Applied Mathematical Modelling 61 (2018) 726–743

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Impact of interlayer on the anisotropic multi-layered medium overlaying viscoelastic layer under axisymmetric loading

Lingyun You[a,b], Kezhen Yan[a,*], Yingbin Hu[a], Wenbo Ma[c]

[a] College of Civil Engineering, Hunan University, Changsha 410082, PR China
[b] Department of Civil and Environmental Engineering, Michigan Technological University, Houghton, MI 49931, USA
[c] College of Civil Engineering and Mechanics, Xiangtan University, Xiangtan 411105, PR China

ARTICLE INFO

Article history:
Received 21 December 2017
Revised 10 May 2018
Accepted 15 May 2018
Available online 24 May 2018

Keywords:
Multi-layered medium
Anisotropic
Viscoelastic
Interlayer condition
Axisymmetric loading
Analytical solution

ABSTRACT

Multi-layered media is the most common structure in artificial and natural surroundings, and it is considered as a good candidate for mathematical model. The anisotropic properties and viscoelastic properties of layer materials have been widely used in multi-layered medium. Furthermore, the interlayer condition between the layers also plays an important role in the mechanical behavior of multi-layered medium. Despite many numerical approaches having been applied in these analyses, only few analytical solution were developed to analyze the effects of these three issues at the same time. The objective of this study is to develop an analytical solution that can be used for analyzing the impact of interlayer conditions on the mechanical behavior of anisotropic multi-layered medium overlaying viscoelastic layer subjected to axisymmetric loading, but the anisotropy property was approximated as transversely isotropy. The interlayer condition between the adjacent layers will also be considered. Details of the mathematical derivation, implementation and verification of the proposed analytical solution were presented. Subsequent numerical results demonstrate that both viscoelastic, transverse isotropy and interlayer condition could substantially contribute to the mechanical behavior of the multi-layered medium.

1. Introduction

Multi-layered media is the most common structure in artificial and natural surroundings [1–4]. It is noteworthy to know that some modern composites, advanced materials, and traditional materials can be regarded as a multi-layered medium, such as flexible pavements, geo-cell layers, microelectronic devices, and protective coating [5–13]. These mediums are prevalent in nature, ranging from macro-scale structures to micro-scale structures [3,14]. In addition, in civil engineering discipline, industrial, and municipal constructions, a multi-layered medium sitting on the half-space foundation is a familiar form for both industrial implementation and municipal constructions, i.e. multi-layered medium, where the medium is a geometry of structure that has semi-infinite or one side infinite [1,15]. As shown in Fig. 1, a multi-layered medium consists of n layers, which include one infinite layer on the bottommost of this medium, i.e. layer-n. The axisymmetric loading tests are usually used to investigate the capacity of multi-layered medium. In this test, the surface of layer-1 is subjected to a vertical circular uniform load q while the loading radius is a. Therefore, accurate analysis of the behavior in multi-layered

* Corresponding author.
E-mail addresses: liyou@mtu.edu (L. You), yankz@hnu.edu.cn (K. Yan).

https://doi.org/10.1016/j.apm.2018.05.020
0307-904X/

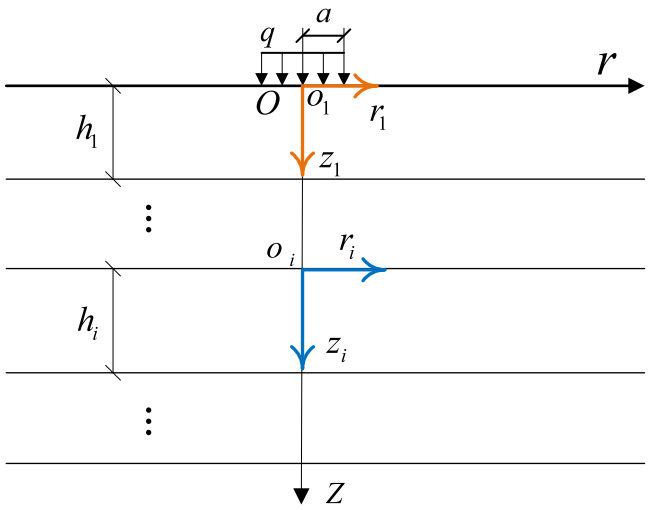

Fig. 1. A multi-layered medium under circular axisymmetric loading.

medium is of great practical interest in many scientific and engineering applications, such as in the study of mechanical behaviors of flexible pavement under axisymmetric loading [8,16].

Viscoelastic materials are usually used in multi-layered medium, like asphalt mixture being comprised as top layer of flexible pavement and epoxy resin being used in epoxy surface coating. Their mechanical behavior is complex and strongly dependent on the distribution and interaction of the mix components, and it is also a typical time-dependent composite materials [17,18]. Unlike an elastic material, because their basic properties are time-dependent, viscoelastic materials have revealed a time-dependent behavior even under a constant load [19]. In contrast to the metal materials, whose elastic properties could show a ±5.0% deviation, there could be a 50% flocculation on elastic and viscoelastic properties of asphalt mixture [20,21]. Lee studied analytical solution for the viscoelastic wave propagation of layered mediums subjected to impact loading, and his research results show that the difference in mechanical behavior, between the elastic and viscoelastic layered medium under same impact loading, cannot be ignored [19]. For example, asphalt pavements, as one type of multi-layered medium, exhibit significant viscoelastic behavior resulting in strains, stresses, and deflections varying with both loading speed/frequency and temperature [22,23]. However, the analytical solutions based on the multi-layered medium rarely consider the case of containing a viscoelastic layer. Hence, for the multi-layered medium to include viscoelastic layers, it is vital to take the viscoelastic property into consideration.

Almost all materials used in multi-layered medium exhibit apparent anisotropic properties, where anisotropy is a prerequisite of being direction-dependent. The anisotropy property implies different characters in the different directions. In comparison to isotropy property, for example, asphalt mixture is composed of differently shaped granular materials, and its inner structure presented obvious anisotropic properties [3,24]. Wang et al. illustrate the stress fields of anisotropic and isotropic pavement under wheel loading through analytical solution and finite-element simulation for several cases, and they discovered that the anisotropic properties of asphalt mixture have significant effect on the pavement behavior [25]. The simplest anisotropic model is that of a transverse isotropy, which an assumption symmetry is considering that the material behaves differently in one direction from the two others. The simplification comes from this assumption equivalent to saying that some coefficients of your anisotropic material are equal or linearly dependent. Thus, for the mechanical analysis of anisotropic media, the anisotropic properties of materials could be approximated as transverse isotropy, and transverse isotropy can be observed as a special case of anisotropy [26,27]. However, only a few of the mentioned articles took the viscoelastic and anisotropic properties of multi-layered mediums into account. As a result, it is necessary to analyze the mechanical behavior of multi-layered mediums considering the viscoelastic and anisotropic properties of layer materials.

The interlayer condition of multi-layered medium is also important to its mechanical properties [28–30]. It is well known that soft polymers are widely used as adhesives and interlayers in multi-layered medium for protection purposes. Stenzler et al. studied the behavior of several polyacrylate adhesives with varying microstructure, and the results illuminates that the interlayer microstructure of polyacrylate has positive effects on the impact behavior of multi-layered polymers [31]. Chupin et al. calculated the mechanical behavior of a viscoelastic layered medium to a moving load when interlayer slip was considered [32]. However, few studies consider the influence of interlayer conditions when performing mechanical analyses of anisotropic multi-layered medium with viscoelastic layer. Therefore, the effect of interlayer condition between the adjacent structure's layers on the mechanical behavior of anisotropic multi-layered medium also should be analyzed.

The objective of this study is to develop an analytical solution that can be used for analyzing the mechanical behavior of anisotropic multi-layered medium overlaying viscoelastic layer subjected to axisymmetric loading, while the anisotropy is