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Araştırma Makalesi Research Article

LONGITUDINAL FORCED VIBRATION ANALYSIS OF POROUS A NANOROD

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Keywords
Nanorods,
Nonlocal Elasticity Theory,
Porosity,
Forced Vibration.

Abstract
In this paper, longitudinal vibration responses of a nanorod subjected to harmonic external load are investigated with porosity based on Nonlocal Elasticity theory. The governing equation of the problem is solved by analytically. Frequency equations and the forced vibration displacements are obtained exactly. In the numerical examples, effects of the nonlocal, dynamic, geometry and porosity parameters on forced vibration responses of the nanorod are investigated.

BOŞLUK YAPILI NANO BİR ÇUBUK ELEMANIN BOYUNA ZORLANMIŞ TİTREŞİM ANALİZİ

Anahtar Kelimeler
Nano Çubuklar,
Yerel Olmayan Elastisite Teorisi,
Boşluk Oranı,
Zorlanmış Titreşim.

Öz
Bu çalışmada, boşluk yapılı nano çubuk bir elemanın harmonik bir dış kuvvet etkisi altında zorlanmış boyuna titreşim cevapları, yerel olmayan elastisite teorisi ile incelenmiştir. Probleme ait hareket denklemi analitik olarak çözülmüş olup, frekans denklemleri ile zorlamış titreşim yer değiştirmeleri kesin bir analitik değerde elde edilmiştir. Sayısal çalışmada, yerel olmayan parametre, dinamik, geometrik ve boşluk oranı parametrelerinin, nano çubuğun zorlanmış titreşim cevaplarına olan etkileri incelenmiştir.

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1. Introduction

With the advancement of technology, the use of nano structures is increasing in the engineering projects. Nano structures have been used many application, such as electro-mechanical devices, actuators, atomic misroscopes. In the mechanical modelling and solution of the nano structures are still difficult problems at the present time. In the mechanical solution of the nanostructures, molecular dynamic simulation is used. However, this solution takes much time and its computational cost is considerably high. So, the nonlocal continuum theories are preferred in the nanostructures. The nonlocal continuum theories consist of size effect in contrast with classical continuum theory.

The main nonlocal elasticity theories are the couple stress theory, strain gradient theory, Eringen's nonlocal elasticity theory.

In the production phase or lifetime of the nano structures, voids and porosities can be occurred naturally or technical problems. The porosity yields to losing strength and the mechanical responses of the nano structure change considerably.

In the last decade, vibration, stability and static behavior of the nano structure have been investigated within nonlocal continuum theories in the literature at large (Eringen (1972,1983), Toupin (1962), Lam et al. (2003), Mindlin (1963a,b)), Yang et al. (2002) Park and Gao (2006), Hasanyan et al. (2008), Loya et al. (2009), Civalek et al. (2009), Civalek and Kiracioglu (2010), Reddy (2010,2011), Hasheminejad et al.

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(2011), Avcar (2010,2017,2018), Liu et al. (2013), Ansari et al. (2011), Civalek and Demir (2011), Wang et al. (2012), Asghari et al. (2010), Liu and Reddy (2011), Salamat-Talab et al. (2012), Akgöz and Civalek (2013,2014a,2014b), Roostai et al. (2014), Peng et al. (2015), Akbaş (2014a,2014b,2014c,2015, Karličić et al. (2015), Kocatürk and Akbaş (2013),Sedighi et al. (2014), Al-Basyouni et al. (2015), Şimşek (2016), Chaht et al. (2015), Zerin (2012), Yaylı (2014,2018), Mercan and Civalek (2017), Akgöz and Civalek (2017), Demir and Civalek (2017), Yaylı et al. (2015), Belkorissat et al. (2015), Akbaş (2016a, 2016b, 2017a, 2017b, 2018c, 2017d, 2017e, 2018a, 2018b,2018c,2018d,2018e),Ke et al. (2012), Demir and Civalek (2016), Arda and Aydogdu (2017), Arda (2018), Eren and Aydogdu (2018)).

In the literature, the studies about porous nanostructures are as follows; Shafiei and Kazemi (2017) analyzed buckling of functionally graded porous tapered nanobeams based on Eringen's nonlocal elasticity theory. Ebrahimi et al. (2017) investigated vibration analysis of porous piezoelectric nanobeams under thermal effects based on strain gradient theory. Sahmani et al. (2018) analyzed nonlinear behavior of functionally graded nano/micro beam with reinforced by graphane with porosity effect. Li et al. (2018) presented nonlinear vibration analysis of porous nanobeams by using the von Kármán type nonlinearity and the strain gradient theory. Ebrahimi and Barati (2018a,2018b) examined dynamic and stability of porous nano beams with couple stress theory. Radić (2018) investigated buckling results of functionally graded nanoplates embedded on foundation with porosity. Karami et al. (2018) examined wave propagation analysis of functionally graded porous nanoplates. Sahmani and Aghdam (2018) studied nonlinear resonance of nanoporous nanobeams based on strain gradient theory. Barati and Zenkour (2018) investigated post-buckling analysis porous nano-composite beam reinforced by Graphane. Ahmed et al. (2019) studied post-buckling of functionally graded porous nanobeams.

In this study, longitudinal forced vibration of a cantilever nanorod is investigated with porosity effect. The nanorod is subjected to a harmonic load at the free end. In the governing equation of the problem, the nonlocal Elasticity theory is used. The solution of problem is obtained by analytically. The explicit frequency and displacements are obtained in domain time by analytically. In this paper, the effects of the nonlocal parameter, dynamic, geometric and porosity ratio values on the forced vibration responses of the nanorod are presented and discussed.

2. Theory and Equations

A clamped-free porous circular nanorod subjected to dynamically point load (P(t)) at the free end is shown in figure 1. In figure 1, L and D indicate the length and diameter of the nanarod, respectively.

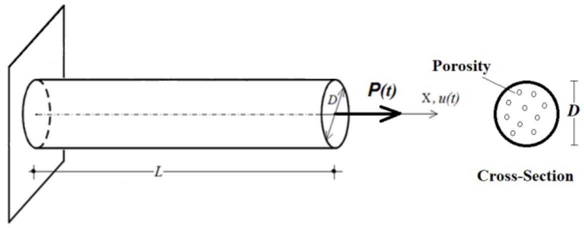

Figure 1. A clamped-free porous circular nanorod subjected to dynamically point load.

According to the nonlocal elasticity theory, constitutive equation of the problem is given as follows (Eringen (1972,1983));

$$\sigma_{xx} - \mu \frac{d^2\sigma_{xx}}{dx^2} = E(p)\epsilon_{xx} \tag{1}$$

where, σ_{xx} is nonlocal normal stress, ϵ_{xx} is normal strain, E is the Young's modulus, p is volume fraction of porosities and $\mu = (e_0 a)^2$. where μ indicates the nonlocal parameter, e_0 indicates the material length scale parameter. By using the equilibrium of forces in the axially direction, the equation of motion can be expressed as follows;

$$E(p)\frac{\partial^2 u(x,t)}{\partial x^2} - \rho(p)\frac{\partial^2 u(x,t)}{\partial t^2} + \rho(p)\mu\frac{\partial^2}{\partial x^2}\left(\frac{\partial^2 u(x,t)}{\partial t^2}\right) = 0 \tag{2}$$

where, ρ is the mass density and u is the axial displacement function. The effective material property of the nanorod is considered as the even porosity distribution as follows:

$$\mathrm{E(p) = E(1-p)}, \qquad \rho(\mathrm{p}) = \rho(1-\mathrm{p}) \tag{3}$$

When p=0, the nanorod becomes perfect. In solution of free vibration problem, the separation of variable is implemented in equation (2):

$$\mathrm{u_h(x,t) = U_h(x)e^{i\omega t}} \tag{4}$$

where $\mathrm{U_h(x)}$ is spatially function. ω is the natural frequency, t indicates the time and i indicates imaginary number.

The boundary conditions of the clamped-free of the nanorod for the free vibration problem are given as follows;

$$\mathrm{u(0,t)} = 0, \qquad \frac{d\mathrm{u}(L,\mathrm{t})}{dx} = 0 \tag{5}$$

Substituting equation (4) into equation (2) gives following equations of motion:

$$\left(\frac{d^2\mathrm{U_h(x)}}{dx^2} + \beta^2\mathrm{U_h(x)}\right)\mathrm{e^{i\omega t}} = 0 \tag{6}$$

where

$$\beta^2 = \frac{\rho(p)\omega^2}{E(p)-\rho(p)\,\mu\,\omega^2} \quad (7)$$

By implementing the boundary conditions in the equation (6) for clamped-free nanorod, the following frequency equation is obtained:

$$cos\beta L = 0 \quad (8a)$$

$$\beta_k L = (k-0.5)\pi, \quad k=1,2,3\ldots \quad (8b)$$

Substituting equation (7) into equation (8b) gives following equations of frequency:

$$\omega_k = \sqrt{\frac{E(p)}{\rho(p)}}\frac{(k-0.5)\pi}{\sqrt{L^2+\mu\,(k-0.5)^2\,\pi^2}}, \quad k=1,2,3\ldots \quad (9)$$

The external dynamically load (P(t)) is considered a harmonic function;

$$P(t) = P_0\sin(\Omega t) \quad (10)$$

where P_0 and Ω are the amplitude and frequency of load, respectively. The boundary conditions of the forced vibration problem are given as follows;

$$u(0,t) = 0, \quad \frac{du(L,t)}{dx} = \frac{P(t)}{E(p)A} \quad (11)$$

where A is the area of the cross section. To solve the forced vibration problem, The solution (u_p) of equation (2) for the forced vibration problem is solved by using the separation of variable ;

$$u_p(x,t) = U_p(x)\sin(\Omega t) \quad (12)$$

Substituting Eq. (12) into equation (2) gives following equations of motion:

$$\left(\frac{d^2U_p(x)}{dx^2}(E(p)-\mu\rho(p)\,\Omega^2)+\rho(p)\,\Omega^2U_p(x)\right)\sin(\Omega t) = 0 \quad (13)$$

After the simplifying expression (13), the following equation is obtained as follows:

$$\left(\frac{d^2U_p(x)}{dx^2}+\gamma^2U_p(x)\right) = 0 \quad (14)$$

where

$$\gamma^2 = \frac{\rho(p)\Omega^2}{E(p)-\rho(p)\,\mu\,\Omega^2} \quad (15)$$

By implementing the boundary conditions in the equation (14) for clamped-free nanorod, the $U_p(x)$ is obtained as follows:

$$U_p(x) = \left(\frac{P_0\sin(\gamma x)}{E(p)\,A\,\gamma\cos(\gamma L)}\right) \quad (16)$$

The dynamic displacement function is given as follows:

$$U_p(x,t) = \left(\frac{P_0\sin(\gamma x)}{E(p)\,A\,\gamma\cos(\gamma L)}\right)\sin(\Omega t) \quad (17)$$

The dimensionless quantities are expressed as follows:

$$\eta = \frac{e_0a}{L}, \quad \bar{\Omega} = \sqrt{\frac{\rho(p)\,L^2}{E(p)}}\Omega, \quad \lambda = \frac{L}{D}, \quad \bar{U} = \frac{U_p}{L} \quad (18)$$

where η and $\bar{\Omega}$ indicate the dimensionless nonlocal parameter and the dimensionless the frequency of the dynamic load, respectively. λ is the aspect ratio and $\bar{U}$ is dimensionless the longitudinal displacement.

3. Numerical Results

In this section, the effects of the dimensionless nonlocal parameter, dimensionless the frequency of the dynamic load and the volume fraction of porosity on the dynamic displacements of the porous nanorod are examined. In the numerical study, the material of the nanorod is considered as epoxy (E=1,44 GPa, $\rho = 1600\ kg/m^3$). The diameter of the nanorod is taken as D=1nm. The length of the nanorod is selected according to the aspect ratio (λ).

In figures 2,3 and 4, relationship between the dimensionless displacements and dimensionless nonlocal parameter (η) for different the volume fractions of porosity (p) is presented for different aspect ratios $\lambda = 10, \lambda = 30$ and $\lambda = 100$, respectively. The displacements ($\bar{U}_m$) are calculated at the free end of the nanorod. In these figures, the the amplitude of the dynamic load is taken as $P_0 = 1$ nN and the dimensionless the frequency of the dynamic load is taken as $\bar{\Omega}$=10.

It is seen from figures 2,3 and 4 that increasing the dimensionless nonlocal parameter yields to increase the difference among of the volume fractions of porosity on the dynamic displacements increase significantly. In the higher values of the dimensionless nonlocal parameter, there is quite large difference among the results of the porosity parameters. Another result of the figures 2,3 and 4 is that the aspect ratio has very influence on the porous nanorods. With increasing aspect ratio, the effects of nonlocal parameter on dynamic displacements change dramatically.

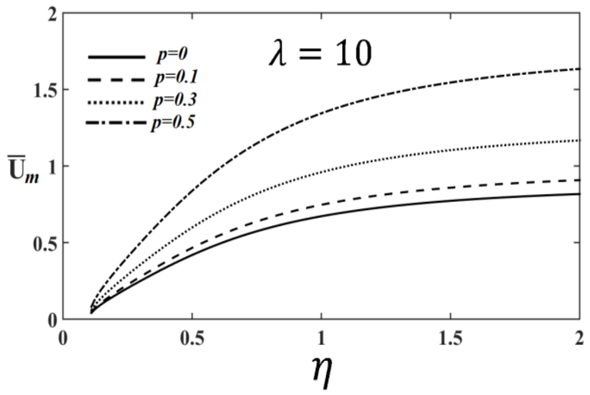

Figure 2. The relationship between dimensionless displacements and dimensionless nonlocal parameter for different the volume fractions of porosity for $\lambda = 10$.

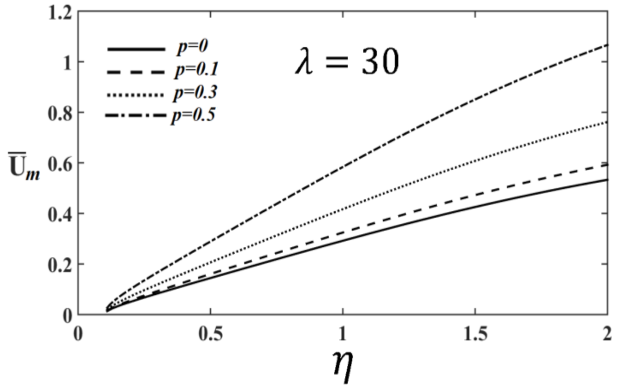

Figure 3. The relationship between dimensionless displacements and dimensionless nonlocal parameter for different the volume fractions of porosity for $\lambda = 30$.

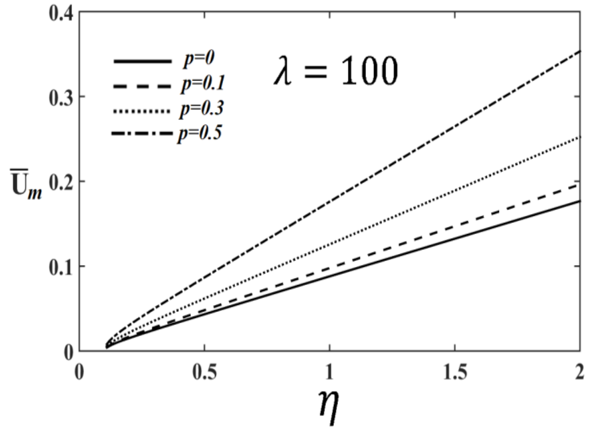

Figure 4. The relationship between dimensionless displacements and dimensionless nonlocal parameter for different the volume fractions of porosity for $\lambda = 100$.

Figures 5, 6 and 7 show the relationship between the dimensionless displacements ($\overline{\mathrm{U}}_{\mathrm{m}}$) and the dimensionless the frequency of the dynamic load ($\overline{\Omega}$) is plotted for different the dimensionless nonlocal parameter (η) for the volume fractions of porosity *p*=0, *p*=0.3 and *p*=0.5, respectively. In figures 5, 6 and 7, the the amplitude of the dynamic load is taken as $\mathrm{P}_0 = 1$ nN and the aspect ratio is taken as $\lambda = 10$.

As seen from figures 5, 6 and 7 that the dynamic responses the porous nanorod change with increasing the nonlocal parameter. Also, the resonance frequency change considerably with increasing the nonlocal parameter. The resonance case can be seen in the vertical asymptote lines in figures 5-7. Increasing of the dimensionless nonlocal parameter yields to decrease the resonance frequency.

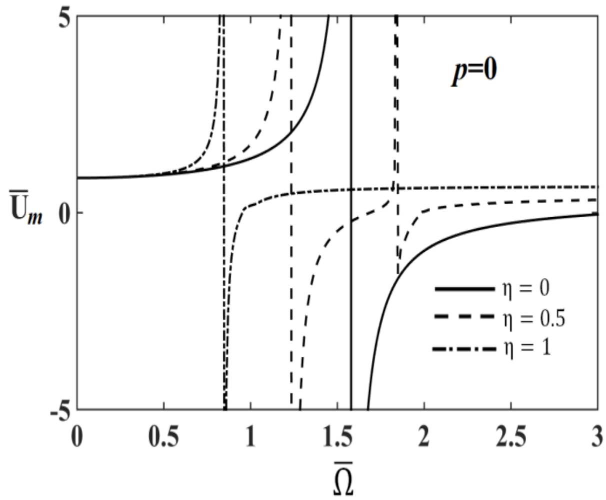

Figure 5. The relationship between dimensionless displacements and dimensionless frequency of the load for different the dimensionless nonlocal values for *p*=0.

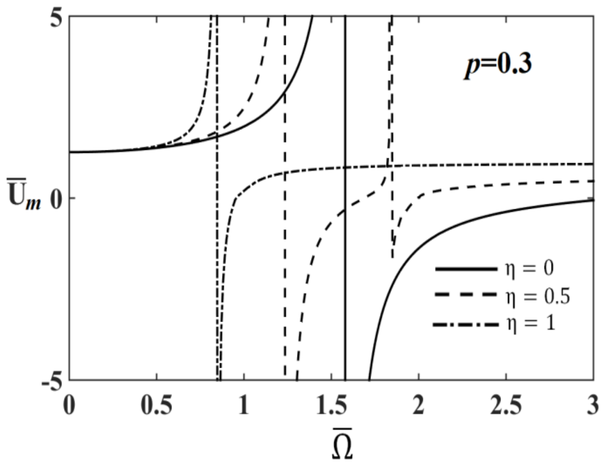

Figure 6. The relationship between dimensionless displacements and dimensionless frequency of the load for different the dimensionless nonlocal values for *p*=0.3.

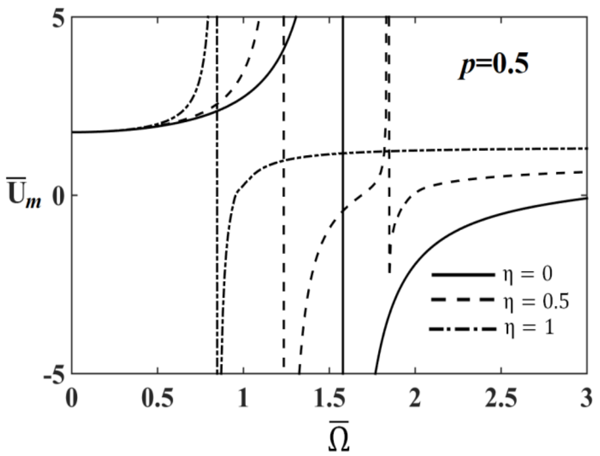

Figure 7. The relationship between dimensionless displacements and dimensionless frequency of the load for different the dimensionless nonlocal values for *p*=0.5.

4. Conclusions

Longitudinal forced vibration results of the porous a nanorod are investigated by using the nonlocal elasticity theory. In the forced vibration analysis, a harmonic external load is considered at the free end of the cantilever rod. In the considered vibration problem dynamic responses are obtained by analytically with using the separation of variable. In the numerical examples, the effects of the nonlocal, dynamic, geometry and porosity parameters on the forced vibration responses of the nanorod are presented and discussed. With using the analytical method in this problem, the exact solution and the dynamic responses of the all domain are obtained.
It is concluded from the results that the nonlocal parameters play important role on the porosity effects. The dynamic responses of the nanorods change with increasing the volume fractions of porosity significantly.

Conflict of Interest

No conflict of interest was declared by the author.

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