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3D dynamics of a prestressed stratified half-space under the action of an oscillating moving load

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ABSTRACT

This paper investigates the three-dimensional (3D) dynamical response to a time-harmonic oscillating moving load of a system comprising a prestressed covering layer and a prestressed half-space, by utilizing the three-dimensional linearized theory of elastic waves in initially stressed bodies (TDLTEWISB).

The materials of the covering layer and half-space are assumed to be homogeneous and isotropic. It is also assumed that perfect contact conditions between the constituents of the system under consideration are satisfied. The analytical solution method, employing double exponential Fourier integral transformation with respect to the space coordinates, and the algorithm for obtaining the numerical results for the originals of the sought values are developed and employed. Numerical results for the critical velocity and for the stress distribution on the interface plane are presented and discussed. In particular, it is established that the minimal value of the critical velocity obtained for the 3D problem coincides with the critical velocity obtained for the corresponding 2D (plane-strain state) problem.

1. Introduction

In recent years, the number of investigations related to the dynamics of a moving load as well as those related to the dynamics of a time-harmonic point-located (or linearly located for a plane-strain state) load acting on a layered medium has been increasing because the results of these investigations have real applications in key branches of modern engineering regarding the various types of high-speed and oscillating mechanical systems. Here we consider a brief review of works related to the dynamics of time-harmonic and moving loads acting on a system consisting of a covering layer and half-space, separately. Note that a more detailed review of the aforementioned investigations was made in a paper by Akbarov [1].

It should be noted that, sometimes the problems related to the dynamics of the time-harmonic forces acting on the half-space are called time-harmonic Lamb's problems. The time-harmonic Lamb's problem for a system consisting of a prestressed covering layer and prestressed half-plane was examined by Akbarov and Ozaydin [2] for the first time for the plane-strain state. Further, this investigation was extended in various aspects by Akbarov and Guler [3,4]. Moreover, the corresponding axisymmetric Lamb's problem for a prestressed half-space with the prestressed layer was the subject of the

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study of papers by Akbarov [5,6]. At the same time, in a paper by Akbarov [7] the related problem for a slab from incompressible functionally graded material on a rigid body was studied. The corresponding three-dimensional (3D) Lamb's problem was investigated in papers by Akbarov et al. [8] and Emiroglu et al. [9].

In all the foregoing papers it was assumed that the materials of the constituents are isotropic ones. But in a paper by Akbarov and Ilhan [10] this assumption was not made and it was assumed that the materials of the covering layer and half-plane are orthotropic ones and the plane-strain state was considered. This concludes the review of works related to the Lamb's problem for the prestressed half-space covered with the prestressed layer and now we review briefly investigations carried out for the corresponding moving load problems. Note that the first attempt in this field was made in a paper by Achenbach et al. [11] where the equations of motion of the covering layer were written within the scope of the approximate plate theory, and those of the half-plane were written within the scope of the classical linear theory of elastodynamics. The plane-strain state was considered and it was assumed that the materials of the constituents are isotropic ones. It was established that if the material of the covering layer is stiffer than the material of the half-plane, the critical velocity of the moving load appears.

Over time, the work by Achenbach et al. [11] has been continuously improved and developed and the subjects of the latest iterations, which are described in papers by Dieterman and Metrikine [12] and Merikine and Vrouwenvelder [13], resemble the subject of our present investigation. It should be noted that in these studies the initial stresses in the components of the systems are not taken into account. Note that the initial (residual) stresses in the elements of constructions can arise as a result of the assembling and welding process, as well the action of the environmental temperature change. Therefore, as it was noted in the monograph by Guz [14], taking account of the residual stresses when analyzing of the dynamics of the foregoing layered systems into account may have a great significance. The first attempt to account for the influence of initial stresses on the values of the critical velocity of the moving load was made by Kerr [15], where a system consisting of an ice plate resting on a water layer was considered. In this paper the motion of the plate is described within the scope of the Kirchhoff theory and it was established that the initial stretching (compression) causes an increase (decrease) in the values of the critical velocity.

In Babich et al. [16], the dynamical response was considered for a system consisting of a layer and prestressed half-plane. The equation of motion for the covering layer was described by the Timoshenko beam theory, but the equation of motion for the half-plane was described by the three-dimensional linearized theory of elastic waves in initially stressed bodies (TDLTEWISB), the field equations and applications of which are detailed in monographs by Biot [17], Truestell and Noll [18], Eringen and Suhubi [19], Guz [14], and others. The corresponding boundary value problem was solved by using the exponential Fourier integral transformation. Numerical investigations were made for the case where the constitutive relations for the half-plane material were described in terms of the harmonic potential. Moreover, it was assumed that the speed of the moving load was constant and the subsonic case had been taken into consideration. These numerical investigations led to further investigation of the parameters' influence on the critical velocity in the second study by Babich et al. [20] by utilizing the complex potentials of the TDLTEWISB. In Babich et al. [21,22] the foregoing investigations of these authors were developed for the supersonic moving load acting for incompressible [21] and compressible [22] bodies.

Akbarov et al. [23] employed the findings of Babich et al. [16,20] in developing a case where the covering layer is also initially strained, and where the equation of motion for this layer is also described by the TDLTEWISB; from this, the influence of the problem parameters on the critical velocity was studied. However, Akbarov et al. [23] assumed the materials of the covering and half-plane to be isotropic. This assumption significantly restricts the theoretical investigations in terms of controlling the critical velocity values for the moving load and the stresses acting on the interface plane through the mechanical properties of the layer and half-plane materials. Therefore, the study by Akbarov and Ilhan [24] further developed the investigation by Akbarov et al. [23] for the case where the materials of the covering layer and half-plane are anisotropic (orthotropic). Note that the anisotropy of the covering layer materials in the aforementioned systems may occur as a result of oriented reinforcing elements present in these materials. At the same time, under certain conditions, multilayered soil (half-plane) or a multilayered covering plate can be modeled as a homogeneous orthotropic material with effective mechanical properties.

As noted by Hussein and Hunt [25], Degrande and Schillemans [26], Auersch [27,28] and many others, in reality, high-speed trains, cars and other high-speed transportation vehicles modeled as moving loads are accompanied by their own oscillations. To determine how these accompanying oscillations act on the dynamical response of the system considered requires corresponding additional investigations. These investigations were the subject of papers by Dieterman and Metrikine [12], Metrikine and Vrouwenvelder [13], Akbarov and Ilhan [29], Akbarov and Salmanova [30] etc.

It should be noted that in all the foregoing investigations related to the dynamics of the moving load acting on the system consisting of the covering layer and half-space, 2D (with respect to the space coordinates) problems, were considered, that is, problems regarding the plane-strain state. Consequently, up until now there has not been any investigation related to the corresponding 3D problem on the dynamics of the moving load or oscillating moving load acting on the aforementioned system. In this paper, the first attempt is made in this field and the dynamics of the point-located oscillating moving load acting on the system consisting of the prestressed covering layer and prestressed half-space is studied. The investigations are carried out within the scope of the piecewise homogeneous body model by utilizing the TDLTEWISB.

The study in this paper can be considered as a development of the studies by Akbarov et al. [8] and Emiroglu et al. [9] for the moving load. At the same time, the study in this paper can be considered as a development of the study by Akbarov and Ilhan [29] for the corresponding 3D problem.