Boundary element method for contact between multiple rigid punches and anisotropic viscoelastic foundation

Van Thuong Nguyen, Chyanbin Hwu*

Department of Aeronautics and Astronautics, National Cheng Kung University, Tainan, Taiwan, R.O.C

A R T I C L E   I N F O

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A B S T R A C T

In this paper both of the elastic-viscoelastic correspondence principle and time stepping method, which can convert viscoelasticity to elasticity, are employed to the boundary element method (BEM) to solve the contact problems between multiple rigid punches and anisotropic viscoelastic foundation. The one based upon the correspondence principle has the restriction on time-invariant boundaries, and hence can only be applied to the cases of complete indentation whose contact region as well as contact status are time-independent. The other based upon the time stepping method is processed step-by-step in time domain, and its boundary conditions may vary in each time step, and hence can be applied to both complete and incomplete indentations. Both methods are valid for the frictionless or frictional contact surface, the punches can be in equilibrium status or in quasi-static sliding condition, and the number of punches and the punch profiles are arbitrary. Benefited by the elastic system used for BEM, both methods hold the feature that no meshes are required on the rigid punches and holes/cracks. Through the iteration procedure and numerical examples presented in this study, we see that the one based upon time-stepping method is much more general and efficient than the other one.

1. Introduction

Polymer matrix composites exhibit not only anisotropic (directional-dependent) but also viscoelastic (time-dependent) behaviors. Although there are many different kinds of commercial software working on the stress analysis of composite materials, most of them only provide the functions for isotropic elastic, anisotropic elastic, or isotropic viscoelastic materials, almost none of them consider the contact analysis of anisotropic viscoelastic solids. Contact problems of anisotropic viscoelastic solids are challenging problems because the complexities arise not only from the directional dependence of anisotropy but also from the time dependence of viscoelasticity as well as the non-linearity of contact caused by the unknown contact area and frictional surface. The problems are even more difficult if the defects such as holes, cracks, and/or inclusions exist inside the contact bodies. In addition to the contact between two viscoelastic bodies, in practical engineering there are also several problems related to the contact of multiple bodies. Among them some problems can be idealized and simulated as an anisotropic viscoelastic solid indented by multiple rigid punches, such as rough surfaces [1–5], tire/road contact [6–8], rubber pad forming [9,10]. In order to solve the viscoelastic contact problems with multiple rigid punches, several works have been done through the analytical approaches such as [11–17] for isotropic viscoelastic solids, [18,19] for orthotropic viscoelastic solids, and [20] for anisotropic viscoelastic solids. However, due to the limitation of analytical solutions most of the results are applicable only for some idealized problems with simple geometry and simple contact conditions such as contact of a rigid punch with smooth or rough surfaces on a half-plane [11–20]. For more complicated problems, numerical methods such as finite element method (FEM) or boundary element method (BEM) are popularly used [3,5,10,20–24]. Comparing to FEM, BEM has been recognized to be more suitable over FEM on solving contact problems because it reduces the problem dimension by one and the contact only occurs on the boundary [25–27].

The main restriction of BEM for anisotropic viscoelastic problems is the availability of fundamental solutions. To overcome this restriction, a common approach is to obtain the viscoelastic solution through its corresponding elastic solution [20,28–32]. Following this concept, recently we employed the elastic-viscoelastic correspondence principle [28] to solve many different viscoelastic problems such as holes/cracks/inclusions in an anisotropic viscoelastic solid [29–32] and contact of an anisotropic viscoelastic solid indented by multiple rigid punches [20]. This principle is simple and easy to implement. However, due to the requirement on time-independent boundaries, this principle can only be applied to the cases of complete indentation whose contact region and contact status are time-independent. Since in engineering applications the cases of incomplete indentation cannot be avoided for the contact on anisotropic viscoelastic solids, a new method for solving the