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Dynamic Analysis of Infinite Composite Beam Subjected to a Moving Load Located on a Viscolastic Foundation Based on the Third Order Shear Deformation Theory

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ABSTRACT

In this paper, the dynamic analysis of an infinite laminated composite beam located on a generalized Pasternak viscoelastic foundation based on the third order shear deformation theory is studied. By using the principle of total minimum potential energy, the governing equations of motion are obtained. The effects of stiffness, shear viscosity coefficients of foundation, velocity of the moving load, number of layers and various angles of layers over the beam response are studied. The results are validated with the known data in the literature.

KEY WORDS: Third Order Shear Deformation Theory, Pasternak Viscoelastic Foundation, Composite Beam, Moving Load

INTRODUCTION

The dynamic analysis of beam like structures under the moving load is one of the most interesting and practical subjects in the field of mechanical engineering. It has been a continuous effort by engineers for several years to elevate the daily speed of trains, specially the passenger types. Therefore, the dynamic analysis of beam under moving load has been considered very important. One of the new researches in this field is referred to the dynamic analysis of laminated composite beams under moving loads using finite element method [1]. In this paper, the dynamic analysis of cross-ply laminated composite beams on the generalized Pasternak viscoelastic foundation subjected to a concentrated moving load based on the third order shear deformation theory is carried out. In addition, deflection, bending moment and shear force distributions and stress, are analytically calculated along the beam span in terms of distance from the position of the moving load. Finally, the results are validated with the known data in the literature.

Formulation

The formulation that is presented here is based on third order shear deformation beam theory. Based on this theory, the displacement field can be written as [2]:

$$U(x,y,z,t) = z\phi_x(x,t) - \frac{4z^3}{3h^2}\left[\phi_x(x,t) + \frac{\partial w(x,t)}{\partial x}\right] \quad ,V(x,y,z,t) = 0 \quad ,W(x,y,z,t) = w(x,t) \tag{1}$$

where U, V and W represent the beam displacement components and $w(x,t)$ and $\psi_X(x,t)$ are the beam deflection and beam slope due to bending, respectively. By assuming some linear springs, normal and rotational dampers for Pasternak viscoelastic foundation, the transferred forces and moments from foundation to the beam can be calculated as:

$$\tilde{M}(x,t) = -k_\phi \phi_x(x,t) - \eta_\phi \frac{\partial \phi_x(x,t)}{\partial t} \quad , \quad q(x,t) = kw(x,t) - \eta \frac{\partial w(x,t)}{\partial t} + \mu \frac{\partial^3 w(x,t)}{\partial t \partial x^2} \tag{2}$$

In which, $q(x,t)$ and $\tilde{M}(x,t)$ are the foundation stimulated force and moment per unit length of beam, k and η are the foundation normal stiffness and damping coefficients, also k_ψ and η_ψ are the foundation rocking stiffness and damping coefficients and μ is the foundation shear viscosity coefficient. By applying the Hamilton's principle, governing differential equations for the dynamic behavior of the composite beam on a Pasternak viscoelastic foundation under a transversal moving load are obtained as:

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$$b\frac{\partial}{\partial x}\left[\overline{A}_{11}\frac{\partial\phi_X}{\partial x}+\overline{A}_{12}\frac{\partial^2 w}{\partial x^2}\right]\frac{4b}{3h^2}-\left[\overline{A}_{21}\frac{\partial^2\phi_X}{\partial x^2}+\overline{A}_{22}\frac{\partial^3 w}{\partial x^3}\right]-b\left[\overline{B}_{11}\phi_x+\overline{B}_{12}\frac{\partial w}{\partial x}\right]+\tilde{M}(x,t)$$
$$+\frac{4b}{h^2}\left[\overline{B}_{21}\phi_x+\overline{B}_{22}\frac{\partial w}{\partial x}\right]=b\left[I_2-\frac{8}{3h^2}I_4+\frac{16}{9h^4}I_6\right]+b\left[-\frac{4b}{3h^2}I_4+\frac{16}{9h^4}I_6\right]\frac{\partial^3 w}{\partial t^2\partial x} \tag{3}$$

$$\left[\frac{4b}{3h^2}\overline{A}_{21}\frac{\partial^3\phi_x}{\partial x^3}+\frac{4b}{3h^2}\overline{A}_{22}\frac{\partial^4 w}{\partial x^4}\right]+b\left[\overline{B}_{11}-\frac{4}{h^2}\overline{B}_{21}\right]\frac{\partial\phi_x}{\partial x}+b\left[\overline{B}_{12}-\frac{4}{h^2}\overline{B}_{22}\right]\frac{\partial^2 w}{\partial x^2}+p(x,t)+q(x,t)=$$
$$bI_0\frac{\partial^2 w}{\partial t^2}+b\left[\frac{4b}{3h^2}I_4-\frac{16}{9h^4}I_6\right]+b\left[-\frac{4b}{3h^2}I_4+\frac{16}{9h^4}I_6\right]\frac{\partial^3\phi_x}{\partial t^2\partial x}-\frac{16b}{9h^4}\frac{\partial^4 w}{\partial t^2\partial x^2} \tag{4}$$

In which K^2, b, $p(x,t)$, A, D, I_0 and I_2 represent the correction factor for the shear force, the beam width, transversal moving load, tensile stiffness matrix, bending stiffness matrix, zero and 2nd-order moment of inertia, respectively. In order to calculate the beam steady-state response, the parameter s which represents the distance from the position of the moving load, is defined as:

$$s=x-vt \tag{5}$$

By using the Eq. (5) and utilizing the differentiation chain rule on Eqs.(3) and (4), the governing equations of composite beam on the viscoelastic foundation under moving load are obtained as:

$$A_1\frac{d^2\psi_x}{ds^2}+A_2\frac{d\psi_x}{ds}+A_3\psi_x+A_4\frac{dw}{ds}=0,\ A_5\frac{d^3w}{ds^3}+A_6\frac{d^2w}{ds^2}+A_7\frac{dw}{ds}+A_8\,w+A_4\frac{d\psi_x}{ds}=F(s) \tag{6}$$

where

$$A_1=b\,D_{11}-b\,I_2\,v^2\ ,\ A_2=\eta_\psi v\ ,\ A_3=-bK^2A_{55}-k_\psi\ ,\ A_4=-bK^2A_{55}\ ,\ A_5=\mu\,v\ ,\ A_6=-bK^2A_{55}+b\,I_0\,v^2$$
$$A_7=-\eta\,v\ ,\ A_8=k \tag{7}$$

By equating the shear viscosity coefficient, the foundation rocking stiffness and damping coefficients to zero in Eq. (6) and employing dimensional analysis and implementing the Fourier transform the following equations are obtained as:

$$\left(-\left(a_2^2-\theta^2\right)q^2-a_1^2\right)\overline{\psi}_x(q)-a_1^2iq\overline{W}(q)=0,\ \left(\left(a_1^2-\theta^2\right)q^2-2\theta\zeta iq+1\right)\overline{W}(q)-a_1^2iq\overline{\psi}_x(q)=F^* \tag{8}$$

The above equation has been reported by Bajer and Dyniewicz [3].

THE METHOD OF SOLUTION

To solution of motion's differential equations, the complex Fourier Transform and its inverse are used. After implementing the Fourier transform on Eq. (6) and calculating the inverse Fourier transforms, the following equations are obtained as:

$$\psi_x(s)=\frac{1}{2\pi}\int_{+\infty}^{+\infty}\frac{(A_4q)F(q)}{B_1q^5+iB_2q^4+B_3q^3+iB_4q^2+B_5q+iB_6}\ ,\ w(s)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}\frac{(iB_7q^2+B_8q+iB_9)F(q)}{B_1q^5+iB_2q^4+B_3q^3+iB_4q^2+B_5q+iB_6} \tag{9}$$

where

$$B_1=-A_1A_5\ ,\ B_2=A_1A_6+A_2A_5\ ,\ B_3=A_1A_7+A_2A_6+A_3A_5\ ,\ B_4=A_4^{\ 2}-A_1A_8-A_2A_7-A_3A_6$$
$$B_5=-A_2A_8-A_3A_7\ ,\ B_6=A_3A_8\ ,\ B_7=-A_1\ ,\ B_8=-A_2\ ,\ B_9=A_3 \tag{10}$$

After applying residue theorem [4] on Eq. (9), w and ψ_x are calculated analytically in terms of distance from the moving load. By using linear strain-displacement relations for small deformations, strain components, stress components, bending moments and shear force can be obtained in terms of distance from the moving load.

RESULTS

The dynamic analysis of an infinite laminated composite beam located on a generalized Pasternak viscoelastic foundation based on the third order shear deformation theory is analyzed. The geometrical data for composite layer are considered as: $N = 4$, $b = 5\,cm$, $\alpha_1 = \alpha_4 = 0$, $\alpha_2 = \alpha_3 = \frac{\pi}{2}$, $h = 10\ cm$. Also, the mechanical properties of composite material and viscoelastic foundation are considered as: $E_1 = 132\,Gpa$, $E_2 = 10.8\,Gpa$, $G_{12} = 5.65\,Gpa$, $G_{13} = G_{23} = 3.38\,Gpa$, $v_{12} = 0.24$, $v_{13} = v_{23} = 0.59$, $\rho = 1540\,{kg}/{m^3}$, $k_\psi = 13.8MN$, $\eta_\varphi = 5520N.S$, $\mu = 100KN.S$, $K = 69MPa$, $\eta = 138\frac{kN.s}{m^2}$. The correction factor for shear force of the beam, the magnitude of the load and the load speed are chosen to be $K = {5}/{6}$, $v = 40\,{m}/{s}$ and $\mathrm{F(s)} = 144600\,\delta(s)$, respectively. The effect of foundation normal stiffness on the beam deflection subjected to the moving concentrated load is shown in Fig.(1). It is seen that by increasing the value of foundation normal stiffness coefficient the deflection will decrease. Fig.(2) show the effect of foundation viscosity coefficient under a moving concentrated load. It is seen that by increasing the value of foundation viscosity coefficient, the maximum deflection decreases. Fig.(3) show the effect of load speed on the beam deflection due to the motion of the concentrated load. By increasing the load speed, the symmetry trend of the beam deflection gets distorted and also the maximum deflection of the beam decreases.

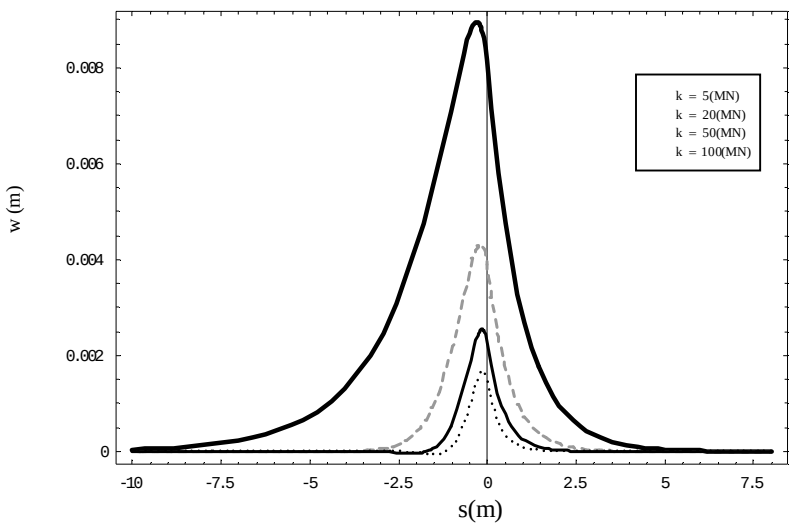

Fig (1): Deflection diagram of laminated composite beam under moving concentrated load, for different foundation normal stiffness coefficients

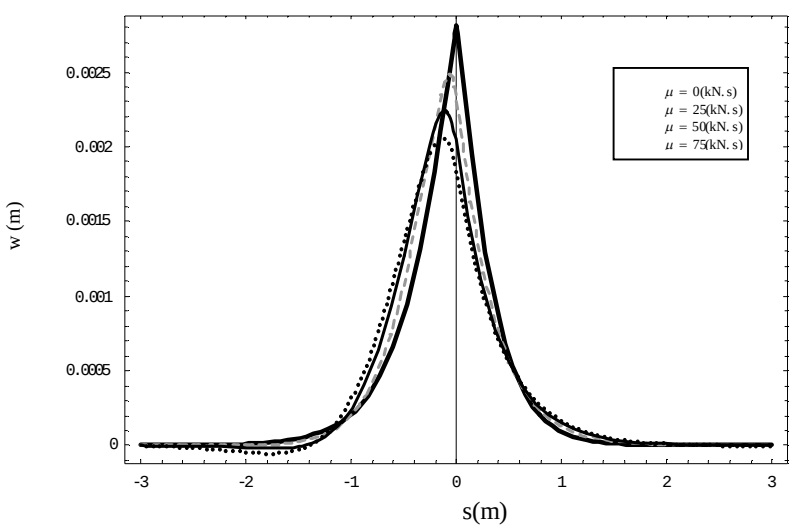

Fig (2): Deflection diagram of laminated composite beam under moving concentrated load, for different foundation viscosity coefficients

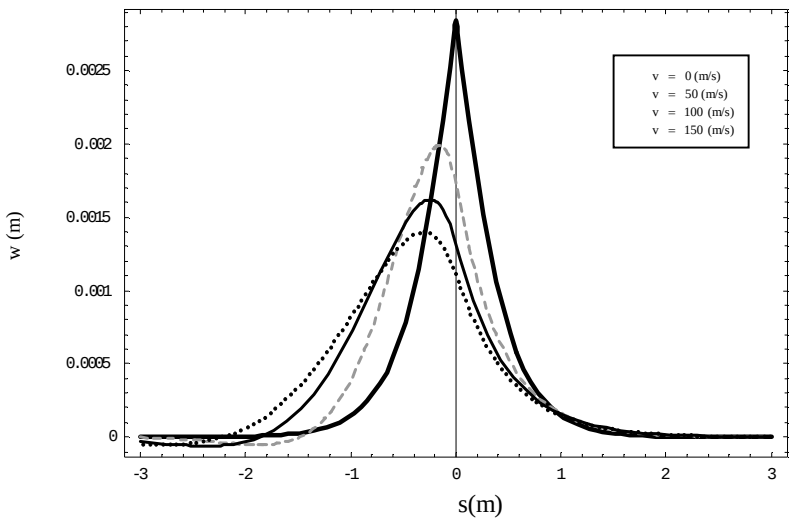

Fig (3): Deflection diagram of laminated composite beam under moving concentrated load, for different load speed

Conclusions

The dynamic analysis of an infinite laminated composite beam located on a generalized Pasternak viscoelastic foundation based on the third order shear deformation theory is studied. It is conclude that:

1- By increasing the foundation normal stiffness coefficients, the magnitude of shear force and the beam deflection decreases.

2- By increase the foundation viscosity coefficient the maximum deflection and shear force decreases along the beam.

3- By increasing the load speed, the magnitude of deflection, shear force, bending moment and normal stress, decreases along the beam.

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