ORIGINAL RESEARCH PAPER

Engineering

FREE VIBRATION OF FUNCTIONALLY GRADED CARBON NANOTUBE REINFORCED COMPOSITE SPHERICAL SHELL PANEL WITH A CUTOUT

KEY WORDS: free vibration, carbon nanotube, spherical shell panel, cutout, finite element method

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ABSTRACT

In this investigation, free vibration of functionally graded carbon nanotube reinforced composite spherical shell panels with cutout is studied using the finite element method based on a higher-order shear deformation theory. An eight noded degenerated isoparametric element with nine degrees of freedom at each node is considered. Fundamental natural frequencies are presented for functionally graded CNT reinforced spherical shell panel with and without a cutout for simply supported and clamped boundary conditions.

INTRODUCTION

The discovery of carbon nanotubes (CNTs) is a major development in science. They possess superior mechanical, electrical and thermal properties. Due to their superior properties, CNTs are used as reinforcement in polymer matrix composites for structural application. The CNTs are reinforced in a matrix of polymer. CNTs may be aligned in one direction .The distribution of CNTs through thickness of a structural component like a plate/shell may vary and hence they are functionally graded through thickness. CNT reinforced polymer composite plates and shells find application in aerospace, nuclear power plants, automobiles and ships.

Shen and Xiang [1] investigated the large amplitude vibration behavior of nanocomposite cylindrical panels resting on elastic foundations in thermal environment. The results reveal that the natural frequencies increased with the increase in CNT volume fraction. Mirzaei and Kiani[2] investigated the free vibration characteristics of shallow cylindrical shell panels based on a Ritz formulation. Parametric studies were carried out to examine the effects of CNT volume fraction, type of CNT distribution and boundary conditions. Kamarian et al. [3] performed free vibration analysis of carbon nanotube-reinforced composite conical shells considering the agglomeration of effect of carbon nanotubes. The effects of CNT volume fraction, boundary conditions and geometric parameters were also considered. Kiani[4] studied the free vibration characteristics of carbon nanotube-reinforced composite spherical panels using first-order shear deformation theory. The shape functions of the Ritz method were obtained using the Gram-Schmidt process. Nejati et al. [5] investigated the static and free vibration of rotating functionally graded truncated conical shells reinforced by carbon nanotubes with a gradual distribution of the volume fraction through thickness. Wang et al. [6] presented free vibration analysis of functionally graded carbon nanotube reinforced copmposite shallow shells with arbitrary boundary conditions. The effects elastic restraint parameters, shear deformation and rotary inertia, shallowness and material properties were studied. Zghal et al. [7] performed the free vibration analysis of functionally graded composite shell structures reinforced by carbon nanotubes. The equations of motion were developed based on a discrete double directors shell finite element formulation which facilitates consideration of transverse shear deformation via a higher-order distribution of the displacement field.

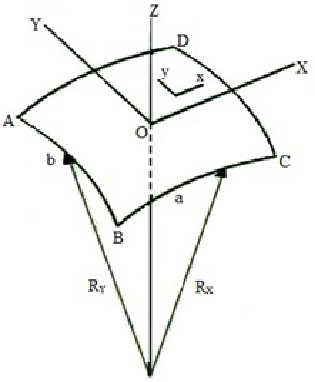
From the review of literature, it may be noted that the free vibration of functionally graded CNT reinforced spherical shell panel with a cutout has not been considered by the earlier researchers. Hence, the objective of this investigation is to analyze the free vibration analysis of CNT reinforced spherical shell panel with a cutout using the finite element method based on higher-order shear deformation theory. A higher-order theory is used to properly account for transverse shear deformation. An eight noded degenerated isoparametric shell element is used with nine degrees of freedom at each node. Fundamental natural frequencies are presented for functionally graded CNT reinforced spherical shell panel with and without a cutout for simply supported and clamped boundary conditions.

FORMULATION

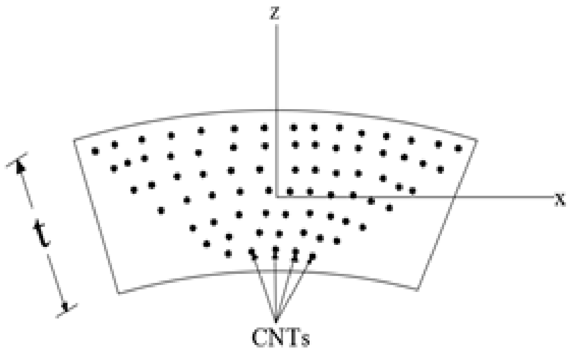
Consider functionally graded CNT reinforced composite spherical shell panel as shown Figure 1. An eight-node degenerated isoparametric element is considered in the present analysis. 9 degrees of freedom are considered at each node. The stiffness matrix and mass matrix of the element are derived using the principle of minimum potential energy. The stiffness matrices and mass matrices of the elements are assembled to obtain respective global matrices [K] and [M]. The natural frequencies ω_n are obtained from the condition.

$$|[K] - \omega_n^2[M]| = 0$$

This is a generalized Eigen value problem and is solved by using the subspace iteration method.



(a) Geometry



(b) Variation Through Thickness
Figure 1

RESULTS AND DISCUSSION

In the present investigation, free vibration of functionally graded carbon nanotube reinforced composite spherical shell panel with a cutout (Figure 2) is studied. Fundamental natural frequencies are presented for functionally graded carbon nanotube reinforced composite spherical shell panel with a cutout (R/a = 5) for simply supported and clamped boundary conditions. In the case of simply supported condition, U_{0i} and V_{0i} are restrained along the supported edge. The spherical shell panel is discretized with 60 elements as shown in Figure 2. The following material properties are used in the investigation.

For CNTs [(10,10)-arm chair SWCNT],

$E_{11}^{CN} = 5.6466\text{TPa}$, $E_{22}^{CN} = 7.08\text{TPa}$, $G_{12}^{CN} = 1.9445\text{TPa}$, $V_{12}^{CN} = 0.175$, $\rho^{CN} = 1400 kg/\text{m}^3$.

For polymeric matrix (PMMA),

$$E_m = 2.5GPa,\ \nu_m = 0.34,\ \rho_m = 1150 kg/\text{m}^3$$

Three different volume fractions of carbon nanotubes are considered. The efficiency parameters considered for each distribution are given below.

$$\eta_1 = 0.137, \eta_2 = 1.022, \eta_3 = 0.7\eta_2 \ for \ V_{CN}^* = 0.12$$

$$\eta_1 = 0.142, \eta_2 = 1.626, \eta_3 = 0.7\eta_2 \ for \ V_{CN}^* = 0.17$$

$$\eta_1 = 0.41, \eta_2 = 1.585, \eta_3 = 0.7\eta_2 \ for \ V_{CN}^* = 0.28$$

Transverse shear moduli of the CNT composite are assumed as. $G_{13} = G_{12}\ and\ G_{23} = 1.2\ G_{12}$.

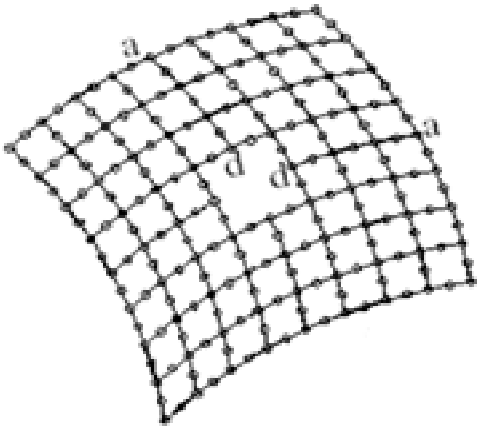


Figure 2 Spherical Shell Panel With A Cutout

Tables 1-4 show the fundamental natural frequencies of simply supported and clamped functionally graded carbon nanotube reinforced composite spherical shell panel with and without a cutout .

Table 1 Non-dimensional fundamental frequency parameter $\omega_n^{'} = \omega_n \frac{a^2}{t}\sqrt{\frac{\rho_m}{E_m}}$ of simply supported spherical shell panel without a cutout (a/b=1,R/a=5)

V*$_{CN}$	a/t	UD	FG-V	FG-O	FG-X
0.12	10	16.56	17.82	15.20	17.26
	50	58.15	55.26	49.10	59.44
0.17	10	20.40	22.15	18.64	21.34
	50	70.13	67.07	59.59	71.71
0.28	10	24.05	25.93	22.50	24.76
	50	87.30	81.74	72.89	89.27

Table 2 Non-dimensional fundamental frequency parameter $\omega_n^{'} = \omega_n \frac{a^2}{t}\sqrt{\frac{\rho_m}{E_m}}$ of clamped spherical shell panel without a cutout (a/b=1,R/a=5)

V*$_{CN}$	a/t	UD	FG-V	FG-O	FG-X
0.12	10	19.63	19.00	18.48	20.03
	50	63.23	60.10	58.16	66.99
0.17	10	24.65	23.85	23.19	25.19
	50	76.48	72.58	70.22	81.21
0.28	10	27.78	27.32	26.90	28.29
	50	94.48	89.94	87.14	99.62

Table 3 Non-dimensional fundamental frequency parameter $\omega_n^{'} = \omega_n \frac{a^2}{t}\sqrt{\frac{\rho_m}{E_m}}$ of simply supported spherical shell panel without a cutout (a/b=1,R/a=5,d/a=0.1)

V*$_{CN}$	a/t	UD	FG-V	FG-O	FG-X
0.12	10	15.73	17.01	14.42	16.44
	50	52.72	53.94	48.10	53.84
0.17	10	19.42	21.17	17.70	20.36
	50	64.15	65.66	58.52	65.65
0.28	10	22.80	24.79	21.23	23.62
	50	78.01	79.50	71.12	80.44

Table 4 Non-dimensional fundamental frequency parameter $\omega_n^{'} = \omega_n \frac{a^2}{t}\sqrt{\frac{\rho_m}{E_m}}$ of clamped spherical shell panel without a cutout (a/b=1,R/a=5,d/a =0.1)

V*$_{CN}$	a/t	UD	FG-V	FG-O	FG-X
0.12	10	19.36	18.64	18.12	19.81
	50	58.92	55.74	53.99	62.70
0.17	10	24.36	23.45	22.78	24.98
	50	71.68	67.76	65.56	76.48
0.28	10	27.31	26.76	26.30	27.90
	50	87.22	82.88	79.95	92.92

CONCLUSIONS

- In the case of FG-CNTRC simply supported spherical shell panel with and without a cutout , for a/t=50, the fundamental natural frequency is generally maximum for FG-X distribution; for a/t = 10, it is maximum for FG-V distribution.
- In the case of FG-CNTRC clamped spherical shell panel with and without a cutout, the fundamental natural frequency is maximum for FG-X distribution for a/b = 10, 50.
- In the case of FG-CNTRC simply supported and clamped spherical shell panels, the fundamental natural frequency decreases with the increase in cutout size (d/a).

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