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On the dynamic stability of viscoelastic graphene sheets

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ABSTRACT

Due to their extraordinary and unique properties, graphene sheets have been attracted tremendous attention in recent years. This paper is concerned with the dynamic stability of an embedded orthotropic single layer graphene sheet (SLGS) subjected to periodic excitation compressive load with various boundary conditions. In order to obtain more accurate results, the material properties of graphene sheet are assumed to be viscoelastic using Kelvin-Voigt model. The surrounding medium is described by visco-Pasternak foundation model, which accounts for normal, transverse shear and damping loads. Adopting the first order shear deformation theory (FSDT) in the framework of Eringen's differential constitutive model, the governing equations of motion are obtained via energy method and Hamilton's principle which are then solved numerically via Ritz method in conjunction with Bolotin method. The parametric studies are carried out to explore the effects of the static load factor, structural damping, nonlocal parameter, stiffness and damping coefficients of the foundation and aspect ratio on the dynamic instability region (DIR) of SLGS for each of the boundary conditions separately. Results indicate that with increasing the structural damping coefficient, the dimensionless pulsation frequency decreases and DIR moves to left, consequently. Moreover, it is observed that when one edge of the nanoplate changes from free to simply supported or from simply supported to clamped, the dimensionless pulsation frequency enhances.

1. Introduction

Graphene, a two-dimensional sheet of sp^2-bonded carbon atoms packed in a honeycomb crystal lattice, is an interesting material for wide potential applications such as oscillators, biomedical, sensors, atomic force microscopes, nanocomposites, micro/nano electro-mechanical systems (MEMS/NEMS) owing to its remarkable thermal, electrical, optical, chemical and mechanical properties. Therefore, it is essential to recognize and analyze behavior of these nanostructures for their effective design and manufacture.

Besides experimental methods, there are two main theoretical modeling approaches that have been developed to analyze the mechanical behavior of nanostructures such as atomistic simulations and continuum mechanics. The atomistic-based method such as molecular dynamics (MD) simulation, tight-binding molecular dynamics (TBMD) and density functional

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theory (DFT) can be utilized for systems with small number of molecules and atoms. Since classical continuum mechanics are not able to consider the small scale effects, several nonclassical continuum theories such as strain gradient theory (Akgöz & Civalek, 2013; Ebrahimi, Barati, & Dabbagh, 2016; Farajpour, Haeri Yazdi, Rastgoo, & Mohammadi, 2016; Ghannadpour, Mohammadi, & Fazilati, 2013; Li & Hu, 2015; Rajabi & Hosseini-Hashemi, 2017; Wang, Zhao, & Zhou, 2010; Xiao, Li, & Wang, 2017), couple stress theory (Akgöz & Civalek, 2012; Barati & Shahverdi, 2017; Dehrouyesh-Semnani et al., 2017; Farokhi, Ghayesh, Gholipour, & Tavallaeinejad, 2017; Ghayesh & Farokhi, 2015; Ghorbanpour Arani, Abdollahian, & Jalaei, 2015; Jomehzadeh, Noori, & Saidi, 2011; Mohammad-Abadi & Daneshmehr, 2014; Tadi Beni & Mehralian, 2017) and nonlocal elasticity theory (Aranda-Ruiz, Loya, & Fernández- Sáez, 2012; Askari, Esmailzadeh, & Zhang, 2014; Ghorbanpour Arani & Jalaei, 2016a, 2016b; Lei, Adhikari, & Friswell, 2013; Reddy, 2007; Thai & Vo, 2012) have been developed to characterize the size effects in micro/nano structures.

Among these theories, the nonlocal elasticity theory introduced by Eringen (1983) has been widely applied because of convenience in formulations and close agreement with lattice dynamics and MD simulation results. So, this nonlocal theory has been extensively utilized to comprehend the scaling effects on the buckling, bending and vibration behaviors of nanostructures such as nanobeams/rods (Adhikari, Murmu, & McCarthy, 2014; Ghannadpour et al., 2013; Tuna & Kirca, 2016; Zhu & Li, 2017), nanoshells (Ansari, Rouhi, & Sahmani, 2014; Fazelzadeh & Ghavanloo, 2012; Hu, Liew, Wang, He, & Yakobson, 2008; Wang & Varadan, 2007) and nanoplates (Alzahrani, Zenkour, & Sobhy, 2013; Daneshmehr, Rajabpoor, & Hadi, 2015; Ebrahimi & Shafiei, 2017; Golmakani & Rezatalab, 2015; Murmu & Pradhan, 2009). In this regard, Aghababaei and Reddy (2009) presented analytical solutions for bending and free vibration of simply supported nanoplate based on nonlocal third-order shear deformation plate theory. Aksencer and Aydogdu (2011) used Eringen's differential constitutive model to implement the buckling and vibration analyses of nanoplates by Navier type solution for simply supported plates and Levy type method for plates at least two opposite edges are simply supported plates based on classical plate theory (CLPT). Roque, Ferreira, and Reddy (2011) utilized the nonlocal elasticity theory to study bending, buckling and free vibration of Timoshenko nanobeams via meshless method. Daneshmehr, Rajabpoor, and Pourdavood (2014) presented a nonlocal elasticity theory for buckling analysis of functionally graded nanoplate subjected to biaxial in plane loadings based on higher order shear deformation plate theory via differential quadrature method (DQM) for various boundary conditions. Hosseini-Hashemi, Kermajani, and Nazemnezhad (2015) investigated small scale effects on the buckling and free vibration analyses of Levy-type nanoplates using an analytical solution based on the Reddy's nonlocal third-order shear deformation plate theory. Sari and Al-Kouz (2016) performed the free vibration analysis of non-uniform orthotropic Kirchhoff plates embedded in elastic medium using Chebyshev spectral collection method. Zhang, Zhang, and Liew (2017) proposed an element free kp-Ritz method for the nonlinear vibration of single layer graphene sheet (SLGS) using nonlocal CLPT.

All the above mentioned researches have been performed on the static behavior of nanomaterials based on Eringen's differential constitutive model. In the field of dynamic analysis of nanoscale structures, Li et al. (2011) investigated the natural frequency, steady-state response and stability of axially loaded simply supported nanobeam based on the nonlocal theory and perturbation method. They found that the initial tension and scale effects have great influence on the instability regions and natural frequency. Ansari, Gholami, Sahmani, Norouzzadeh, and Bazdid-Vahdati (2015) studied the dynamic stability of embedded simply supported single walled carbon nanotube (SWCNT) including thermal environment effects based on the nonlocal Euler-Bernoulli and Timoshenko beam theories. Results show that the system tends to become unstable with increasing temperature change at high temperatures. Ghorbanpour Arani, Kolahchi, and Hashemian (2014) analyzed dynamic stability of double-layered boron nitride nanotubes (DWBNNT) conveying viscous fluid based on nonlocal Euler-Bernoulli beam theory, Timoshenko beam theory, and cylindrical shell theory applying incremental harmonic balance method (IHBM) and Galerkin method. They showed the effects of nonlocal parameters, fluid velocity, surrounding medium and surface stress on dynamic instability region (DIR) of a DWBNNT. Pavlović, Pavlović, Ćirić, and Karličić (2015) investigated dynamic stability problem of a simply supported viscoelastic nanobeam subjected to compressive axial loading utilizing the direct Liapunov method and moment Liapunov exponents based on nonlocal Rayleigh beam theory. Ghorbanpour Arani, Kolahchi, and Zarei (2015) investigated nonlinear dynamic stability of simply supported graphene sheets integrated with ZnO sensors and actuators based on viscoelastic surface and nonlocal piezoelasticity theories via refined Zigzag theory. Hosseini-Hashemi, Mehrabani, and Ahmadi-Savadkoohi (2015) employed an analytical method to study the nonlocal forced vibration of single layer viscoelastic graphene sheet resting on visco-Pasternak foundation on the basis of CLPT. Ghorbanpour Arani and Jalaei (2016b) performed size-dependent transient analysis of simply supported viscoelastic orthotropic SLGS embedded in orthotropic visco-Pasternak foundation based on the nonlocal first order shear deformation theory (FSDT). They employed Navier's approach in conjunction with Laplace inversion technique to discretize the equations in the space and time domains, respectively. Pavlović, Karličić, Pavlović, Janevski, and Ćirić (2016) studied a stochastic stability of simply supported multi-nanobeam system by means of the direct Liapunov method and moment Liapunov exponents based on the nonlocal Euler-Bernoulli beam theory. The beams are continuously joined by a viscoelastic layer, and axial forces acting on their ends consist of a constant part and a time dependent stochastic function. Karličić, Kozić, Pavlović, and Nešić (2017) investigated nonlinear vibration and dynamic stability of a SWCNT with various boundary conditions embedded in a viscoelastic medium under longitudinal magnetic field and time-varying axial load based on nonlocal Euler-Bernoulli beam theory. Their results were obtained using perturbation method of multiple scales and IHBM. Bakhshi Khaniki and Hosseini-Hashemi (2017) investigated dynamic response of double layered simply supported viscoelastic orthotropic nanoplate systems under a moving nanoparticle based on Kirchhoff plate and Eringen's differential constitutive model. They used Galerkin's and Laplace transform methods to solve the governing equations. Ghorbanpour Arani and Jalaei (2017) studied the influence of a longitudinal