

Three-dimensional finite/infinite elements analysis of fluid flow in porous media

Kaiming Xia ^{a,*}, Zhijun Zhang ^b

^a *Department of Civil and Material Engineering, University of Illinois at Chicago, Chicago, IL 60607, USA*

^b *Department of Biological, Chemical and Physical Sciences, Illinois Institute of Technology,
3101 South Dearborn Street, Chicago, IL 60616, USA*

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Abstract

Fluid flow in naturally fractured porous media can always be regarded as an unbounded domain problem and be better solved by finite/infinite elements. In this paper, a three-dimensional two-direction mapped infinite element is generated and combined with conventional finite elements and one direction infinite element to simulate poroelasticity. Therefore, the entire semi-infinite domain can be included in the numerical analysis. Both single- and dual-porosity porous media are considered. For the purpose of validation, we compare the results of finite/infinite elements with those of finite elements under two extreme boundary conditions. The comparison indicated that mapped infinite element is an appropriate approach to model fluid flow in porous media and provides an intermediate solution.

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1. Introduction

The fluid flow in porous media is an important engineering phenomenon. In the past few decades, finite element method (FEM) has been widely used to simulate fluid flow and solid

* Corresponding author. Present address: Machine Research, TC-E 852, P.O. Box 1875, Peoria, IL 61656-1875, USA.
Fax: +1 309 578 4277.

E-mail address: xia_kaiming@cat.com (K. Xia).

deformation in geotechnical engineering, environmental engineering and oil reservoir engineering. As one of the most interesting system, dual-porosity reservoir is a system where two distinct types of porosity coexist in a representative rock mass. Naturally fractured reservoir typifies such a system and it has been consistently studied with finite element method pertaining to the double-based fractured porous media equations by Duguid and Abdel [1], Bibby [2], Khaled et al. [3], Lewis and Schrefler [4], Ghafouri and Lewis [5], Elsworth and Bai [6], Bai and Meng [7], etc.

Many finite element problems can be solved as unbounded problems, especially for fluid flow in porous media. One of the most encountered difficulties associated with numerical analysis of fluid flow problems is proper dealing with an unbounded exterior domain. For years, it has shown that determination of the finite boundary of the simulation is very crucial for accurate solutions and the selection of the minimum analytical distance is often regarded as a matter of experience. In most cases, the simplest solution to such difficulties is to truncate the mesh at some large but finite distance, which results in a relative approximation to infinity. Unfortunately this method is inaccurate and computationally inefficient. Moreover, this method cannot satisfy the real boundary conditions pertaining to the infinite boundary since displacements and pore pressures are fixed only at infinity. To overcome this weakness, Bettess [8], Zienkiewicz et al. [9], Ungless [10], and Lynn and Hadid [11] have subsequently developed several infinite elements models. Zienkiewicz et al. [9] presented an improved infinite element model based on mapping for modeling the unbounded domain problems. The novelty of this method is the fact that the same simple mapping is applied for both the geometry transformation and for transforming the unknown function variation from the local to the global co-ordinate system. Another efficacy associated with Zienkiewicz's method is that no new integration rule is needed when coupled with conventional finite elements, and the general Gauss–Legendre integration can be used directly for this mapped infinite element. In 1992, Bettess [12] published the first book on infinite elements, which introduced many types of infinite elements. Marques and Owen [13] used the mapped infinite element coupled with finite elements to solve elasto-plastic material problems. Djamanic and Owen [14] applied mapped infinite elements to study transient thermal analysis. Simoni and Schrefler [15], and Xia and Bai [16] presented application of the infinite elements in fluid flow and soil consolidation. All these formulations of infinite elements are generally based on two methods. One deals with elements with decay functions in the infinite direction, which multiplies the usual shape functions. Another is mapped infinite element with associated mapping technique on the coordinates.

Based on the dual-porosity poroelasticity, a novel three-dimensional mapped infinite elements model coupled with three-dimensional finite elements is presented. The accuracy and efficacy of finite/infinite element approach under current study are demonstrated by comparing its results to those applying three-dimensional finite element modeling alone.

2. Three-dimensional mapped infinite elements

In the three-dimensional unbounded domain, it is always necessary to discretize the entire infinite domain for applying one-direction and two-direction infinite elements, which can be coupled with conventional 8-node three-dimensional finite elements. The one-direction infinite element (Fig. 1) is used to denote elements that extend to infinity in one direction while the two-direction infinite element (Fig. 2) extends to infinity in two directions. The relative mapping functions

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