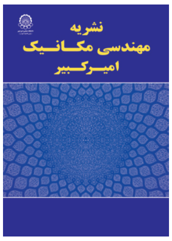

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Surface Effect on Free Vibration Behavior of Circular Graphene Sheet with an Eccentric Hole

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ABSTRACT: In this article, an analytical method is used to study effects of surface and geometrical defect on free vibration behavior of circular nanoplates. Due to production process and constrains conditions, nanoplates may be opposed to structural defect. Some of defects can be modelled as an eccentric hole. Gurtin-Murdoch and thin plate theories are employed to model the eccentric circular nanoplate. In order to solve equation of motion, the separation of variables method as well as additional theorem for the regular and modified first and second kinds of Bessel functions are used. Both of symmetric and antisymmetric vibration modes are analyzed. Finally, effects of various geometrical and material properties on natural frequencies of the nanoplates are investigated. Also, effects of various boundary conditions as free, clamped and simply supported are investigated on the natural frequencies using a wide range of results. Results show that surface effects and eccentric circular defect play an important role in vibrational behavior of an eccentric circular nanoplate. It is observed that the free boundary condition has no more effect on the fundamental natural frequency.

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1- Introduction

The hole in any place of plate may be created to decrease the weight, gain access to other parts of construction or to increase the natural frequency of the plate and avoid escalation in it. Cut out a portion of a plate affects its behavior, changes the buckling ratio and natural frequency. For this reason, the analysis of these plates have been studied in the past and has expressed several ways to solve them. Nonlocal theory was first presented by Eringen [1], indicating that stress is not only a function of strain field a point but also a function of strain in all parts of the continuum. This theory has a surprising ability to express the stress field in points (such as point of load or end of crack), which is not expressible using the theory of classical mechanics. Eringen nonlocal theory has been recently used to solve nanostructures. Results suggest that nonlocal theory of Eringen, in addition to avoid to solve complex equations, has the ability to predict the behavior of nanostructures as well. Wang and Duan [1] studied free vibrations of a nano curved beam using nonlocal elasticity theory. They found the exact natural frequency and checked the length scale effect. Asadi [2] solved forced vibration of a rectangular plate with considering the surface effects by using Kirchhoff thin plate theory analytically. Asadi and Farshi [3] studied vibration of circular nanoplate. Farajpour et al. [4] examined the buckling of a circular single-layer plate and announced that the results have good agreement with the molecular dynamic method. Malekzadeh et al. [5] investigated the effect of small scale on buckling of an orthotropic plate.

The main purpose of this article is to analyze free vibrations of a circular plate including surface effects with an eccentric hole. The effects of the important parameters such as eccentricity and geometrical defect on natural frequencies of circular plate are considered. The present analysis is a good source for the other researchers to investigate the effects of geometrical defects on the mechanical behavior of nanoplates.

2- Governing equations

A circular graphene sheet with an eccentric hole is depicted in Figure 1. The graphene sheet's geometric properties are denoted by inside radius R_2, outside radius R_1, eccentricity ε, and thickness h. The elastic modulus, Poisson's ratio and mass density of the bulk part are respectively indicated by E, ν and ρ The parameters λ and μ indicate the classical Lame constants while the surface Lame constants are shown by λ^s and μ^s.τ^s is the surface residual stress which is uniformly distributed on the upper and lower surfaces. The surface mass density and the surface elastic modulus of the are also indicated by ρ^s and E^s, respectively. To interpret mathematical formulations, two polar coordinates (r_1, θ_1) and (r_2, θ_2) are taken to coincide with the center of the outer and inner circles, respectively. The upper and lower surfaces at $z=\pm h/2$ are denoted by s^+ and s^-, respectively.

The displacement components (u,v,w) for an isotropic plate according to the classical plate theory can be written in a general form as

$$u(r_2,\theta_2,z) = -z\,\frac{\partial w(r_2,\theta_2)}{\partial r_2}$$
$$v(r_2,\theta_2,z) = -z\,\frac{1}{r_2}\frac{\partial w(r_2,\theta_2)}{\partial \theta_2} \qquad (1)$$
$$w(r_2,\theta_2,z) = w(r_2,\theta_2)$$

Using nonlocal and Gurtin-Murdoch theory, it can be concluded that

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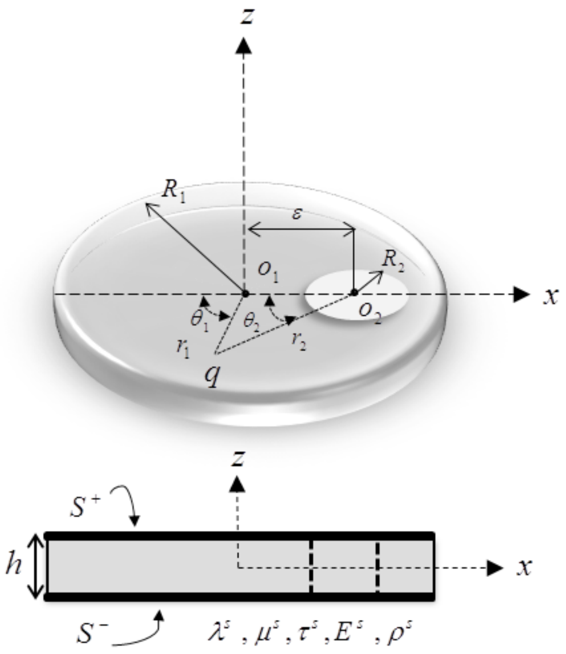

Figure 1. Schematic of a circular nanoplate with upper and lower thin skin layers carrying surface effects

$$\left(D+\frac{2\mu^s+\lambda^s}{4}h^2\right)\nabla^4 w+\rho h\left(1+\frac{2\rho^s}{\rho h}\right)\frac{\partial^2 w}{\partial t^2} -2\tau^s\nabla^2 w-\rho h\mu^2\nabla^2\left(\frac{\partial^2 w}{\partial t^2}\right)=0 \quad (2)$$

Thus, final and the general solution takes the following form

$$W(r_2,\theta_2)=\sum_{n=0}^{\infty}\begin{pmatrix}A_{1n}J_n(\eta r_2)+A_{2n}Y_n(\eta r_2)\\+A_{3n}I_n(\xi r_2)+A_{4n}K_n(\xi r_2)\end{pmatrix}cos(n\,\theta_2) +\sum_{n=1}^{\infty}\begin{pmatrix}B_{1n}J_n(\eta r_2)+B_{2n}Y_n(\eta r_2)\\+B_{3n}I_n(\xi r_2)+B_{4n}K_n(\xi r_2)\end{pmatrix}sin(n\,\theta_2) \quad (3)$$

where $\eta=\sqrt{\left(-\alpha^2+\sqrt{4\beta^4+\alpha^4}\right)/2}$ and J_n, Y_n are the regular Bessel functions of first and second kinds, respectively. $\xi=\sqrt{\left(\alpha^2+\sqrt{4\beta^4+\alpha^4}\right)/2}$ and I_n, K_n are the modified Bessel functions of first and second kinds, respectively. A_{1n}, A_{2n}, A_{3n}, A_{4n} and B_{1n}, B_{2n}, B_{3n}, B_{4n} are the mode shape coefficients, which are determined by the boundary conditions of the nanoplate. In Eq. 3, the cosine series is corresponding to symmetric vibration modes of graphene sheet and that with $sin(n\theta_2)$ is for antisymmetric modes.

3- Results and Discussion

Effects of the surface elastic modulus parameter in conjunction with the eccentricity on the fundamental frequency of the plate are presented in Figure 2. It shows that as much as the eccentricity and elastic modulus increase, the fundamental frequency increases.

Table 1 reports the first three fundamental natural frequencies of the plate. It can be concluded that by increasing elastic modulus and surface residual stress, the frequencies increase.

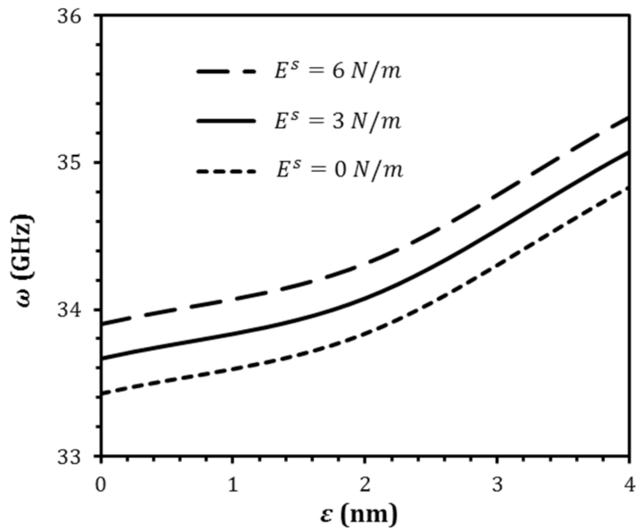

Figure 2. The influence of the eccentricity on the frequency

Table 1. Three natural frequency with clamp boundary condition

E_s(N/m)	τ_s(N/m)	ω_1(GHz)	ω_2(GHz)	ω_3(GHz)
0	0.4	52.57	126.11	234.85
	0.6	57.46	133.50	240.60
	0.8	61.92	140.48	246.53
5	0.4	53.41	128.63	238.04
	0.6	58.24	135.89	235.99
	0.8	62.65	142.75	243.36

4- Conclusions

This article considered free vibration of eccentric annular graphene sheet including surface effects. The problem has been analytically solved using translational addition theorem. Results show that the eccentricity has significant effects on fundamental frequency. Also, surface effects increase stiffness of the sheet.

References

[1] C.M. Wang, W.H. Duan, Free vibration of nanorings/arches based on nonlocal elasticity, *Journal of Applied Physics*, 104(1) (2008) 014303.

[2] A. Assadi, Size dependent forced vibration of nanoplates with consideration of surface effects, *Applied Mathematical Modelling*, 37(5) (2013) 3575-3588.

[3] A. Assadi, B. Farshi, Vibration characteristics of circular nanoplates, *Journal of Applied Physics*, 108(7) (2010) 074312.

[4] A. Farajpour, M. Dehghany, A.R. Shahidi, Surface and nonlocal effects on the axisymmetric buckling of circular graphene sheets in thermal environment, *Composites Part B: Engineering*, 50 (2013) 333-343.

[5] P. Malekzadeh, A.R.Setoodeh, A.AlibeygiBeni, 2011. “Analysis of the buckling of rectangular nanoplates by

use of finite difference method", *Composite Structures*, 93, pp. 2083.

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