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Vibration Analysis of Cylindrical Shells Using Finite Element Method

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Abstract

Free vibration analysis of cylindrical shell is the purpose of this work. The effect of the various parametric ratio like the diameter of the cylinder to the thickness of the cylinder i.e., D/t ratio, length of the cylinder to the diameter of the cylinder i.e., L/D ratio for cylindrical shell is studied using ANSYS parametric design language (APDL) based on First-order Shear Deformation Theory (FSDT) for different boundary conditions like CC, CS, and CF (S - simply supported, C - Clamped, and F - Free) . The study has been compared with different material with different properties like Young's modulus, Poisson's ratio, etc. for the CC boundary conditions.

Keywords

Cylindrical shells, ANSYS parametric design language, First-order shear deformation theory, Vibration, Finite element method

Introduction

Cylindrical shells represent an essential structural component that is commonly used in many engineering fields, such as pipelines, rockets, oil tanks, marine constructions, aerospace applications, railways, and other applications. Whenever cylindrical shells are subjected to dynamic loads, investigation of vibration characteristics like mode shape and natural frequency becomes an interesting field of study. Many scholars have studied vibration analysis of elementary shells like spherical, cylindrical, and conical shells. Among them, Gurve and Satankar [1] analyzed free vibration characteristics of curve shell using Finite Element Method (FEM). "The effect of the radius of curvature, the orientation of stiffener with the different cross section on natural frequency is studied using APDL for different boundary conditions. They have also studied the effect of various parameters like aspect ratio and the thickness ratio with CCCC (C - clamped) boundary condition". He et al. [2] "studied the free and forced vibration of joined cylindrical-spherical shells subjected to classical boundary conditions are investigated by a variational method. They used Donnell shell theory to formulate the theoretical model". Bao and Liu [3] "examined the vibration characteristics of a conical shell with a fixed support for the conical shell. They have used Donel shell theory to calculate the first nine mode numerically with MATLAB. Then with the help of the ANSYS Workbench simulation platform FEM an element model of conical shell has been built also convergence verification is done on ANSYS". "Stanley and Ganesan [4] investigated the natural frequencies for short and long stiffened cylindrical shells subjected to clamped-clamped boundary condition. For analysis, they used semi-analytical FEMs and obtained results are compared with existing experimental and theoretical results". "Blevins [5] studied free vibration behavior of cylindrical curved panels using direct computation of natural frequency and mode shapes for different boundary conditions. Tian et al. [6] proposed an enhanced dynamic stiffness method to examine the free and forced vibration of combined conical-cylindrical shells with general boundary conditions. To formulate the motion equations of each shell component Flügge shell theory is utilized. He et al. [7] analyzed the vibration characteristics of the concave thin-walled conical shell. They also examined the model test to verify the scaling laws".

In this paper free vibration analysis of cylindrical shell is the purpose of this work. The effect of the various the parametric ratio like the diameter of the cylinder to the thickness of the cylinder i.e., D/t ratio, length of the cylinder to the diameter of the cylinder i.e., L/D ratio on the natural frequency of a cylindrical shell is studied 'using APDL the codes were based on FSDT for different boundary conditions like CC, CS, and CF (S - simply supported, C - Clamped, and F - Free)". The study has been compared with different material with different properties like Young's modulus, Poisson's ratio, etc. for the CC boundary conditions.

Methodology

Modal analysis of cylindrical shell

The model to be studied in this paper is developed in ANSYS 18.0 and modal analysis of cylindrical shell has been done in the ANSYS workbench. In this analysis natural frequencies are studied for different parametric ratios when subjected to free vibration. As we know, continuous systems like beams and curve shell have an infinite degree of freedom; thus, to come to result partial differential equations are become essential when these structures are subjected to vibration. "In the FSDT, straight lines perpendicular to the mid surface of the plate i.e., transverse normal remains straight before and after deformation, they are inextensible and transverse normal rotate such that they do not remain perpendicular to the mid surface after deformation" [1]. The transverse shear strain and stress is constant throughout the thickness of the plates.

$$x(u, v, w, t) = x_0(u, v, t) + w\;_{u} \qquad) \tag{1}$$

$$y(u, v, w, t) = y_0(u, v, t) + w\;_{v} \qquad) \tag{2}$$

$$z(u, v, w, t) = z_0(u, v, t) + w\;_{w} \qquad) \tag{3}$$

Where, x, y, and z are displacement of any point on the layer of the plate at time t. u, v, w are co-ordinate axes of material also x_0, y_0, z_0 are displacement point at the mid plane. φ_u and φ_v are the rotation of normal to the mid surface about x and y material principal axes including thickness stretching term φ_w [1]. The modal frequency of vibrating structure can be obtained by eigen value equation by solving Block -Lancoz method:

$$\left([S] - m^2 [m]\right)\{\quad 0\} =$$

Where, [S] is stiffness, [m] is a mass matrix and $\{\delta_m\}$ is the mode shape of corresponding frequency and ω represents the natural frequency of the structure.

Modal analysis of cylindrical shell

Sometime if we imported the model into ANSYS from another modeling software, there will be a certain chance of element loss. Since modeling of cylindrical shell is not a complicated task and ANSYS is capable of a simple modeling module so the model to be studied in this paper is built in ANSYS 18.0. Figure 1 and figure 2 show the model and mesh generation, respectively.

Results and Discussion

Effect of D/t ratio in cylindrical shell

Aluminium alloy is used in the cylindrical shell with material properties E = 71 GPa, ρ = 2699 kg/m^3, μ = 0.34. The length and thickness of cylinder are fixed throughout the analysis whereas diameter is kept on changing to satisfy the D/t ratio. Dimensions (mm) used in cylinder are shown in table 2. Length L = 250 mm and thickness t = 3 mm.

The effect of L/D ratio in cylindrical shell

Aluminium alloy is used in the cylindrical shell with ma-

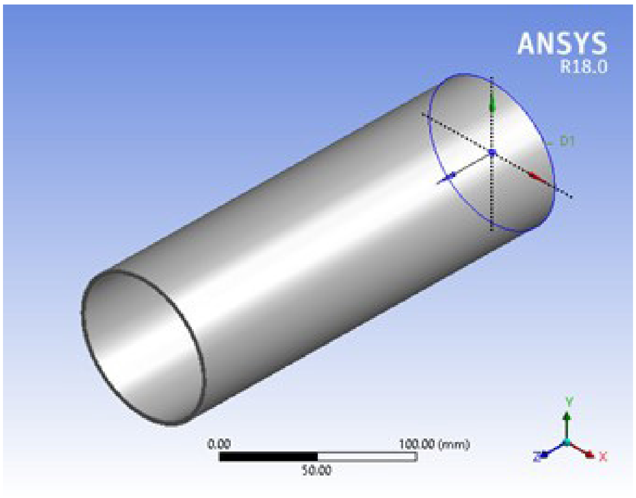

Figure 1: Cylindrical shell.

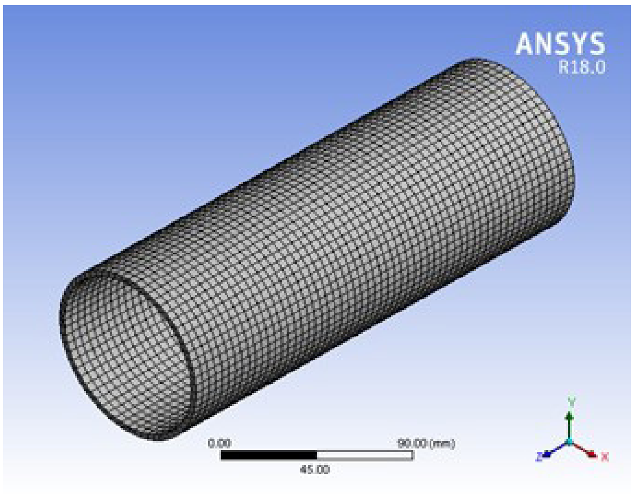

Figure 2: Mesh generation.

Table 1: Ratios and diameters of cylindrical shell.

D/t Ratio	Diameters (in mm)
30	90
35	105
40	120
45	135

Table 2: The variation of Natural frequency (in Hz) w.r.t. D/t ratio for a cylindrical shell with different boundary conditions.

D/t Ratio	Mode No	CC	SC	CF
30	1	2335.4	1946.9	1139.4
	2	2336	1947.8	1141
	3	3260	3158.2	1169.8
	4	3262	3160.3	1169.8
	5	3970.5	3429.7	2489.5
35	1	2350.6	1942.8	916.19
	2	2350.8	1943.1	916.76
	3	2589.7	2440.8	1299.1
	4	2590	2441.1	1299.1
	5	3908.9	3583.4	2169
40	1	2223.1	1996.6	809.36
	2	2223.5	1996.7	809.55
	3	2398.3	2029.4	1408.5
	4	2398.3	2029.7	1408.5
	5	3356.7	3293.4	1668.2
45	1	2025.5	1796.4	768.56
	2	2025.9	1796.9	768.75
	3	2447.4	2064.3	1334.4
	4	2447.5	2063.4	1335.1
	5	2749.2	2664.1	1500.5

Table 3: Ratios and lengths of cylindrical shell.

L/D Ratio	Length (mm)
1	90
1.5	135
2	180
2.5	225

terial properties, E = 71 GPa, ρ = 2699 kg/m^3, μ = 0.34. Diameter and thickness of the cylinder (Figure 1) are fixed throughout the analysis whereas, Lengths are variable to satisfy the L/D ratio. Dimensions (mm) used in the cylinder shown in table 3. D = 90 mm and thickness t = 3 mm

The effect of different materials

Aluminum alloy, Structural steel, Titanium Alloy, and Gray cast iron are used in the cylindrical shell to compare their effect on natural frequencies in the free vibration with CC boundary condition while D/t = 30, L = 250 mm, and thickness t = 3 mm. Properties of material are shown in table 5.

Conclusions

For cylindrical shell free vibration properties were analyzed using APDL and FSDT code. Vibration characteristics like natural frequencies were studied for different boundary conditions using FEM. From previous literature available the results were compared and validated to set up the reliability and accuracy of the code. Investigation has been done for convergence to find the element size for accurate results and

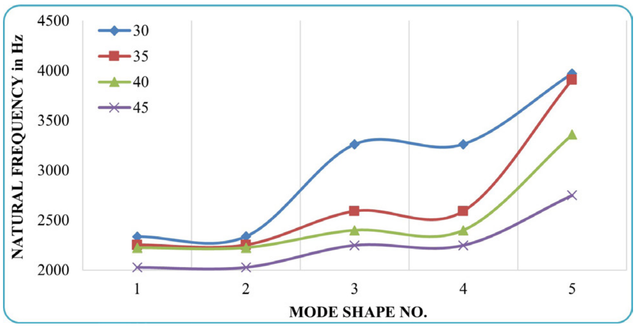

Figure 3: Variation of the frequency w.r.t. D/t ratio for a cylindrical shell with CC boundary condition.

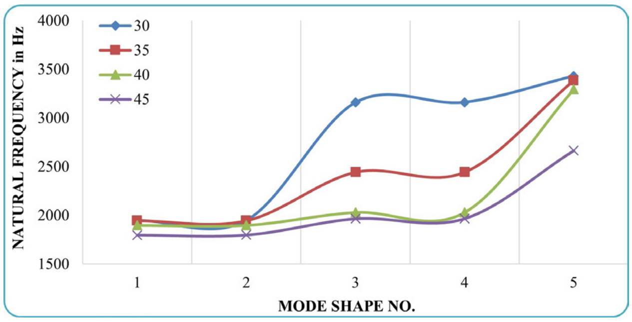

Figure 4: Variation of the frequency w.r.t. D/t ratio for a cylindrical shell with CS boundary condition.

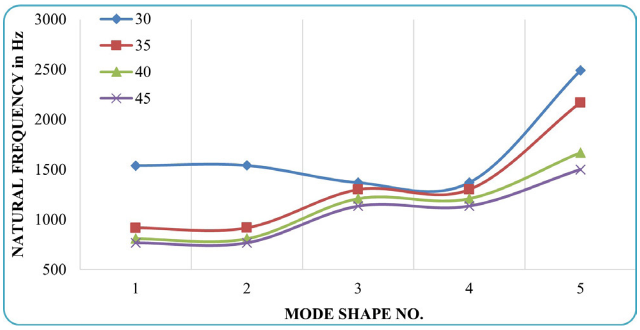

Figure 5: Variation of the frequency w.r.t. D/t ratio for a cylindrical shell with CF boundary condition.

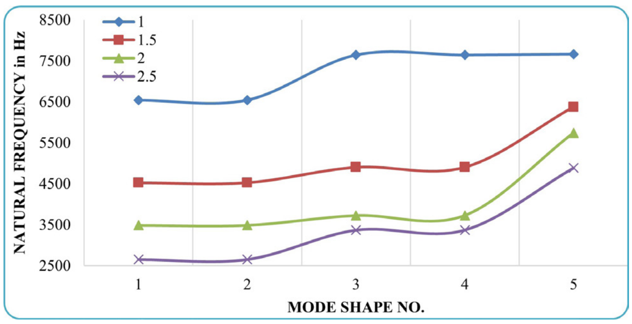

Figure 6: Variation of the frequency w.r.t. the L/D ratio for a cylindrical shell with CC boundary condition.

Table 4: The variation of Natural frequency (in Hz) w.r.t. the L/D ratio for a cylindrical shell with different boundary conditions.

L/D	Mode No	CC	SC	CF
1	1	6543.7	5821	2848.9
	2	6545.1	5822.7	2849
	3	7643.9	6933.3	3405.4
	4	7644.7	6933.6	3409
	5	7666.2	7185.5	5163.2
1.5	1	4526.6	4097.3	1720.5
	2	4527.9	4098.9	1721.4
	3	4904	4250	3050.5
	4	4904.5	4250.3	3050.8
	5	6372.4	6186.1	3073
2	1	3485.9	2933.7	1331.4
	2	3486.2	2934.2	1332.7
	3	3726.2	3484.2	1996
	4	3728.5	3486	1996.1
	5	5744.1	5171	2992.5
2.5	1	2653.1	2208.6	1181.3
	2	2653.6	2209.3	1182.9
	3	3370.5	3233	1396
	4	3372.4	3235	1396
	5	4887.4	3930.3	2858.7

Table 5: Properties of different materials.

Materials	Young Modulus (E) GPa	Density(ρ) kg/m³	poisson's ratio (μ)
Aluminum alloy	71	2699	0.34
Structural steel	212	7800	0.3
Titanium Alloy	96	4620	0.36
Gray cast iron	83.33	7200	0.28

Table 6: Shows the natural frequencies for first the five modes for different materials with CC boundary condition.

Mode No.	Aluminum alloy	Structural steel	Titanium Alloy	Gray cast iron
1	2335.4	2326.7	2105.5	1801.5
2	2336	2327.4	2106.1	1802
3	3260	3221.2	2965.1	2481
4	3262	3223.2	2967	2482
5	3970.5	3985.9	3551.2	3101.2

results obtained shows good agreement with available results with less than 1% error. Natural frequencies for the different parametric ratio, i.e., D/t and L/D were computed for cylindrical shell. It was observed that for the first five modes while studied for D/t by making length and thickness constant, with CC boundary condition natural frequencies come out to be the maximum followed by SC and CF boundary conditions. When D/t ratio increases i.e., diameter increases for the same length and thickness, the natural frequencies decreases and least for the CF boundary condition. Similarly, the impact

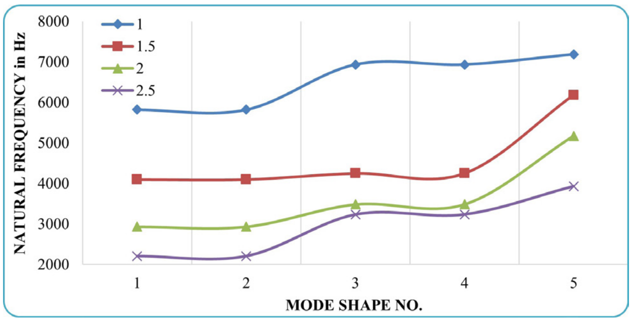

Figure 7: Variation of frequency w.r.t. the L/D ratio for a cylindrical shell with CS boundary condition.

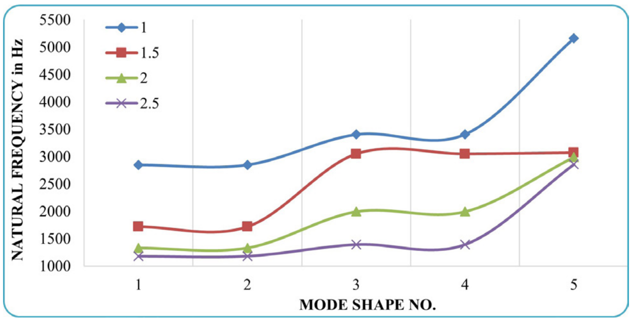

Figure 8: Variation of frequency w.r.t. L/D ratio for a cylindrical shell with CF boundary condition.

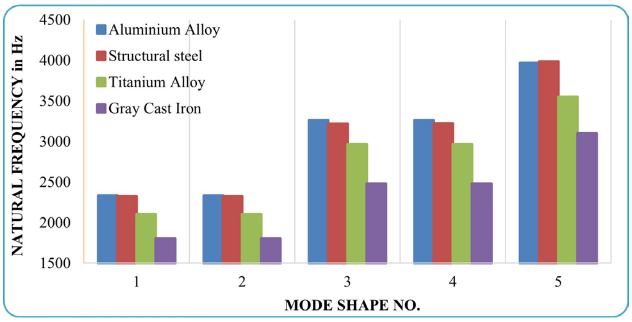

Figure 9: Graphical representation natural frequencies vs mode shape no. of different material with CC boundary condition.

of L/D ratios for cylindrical shell were studied by taking diameter and thickness constant, observed the same result as D/t but frequencies range was different. Different materials were investigated for fixed geometry with CC boundary condition and was found that variation in natural frequencies not much dependent on material, whereas there is accountable difference in natural frequencies for change in parameter and boundary conditions.

Acknowledgements

None.

Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Md Imtiyaz Alam: Formal analysis, Investigation, Writing - original draft preparation, Writing - review and editing; A.K. Jain: Resources, Supervision. All the authors read and approved the manuscript.

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