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Theoretical and Experimental Investigations of Vibration Characteristics of a Combined Composite Cylindrical-Conical Shell Structure

Dr. Muhsin J. Jweeg*, Dr. Adnan D. Mohammed & Dr. Mohsin A.Alshamari*****

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Abstract

In this work, the effect of variation of several variables on linear free and transient vibration response of combined cylindrical-conical shell is presented. The shell is made of polyester resin reinforced by a continuous type E-glass. The problem is solved experimentally and numerically for both orthotropic and isotropic shell structures. Clamped – free boundary conditions is used for the analyzed structure. The experimental program is conducted using digital oscilloscope with built-in FFT analyzer with aid of hammer transducer. Software named SIGVIEW was used to calculate the natural frequencies experimentally for each specimen. The numerical investigation is adopted using ANSYS Finite Element software to verify the experimental results which show how the natural frequencies and mode shapes are affected by changing these variables. The results show that this investigation will assist the study for the advanced development of the cross-ply laminated composite coupled shell structures.

دراسة نظرية وعملية للخواص الاهتزازية لهيكل اسطواني - مخروطي مصنوع من مواد مركبة

الخلاصة

في هذا العمل أجريت دراسة تجريبية وعددية لتأثير زاوية المخروط على الأستجابة الأهتزازية الخطية والعابرة للهيكل القشري ذي المزدوج المخروطي – الأسطواني. صنع الهيكل القشري من مادة البولستر الرابطة مقواة بكمية قليلة من الألياف المستمرة والعشوائية الزجاجية نوع E. تم حل المسألة عمليا وعدديا لكلا النوعين المستخدمين وهما المواد المتساوية الخواص والمختلفة الخواص. في هذا الأختبار استخدمت الظروف الحدية ذي النوع مثبت – حر. انجز الجانب العملي باستخدام محلل FFT بمساعدة مقياس التعجيل ومطرقة مزودة بمتحسس قياس القوة. اختبرت تجريبيا عشرة نماذج لدراسة تأثير بعض العناصر التصميمية على المميزات الأهتزازية والأستجابة للهياكل القشرية. صنعت خمسة من هذه النماذج من المادة المختلفة الخواص بزوايا مخروطية مختلفة وميلانين للألياف الزجاجية. وصنعت الخمسة نماذج الأخرى من المادة السوية الخواص (مقواة بواسطة الألياف العشوائية) لدراسة تأثير زاوية المخروط وسمك القشرة وميلان الألياف على استجابة الهيكل.

Introduction

Components such as cylindrical, conical, joined conical-cylindrical and joined conical annular plate shells are commonly encountered as principal structural elements in the design of aerospace and nuclear Structures. The joined conical–cylindrical shells have wide spread Applications in mechanical, marine,

* Engineering College, University Al-Nahrain of / Baghdad
**Electro-Mechanical Engineering Department, University of Technology/Baghdad
*** Engineering College,University of Baghdad/ Baghdad

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

aeronautical, chemical, and civil and power engineering. They may consist of thin-walled structures composed of two or more simple components having one common axis of revolution and presenting a slope discontinuity in the shell meridian across the joint. The localized high stresses generally develop within a narrow region enclosing the joint and may significantly affect the response behavior. Although for the preliminary design purpose, the structural response of the individual components may be examined. However, for the prediction of global behavior and rigorous optimal design, it may be more appropriate to analyze the joined complete shell system experimentally and numerically. Zhao [1] presented the first experimental study on ring-stiffened cone–cylinder intersections under internal pressure. In addition to the presentation of test results including geometric imperfections, failure behavior and the determination of buckling mode and load based on displacement measurements, results from nonlinear bifurcation analysis using the perfect shape and nonlinear analysis using the measured imperfect shape were presented and compared with the experimental results. Zhaoa and Teng [2] described a rational finite element model based on the experimental and the corresponding numerical results. Finite element results from a major parametric study on the post buckling behavior and strength of cone–cylinder intersections employing this finite element model were then presented. Parametric instability study of conical-cylindrical shell subjected to periodic in-plane load was examined by Kamat *et al* [3] by considering two-nodded axisymmetric shell element based on shear flexible theory. Irie *et al* [4] presented an analysis for the free vibration of joined conical-cylindrical shell. The flügge equations of free vibration of conical and cylindrical shell have been expressed in a matrix equation by using the transfer matrix of the shell. With the vibration theory and the transfer matrix method combined, the dynamic characteristics of a symmetric cross-ply laminated conical shell with an annular plate at the top end were investigated in detail by Liang *et al* [2]. Liang and Chen [1] investigated in details the natural frequencies and mode shapes for a conical shell with an annular end plate or a round end plate by combining the vibration theory with the transfer matrix method.

Experimental Determination of Material Properties

The strength characteristics of the present test of orthotropic specimens are just as important for theoretical investigation of dynamic characteristic values. Since it is physically impossible to obtain the strength characteristics of a lamina at all possible orientation, a means must be determined of obtaining the characteristics at any orientation in terms of characteristics in the principal direction. In this work, certain basic experiments are performed for obtaining the mechanical properties in the principal material directions. The main results of tensile tests are shown in table.1

1. Fabrication of filament wound specimen

The specimens used in this study are manually prepared. The First set of molds is made in a carpentry workshop using a wood lathe machine. Four molds are manufactured with four different semi angle of cone, namely 15^o, 30^o, 45^o and 60^o as shown in figure (1). The next step is the fabrication of the second set of molds that would be used to make the final test molds. Each one of these molds is made with two parts of fiber reinforced resin. The two parts are then welded together to obtain the molds that are used to fabricate the final molds during the last step, as shown in Figure (2). The molder applies a pigmented "release" material to the mold as the first step in making any open mold product. Without such material, the part permanently bound the mold to the mold surface. Many different release systems are available. The choice depends upon the type of inner surface to be molded, the degree of luster desired on the finished product and whether or not painting is required. The second step in this open mold process, is the application of a specially formulated resin layer called a "gel coat". The polyester layer is first applied on the mold which becomes the inner surface of the laminate when completed. A moderately skill worker can maintain this activity by spreading the polyester fine layer with a fine brush homogeneously as possible as he could. This produces a decorative, high protective, glossy, colored surface which requires little or no subsequent finishing. After properly preparing the mold and gel coating, the next step in the molding process is the E-glass fibers preparation. A fiberglass strands is used in the fabrication process, as shown in figure (3). In order to align the fiber strands on the semi-soldered film of polyester layer previously mentioned, a sufficient number of pins are fixed on the two sides of the mold, and then the mold is held suitably between centers of the easily constructed winding machine shown in figure (4) After a short time, an additional film of polyester layer is gently coated on the mold surface to perform the single ply of the shell. The fiber orientation, in the style of composition, is referred to (0^o) scheme of layer configuration, i.e., the direction of fibers is horizontally made with the open mold centerline. To fabricate a 90^o scheme of a single fiber-polyester layer of a cylindrical shell, the fibers orientation must be made normal to the open mold centerline. This trend of construction does not differ very much from the previous 0^o ply construction in processing of the matrix (polyester) films within the complete shell wall. However, the difference here is related to the opposite alignment of the fiber strands on the first polyester surface. The fabrication of the chopped fiber is simpler than the others since it is tailored to the precise dimension of the mold. The general procedure, explained above, is repeated for each design angle to produce the overall schemes of the design composite cylindrical-conical shell. The fabricated shell is then simply ejected from the mold by hammering on the conical edge of the product. The ends are then cut to final precise dimension. For the isotropic shell structure, the procedure of fabrication is easier compared with that of the orthotropic shell structure. Four different composite shells are manufactured in the light of procedure explained above as illustrated in table (2).

2. Vibration tests

Each manufactured specimen described in the previous section, is attached to the test rig as shown in figure (5). The rig consists of an isolated earthquake testing table. The foundation is considered to be very stiff, so that the fundamental natural frequency of the fixture may be considered as approximately infinite. The specimen is fixed at one end and the other end is left free to perform a cantilever configuration. Each specimen is supplied with small nut of mass of 1 gm. This nut is pasted on the upper side of the shell on the cone-cylinder intersection circle. This nut is used to fix the 4 grams *KISTLER* type accelerometer. The accelerometer and impact hammer cables are connected to the data acquisition system (DAS). The output signal from DAS is fed to the FFT analyzer as shown in schematic diagram of figure (6). The complete experimental setup is shown in figure (7).

Results and Discussion

1. Results of free vibration

1.1. Effect of variation of shell thickness

1.1.1. Orthotropic shell structure

The effect of shell thickness on the vibration characteristics and response of the coupled cone cylinder structure made of orthotropic material is studied. The numerical results obtained from FEM model are shown in figure (8). The figure shows that as the shell thickness increases, the fundamental frequency increases. The reason of this increase is due to the increase in the stiffness of the structure. The natural frequency exhibits a constant value for all values of thickness above the value of 1.4 mm. The structure behaves like that because the increase in the shell thickness leads to an increase in the modal mass in addition to the increase in the modal stiffness.

1.1.2. Isotropic shell structure

For the isotropic shell structure of the cone cylinder system, the effects of varying thickness on the natural frequencies and response are studied numerically and experimentally. The results of the natural frequency are shown in figure (9). The two curves show a similar trend as that of the orthotropic shell. A good agreement is noticed between the numerical and experimental results and a maximum discrepancy of 5.56% is noticed. Again, the value of natural frequency reaches an asymptotic level for the values of shell thickness of more than 1.5 mm. The reason of this behavior is the same as that explained for isotropic shell structure. Figures (10) to (12) display the response spectra obtained from the experimental investigation of the coupled cone-cylinder structure made of isotropic material of shell thickness 1.167 mm , 2.183 mm and 3.014 mm respectively. They are all of the same semi - cone angle of 45^o and an aspect ratio (L/D) of the value of 2. They are inferred from the Fourier transform of the time history of the transient response of the excited structure. They show clearly the first resonance peak response which indicates the position of the fundamental natural frequency of the coupled cone-cylinder structure on the frequency axis. They show also that the natural frequencies increase as the shell thickness increases.

1.2. Effect of variation of aspect ratio (L/D)

The aspect ratio L/D has a great effect on the fundamental frequency obtained from the numerical model. The results are shown in figure (13). The figure shows that as the parameter L/D increases, the values of the fundamental frequencies decrease. A similar trend for the curve of isotropic shell is noticed as shown in figure (14)

1.3 Effect of variation fiber orientation

1.3.1. Two-layer configuration

The study of fiber orientation on the value of fundamental frequency is performed for the coupled cone-structure made of orthotropic material only. This study is divided into two categories; the first is for a structure made of two layers only. The results of the first category are shown in table (3) and figure (15). The figure shows that the fiber orientation 0^o, 90^o gives the maximum value of the fundamental natural frequency and the orientation of 30^o, 60^o gives the minimum value. The reason is that the former configuration results in higher stiffness.

1.3.2 three-layer configuration

The second category is for structures made of three layers with different fiber orientations and constant thickness of 1.825 mm as shown in table (4) and figure (16). One of these structures is made of chopped material to compare its result with the other results. This study includes numerical and experimental investigations. The figure shows that the orientation 0,90,0 gives the maximum numerical value of the natural frequency and the orientation -30, 30,-30 gives the minimum one. The reason is that the orientation 0,90,0 offers a higher value of modal stiffness which leads to the maximum value of the fundamental frequency. Table (4) shows that there is a good agreement between the results of the numerical model compared with those of the experimental one. The maximum discrepancy is about 1.5%. The value of the discrepancy is not an accurate one because there is a difference between the thickness of the numerical model and the real thickness of the experimental model for each one of the structures.

1.4 Effect of variation of number of layers

The effect of varying number of layers is studied using a structure of a fixed thickness of 3.6 mm and different fiber orientations shown in table (5). This study is numerically performed for the shell structure made of orthotropic material with L/D value of 2. Five numbers of layers are chosen starting from 2 layers to 6 layers. From figures (17) and (18), it is clear that the fiber orientation 0, 90,90,0 has the maximum value of the fundamental frequency for a constant thickness when compared with the results obtained for other configurations.

Concluding remarks

From the theoretical and experimental investigations of the present work, the following concluding remarks may be drawn:

1. As the shell thickness increases, the fundamental natural frequency increases.

The value of the fundamental natural frequency exhibits a constant value for all values of thickness above the value of 1.4 mm for orthotropic structures and 1.5 mm for isotropic structures.

2. As the aspect ratio (L/D) increases, the values of the fundamental natural frequency decrease for both orthotropic and isotropic structures.
3. Orthotropic shell structures made of two layers with the fiber orientation 0,90 has a maximum fundamental natural frequency, while the structure with the 30,60 orientation shows the minimum values.
4. Orthotropic shell structures made of three layers with the fiber orientation 0,90,0 has a maximum fundamental natural frequency, while the structure with the -30,30,-30 orientation shows the minimum values.
5. The orthotropic structure made of 4 layers with the configuration 0, 90,90,0 has the maximum value of the fundamental natural frequency.

References

[1]Y. Zhao, "Buckling behavior of imperfect ring-stiffened cone-cylinder intersections under internal pressure". International Journal of Pressure Vessels and Piping, 82, pp. 553–564, 2005.

[2]Y. Zhao and J. G. Teng, "A stability design proposal for cone–cylinder intersections under internal pressure". International Journal of Pressure Vessels and Piping, 80, pp. 297–309 , 2003.

[3]S. Kamat, M. Ganapathi, and B.P. Patel, "Analysis of parametrically excited laminated composite joined conical-cylindrical shells". Computers and Structures, 79, pp. 65-76, 2001.

[4]T. Irie, G. Yamada and Y. Muramoto, "Free vibration of joined conical-cylindrical shells, journal of sound and vibration, 95(1), pp. 31-39, 1984.

[5]S. Liang, H.L. Chen, T. Chen, and M. Y. Wang, "The natural vibration of a symmetric cross-ply laminated composite conical-plate shell". Composite Structures, 80, pp. 265–278, 2007.

[6]S. Liang, and H.L. Chen, "The natural vibration of a conical shell with an annular end plate". Journal of Sound and Vibration, 294, pp. 927–943, 2006.

Table (1): Results of Tensile tests of orthotropic specimens

Specifications	Orthotropic specimens
E_1	9.27 GPa
E_2	1.8278 GPa
E_3	1.8278 GPa
G_{12}	1.1755 GPa
G_{13}	1.1755 GPa
G_{23}	0.9607 GPa
ν_{12}	0.43
ν_{13}	0.43
ν_{23}	0.66
Density	1452 (kg/m^3)
Volume fraction	0.11

Table (2): Specifications of test specimens

Sample No.	Cone-angle	Orientation	Thickness (mm)	Mass (gm)
1	60^o	0-90-0	1.825	439.5
4	15^o	0-90-0	1.73	499
5	30^o	0-90-0	1.746	461.5
6	45^o	0-90-0	1.93	500.5

Table (3): Effect of the fiber orientation on the fundamental frequency for two layers only, constant thickness 1.825 mm and 45^o semi - cone angle.

No.	Orientation	Fundamental Frequency (Hz)
1	30 , 60	278.91
2	30 , -30	299.13
3	60 , -60	311.87
4	45 , -45	317.65
5	-45 , 60	318.42
6	0 , 90	325.18

Table (4): Effect of the fiber orientation on the fundamental frequency for orthotropic shell made of three layers of constant thickness (1.825 mm) with 45^o Semi - cone angle.

No.	Fiber Orientation	Fundamental Natural Frequency (Hz)		Real thickness (mm)	Discrepancy %
		Numerical	Experimental		
1	90,0,90	315.87	314.94	1.775	0.3
2	0,90,0	324.41	322.27	1.825	0.018
3	Chopped	320.90	325.93	2.183	1.5
4	-30,30,-30	300.58			
5	45,-45,45	315.35			

Table (5): Effect of the No. of layers on the fundamental frequency for a shell structure of the thickness of (3.6mm)

No.	Fiber Orientation	No. of layers	Fundamental Frequency
1	0,90	2	326.46
2	0,90,0	3	325.12
3	0,90,90,0	4	329.57
4	0,90, 0,90,0	5	329.20
5	0,90, 0, 0,90,0	6	325.30

Figure (1): The wooden molds and the female mold

Figure (2): Final molds

Figure (3): Hand winding process of the E-glass

Figure (4): Fiber winding machine

Figure (5): Clamped end of the system

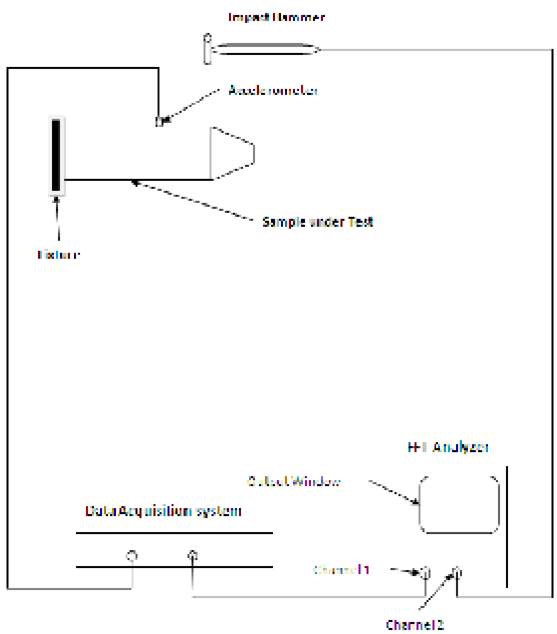

Figure (6): Block diagram of the test rig

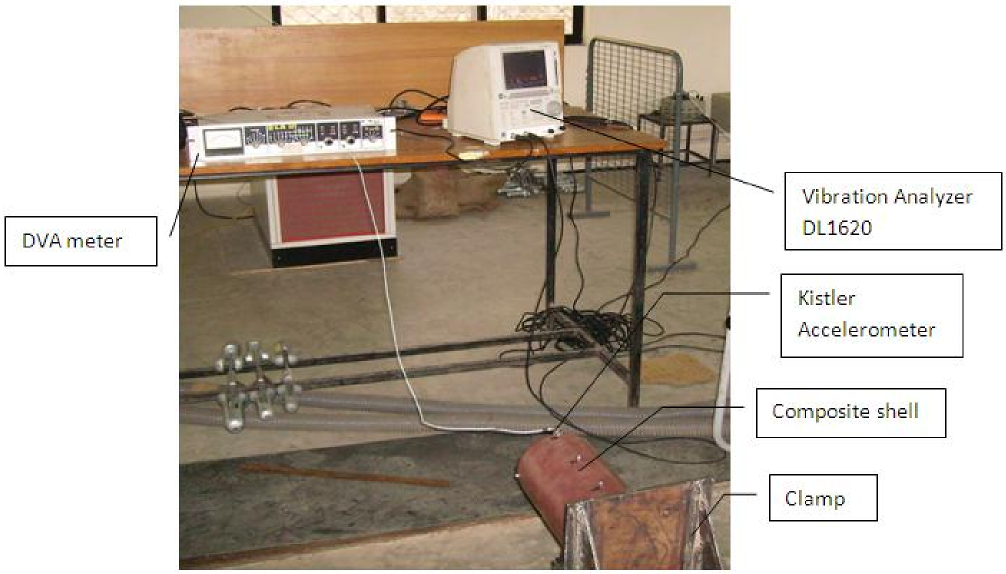

Figure (7): Test Rig

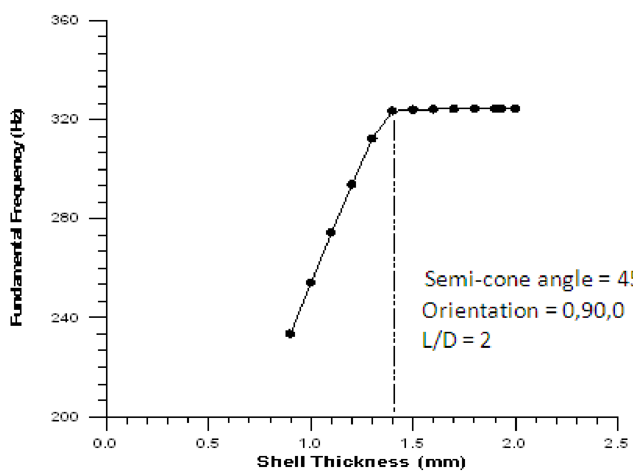

Figure (8): Effect of shell thickness on the fundamental frequency for a coupled cylindrical-conical shell.

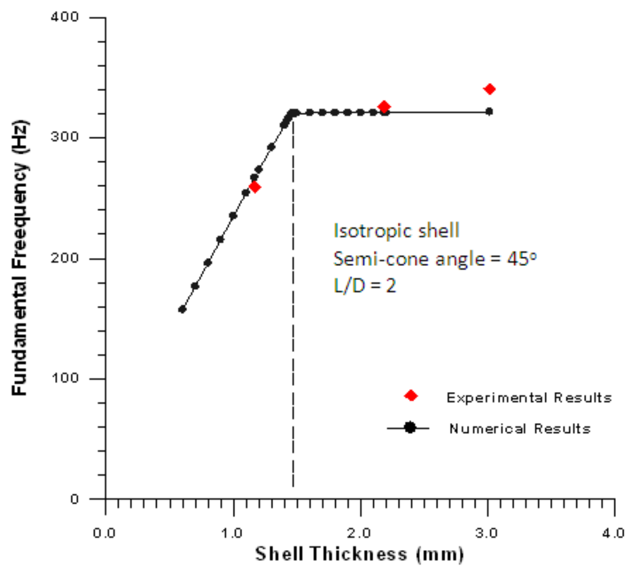

Figure (9): Effect of shell thickness on the fundamental frequency for a coupled cylinder-cone shell structure.

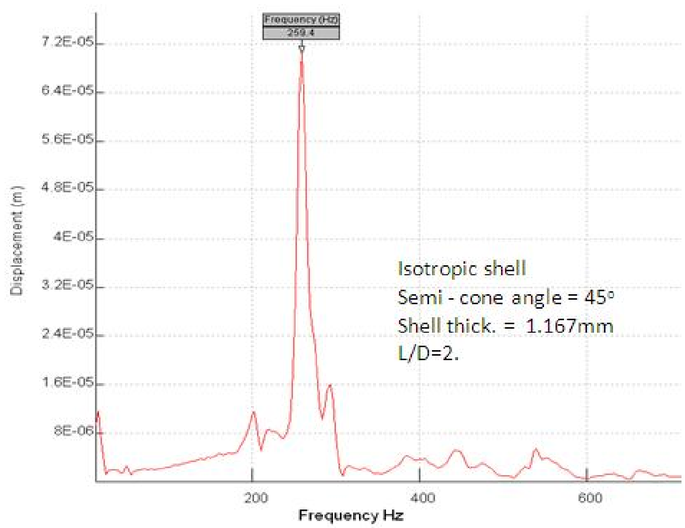

Figure (10): Experimental response (displacement) spectrum of the coupled cone-cylinder shell structure.

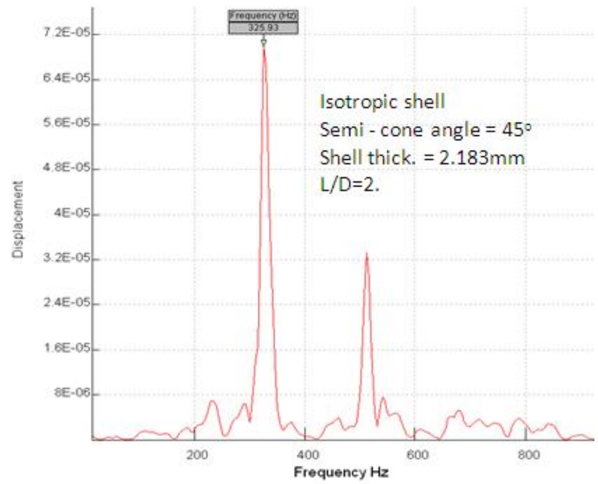

Figure (11): Experimental response (displacement) spectrum of the coupled cone-cylinder shell structure.

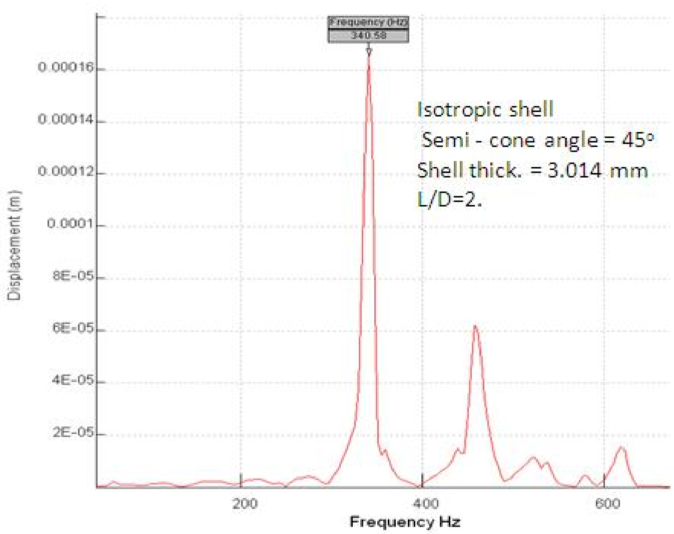

Figure (12): Experimental response (displacement) spectrum of the coupled cone-cylinder shell structure.

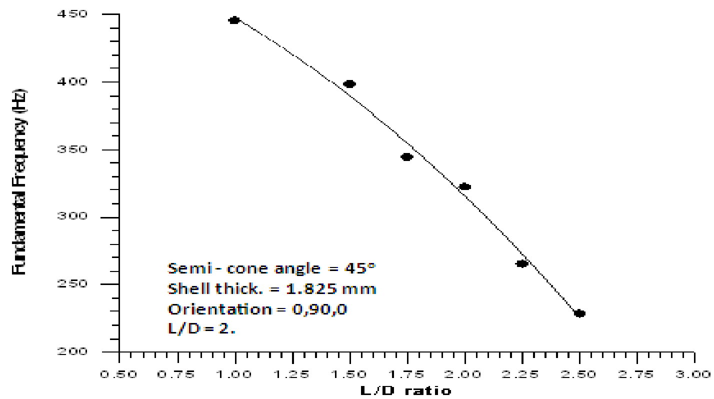

Figure (13): Effect of L/D ratio on the fundamental frequency for orthotropic shell.

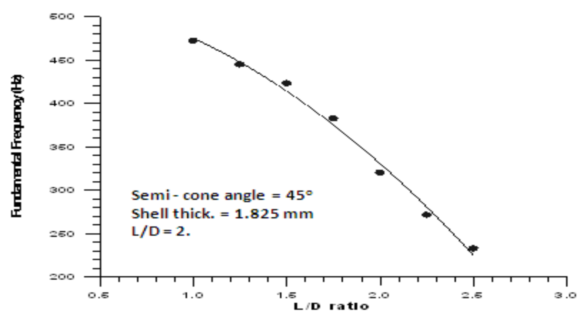

Figure (14): Effect of L/D ratio on the fundamental frequency for isotropic shell structure.

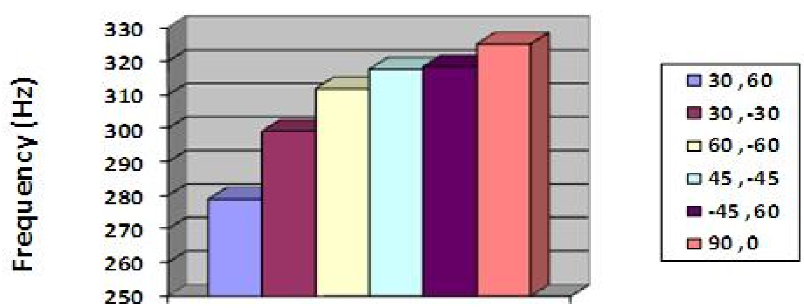

Figure (15): Effect of the fiber orientation on the fundamental frequency for orthotropic shell of constant thickness of 1.825 mm with 45^o Semi-gle of cone.

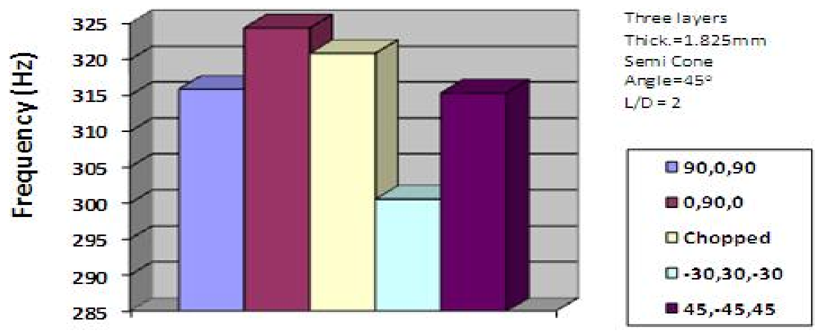

Figure (16): Effect of fiber orientation on the fundamental frequency for the orthotropic shell structure.

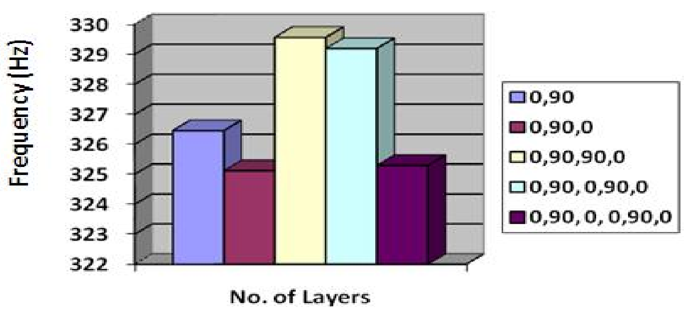

Figure (17): Effect of the number of layers on the fundamental frequency for a shell structure of the thickness of 3.6 mm

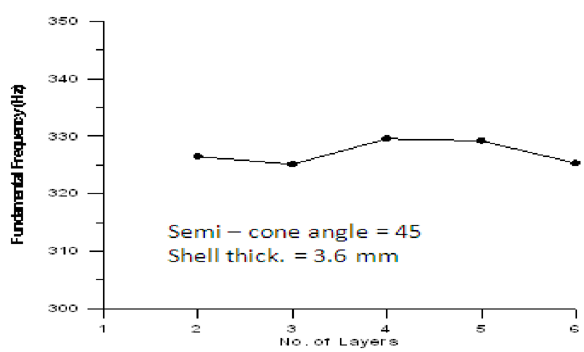

Figure (18): Effect of the number of layers on the fundamental frequency for the orthotropic shell structure.