Soil Dynamics and Earthquake Engineering 31 (2011) 1480–1495

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

Boundary integral formulation and two-dimensional fundamental solutions for dynamic behavior analysis of unsaturated soils

Pooneh Maghoul [a], Behrouz Gatmiri [a,b,*], Denis Duhamel [a]

[a] Université Paris-Est, UR Navier, Ecole des Ponts, 6 et 8 Avenue Blaise Pascal, Cité Descartes, Champs sur Marne, 77455 Marne la Vallée, Cedex 2, France
[b] Department of Civil Engineering, University of Tehran, P.O. Box 11365-4563, Tehran, Iran

ARTICLE INFO

Article history:
Received 9 December 2009
Received in revised form
10 May 2011
Accepted 19 May 2011
Available online 7 July 2011

ABSTRACT

In this paper the coupled equations governing the dynamic behavior of unsaturated soils are derived based on the poromechanics theory within the framework of the suction-based mathematical model presented by Gatmiri (1997) [Gatmiri B. Analysis of fully coupled behavior of unsaturated porous medium under stress, suction and temperature gradient. Final report of CERMES-EDF, 1997] and Gatmiri et al. (1998) [Gatmiri B, Delage P, Cerrolaza M, UDAM: a powerful finite element software for the analysis of unsaturated porous media. Adv Eng Software 1998; 29(1): 29–43]. In this formulation, the solid skeleton displacements, water pressure and air pressure are presumed to be independent variables. The Boundary Integral formulations as well as fundamental solutions for such a dynamic u–p_w–p_a theory are presented in this paper for the first time. The boundary integral equations are derived via the use of the weighted residuals method in a way that permits an easy discretization and implementation in a Boundary Element code. Also, the associated two dimensional (2D) fundamental solutions for such deformable porous medium with linear elastic behavior are derived in Laplace transform domain using the method of Hörmander. Finally, some numerical results are presented to show the accuracy of the proposed solutions. The derived results are verified analytically by comparison with the previously introduced corresponding fundamental solutions in elastodynamic limiting case.

1. Introduction

Unsaturated soils are encountered near the earth's surface where most engineering structures are ultimately supported. Even though geotechnical engineering projects encounter saturated, dry and unsaturated soils, most of the past studies have been done only on saturated and dry soils. Saturated and dry soils can become unsaturated due to seasonal variations.

The dynamic behavior of the saturated soils has been extensively investigated [3–7 among others]. In the current state of the art, it could be claimed that behavior of the saturated porous media has been well understood. Conversely, the study of the dynamic behavior of the unsaturated porous media is a relatively new area in the field of geotechnical earthquake engineering. Accurate measurement of various quantities such as dynamic water and air pressures, and degree of saturation in partially saturated soils is a difficult task during dynamic loadings [8].

Wave propagation in unsaturated soils in arid areas and the dynamic response of such media are of great interest in geophysics, soil and rock mechanics, and many earthquake engineering problems. However, in geomechanics, the behavior of many media including more than two phases is not consistent with the principles and concepts of classic saturated soil mechanics. Thus, the prediction and simulation of unsaturated soil behavior are of great importance in making critical decisions that affect many facets of engineering design and construction.

An unsaturated porous medium can be represented as a three-phase (gas, liquid, and solid), or three-component (water, dry air, and solid) system in which two phases can be classified as fluids (i.e. liquid and gas). The liquid phase is considered to be pure water containing dissolved air and the gas phase is assumed to be a binary mixture of water vapor and 'dry' air in a non-isothermal case. The air in an unsaturated soil may be in an occluded form when the degree of saturation is relatively high. At a lower degree of saturation, the gas phase is continuous.

In order to model unsaturated soil behavior, first the governing partial differential equations should be derived and solved. Because of the complexity of the governing partial differential equations, with the exception of some simple cases, their closed-form solutions are not available. Therefore the numerical methods, such as the Finite Element Method (FEM) and the Boundary Element Method (BEM), should be used for such partial differential equations.

The FEM has proven to be very effective in solving problems with bounded domains, particularly when inhomogenities and

* Corresponding author at: Université Paris-Est, UR Navier, Ecole des Ponts, 6 et 8 Avenue Blaise Pascal, Cité Descartes, Champs sur Marne, 77455 Marne la Vallée, Cedex 2, France. Tel.: +33 146118326; fax: +33 164153741.
E-mail addresses: Pooneh.Maghoul@enpc.fr (P. Maghoul), Behrouz.Gatmiri@andra.fr (B. Gatmiri), Denis.Duhamel@enpc.fr (D. Duhamel).

0267-7261/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soildyn.2011.05.016