International Journal of Solids and Structures 48 (2011) 2288–2303

Contents lists available at ScienceDirect

International Journal of Solids and Structures

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

Dynamic Green's functions of a two-phase saturated medium subjected to a concentrated force

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ARTICLE INFO

Article history:
Received 24 March 2009
Received in revised form 11 April 2011
Available online 22 April 2011

Keywords:
Green's function
Concentrated force
Impulsive loading
Two-phase saturated medium

ABSTRACT

The Green's functions of a two-phase saturated medium subjected to a concentrated force are known to play an important role in seismology, earthquake engineering, soil dynamics, geophysics, and dynamic foundation theory. This paper presents a physical method for obtaining the dynamic Green's functions of a two-phase saturated medium for materials considered to be isotropic and for low frequencies. First, the pore-fluid pressure in a two-phase saturated medium is divided into two parts: flow pressure and deformation pressure. Next, based on the compatibility condition of Biot's equation and the property of the δ-function, the problem of coupled_fast and slow dilational waves is solved using the decomposition condition of the potential dilation field. The Green's function for a concentrated force is then obtained by solving Biot's complex modular equations, and their physical characteristics are discussed. The behavior of Green's functions for the solid and fluid phases of a δ-impulsive force is investigated, from which the Green's functions for a unit Heaviside force are also obtained by time integration. Finally, the present Green's functions for a unit Heaviside force are compared with those obtained by a purely mathematical method; the two differ in form, but the numerical results are identical. The physical meaning of the expressions of Green's functions obtained in this paper is evident. Therefore, the results may benefit future research on the dynamic responses of a two-phase saturated medium.

1. Introduction

Despite their intricate mathematics, Green's functions for concentrated forces have attracted much interest from geophysicists (Das and Aki, 1977; Luccio et al., 2005). Note that elastic dislocation theory, based mainly on Green's functions of the displacement field subjected to a concentrated force, has become an important part of seismology. Because fractures within the earth, such as faults, can be idealized as an abrupt displacement of transient jump in an elastic medium, the theory of elastic dislocation can be used to study the displacement field caused by an earthquake under given conditions. If the distribution of an elastic displacement field is known, then the source causing the field can be identified by the theory of elastic dislocation (i.e., the dislocation model). Over the past 50 years, many researchers have contributed to this field of research, including Steketee (1958), Maruyama (1964), and Ben-Menaham and Singh (1981). Das and Aki (1977) developed a new model for crack rupture, expressed using Green's functions, based on the work of Griffith (1920). In developing these models, significant progress has been made regarding our understanding of the propagation and diffraction of stress waves in cracked solid media (Bouchon, 1990; Geubelle and Rice, 1995; Madariage et al., 1998; Oreste, 2002; Grimal et al., 2004; Luccio et al., 2005). However, whether using the cracked model or the dislocation model of a solid medium, the deformation field on the earth's surface appears to be stable after the event has been triggered, which is inconsistent with observations.

To overcome this discrepancy, Nur (1972) proposed the Dilation–Drain (DD) model, based on observations of experiments in which rocks were broken under pressure. Based on the DD model, Scholz and Sykes (1973) divided the pregnant process of an earthquake into four stages: (1) stress increase; (2) many cracks occur (with volume expanding); (3) water flows into fissures, continuously inducing cleavage formation; and (4) the ambient effective pressure decreases but pore pressure increases, triggering fracture and resulting in an earthquake.

The most convincing evidence for the validity of this model is derived from the 1995 Kobe earthquake in Japan (M7.3), for which the tomography of seismic wave velocity distribution describes a large volume of fluid at the hypocentre (Zhao et al., 1996; Mishra and Zhao, 2003). Therefore, a mathematical seismic model dealing with a two-phase saturated medium should be considered in order to simulate the earthquake process (Zhao et al., 2002; Salah and Zhao, 2004). In this respect, the associated Green's functions for two-phase saturated media are appropriate.

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doi:10.1016/j.ijsolstr.2011.04.006