A STUDY OF THE EFFECT OF SEMI-ANGLE OF CONE ON THE VIBRATION CHARACTERISTICS OF CYLINDRICAL-CONICAL COUPLED SHELL STRUCTURE

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ABSTRACT
In this work, the effect of variation of semi-angle of the conical part on the vibration characteristics of cylindrical-conical coupled structure is investigated. The shell is made of polyester resin reinforced by continuous E-glass fibers. The case is analyzed experimentally and numerically for orthotropic shell structures. The experimental program is conducted by exciting the fabricated structure by an impact hammer and monitoring the response using an attached accelerometer for different semi-angles of the conical part. Software named SIGVIEW is used to perform the signal processing on the acquired signal in order to measure the natural frequencies and the corresponding mode shapes. The numerical investigation is achieved using ANSYS (Finite Element software) which was verified by the experimental results. Good agreement is achieved when comparing the experimental and numerical results. The maximum deviation in results was found to be (5.9%). The maximum relative nodal rotational and translational amplitudes associated with the first normal mode of the orthotropic and isotropic shells are noted for the structure of semi-angle of cone of 45^o.

الخلاصة
في هذا العمل أجريت دراسة تجريبية وعددية لتأثيرتغير نصف زاوية المخروط على الخواص الأهتزازية للهيكل القشري المخروطي – الأسطواني المرتبط المختلف والسوي. لقد تم تصنيع الهيكل القشري من مادة البولستر الرابطة المقواة بكمية من الألياف الزجاجية نوع E المستمرة. انجز الجانب العملي لحساب الترددات الطبيعية للهيكل باستخدام محال FFT بمساعدة مقياس التعجيل ومطرقة مزودة بمتحسس قياس القوة. لقد تم انجاز الجانب العددي باستخدام طريقة العناصر المحددة (برنامج Ansys). لقد تم الحصول على تطابق جيد عند مقارنة النتائج العددية والعملية لقيم التردد الطبيعي الاول للهيكل.ان قيمة الأنحراف القصوى بالنتائج هي (5.9%). لقد تم التوصل الى ان القيم النسبية العظمى للعقد للسعات الانتقالية والدورانية الخاصة بشكل النسق الاول وللهياكل المصنعة من مواد مركبة مختلفة او سوية تحصل عند زاوية نصف زاوية مخروط مقدارها 45 درجة.

Key words: Coupled, Cylindrical-Conical, Orthotropic, Frequency

INTRODUCTION

The term “composite”, nowadays, is referred to those engineering products exhibiting such diametrical opposite features to the familiar homogenous materials. Now, it is possible to earn a composite product relatively strong but light, flexible but tough and expensive but prosperous with similar products of a single constituent. Cone–cylinder intersections are commonly used in pressure vessels, aerospace structures and piping. Examples include conical end closures to cylindrical vessels and conical reducers between cylinders of different radii. The vibrational load is often an important loading condition for these intersections. 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. The experimental work was done in ERDA company (Electrical Research Development Association), Gujarat, India, the experimental models were made in MARUTI Fibers, Maharashtra, India, and the tensile test was achieved in KEMROCK company , Gujarat, India.

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. The feasibility of using the transfer matrix method to analyze a composite laminated conical-plate shell was explored theoretically by **Liang** et. al. [2]. The conclusions illustrated that this investigation will provide an important foundation for the advanced development of the laminated composite combination shells, it showed that the transfer matrix method can reveal the dynamic characteristics of the composite laminated conical-plate structures. Parametric instability study of a conical-cylindrical shell subjected to a periodic in-plane load was examined by **Kamat** et. al. [3] by considering a two-nodded axisymmetric shell element based on the shear flexible theory. Numerical results have been obtained for isotropic, orthotropic, and laminated shells with different conical sections joined with circular cylindrical shells. Segmented shells are shells that are built of several pieces form together an axisymmetric shell with a joint axis. These can be cylindrical, conical or plate segments, which are connected to form a complete shell. **Efraim** and **Eisenberger** [4], derive the exact dynamic stiffness matrix for each segment which was then used in the assembly of the complete structure dynamic stiffness matrix. The natural frequencies of the vibrations were found as the frequencies that cause this matrix to become singular. Examples were given for the frequencies and modes of segmented shells made of conical, cylindrical, and plate segments. The truncated conical shape having a superimposed top cylindrical cap is widely used as a containment vessel for elevated water tanks. The evaluation of the wind and seismic responses of these tanks requires the knowledge of the dynamic characteristics of the vessels. A study done by **El Damatty** et. al. [5] who reported the results of the first experimental and numerical investigation conducted to assess the dynamic behavior of the combined conical vessels. **Irie** et. al. [6] presented an analysis for the free vibration of the joined conical-cylindrical shell. The flügge equations of the free vibration of the conical and cylindrical shells have been expressed in a matrix equation by using the transfer matrix of the shell.

FABRICATION OF EXPERIMENTAL MODELS

The Cylindrical-Conical shell models used in this study are manually fabricated. The first set of molds is made at a carpentry workshop using a wood lathe machine. Four molds are prepared with four different semi-cone angles; 15^o, 30^o, 45^o and 60^o as shown in **Fig.1**. The next step is to fabricate the second set of molds that would be used to make the test final molds. Each one of these molds are made with two parts of fiber reinforced resin, which are then welded together to obtain the molds that are used to fabricate the test models in the last step, as shown in **Fig.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 to 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. 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 preparation of E-glass fibers. A fiberglass strands is used in the fabrication process, as shown in **Fig.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 **Fig.4**. After a while, an additional film of polyester layer is gently spread 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 now 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 general procedure, explained above, is repeated for each design angle to produce the overall schemes of the design composite cylindrical-conical shell structure. The final product 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. Four different composite shells are manufactured in the light of procedure explained above described as shown in **Table 1**

VIBRATION TESTS

Before commencing any vibration test on the fabricated test models, the mechanical properties of the coupled structure are obtained by performing tensile tests on specimens made of the same material as that of the Cylindrical-Conical coupled composite shell structure. The results are shown in **Table 2**. Each manufactured test model, described above, is attached to the test rig (an isolated earthquake table) as shown in **Fig. 5**. The foundation of the rig is very stiff, so the fundamental natural frequency of the fixture was considered to be infinite. The test model is fixed to the test rig at the end of the cylindrical part while the end of the conical part is left free to simulate a cantilever configuration. Each test model is supplied with small stud of a mass of 1 gm. This stud is glued on the top face of the shell at the intersection circle of the Cylindrical-Conical coupled structure. This stud 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 **Fig.6**. The complete experimental setup is shown in **Fig.7**.

RESULTS AND DISCUSSION

The effect of the semi-angle of cone on the vibrational characteristics of the orthotropic Cylindrical-Conical shell structure is experimentally and numerically investigated. The coupled shell structure made of composite material, described above, has a thickness of 1.825 mm, L/D=2 and 0,90,0 fiber orientation. The numerical and experimental results of the fundamental natural frequency of the coupled structure for different semi-cone angles are shown in **Fig.8**. This figure shows that the value of fundamental natural frequency increases as the value of semi-angle of cone increases. The frequency behaves in such manner because the structure becomes stiffer. Also, this figure shows that the fundamental natural frequency exhibits an asymptotically constant value for structures with a semi-angle of cone of more than 45^o. The reason is that the modal mass of the structure increases proportionally as the modal stiffness of the structure does. The comparison shows a good agreement between the experimental and numerical results. A maximum deviation of 5.9% is noted. **Fig.9** displays the response spectrum obtained from the vibration test of the coupled shell structure for a value of semi-angle of cone of 60^o. The curve shown in this figure is inferred from the Fourier transform of the time history of the transient response of the excited structure. It displays clearly the first resonance peak response that indicates the position of the fundamental natural frequency of the coupled Cylinder-Conical structure on the frequency axis. **Fig.10** shows the variation of the fundamental natural frequency of an isotropic shell structures for different semi-angle of cone. Similar behavior for the natural frequency is noted as that for the orthotropic shell. It can be seen from **Table 3** displays the effect of variation of the semi-angle of cone of orthotropic shell structures on the instantaneous maximum nodal configurations (translation and rotation) associated with the fundamental normal mode. The variation of angle, in general, has very little effect on the relative displacement amplitudes at x, y and z coordinates. The large values of the instantaneous relative nodal displacement amplitudes (translation and rotation), are noted for the shell structure of 45^o angle. For isotropic shell structures, it can be seen from **Table 4** that the effect of variation of the semi-angle of cone on the maximum, relative nodal displacement amplitudes is the same as that of the orthotropic shell structures. Also, it can be seen that the y-translational amplitudes for all angles are of large values compared with the other values. This table shows also that the values of the rotational amplitudes about the y-axis and those of the z-translational relative amplitudes are the largest for the angle of 45^o. The y-translational amplitudes and rotational amplitude about the z-axis are the lowest among the others for the same semi-angle of cone.

CONCLUSIONS

From the experimental and numerical investigations of the effect of variation of semi-angle of conical part on the vibration characteristics of a coupled Cylindrical-Conical composite shell structure, the following conclusions may be drawn;

I. The value of the fundamental natural frequency increases as the semi-angle of cone increases. The frequency exhibits an asymptotically constant value for structures having a semi-angle of cone of more than 45^o. This behavior is noted for both orthotropic and isotropic shell structures. Very good agreement is reported during the comparison between experimental and numerical results.

II. The maximum relative nodal rotational and translational amplitudes associated with the first normal mode of the orthotropic and isotropic shells are noted for the structure of semi-angle of cone of 45^o.

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7. FE package (ANSYS).

Table 1: Geometrical data of test Specimens

Sample No.	Semi Cone-angle	Orientation	Thickness (mm)	Mass (gm)
1	15^o	0-90-0	1.73	499
2	30^o	0-90-0	1.746	461.5
3	45^o	0-90-0	1.93	500.5
4	60^o	0-90-0	1.825	439.5

Table 2: 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 3: Values of the maximum nodal amplitudes (translation and rotation) of the first normal mode of the coupled cone-cylinder shell structure made of orthotropic material.

Semi - cone angle	**Translation**			**Rotation**		
	x	y	z	x	y	z
15^o	0.39	2.74	2.74	2.7	7.72	4.34
30^o	0.466	0.248	2.7	2.39	8.7	3.92
45^o	0.5	2.73	2.7	11.45	9.0	8.0
60^o	0.48	0.17	2.6	2	9.04	4.8

Table 4: Values of the maximum nodal amplitudes (translation and rotation) of the first normal mode of the coupled cone-cylinder shell structure made of orthotropic material

Semi - cone angle	**Translation**			**Rotation**		
	x	**y**	**z**	**x**	**y**	**z**
30^o	0.54	2.46	1.5	1.646	7.75	10.3
45^o	0.57	0.26	2.8	1.726	12.96	5.76
60^o	0.58	1.42	2.348	1.883	12.43	9.32

Fig.1: The wooden molds (up) and the female mold (down)

Fig. 2: The final molds

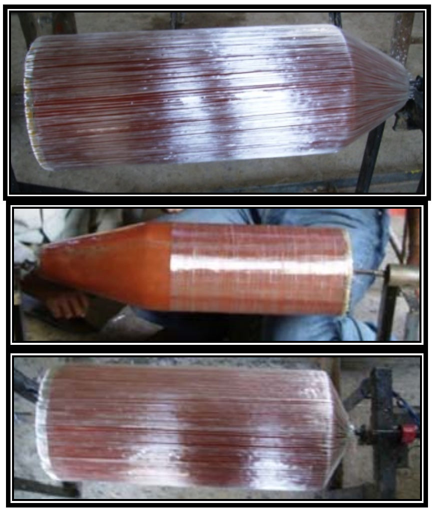

Fig. 3: Applying the E-glass to the mold

Fig. 4: A basic winding machine

Fig. 5: The fixed end of the structure

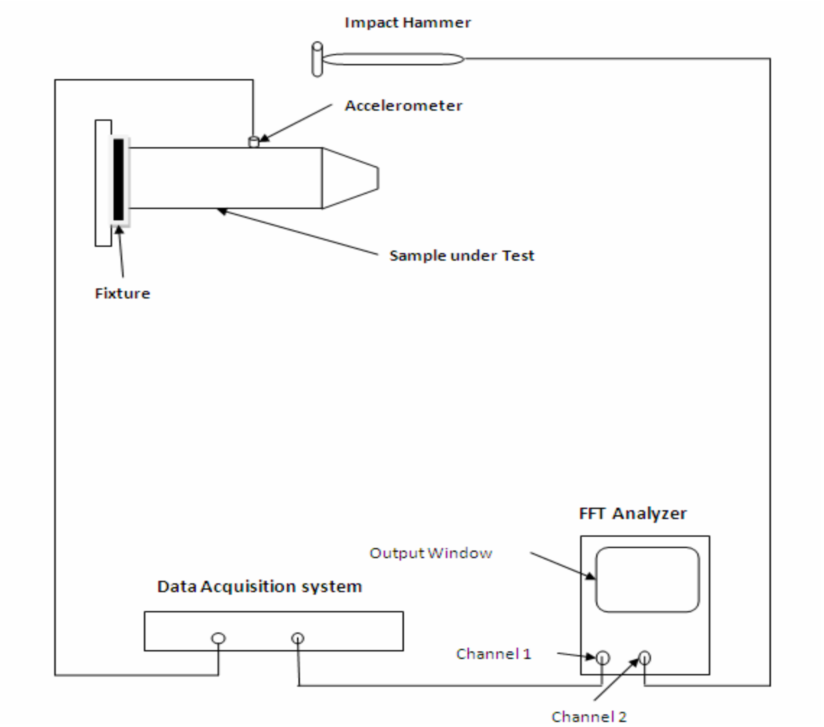

Fig. 6: A schematic diagram for the experimental set-up

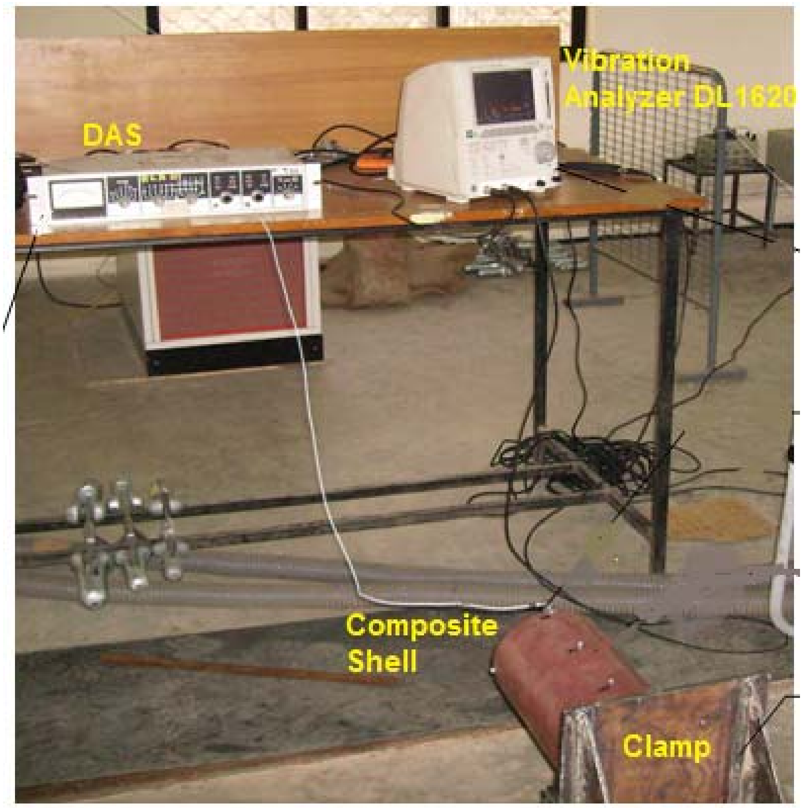

Fig. 7: The test rig

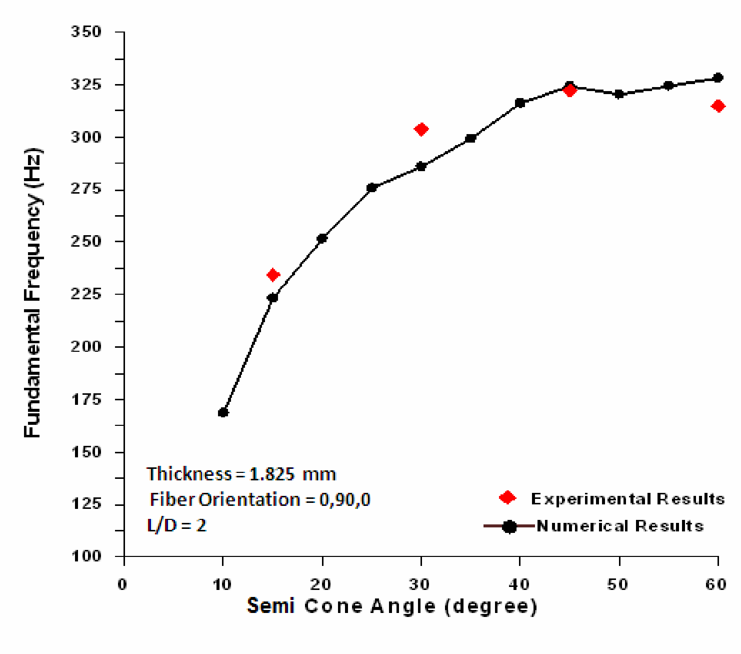

Fig.8: Fundamental frequencies of the coupled shell structures, made of orthotropic material, having different semi-angle of cone.

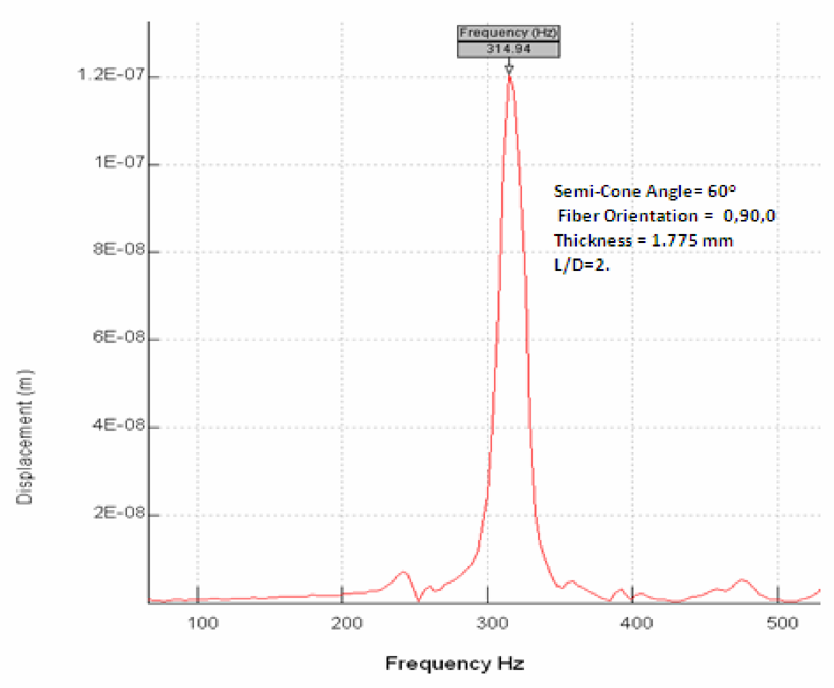

Fig. 9: Experimental results of the displacement response spectrum of the coupled Cylindrical-Conical shell structure.

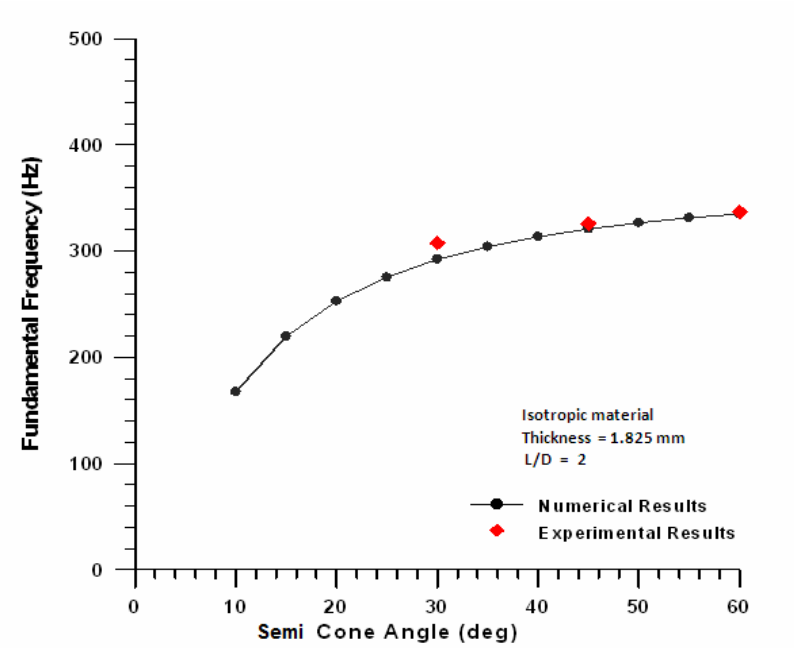

Fig. 10: Fundamental frequencies of the coupled shell structures, made of isotropic material, having different semi-angle of cone.