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International Journal of Solids and Structures 43 (2006) 393–412
INTERNATIONAL JOURNAL OF SOLIDS and STRUCTURES
www.elsevier.com/locate/ijsolstr

Vibration and dynamic buckling of shear beam-columns on elastic foundation under moving harmonic loads

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Received 7 September 2004; received in revised form 7 June 2005
Available online 27 July 2005

Abstract

The vibration and buckling of an infinite shear beam-column, which considers the effects of shear and the axial compressive force, resting on an elastic foundation have been investigated when the system is subjected to moving loads of either constant amplitude or harmonic amplitude variation with a constant advance velocity. Damping of a linear hysteretic nature for the foundation was considered. Formulations in the transformed field domains of time and moving space were developed, and the response to moving loads of constant amplitude and the steady-state response to moving harmonic loads were obtained using a Fourier transform. Analyses were performed to examine how the shear deformation of the beam and the axial compression affect the stability and vibration of the system, and to investigate the effects of various parameters, such as the load velocity, load frequency, shear rigidity, and damping, on the deflected shape, maximum displacement, and critical values of the velocity, frequency, and axial compression. Expressions to predict the critical (resonance) velocity, critical frequency, and axial buckling force were proposed.
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Keywords: Axial compression; Beam-column; Buckling; Elastic foundation; Frequency; Harmonic load; Moving load; Resonance; Stability; Shear beam; Velocity

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doi:10.1016/j.ijsolstr.2005.06.025

1. Introduction

To investigate the dynamic response of pavement systems subjected to moving loads, beams and plates on an elastic foundation have widely been employed as the models of the pavement systems (Kim and Roesset, 1998; Liu and Gazis, 1999; Liu et al., 2000; Kim et al., 2002; Kim and McCullough, 2003). When those systems are analyzed with moving loads, the effects of shear and the forces in the plate's in-plane or beam's axial direction are normally ignored. However, asphalt mixtures of the flexible pavement systems are very sensitive to shear and the shear deformations in the thick cement concrete slabs of the rigid pavement systems may not be negligible. Moreover, most rigid pavement systems are subjected to in-plane compressive forces due to environmental loads such as changes in temperature and moisture. If temperature increases, concrete slabs expand and compressive forces are induced because the slabs push each other. Due to these in-plane compressive forces, the concrete pavements sometimes experience buckling, which is also called blowup (Kerr and Dallis, 1985). Blowups are observed both in jointed concrete pavements and continuously reinforced concrete pavements. The in-plane compressive forces are also induced in prestressed concrete pavements (Brunner, 1975; Cable et al., 1986; Powers and Zaniewski, 1987; Okamoto and Tayabji, 1995). Failures of the prestressed concrete pavements caused by high compressive forces sometimes occur. Therefore, the effects of shear and the in-plane compressive forces in the pavement systems need to be investigated when they are subjected to moving loads.

The load amplitude of the moving loads is often assumed to be constant. However, the moving loads created by vehicles in fact have variations in load amplitude with time that result from the pavement surface roughness and the mechanical systems of the vehicles (Nasim et al., 1991; Kim et al., 2002; Kim and McCullough, 2003). In addition, nondestructive testing vehicles such as the rolling dynamic deflectometer apply a steady-state harmonic force while continuously moving (Bay et al., 1995; Kim et al., 1999). The moving loads with such variations in load amplitude need to be considered in addition to the moving loads of constant amplitude. Since the dynamic responses of the pavement systems and their simplified models such as beams and plates on an elastic foundation show similar trends under moving loads (Kim and Roesset, 1997), it is efficient to use beams on an elastic foundation to predict general behaviors of those systems and to investigate the effects of shear and axial compression when they are subjected to moving loads.

The objective of this paper is to discuss the stability and dynamic displacement response of an infinite shear beam on an elastic foundation when the system is subjected to a static axial compressive force and lateral moving loads of either constant amplitude or harmonic amplitude variation. Beams considering the effect of shear and subjected to axial compression and lateral loads are called shear beam-columns. The geometry and material properties were assumed to be linearly elastic. The elastic foundation was considered as either a Winkler-type or a two-parameter foundation and damping of a linear hysteretic or a viscous nature was considered for the foundation. A distributed load with a constant advance velocity was considered instead of a point load because moving loads in practice have normally a finite area over which they are distributed and the point load represents only an extreme case. Formulations in the transformed field domains were developed and the solutions were obtained using a double Fourier transform in time and moving space for moving loads with arbitrary load variation, and a Fourier transform in moving space for the steady-state response to moving harmonic loads and for the response to moving loads of constant amplitude. Analyses were performed to investigate the effects of various parameters, such as the load velocity, load frequency, shear rigidity, and damping, on the displacements and critical values of the velocity, frequency, and axial compressive force, and to examine how the consideration of shear and axial compression affect the displacement response and stability of the system. By conducting a large number of parametric studies, equations to predict the resonance velocity, resonance frequency, and axial buckling force were developed.

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