EFFECT OF HOLE SHAPE ON FREE VIBRATION CHARACTERISTICS OF UNIDIRECTIONAL COMPOSITE PLATES.

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ABSTRACT

In this research, a free vibration of unidirectional composite laminated plate with different holes shape effect investigation is done experimentally and numerically. The natural frequency and deflection response of a unidirectional composite plate are studied with different holes shape effect as (rectangular or triangular or square or ellipse or circular shape, for simply supported and clamped composite laminated plate boundary conditions. This effect is studied for different shape cutout with the same area of different cutout shapes. The results of natural frequency evaluated by experimental work are compared with those evaluated by numerical method using a finite element method, (ANSYS program Ver. 14). The deflection of composite laminated plate with different holes effect is evaluated using finite element method.

The results showed that the maximum natural frequency of unidirectional composite plate occurs at the clamped supported boundary composite plate with circular cutout. The experimental results of natural frequency of composite plate with different cutout shape are compared with those obtained using FEM. The comparison of results showed that the maximum discrepancy between experimental and numerical natural frequency is about (14.85%).

الخلاصة :

في هذا البحث تم دراسة الاهتزاز الحر للصفائح المركبة الغير متماثلة الخواص المكونة من عدة طبقات بتأثير شكل الثقب بالأسلوبين العملي والعددي. تم دراسة التردد الطبيعي والانهيار للصفائح المركبة الناتج بسبب وجود ثقب وسط الصفيحة بأحد الأشكال (مستطيل أو مثلث أو مربع أو بيضوي أو دائري) للصفائح المثبتة بطريقة الإسناد الحر أو الإسناد الثابت للصفائح. أجريت هذه الدراسة بتأثير نفس المساحة للثقب المقطوع من الصفائح. تم مقارنة النتائج العملية للتردد الطبيعي مع النتائج التي تم ايجادها بالأسلوب العددي باستخدام طريقة العناصر المحددة باستخدام برنامج ANSYS الاصدار 14. أما حسابات نتائج الانهيار للصفائح المركبة بتأثير شكل الثقب أجريت باستخدام طريقة العناصر المحددة فقط.

بينت النتائج التي تم الحصول عليها ان اعلى قيمة للتردد الطبيعي تحدث للصفيحة المركبة الغير متماثلة الخواص المثبتة بصورة اسناد ثابت والمحتوية على ثقب على شكل دائري. اجريت عملية مقارنة بين النتائج العملية للتردد الطبيعي للصفائح المركبة مع النتائج العددية التي تم الحصول عليها بالأسلوب العددي باستخدام طريقة العناصر المحددة، وقد بينت المقارنة بان اعلى قيمة للتفاوت بين نتائج الأسلوب العددي والأسلوب العملي كانت بحدود (14.85%).

KEYWORDS

Holes, Plates, Vibration, FEM.

1. INTRODUCTION :

Cutouts are inevitable in structures. In actual applications, cutouts may exist in the composite parts, which reduce their strength, stiffness and inertia. Cutouts are structural requirements of many aeronautical, mechanical and civil structures. In aircrafts components (such as wing spars and ribs) cutouts are provided to reduce the weight, to lay fuel lines and electrical lines and for altering the resonant frequency of the structures. The designers often need to incorporate cutouts or openings in a structure to serve as doors and windows. These are also provided for access to and service of interior parts in aircrafts and in bridges having plated structures such as box girders. In liquid retaining structures cutouts at the bottom plate are needed for passage of liquid. Cutouts are required for ventilation as well, **Sanjib Kumar Dey (2012)**.

Muhannad Al-Waily(2013) presented an analysis of the natural frequency of composite laminated plate with different sizes and locations of delaminations through the longitudinal and the transverse directions of the composite plate in addition to the effect of the delamination through the thickness of the plate. The studied composite plate is made of woven reinforcement glass fiber and polyester resin with eight layers with different delaminations shapes through the plate. The natural frequency of woven composite plate is calculated by using experimental work for different aspect ratios and boundary conditions of the plate and is compared with numerical results by using the finite element method.

S. B. Singh et al (2012), presented an experimental investigation of the effect of cut-outs on the natural frequency and damping ratio of the plate. Composite laminates were made from unidirectional glass fiber with stacking sequence of [0/90]s. The comparison of natural frequency as well as damping coefficients has been made for composite laminate without cut-outs with those square cut-outs. In laminates, the square cut-outs edges were of size 20%, 30% and 40% of the edges of the laminate. The experimental results showed that natural frequency decreases while damping coefficient increases with increasing in the size of cut-out in the laminated plate.

A.R. Abu Talib et al (2013), presented the effect of cut-out hole on multi-layer of Kevlar-29/epoxy composite laminated plates and fiber orientation angle. An experimental procedure was developed to study the performance of these effects under quasi-static compressive and tensile load using a servo-hydraulic testing machine. The work involved an investigation on the variety of orientation angles of Kevlar-29 fiber. The ultimate load of failure for each Kevlar-29/epoxy laminated plates had been determined and specified the optimum angle orientation, and the load reduction due to the effect of fiber orientation angle ($+45^o/-45^o$) was low if compared with ($0^o/90^o$) orientation angle of fiber. To simulate this problem the researcher used Explicit Mesh for AUTODYN under ANSYS-12.1 software, where the researcher found that the results obtained via this simulation agreed reasonably well with the experimental results and the maximum difference between the experimental conditions and the simulation and it had the value of discrepancy 5.8%.

Husam Al Qablan et al (2009), evaluated the effect of various parameters on the buckling load of square cross-ply laminated plates with circular cut-outs. The parameters considered in this study are: (1) cut-out size (2) cut-out location (3) fiber orientation angle and (4) type of loading. Three types of in-plane loading were considered; namely, uniaxial compression, biaxial compression and shear loading. The reduction in the buckling load due to the increase of cut-out size was significant in the case for shear loading as compared to uniaxial and biaxial compression. For relatively small size cut-outs, a better performance was achieved if the cut-out is kept close to the edge of the plate, however, for relatively large size cut-outs, a higher buckling load is achieved if the cut-out is kept in the middle of the plate. Several other imperative findings based upon the various parameters were also presented.

One of the factors influencing the stiffness and stresses of the plate is the thickness ratio of the laminated composite plate. **SridharaRaju. V.V et al (2001)** focused on the evaluation of the effect of thickness ratio 'S' on the geometric nonlinear behavior of a four layered symmetric ($+45^o/-45^o/-45^o/+45^o$) skew bidirectional FRP laminated composite plate with a circular cut out at the geometric centre of the plate. The problem is modeled in ANSYS software and executed for satisfactory results by performing convergence of the finite element mesh. Results are obtained for a uniform transverse pressure of 0.5 MPa for seven different thickness ratios of the plate. The limitations of the linear assumption and the need for nonlinear analysis are stated.

In this work an experimental vibration study of different holes shape and size effects on natural frequency of unidirectional composite plate with different boundary condition are presented, and a comparison with numerical results of natural frequency for composite plate with different boundary condition are evaluated using finite element method (ANSYS program Ver. 14). Also, this research evaluated the effect of holes shape on the stress of composite plate with different boundary conditions using the finite element methods.

2.EXPERIMENTAL INVESTIGATIONS

The experimental work including the vibration test is done to calculate the fundamental natural frequency of unidirectional composite laminated plate with and without different hole shapes effect for different boundary conditions of composite plate. The shape effect on the natural frequency of unidirectional composite plate is studied with circular hole, rectangular hole, square hole, ellipse hole and triangular hole with different plate boundary conditions. The unidirectional composite plate samples used in the experimental part of this study with different holes and without hole are shown in the Fig. 1.

The dimensions of the composite plate used, are,

$$a_t = a\ (\text{Length of Plate}) + 10\ \text{cm}\ (\text{Supported})$$
$$b_t = b\ (\text{Width of Plate}) + 10\ \text{cm}\ (\text{Supported}) \qquad (1)$$

Where,

$$b = 24\ \text{cm},\ b_t = 24\ \text{cm} + 10\ \text{cm}\ (\text{Supported}) = 34\ \text{cm},$$
$$a = 24\ \text{cm},\ a_t = 24\ \text{cm} + 10\ \text{cm}\ (\text{Supported}) = 34\ \text{cm},$$
$$t = 5.5\ \text{mm} \qquad (2)$$

The holes are classified into five forms. The area of each hole was calculated to be one-tenth of the original area of the plate. The area of the plate was ($24\ \text{cm} * 24\ \text{cm}$) and the area of each hole was about (($64\ \text{cm}^2$)), as shown in Fig. 2,

1. Square hole area of the hole is calculated by ($\text{Area} = a_h * a_h$) so, $a_h = 8\ \text{cm}$.
2. Rectangular hole area is calculated by ($\text{Area} = a_h * b_h$) so, $a_h \approx 11.3\ \text{cm}, b_h \approx 5.65\ \text{cm}$.
3. Triangular hole area is calculated by ($\text{Area} = 0.5 * a_h * b_h$) so, $a_h = b_h \approx 11.3\ \text{cm}$.
4. Circular hole area is calculated by ($\text{Area} = \pi * (R_h)^2$) so, $R_h \approx 4.5\ \text{cm}$.
5. Ellipse hole area is calculated by ($\text{Area} = \pi * a_h * b_h$) so, $a_h \approx 6.4\ \text{cm}, b_h \approx 3.2\ \text{cm}$.

And, the weight required of composite plate samples can be calculated by,

$$\text{Weight of Fiber} = \rho_f * \forall_t * \forall_f$$
$$\text{Weight of Resin} = \rho_m * \forall_t * \forall_m$$
$$\forall_t = a_t * b_t * t \qquad (3)$$

Where, $\forall_f, \forall_m$ are volume fraction of reinforcement fiber and resin materials, respectively.And, ρ_f, ρ_m are mass density of unidirectional fiber and polyester resin, respectively, defied experimentally as, **Muhsin J. Jweeg et al (2012)**,

$$\text{Density of unidirectional Glass Fiber} \approx 2750\ \text{kg/m}^3$$
$$\text{Density of Polyester Resin} \approx 1000\ \text{kg/m}^3 \quad (4)$$

Then, the weight required of unidirectional reinforcement glass fiber and polyester resin for composite plate samples, with volume fraction of unidirectional reinforcement fiber of 30%, are,

$$\text{Weight of Unidirectional Fiber} = 524.5\ \text{g}$$
$$\text{Weight of Resin Materials} = 445\ \text{g} \quad (5)$$

The vibration of unidirectional composite plate with different holes effect samples are studied with different boundary conditions, as shows in the Fig. 2, as,

1. Simply supported along all edges (SSSS).
2. Clamped supported along all edges (CCCC).

The composed parts of the vibration structure rig, shown in the Fig. 3, are,

1. Structure to support the plate sample,
2. Support of the fixed plate sample.
3. Impact hammer tool, model (086C03) (PCB Piezotronics vibration division), with the information about measurement range (2224 N), resonant frequency (≥ 22 kHz), excitation voltage (20 to 30 VDC), constant current excitation (2 to 20 mA), output bias voltage (8 to 14 VDC), discharge time constant (≥ 2000 sec), hammer mass (0.16 kg), head diameter (1.57 cm), tip diameter (0.63 cm), and hammer length (21.6 cm).
4. Accelerometer, model (4371), with the information; lower frequency (determined by the amplifier used), upper frequency limit (+10%) (12.6 kHz), mounted resonance frequency (42 kHz), and weight (11 g).
5. Amplifier, type 7749, the amplifier measures the response signal from accelerometer and gives output signal to the digital storage oscilloscope.
6. Digital storage oscilloscope, modal GDS-810, with the information; maximum frequency (100 MHz), maximum read of sample per second (25 GS/s), FFT spectrum analysis, and two input channels, this digital storage oscilloscope system can be driven with a computer (by using the RS-232 serial connection).

The response signal is read from the digital storage oscilloscope then a fast Fourier transform (FFT) is applied on this signal by using Sig-View program to get the fundamental natural frequency of the studied plates with different parameters, as shown in the Fig. 4. Where, the signal analysis with FFT function of different holes shape for different boundary conditions composite plate are shown in Fig. 5. The flow chart in Fig. 6 shows the sketch of the vibration structure rig shown in Fig. 3.

The natural frequency results of unidirectional composite plate with different holes shape, with same holes area, and different boundary conditions, clamped and simply supported plate, obtained from experimental work are compared with natural frequency of composite plate results obtained from numerical results by using finite element method using ANSYS program ver. 14.

Where, the mechanical properties of unidirectional composite plate with 30% unidirectional reinforcement fiber glass and 70% resin materials are, **Muhsin J. Jweeg et al (2012)**,

$$\text{Modulus of elasticity in } 1-\text{direction} = E_1 = 31.16\ \text{Gpa}$$
$$\text{Modulus of elasticity in } 2-\text{direction} = E_2 = 5.34\ \text{Gpa}$$

$$\begin{aligned}&\text{Modulus of Rigidity in 1,2} - \text{direction} = G_{12} = 1.96 \text{ Gpa}\\&\text{Density} = \rho = 1525 \text{ kg/m}^3\\&\text{Poisson's Ratio} = \nu = 0.355\end{aligned} \tag{6}$$

3.NUMERICAL INVESTIGATION

The numerical study of different composite laminated plate with cut-out shape effect on deflection and natural frequency of unidirectional composite plate evaluated by using the finite elements method was applied using the ANSYS program (ver. 14). The three dimensional model was built and the element (Shell 8 node 281) was used. Shell 281 is suitable for analyzing thin to moderately-thick shell structures. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes. (When using the membrane option, the element has translational degrees of freedom only.)

Shell 281 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. The element accounts for follower (load stiffness) effects of distributed pressures. Shell 281 may be used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first-order shear-deformation theory (usually referred to as Mindlin-Reissner shell theory). The element formulation is based on logarithmic strain and true stress measures. The element kinematics allow for finite membrane strains (stretching). However, the curvature changes within a time increment are assumed to be small.

The Fig. 7 shows the geometry, node locations, and the element coordinate system for this element. The element is defined by shell section information and by eight nodes (I, J, K, L, M, N, O and P). Shell 281 can be associated with linear elastic, elasto-plastic, creep, or hyper-elastic material properties. Only isotropic, anisotropic, and orthotropic linear elastic properties can be input for elasticity. Hyper-elastic material properties can be used with this element.

4.RESULTS AND DISCUSSION :-

The experimental and numerical work is done on several sheets composed of composite materials made of longitudinal glass fiber with polyester resin. The effect of the hole on the natural frequency and deflection and offsets in the plate were studied.

The studied unidirectional composite plate was of 30% unidirectional fiber and 70% polyester resin. The mechanical properties used obtained as in Eq. 6, and the holes shape studied are (rectangular, triangular, square, ellipse, and circular holes). The value of natural frequency of composite plate with holes shape effect is estimated by experimental work and compared with numerical finite element results. The deflection of composite plate is evaluated with effect of holes shape by finite element method. The effect of holes shape is studied for same cutout area for different holes shape. The results of natural frequency evaluated with experimental work for different holes shape effect and the comparison with results evaluated by using numerical method were shown in Table 1, for simply supported and clamped supported plates. The comparison between experimental and numerical natural frequency results is shown in Figs. 8 and 9 for clamped supported and simply supported unidirectional composite plate with different holes shape effect, and, the comparisons between simply supported and clamped supported natural frequency experimental results of unidirectional composite plate is shown in Figs. 10 and 11.

The results of natural frequency showed that the maximum natural frequency of composite plate with cutout shape effect occur with circular cutout shape for clamped supported composite plate. The minimum natural frequency occurred with square cutout shape for simply supported composite plate. Since, the stress distribution of the plate with circular cutout are more uniform from stress distribution of plates with other cutout shapes. Then, the strength to weight ratio with circular cutout shape is more than the strength to weight ratio of plates with other cutout shapes. And, the plate with square cutout shape, has the strength to weight ratio less than the strength to weight ratio of the plates with the other cutout shape.

Figs. 12 to 14 show the displacement distribution in the x, y, and z-directions, respectively, of clamped supported unidirectional composite plate without and with different cutout shapes. The maximum displacement in x-direction occurred with circular cutout shape but the minimum displacement occurred with rectangular cutout shape, and, the maximum displacement in y-direction occurred with circular cutout shape but the minimum displacement occurred with rectangular cutout shape. The maximum displacement in z-direction occurred with circular cutout shape but minimum displacement occurred with square cutout shape.

5.CONCLUSIONS :-

1. A comparison is made between the experimental investigation results of natural frequency of unidirectional simply and clamped supported composite plate with different cutout shapes effect and the numerical results of finite element study; using FEM. This comparison showed that the maximum discrepancy between the experimental and the numerical results is about (14.85%).
2. The value of natural frequency of unidirectional clamped supported composite plate with circular cutout shape is more than the value of natural frequency of composite plate with other cutout shapes. And, the value of natural frequency of square shape cutout of simply supported composite plate is less than the value of natural frequency of plate with other cutout shapes.
3. The effect of circular cutout shape on the deflection of unidirectional clamped supported composite plate structure is more than the effect of other cutout shapes, and the minimum cutout shape effect on the deflection of composite plate occurred when the cutout is rectangular cutout shape, with the same cutout area.

Table 1. Experimental and Numerical Natural Frequency (rad/sec) Results for Simply Supported and Clamped Supported Composite Plates with Different Holes Shape Effect.

ShapeNumber	Shape Name	Clamped Supported Plate			Simply Supported Plate		
		Exp.	Num.	Error (%)	Exp.	Num.	Error (%)
1	None	225.5	235.5	4.11	213.8	212.1	0.81
2	Rectangular	208.98	237.67	12.07	247.07	263.63	6.28
3	Ellipse	240.23	262.5	8.42	233.36	235.17	0.76
4	Triangle	231.4	264.45	12.49	208.4	244.35	14.71
5	Circular	247.07	278.4	14.84	232.4	270.46	14.07
6	Square	234.86	270.4	13.114	195.8	179.04	9.36

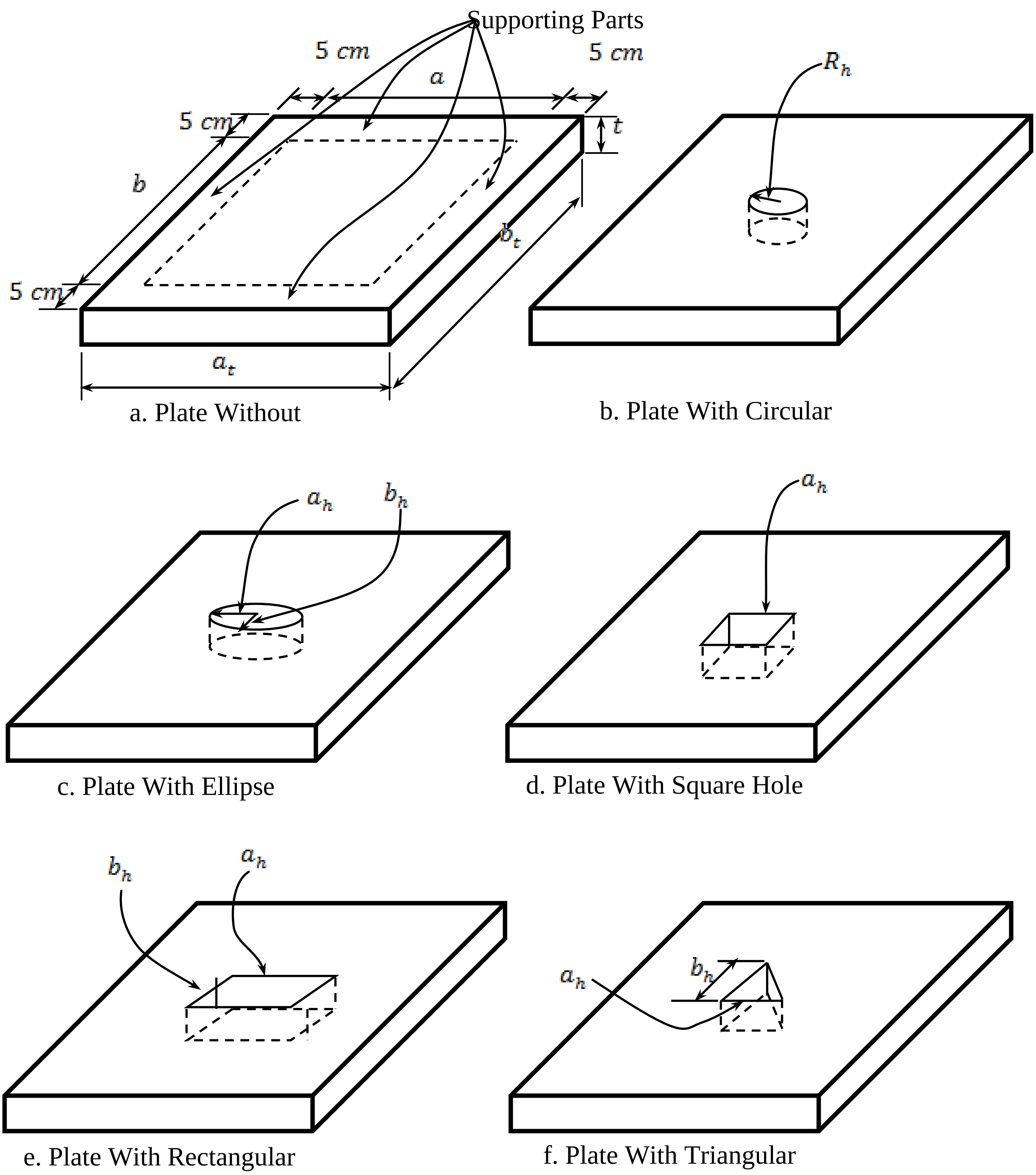
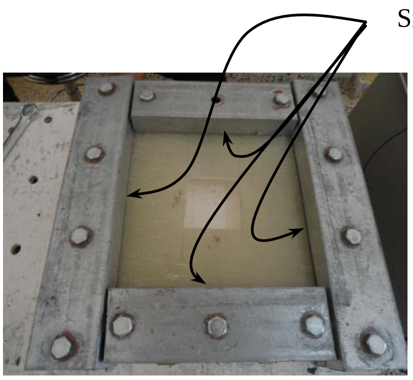
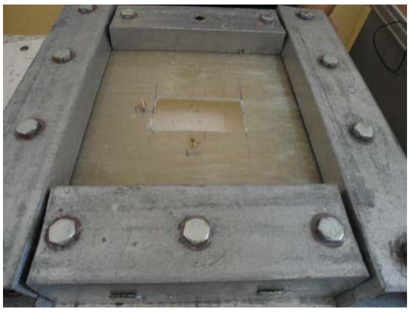


Fig. 1. Dimensions and Shape of Composite Plate Sample with Different Hole Configurations.



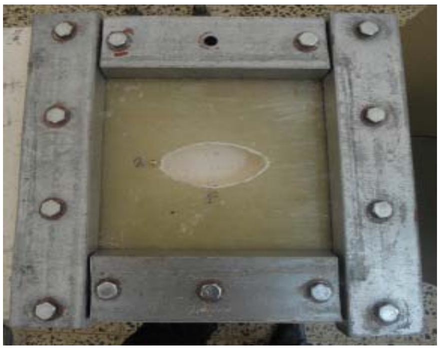
a. Plate With Square Hole

b. Plate With Triangular Hole



c. Plate With Rectangular

d. Plate With Circular Hole



e. Plate With Ellipse Hole

Fig. 2. Experimental Sample with Different Holes Shape for Simply Supported Plate.

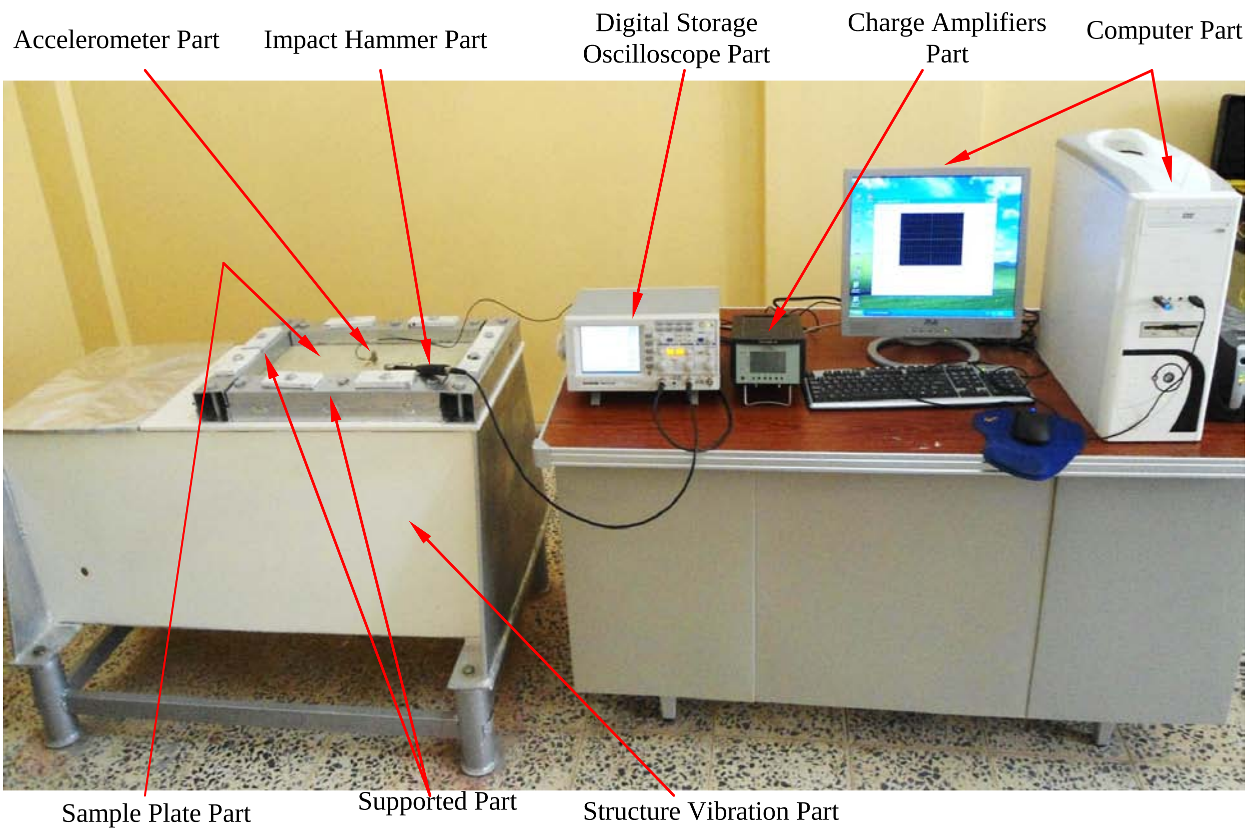


Fig. 3. Rig and Vibration Test Machine of Composite Plate Structure.

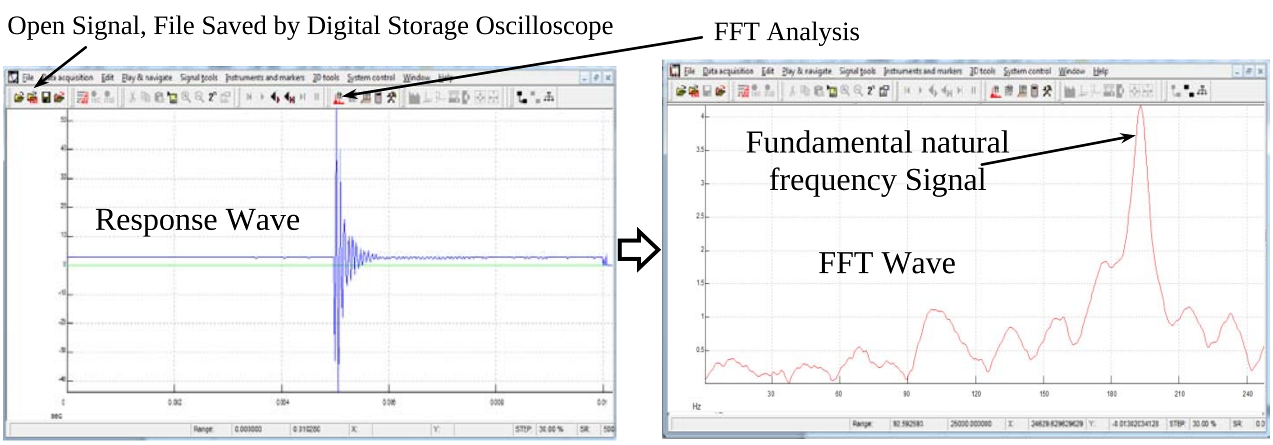
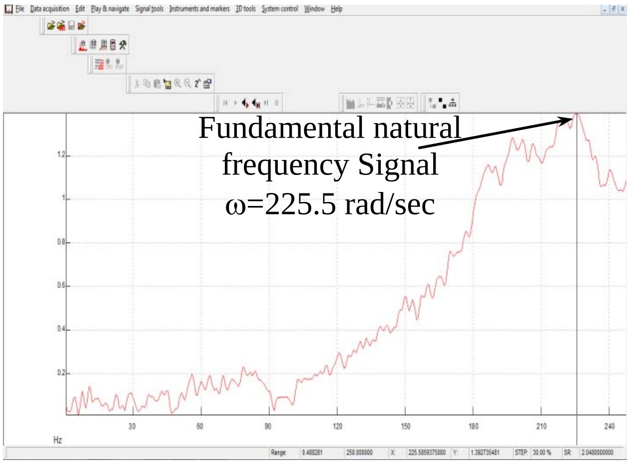
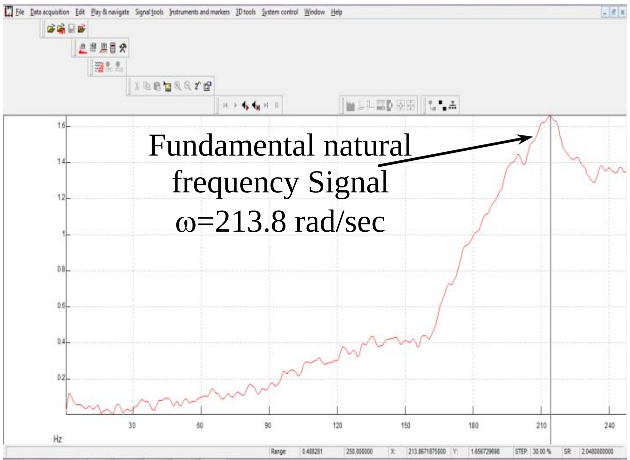


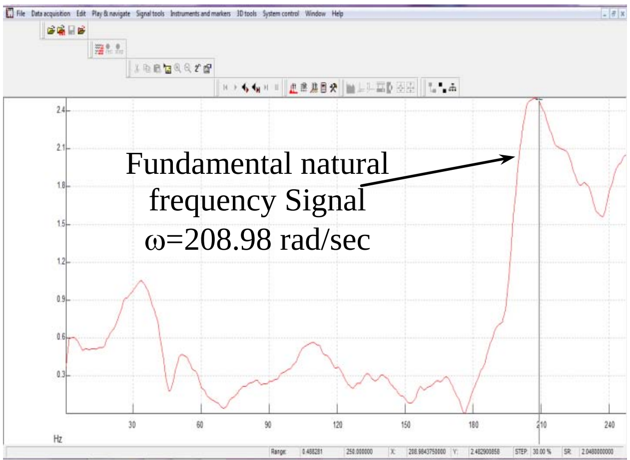
Fig. 4. Sig-View Program for FFT Analysis Function.



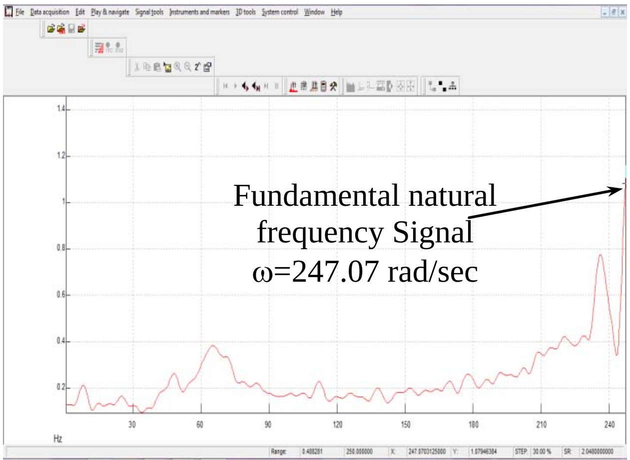
a. CCCC Plate-Without Hole



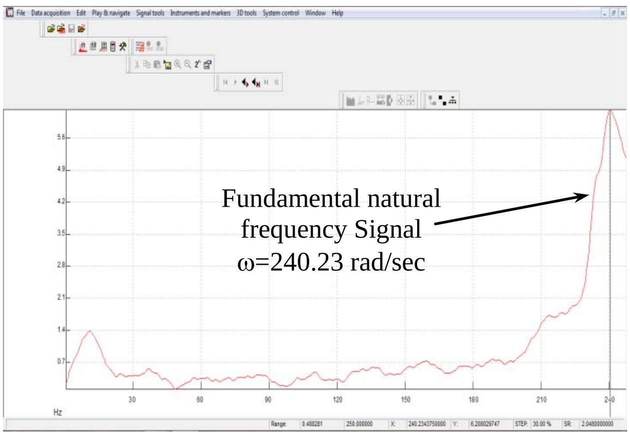
b. SSSS Plate-Without Hole



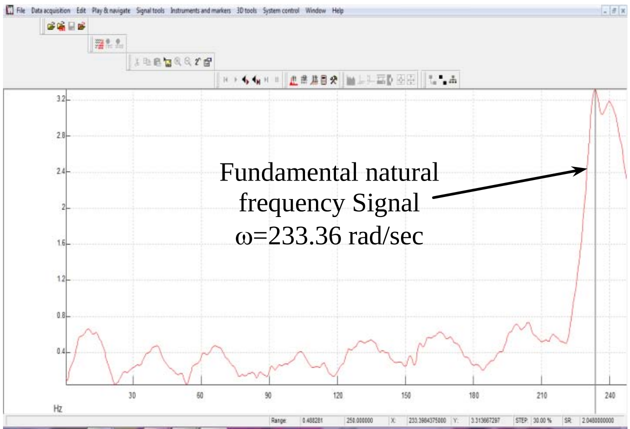
c. CCCC Plate-Rectangular Hole



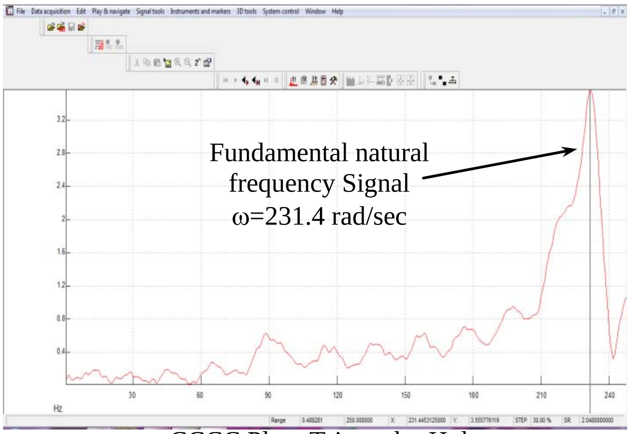
d. SSSS Plate-Rectangular Hole



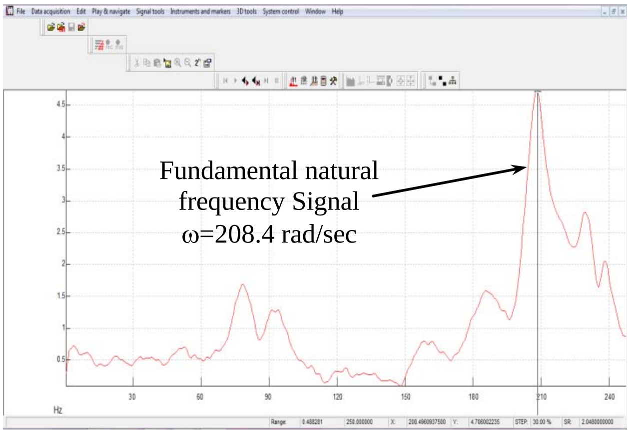
e. CCCC Plate-Ellipse Hole



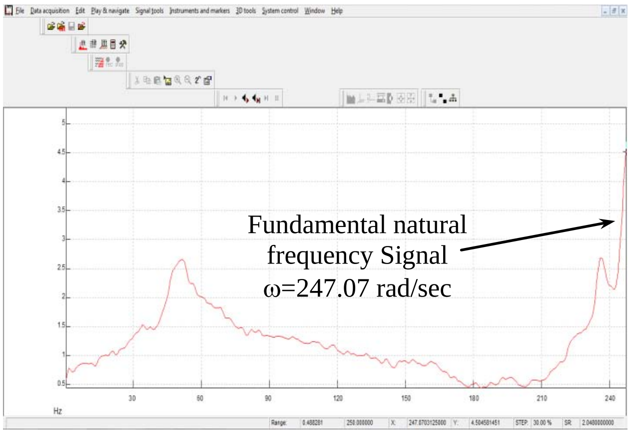
f. SSSS Plate-Ellipse Hole



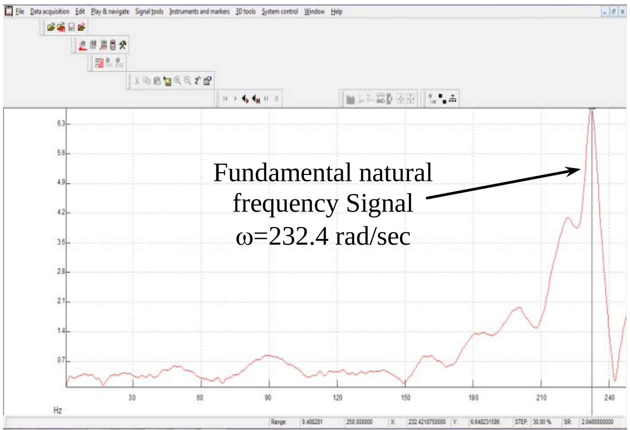
g. CCCC Plate-Triangular Hole



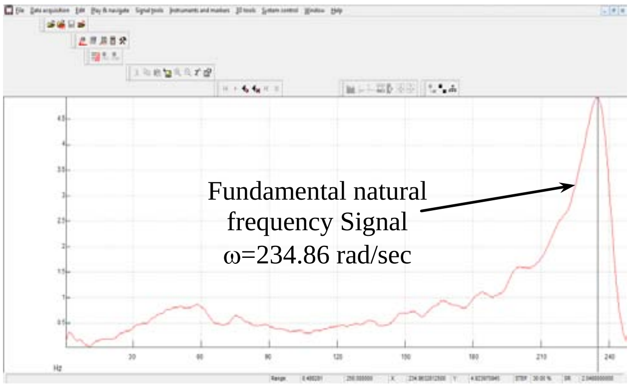
h. SSSS Plate-Triangular Hole



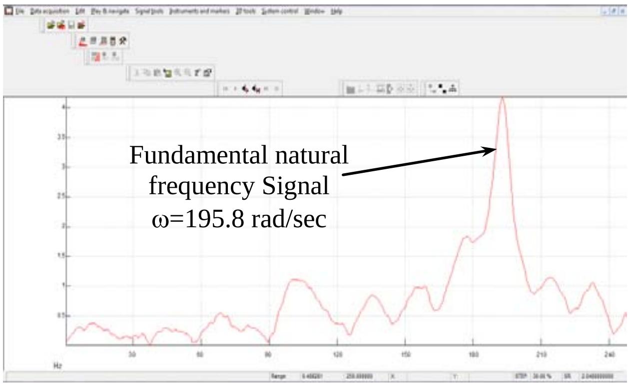
i. CCCC Plate-Circular Hole



j. SSSS Plate-Circular Hole



k. CCCC Plate-Square Hole



l. SSSS Plate-Square Hole

Fig. 5. Signal FFT Function of Plate Responses with Different Boundary Conditions and Holes.

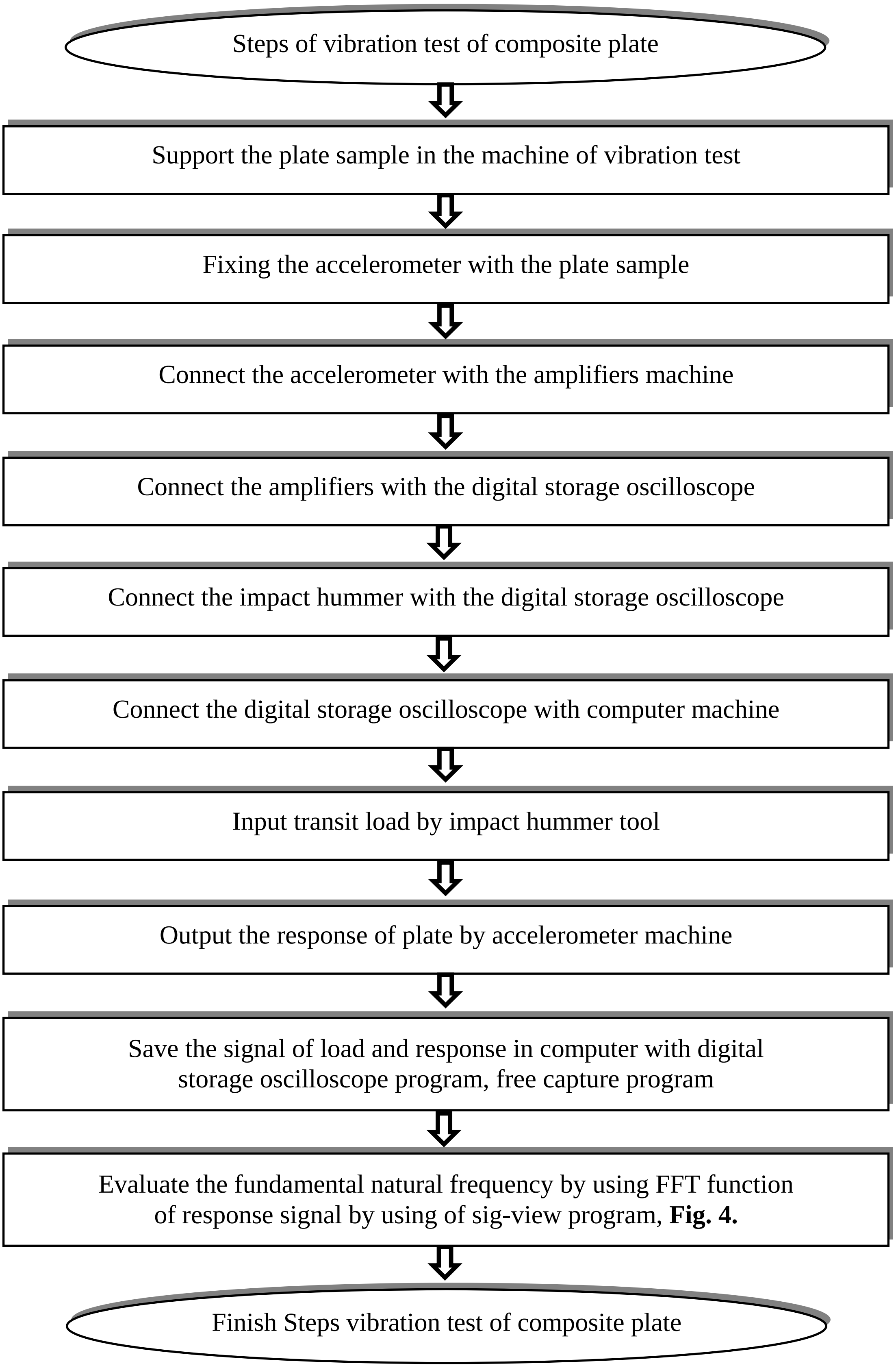


Fig. 6. Flowchart Stepping of Vibration Test of Composite Plate

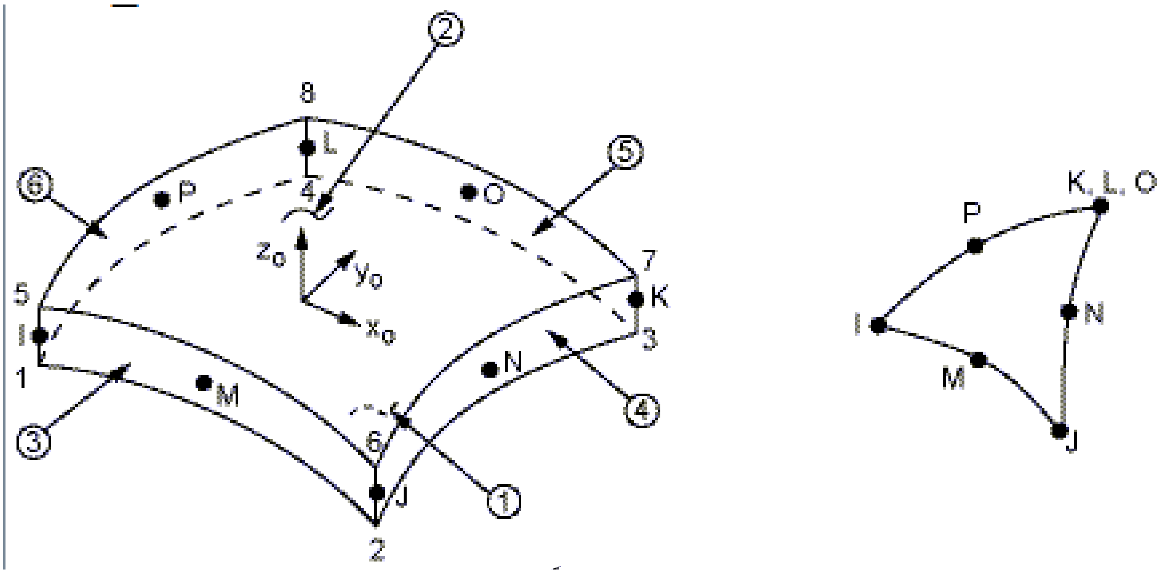


Fig.7. Shell 281 Geometry.

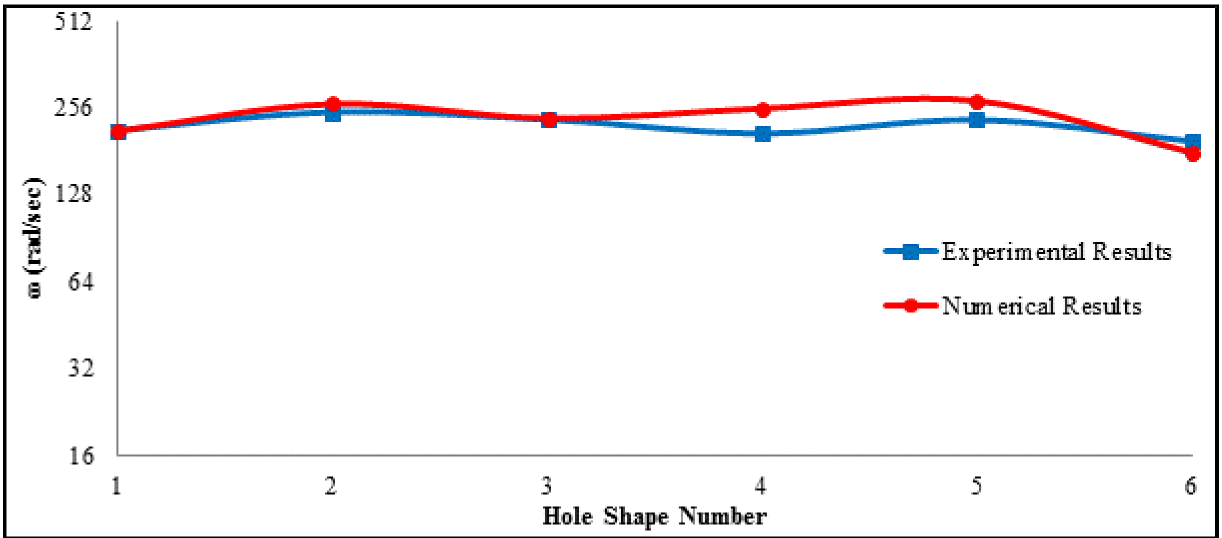


Fig. 8. Comparison Between Experimental and Numerical Natural frequency Results of Unidirectional Composite Simply Supported Plate with Different Holes Shape Effect.

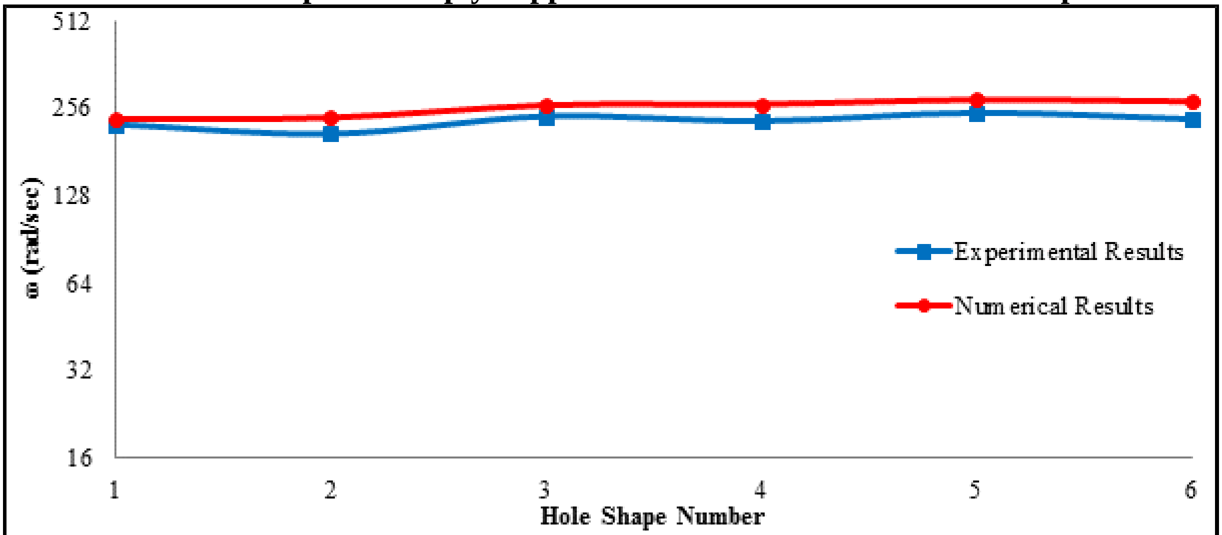


Fig. 9. Comparison Between Experimental and Numerical Natural frequency Results of Unidirectional Composite Clamped Supported Plate with Different Holes Shape Effect.

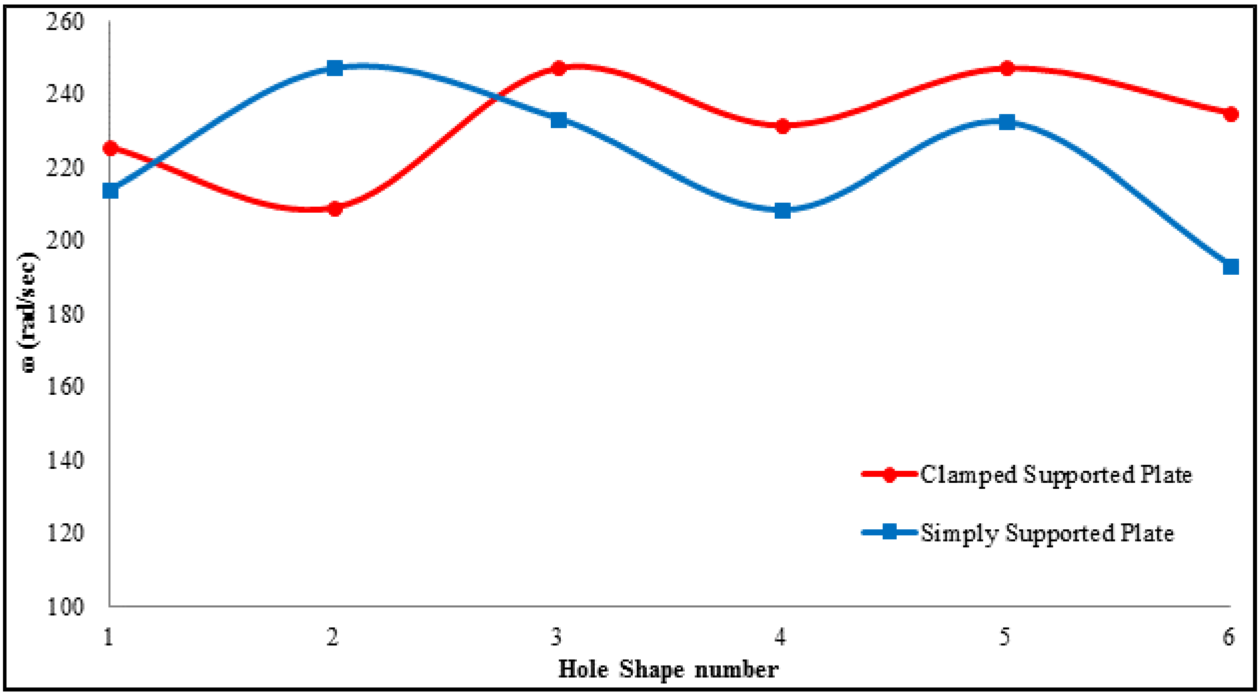


Fig. 10. Comparison Between Simply Supported and Clamped Supported Experimental Natural Frequency Results of Unidirectional Composite Plate with Different Holes Shape Effect.

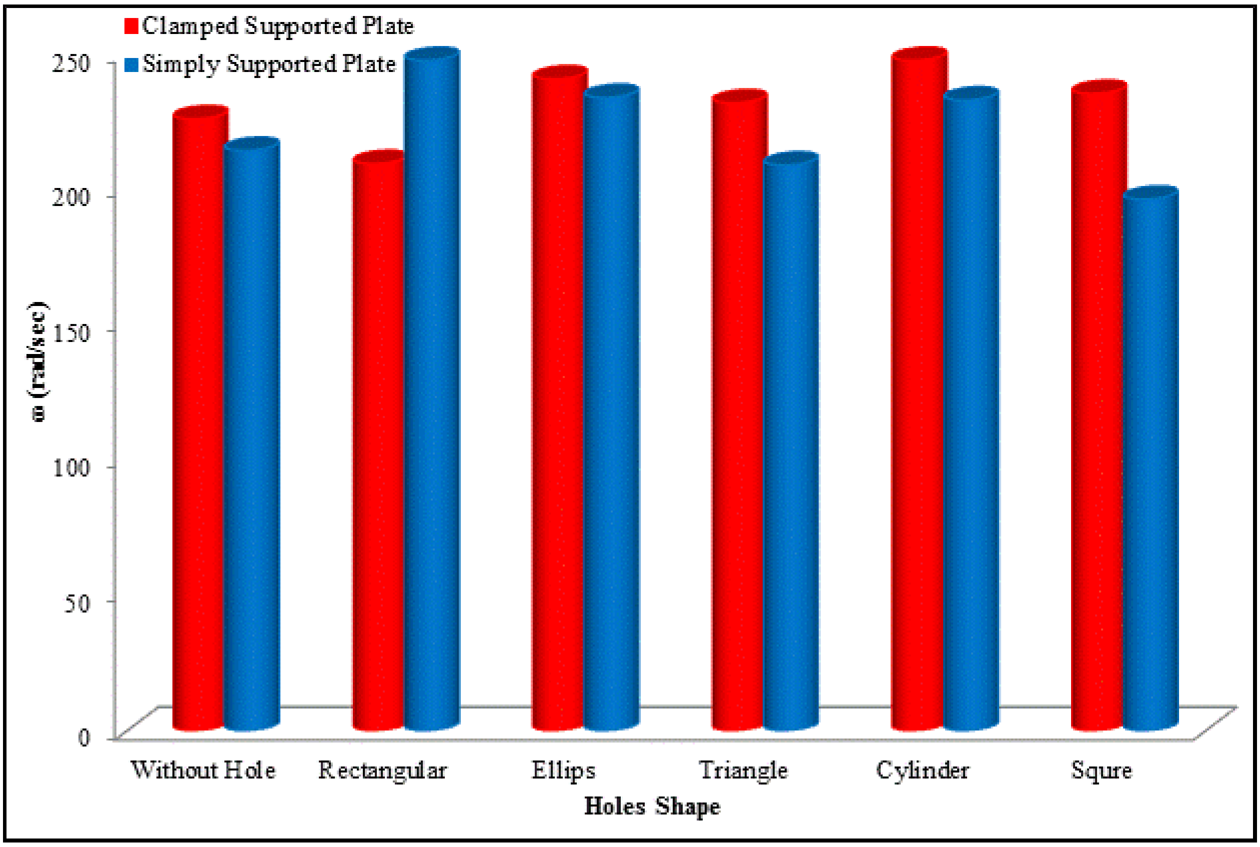
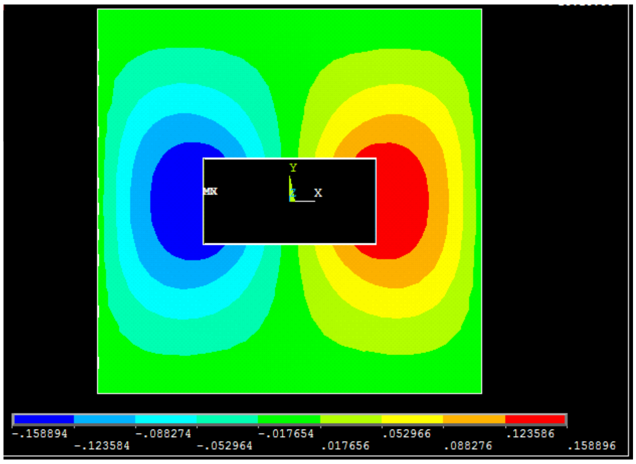
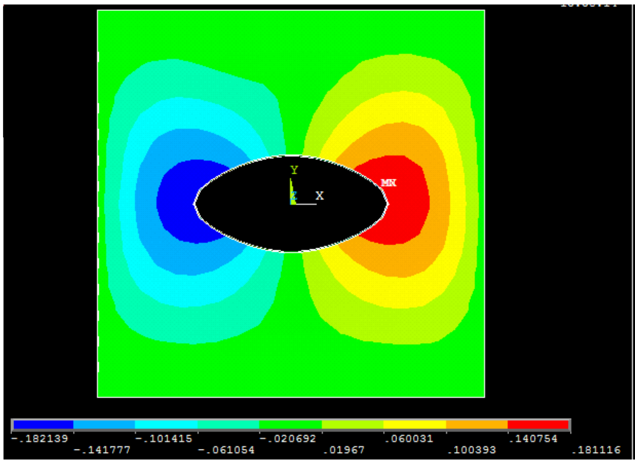


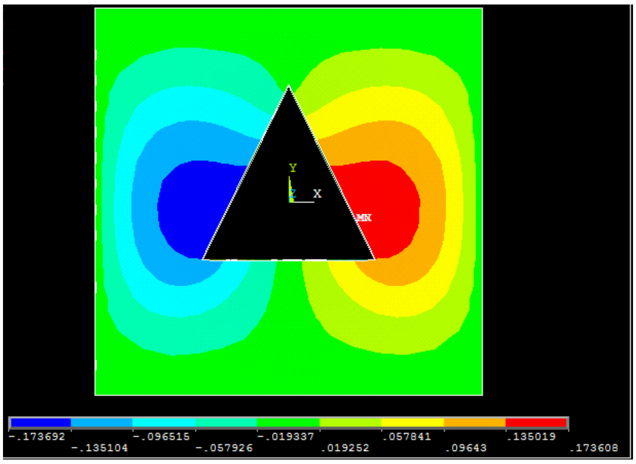
Fig. 11. Experimental Natural Frequency Results of Unidirectional Composite Plate with Different Holes Shape Effect, for Simply Supported and Clamped Plate Supported.



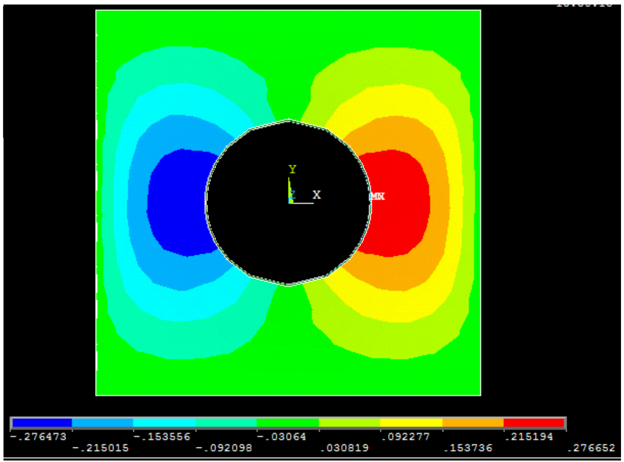
a. Rectangular Cutout Effect



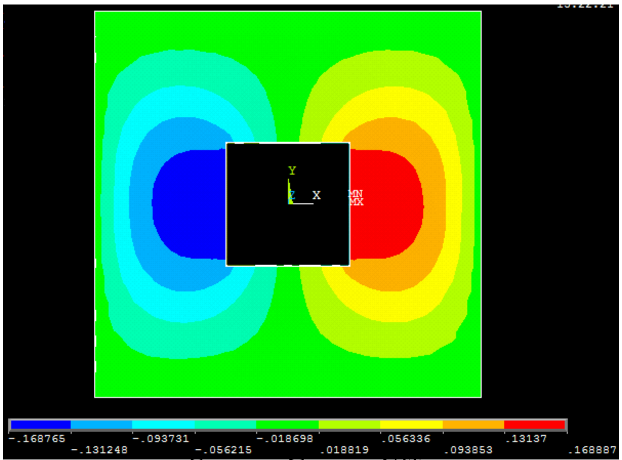
b. Ellipse Cutout Effect



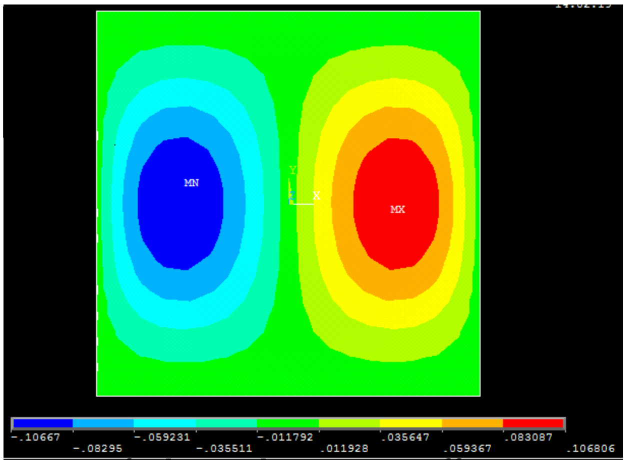
c. Triangular Cutout Effect



d. Circular Cutout Effect

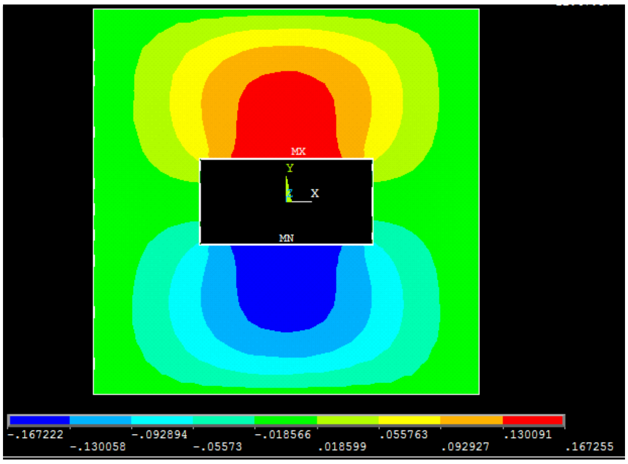


e. Square Cutout Effect

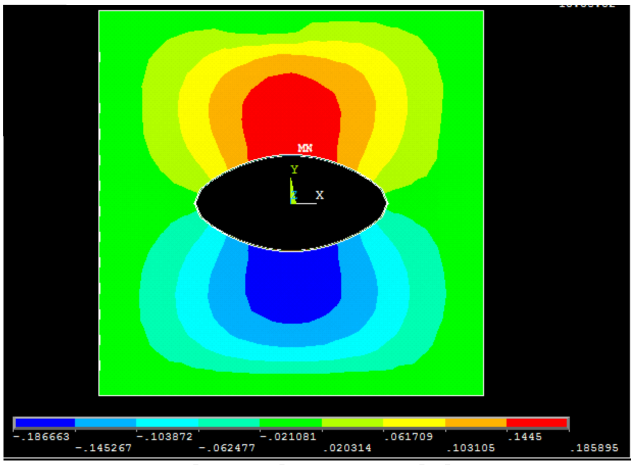


f. Plate without Cutout Effect

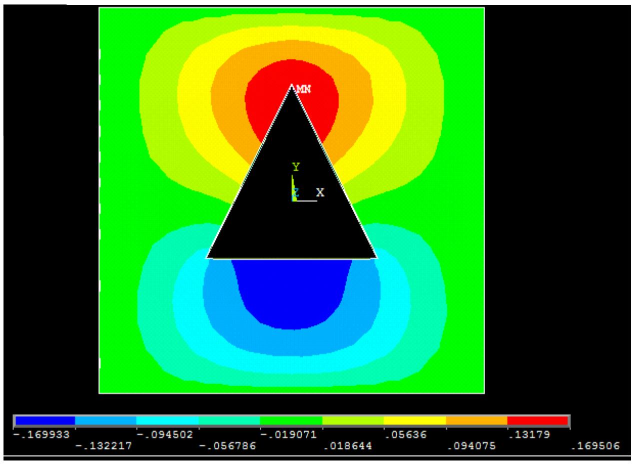
Fig. 12. Displacement in x-Direction of Plate withand without Different Cutout Shape Effect, with Same Cutout Area, for Clamped Supported Unidirectional Composite Plate.



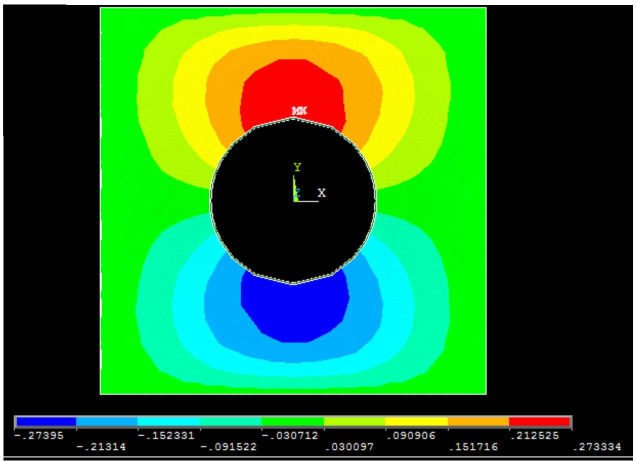
b. Simply SupportedPlate



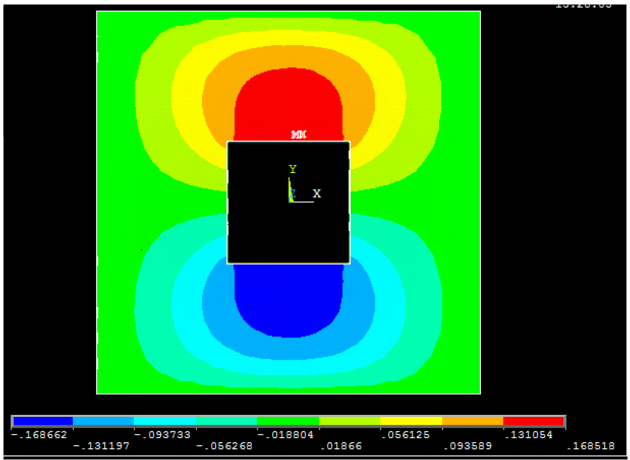
a. Clamped SupportedPlate



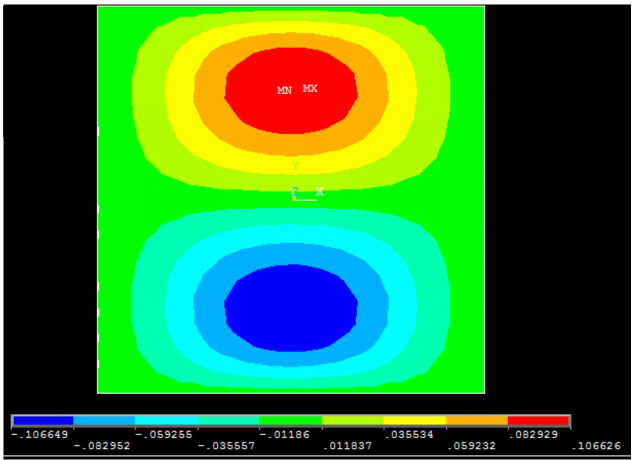
a. Clamped SupportedPlate



a. Clamped SupportedPlate

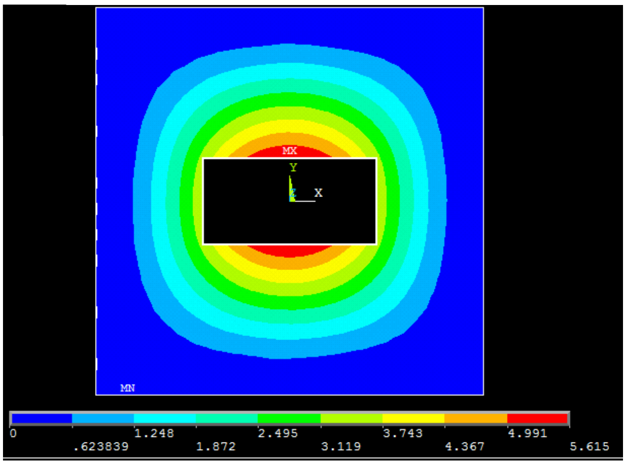


b. Simply SupportedPlate

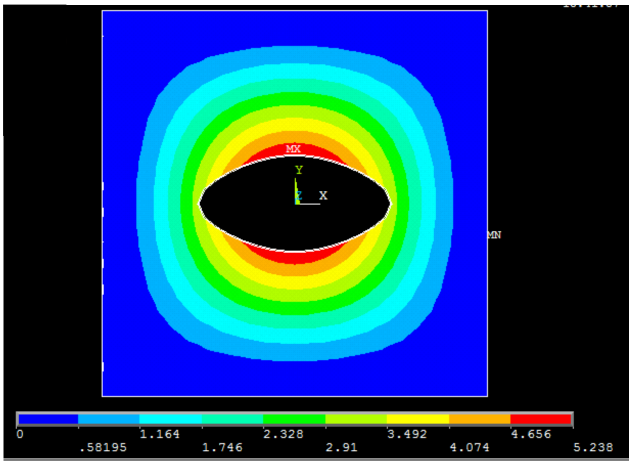


b. Simply SupportedPlate

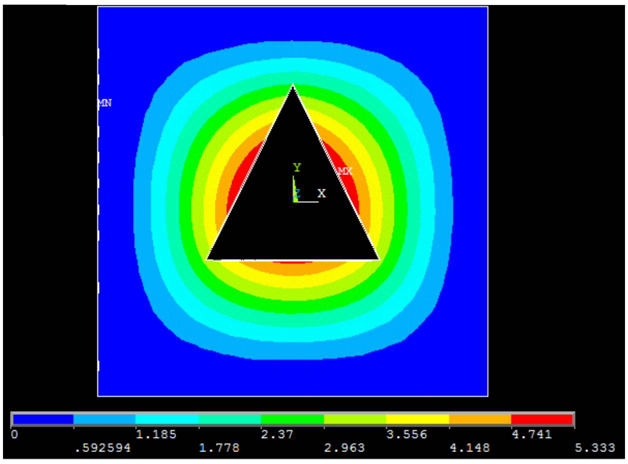
Fig. 13. Displacement in y-Direction of Plate with and without Different Cutout Shape Effect, with Same Cutout Area, for Clamped Supported Unidirectional Composite Plate.



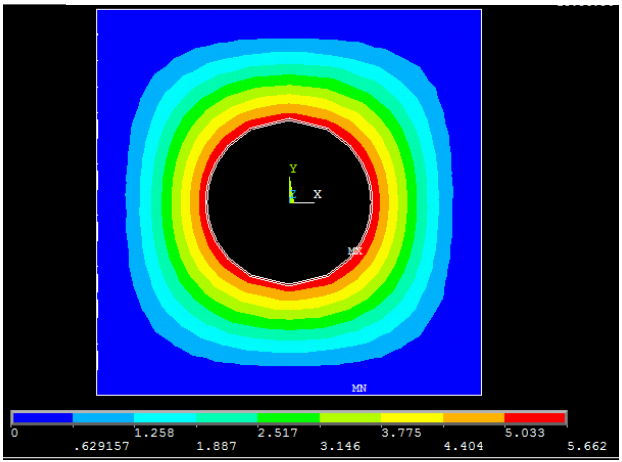
a. Clamped SupportedPlate



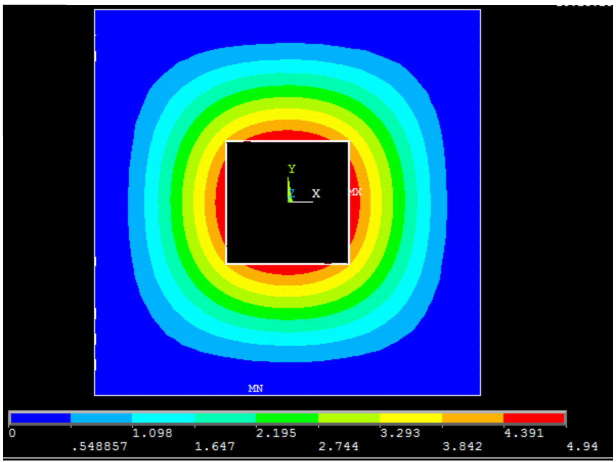
b. Simply SupportedPlate



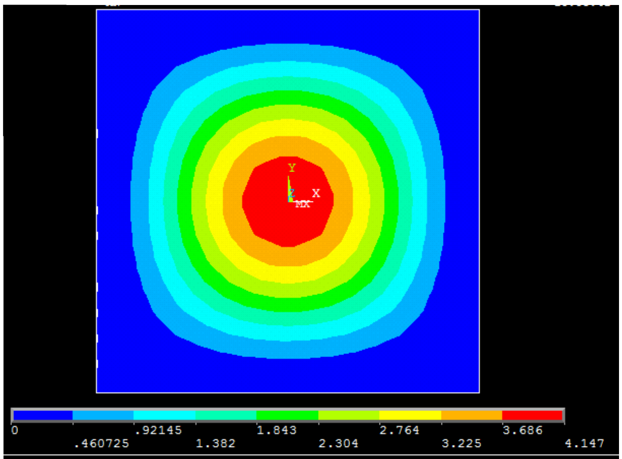
b. Simply Supported Plate



b. Simply Supported Plate



b. Simply Supported Plate



a. Clamped Supported Plate

Fig. 14. Displacement in z-Direction of Plate with and without Different Cutout Shape Effect, with Same Cutout Area, for Clamped Supported Unidirectional Composite Plate.

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