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On the analysis of microbeams

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ABSTRACT

The most widely used theory in the analysis of nanostructures is Eringen's nonlocal elasticity theory. But many researchers have mentioned that this theory has a paradox for the cantilever boundary condition. In order to overcome this paradox, different methods of mathematical complications have been applied. By adding additional parameters to Eringen's nonlocal elasticity theory, enhanced Eringen differential model was developed as an alternative solution method without the necessity of these complications. In this paper, bending of nano/micro beams under the concentrated and distributed loads has been investigated by using Euler Bernoulli beam theory via the enhanced Eringen differential model. Singularity function method is used to calculate the deflection of concentrated and distributed loaded beam. Various types of boundary conditions are considered for the beam such as cantilever, clamped, propped cantilever and simply supported. In each case of boundary conditions, closed form solutions for the bending of the beam are presented for various loading locations. Deflection, bending moment and shear force are presented comparatively for variable loadings in figures and tables.

1. Introduction

Nano/micro sized devices and systems have been developed and being used extensively in many applications, such as microsensors, microactuators, atomic force microscopes (AFMs), nanoelectromechanical and microelectromechanical systems mass detection, frequency synthesis. With nanoscience and nanotechnology, a new era has begun for many areas (chemical, medicine, engineering, electronics, etc.). Some of recent applications of nanobeams in engineering structures are nonvolatile random access memory, nanotweezers, tunable oscillator, rotational motors, nanorelays, feedback-controlled nanocantilevers. These nanodevices have great importance in the rise of nanotechnology. Nonvolatile random access memory (NVRAM) retains its information when power is turned off. NVRAM is mostly used in flash memory devices. Nanobeams and nanostructures provide to read and write information into bigger blocks due to their very small size and density comparing to older silicon based random access memories. Another nanostructure which is commonly used in engineering application is nanotweezer. Nanotweezer is a nanodevice which is composed of two carbon nanotube arms which are cantilevered. It is used for the manipulation of nanostructures and two-tip scanning-tunneling microscope (STM) or atomic force microscope (AFM) (Akita et al., 2001; Kim & Lieber, 1999). On the other hand, rotational motors are used in nanoactuators and they provide to transmit electromagnetic radiation (Fennimore et al., 2003). Furthermore, tunable oscillators are generally used to transduce very small forces. Besides these devices nanorelays and feedback-controlled nanocantilevers are used to turn on/off electric circuits in almost every nanodevices. This paper aim to simulate to bending behavior of nanostructures in-

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cluding the size effect such as Carbon nanotube, Silicon carbide nanotube, Boron nitrite nanotube etc. more precision and realistic than classical continuum models.

For the application of nano/micro structures, it is necessary to predetermine first the device characteristics at the design level. It has been experimentally observed that many nano/micro structured materials under bending load have size dependent parameters which affect their mechanical properties. Experimental research is very difficult and expensive. Some methods such as Hybrid atomistic–continuum mechanics and related to the atomic modeling; molecular dynamics, tight-binding molecular dynamics, the density functional theory take the size effect into account. But solutions with these methods are very time-consuming and require high-capacity computers. For this reasons, researchers had turn towards to the theoretical analysis (continuum mechanics).

For materials which are sized in nano/micro scale, the size effect is significant (Kahrobaiyan, Asghari, Rahaeifard, & Ahmadian, 2010; Narendara, Mahapatra, & Gopalakrishnan, 2011; Shaat & Abdelkefi, 2015; Uzhegova, Svistkov, Lauke, & Heinrich, 2014). But classical continuum mechanics does not take into account the small scale effect. Thus, various theories have been developed that give importance to the effects of small scale such as strain gradient theory (Akgoz & Civalek, 2011, 2013, 2014; Fleck & Hutchinson, 1997; Kahrobaiyan, Asghari, Rahaeifard, & Ahmadian, 2011; Lam, Yang, Chong, Wang, & Tong, 2003), modified couple stress theory (Asghari, Kahrobaiyan, & Ahmadian, 2010; Farokhi, Ghayesh, & Gholipour, 2017; Hosseini & Bahaadini, 2016; Ma, Gao, & Reddy, 2008; Mojahedi, 2017; Park & Gao, 2006; Shafiei, Kazemi, & Ghadiri, 2016; Simsek & Reddy, 2013), nonlocal elasticity theory (Ebrahimi & Barati, 2016; Eringen, 1972, 1981), nonlocal strain gradient theory (Ebrahimi, Barati, & Dabbagh, 2016; Li & Hu, 2016; Li, Li, & Hu, 2016), surface elasticity (Attia, 2017; Kiani, 2016; Sahmani, Bahrami, & Aghdam, 2016). The nonlocal elasticity theory, which adds the atom length scales to the constitutive equations, is the most commonly used theory. Applying first the nonlocal elasticity theory to nanotechnology is by Peddieson, Buchanan, and McNitt (2003). They investigated the bending of the nano-micro scaled beam and importance of small-scale length. Wang and Liew (2007) observed the static deformation of Euler and Timoshenko beam subjected to a point load. Wang and Shindo (2006) have investigated the bending of carbon nanotube with the small scale effect under distributed and concentrated loads. Nejad and Hadi (2016a) studied the static bending analysis of Euler–Bernoulli nanobeams made of bi-directional functionally graded material with nonlocal elasticity theory. Li and Hu (2016) have studied bending and free vibration analysis of functionally graded Timoshenko beam with the nonlocal strain gradient elasticity theory. Application of nonlocal continuum mechanics for nano/micro structures have been implemented by many researchers for static and dynamic analysis (Nejad & Hadi, 2016b; Nejad, Hadi, & Rastgoo, 2016; Reddy, 2007; Reddy & Pang, 2008; Thai, 2012). In recent times, the mechanical behaviors of small-sized devices in micro/nano-electromechanical systems have been determined by applying nonlocal elasticity theory. For instance, frequency analysis of carbon nanotube based cantilever biosensors is performed via nonlocal elasticity theory (Murmu & Adhikari, 2012). In another study, single-layered graphene sheets (SLGSs) are modeled as a nanoscale label-free mass sensor and the vibrational response of these structures is investigated by nonlocal elasticity theory (Murmu & Adhikari, 2013). In addition, the pull-in instability of nano-switches under electrostatic and intermolecular forces is studied within the framework of nonlocal elasticity theory (Taghavi & Nahvi, 2013; Yang, Jia, & Kitipornchai, 2008). Similarly, dynamic pull-in stability of functionally graded nano-actuators is examined based on nonlocal elasticity theory by considering Casimir attraction (Sedighi, Daneshmand, & Abadyan, 2016). The studies about the application of the nonlocal elasticity theory in modeling of carbon nanotubes and graphene sheets are reviewed by Arash and Wang (2012).

Most of articles have investigated bending, buckling and vibration analyses using the simplified nonlocal elastic model. To be able to follow the technology rapidly, however, the most important factors is to recognize the nanostructures, the correct modeling and the correct solution method. Making the wrong solution causes incorrect design. Several authors declared a discrepancy between the results which are obtained by Eringen differential model (EDM) from other boundary conditions than cantilever beam (Barretta, Feo, Luciano, & de Sciarra, 2016; Challamel & Wang, 2008; Challamel et al., 2014; Challamel, Reddy, & Wang, 2016; Fernández-Sáez, Zaera, Loya, & Reddy, 2016; Khodabakhshi & Reddy, 2015; Romano & Barretta, 2017; Tuna & Kirca, 2016). The paradoxes are about the solution of beam problems. One of them is at the cantilever beam under point load at the end, there is no effect of small scale parameter. Another problem is when a distributed load is applied, softening effect is observed in all other boundary conditions, but stiffening effect occurs in the cantilever boundary condition. Challamel et al. (2016) said that this paradox can be derived from a superposition of an integral non-local elastic model based on the combination of local and non-local curvatures in the constitutive elastic relation. Fernández-Sáez et al. (2016) pointed out that the solution of the Eringen integral equation coincided with the differential form of the Eringen model if the relevant boundary conditions (Benvenuti & Simone, 2013; Polyanin & Manzhirov, 2008) are used. They suggest a general method for solving the integral equation. The results were compared with the widely used differential Eringen model. Challamel et al. (2016) solved this paradox with the nonlocal differential model itself via some related discontinuous nonlocal kinematics. They have shown that the kinematics of nonlocal constitutive law leads to the use of moment or shear discontinuities. Many researchers suggested different methods to solve this problem (Lu, Guo, & Zhao, 2017; Romano & Barretta, 2017; Tuna & Kirca, 2017; Zhu, Wang & Dai, 2017). Khodabakhshi and Reddy (2015) investigated the behavior of Euler–Bernoulli beams under transverse loads. They developed a general finite element formulation for local/nonlocal two phase integral equations. Recently, Lim, Zhang, and Reddy (2015) have done wave propagation analysis by providing a high-level model that combines strain gradients and non-local stresses. Romano and Barretta (2017) Investigated the stress-driven integral model for nonlocal elasticity. Finally, Barretta et al. (2016) have identified a simple constitutive strategy for nanotechnological applications by replacing the problematic (but popular) Eringen differential law with a more