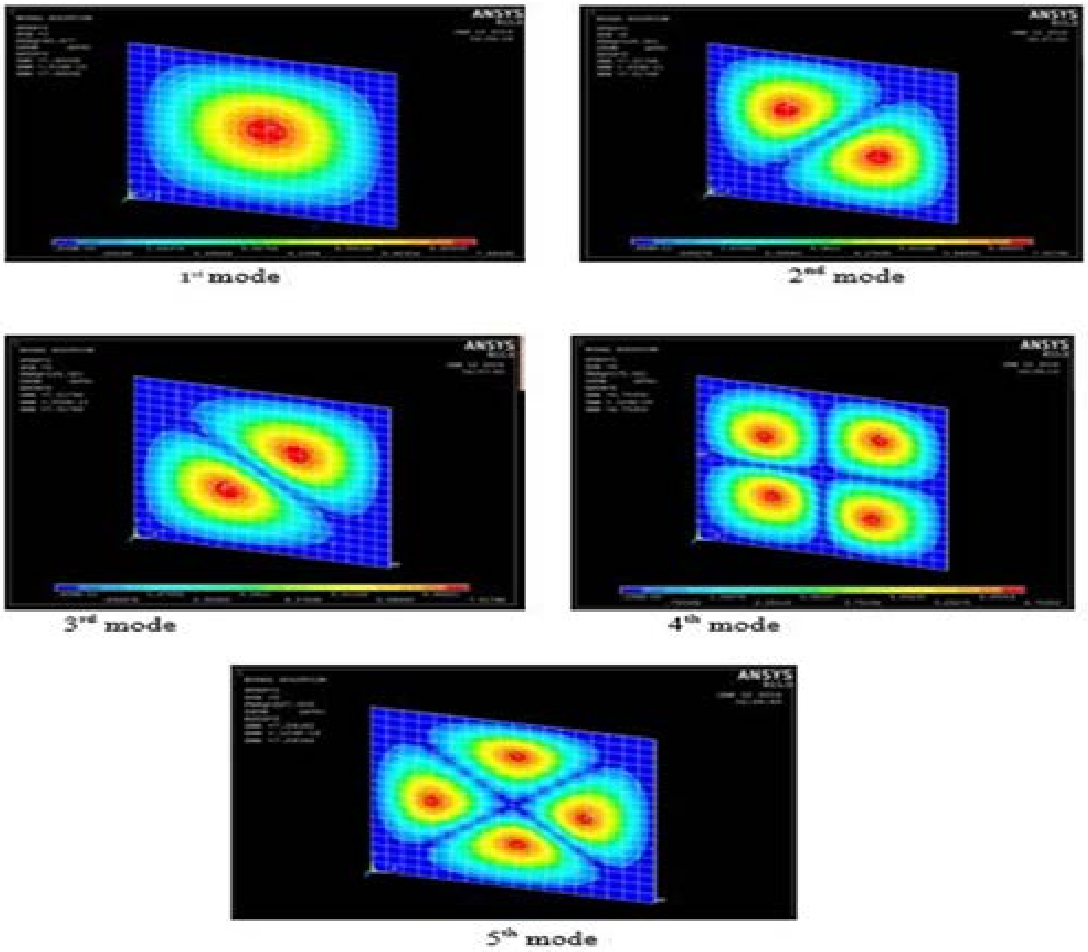


Figure (3) ANSYS results for five modes of undamaged 16 layer plate CCCC boundary conditions

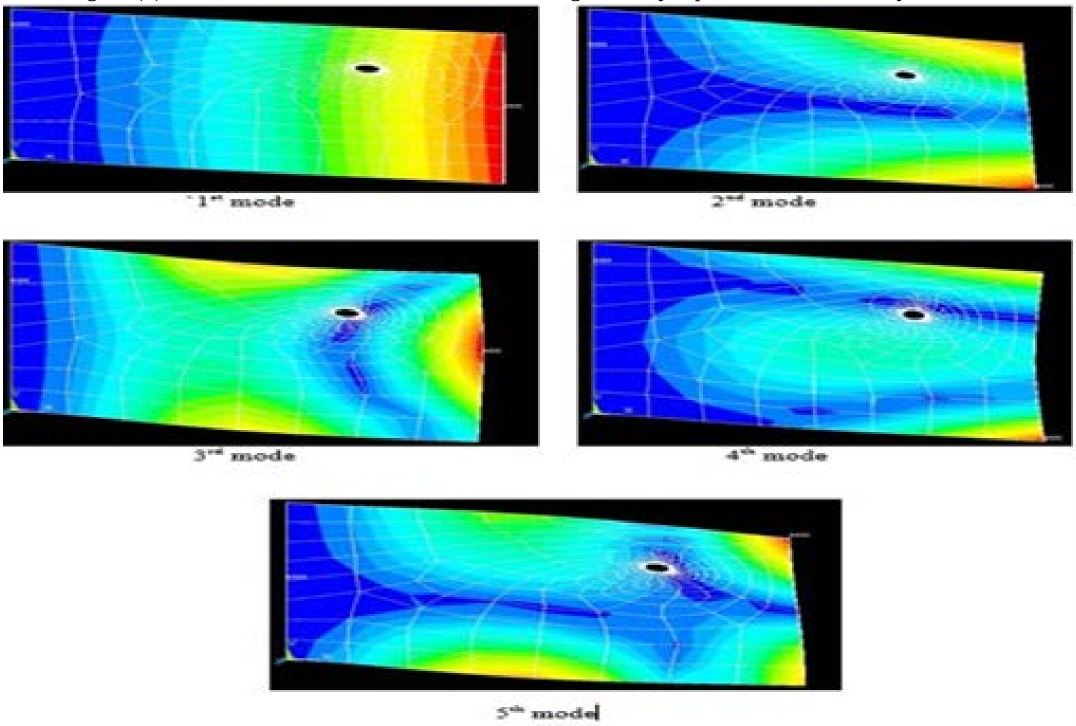


Figure (4) ANSYS results for fifth modes of 15 mm hole 16 layer plate CFFF boundary conditions

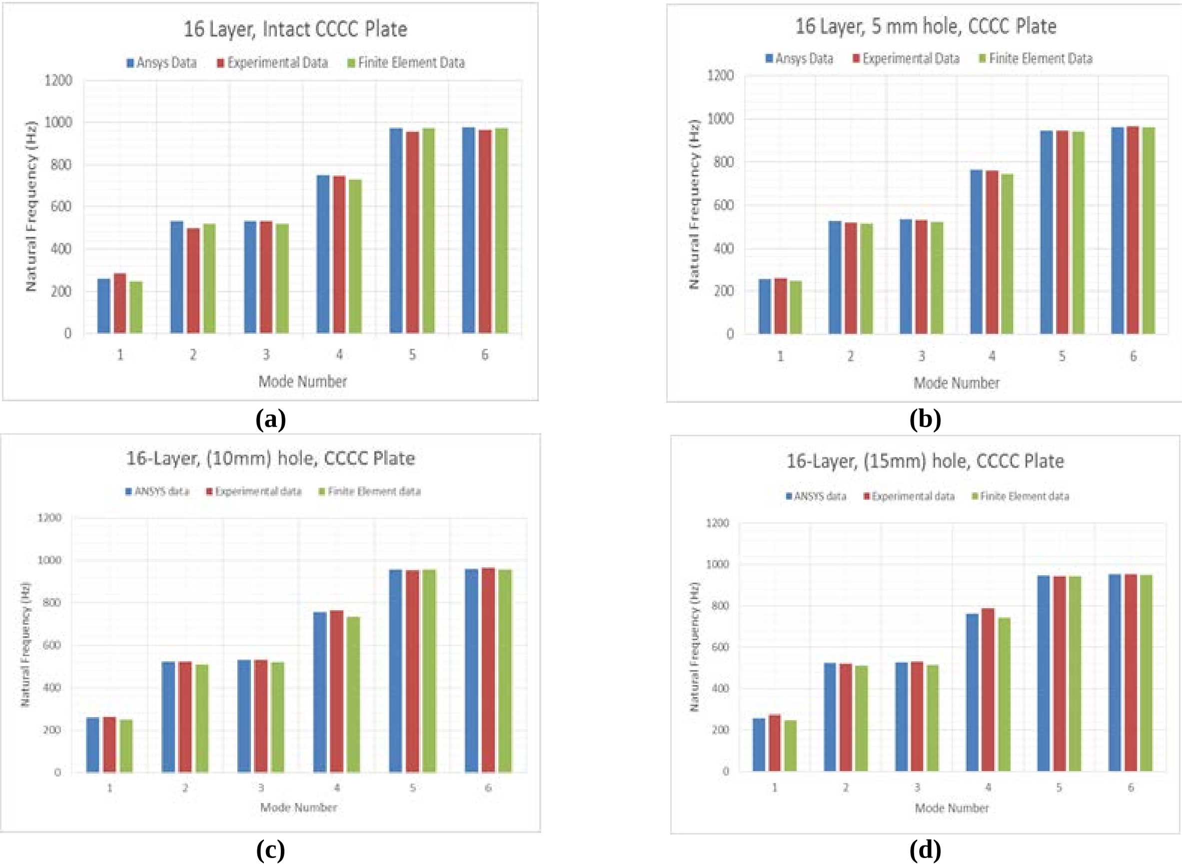


Figure (5): comparison among experimental, ANSYS, and Matlab natural frequencies 16 layer plate (a): intact, (b): 5mm hole, (c: 10mm hole, D: 15mm hole) for CCCC boundary condition

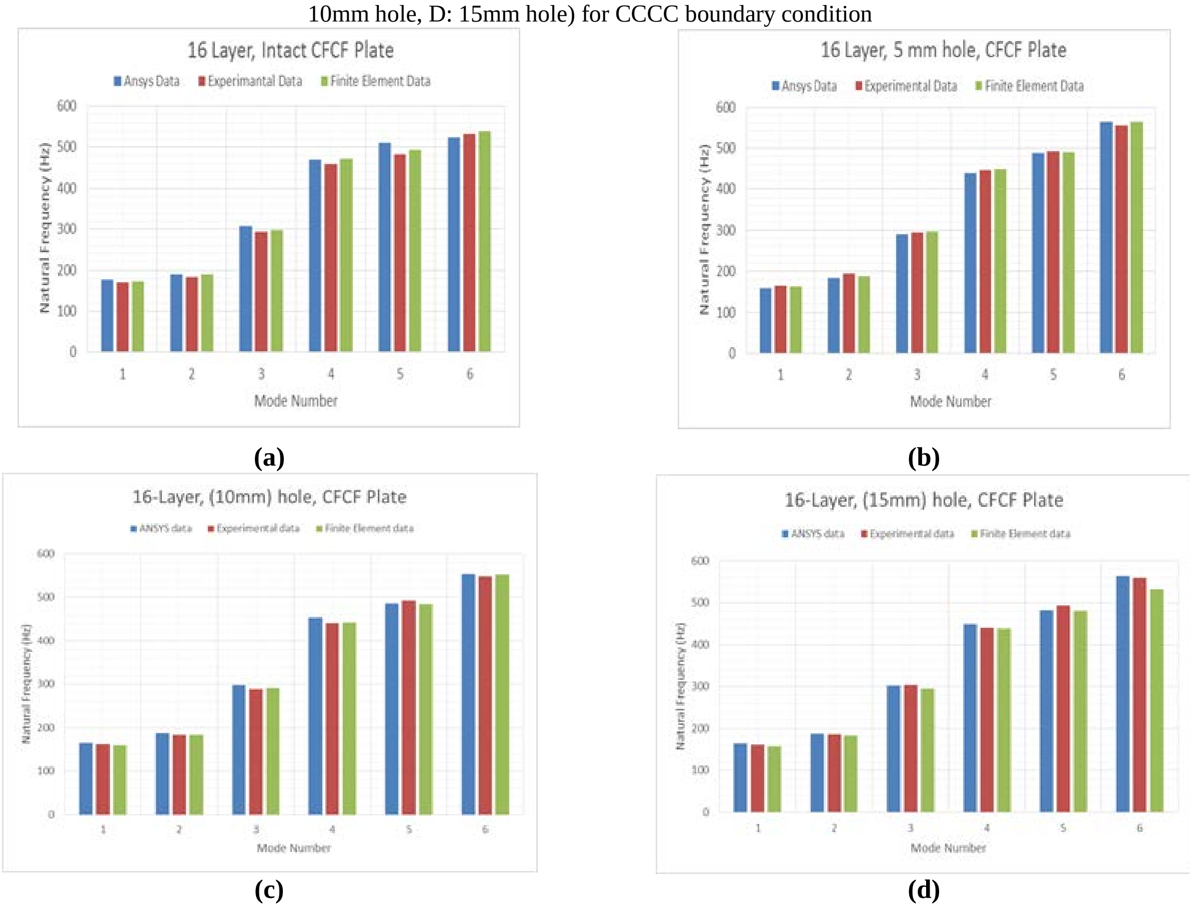
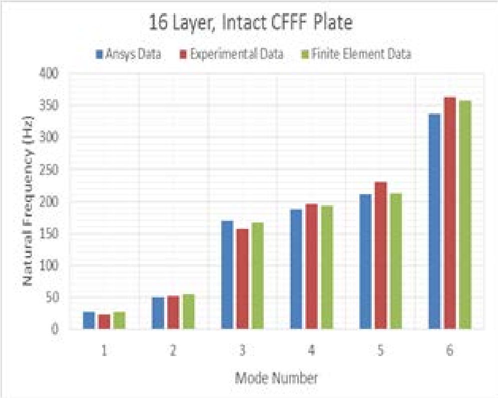
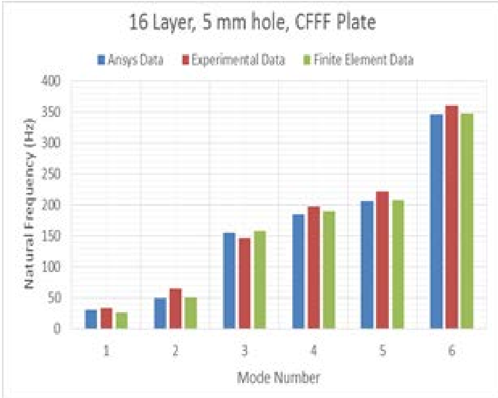


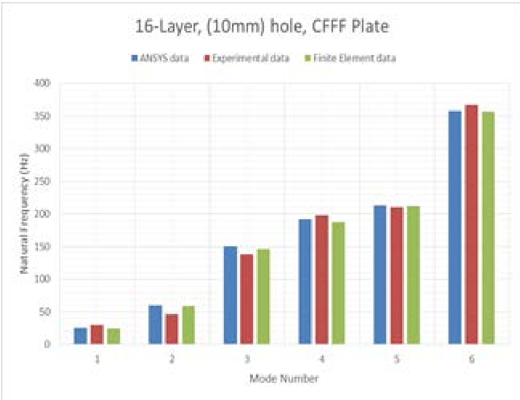
Figure (6): comparison among experimental, ANSYS, and Matlab natural frequencies 16 layer plate (A: intact, B: 5mm hole, C: 10mm hole, D: 15mm hole) for CFCF boundary conditions



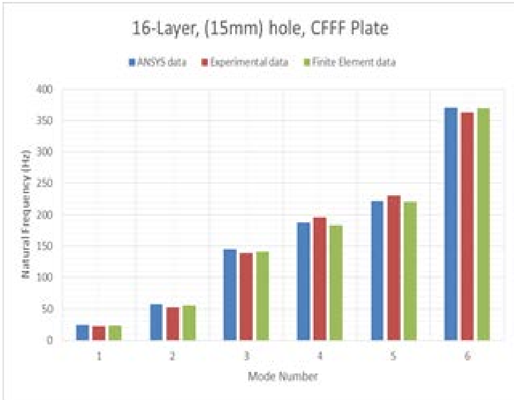
(a)



(b)



(c)



(d)

Figure (7): comparison among experimental, ANSYS, and Matlab natural frequencies 16 layer plate (A: intact, B: 5mm hole, C: 10mm hole, D: 15mm hole) for CFFF boundary conditions

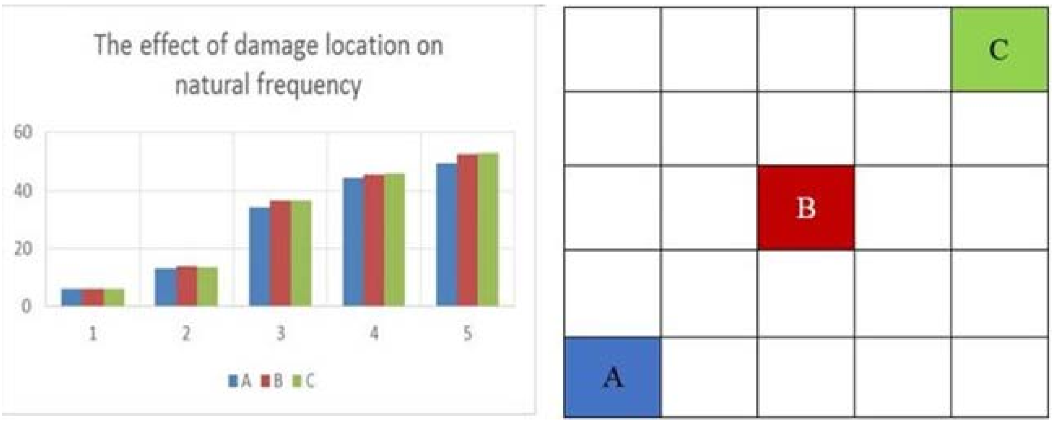


Figure (8): the effect of damage location on natural frequency of CCCC boundary conditions 6 layer plate

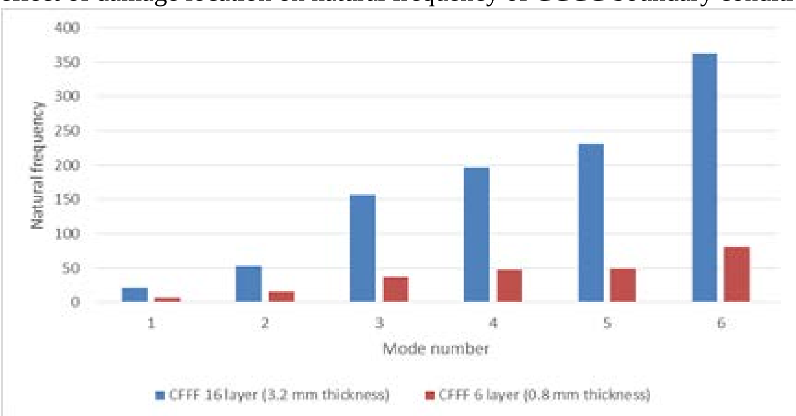


Figure (9): the effect of plate thickness on natural frequency of CFFF plate

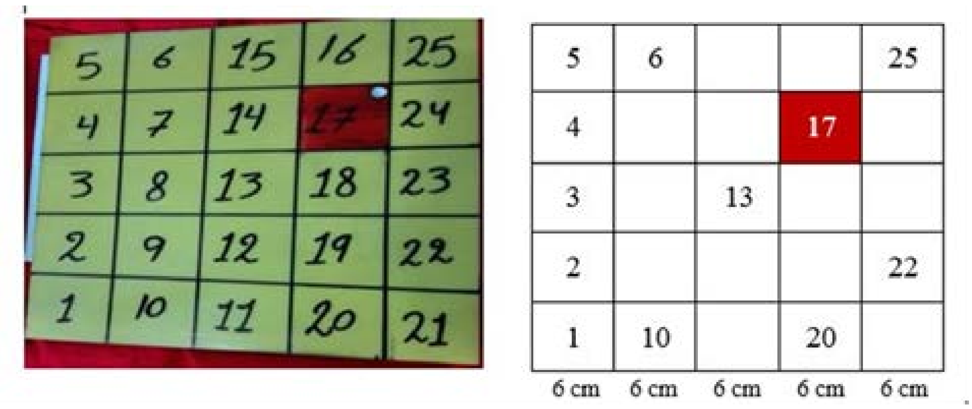


Figure (10): plate mesh for damage location

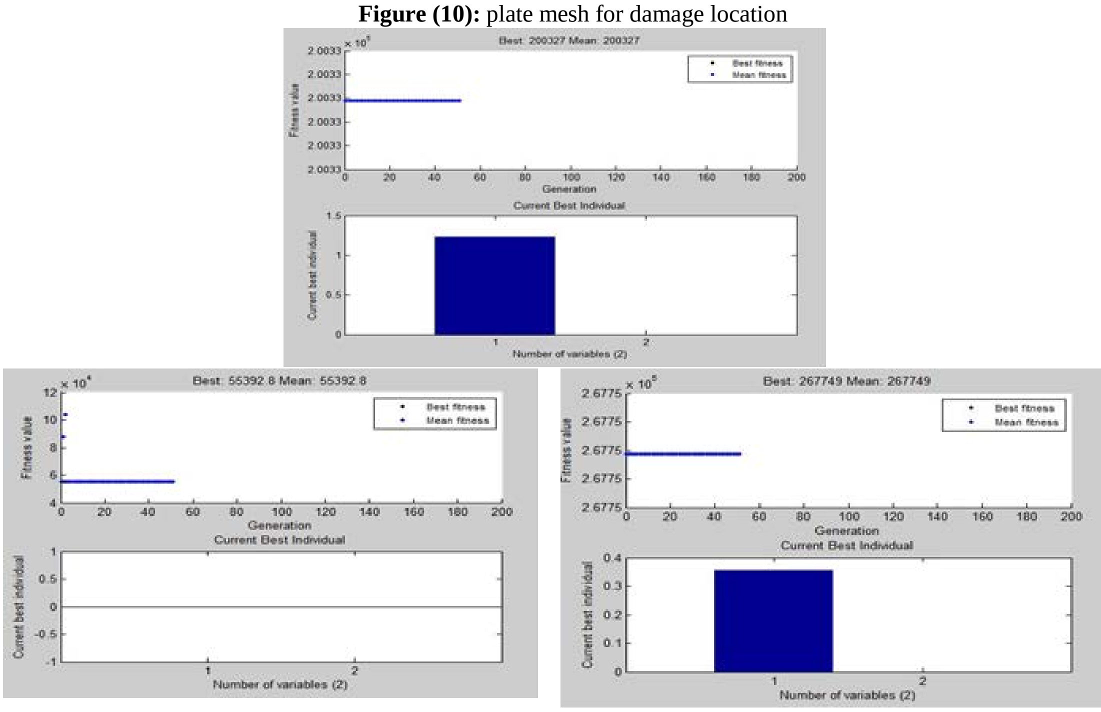


Figure (11) Genetic algorithm results for 16 layer intact plate, (A) CCCC, (B) CFCF, (C) CFFF boundary conditions

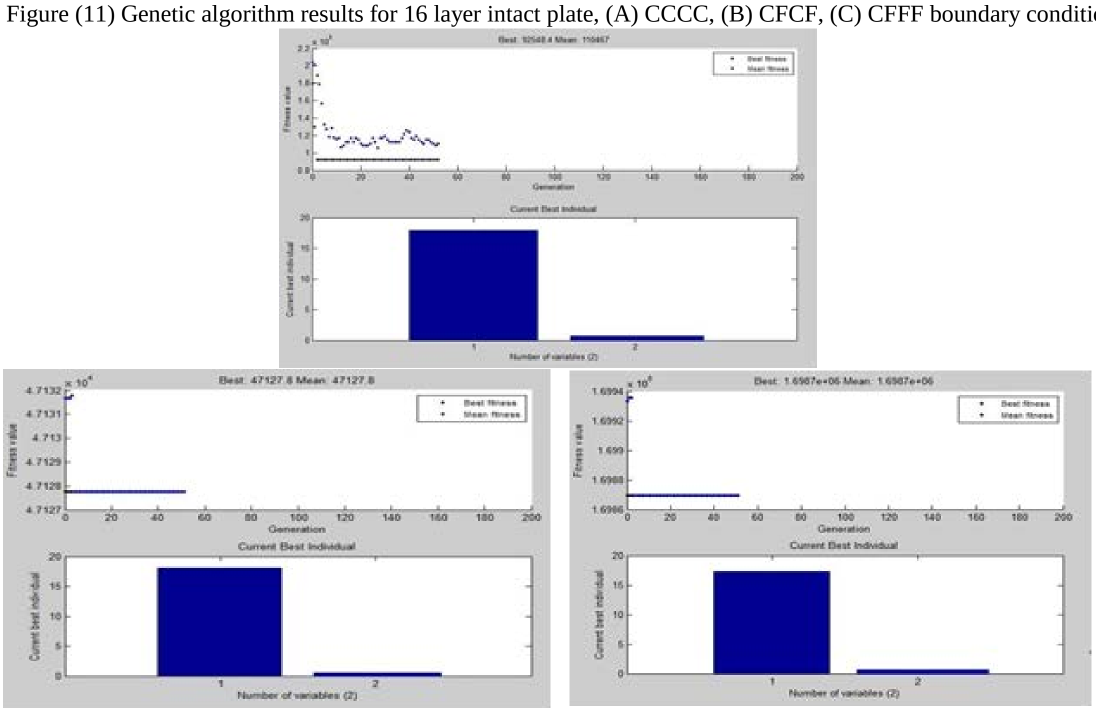


Figure (12): Genetic algorithm results for 5mm hole 16 layer plate, (A) CCCC, (B) CFCF, (C) CFFF boundary conditions

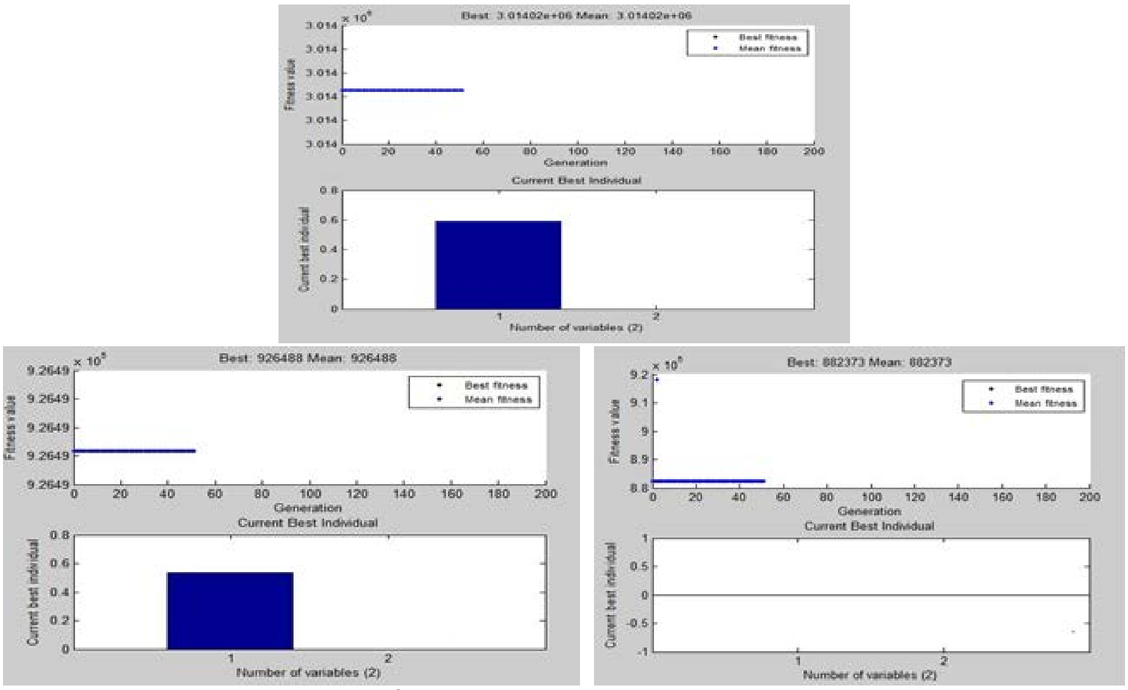


Figure (13) Genetic algorithm results for 6 layer intact plate, (A) CCCC, (B) CFCF, (C) CFFF boundary conditions

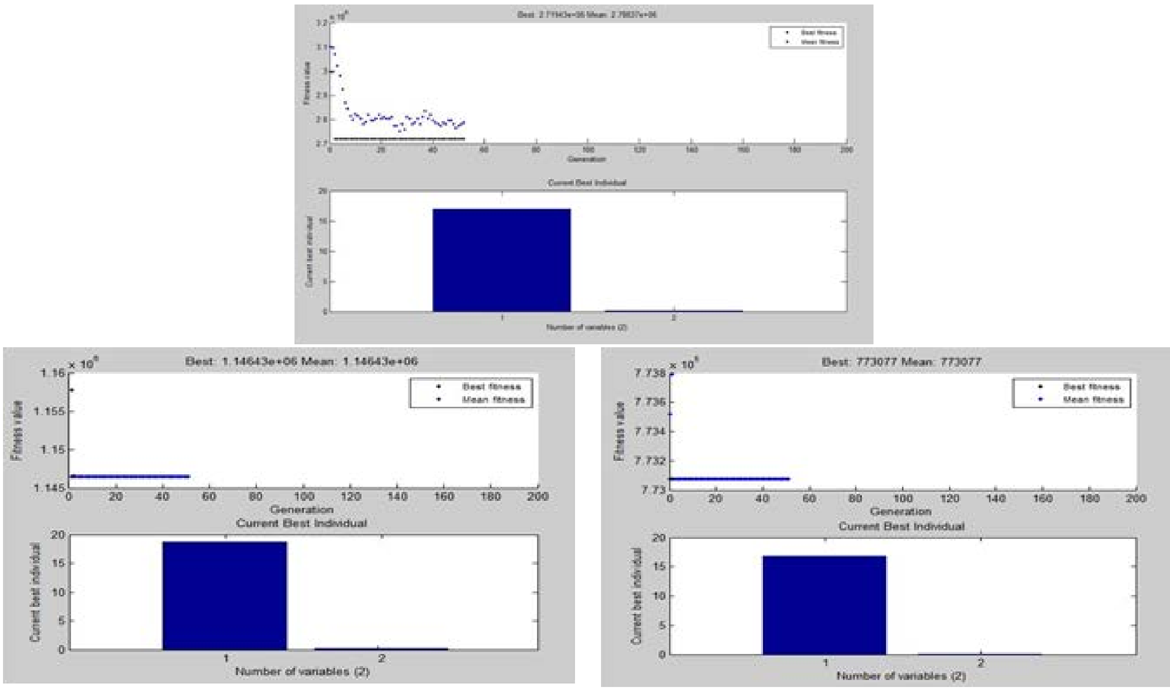


Figure (14) Genetic algorithm results for 15mm hole 6 layer plate, (A) CCCC, (B) CFCF, (C) CFFF boundary condition

5. Conclusions

The main conclusions of this work are:-

- Results show that genetic algorithm is an efficient method in damage identification for different boundary condition of structures with high precision and is capable of detecting small damage.
- The length of run (related to generation number) and results rely on the first randomly procreated population and genetic algorithm factors and the test point.
- The objective function based on variation in natural frequency is the greatest method used, because the stiffness decrease has a relatively large influence on the natural frequencies.
- The natural frequency effected by damage and size of damage and position.
- The number of layers, thickness of plate and boundary conditions affect in nature frequency and results show that the maximum difference in (CCCC) BC's and at 3.2 mm (16 layer) thickness of plate.
- Increase the diameter of hole reduces natural frequency of the plate.
- Whenever damage location close to the center of plate at increase the variation of natural frequency.

6. References

[1] Z. Zhang, K. Shankar, M. Tahtali and E. V. Morozov 2010 "Vibration Modelling of Composite Laminates with Delamination Damage" School of Engineering and Information technology", University of New South Wales at the Australian Defense Force Academy

[2] M. I. Friswell, J. E. T. Penny, S. D. Garvey (1998). "A combined genetic and eigensensitivity algorithm for the location of damage in structures". Journal of Computers and Structures. Vol. 69, Pages 547-556.

[3] Raich and Liszkai (2003). "Solving inverse problem in structural damage identification using advanced genetic algorithm representations" World Congresses of Structural and Multidisciplinary Optimization.

[4] Mohammad-Taghi Vakil-Baghmisheh, Mansour Peimani, Morteza Homayoun Sadeghi, Mir Mohammad Ettefagh (2008). "Crack detection in beam-like structures using genetic algorithms" Journal of Applied Soft Computing. Vol. 8, Pages 1150-1160

[5] Seyed A. Ravanfar, Hashim A., and Zubaidah I.2015 "A two-step damage identification approach for beam structures based on wavelet transform and genetic algorithm"

[6] W. M. Ostachowicz, M. Krawczuk and M. P. Cartmell (1996). "Genetic algorithms in health monitoring of structures", University of Glasgow

[7] Aveen A. abdulkareem 2009 "Damage Detection and Assessment in Mechanical Beams Using Genetic Algorithm", Baghdad University, M.Sc. Thesis

[8] Seth S. Kessler, S. Mark Spearing, Mauro J. Atalla, and Carlos E. S. Cesnik" Damage detection in a composite materials using frequency response methods"

[9] Nabil Hassan Hadi, Basim Jameel 2015 "Vibration Analysis of a Composite Plate with Delamination" Journal of Engineering 17264073: ISSN

[10] Felipe Schaedler de Almedia and Armando Miguel Awruch, 2007 "Optimization Of Composite Plates And Shells Using A Genetic Algorithm And The Finite Element Method", Journal of de Mecànica Computacional, Vol. (XXVI), pp. 372-385, October

[11] N. Navabian, M. Bozorgnasab, R. Taghipour, O. Yazdanpanah 29 September 2015 "Damage identification in plate like structure using mode shape derivatives"

[12] Marco A. Péreza, Lluís Gila, and Sergio Ollerb 2014 "Impact damage identification in composite laminates using vibration testing"

[13] Yassr Yaarb K."Investigation of Biaxial Fatigue Behavior of Fiber Reinforced Plastic Using Experimental and Numerical Techniques" 2014Ph.D. thesis

الكشف عن العيوب للصفائح المركبة باستخدام الخوارزمية الجينية معتمدا على قياسات الاهتزاز

رفل طه عد الحسين **محمد عبد الستار محمد**
قسم الهندسة الميكانيكية – كلية الهندسة – جامعة النهرين

الخلاصة

طالما كان تاثير العيوب سلبيا على الهياكل والالات لذلك فقد شغل هذا الموضوع اهتمام الباحثين وبات من الضروري ايجاد حلول ناجعة للكشف عن مواقع تلك العيوب.

في هذا البحث تمت دراسة تاثير ثقب متغير الحجم على صفيحة مركبة مربعة الشكل بضروف تثبيت مختلفة واسماك مختلفة حيث تم حساب الترددات الطبيعية للصفيحة عمليا ونظريا, الجانب النظري تم بواسطة التحليل العددي عن طريق برنامج (MATLAB 14) وبرنامج (ANSYS mechanical APDL 15) وتمت مقارنة نتائج كلى الجانبين العملي والنظري مع بعضهما واظهرت النتائج توافقا كبيرا اما الجانب العملي من هذا البحث تم باستخدام معدات قياس الاهتزازوكان معدل الخطا بين الجانبين العملي والنظري اقل من 15%. وقد استخدمت تلك النتائج كمدخلات للخوارزمية الجينية التي تم عن طريقها تحديد موقع الثقب بنسبة نجاح عالية.