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Performance analysis tools applied to a finite element adaptive mesh free boundary seepage parallel algorithm

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Abstract

A finite element, adaptive mesh, free surface seepage parallel algorithm is studied using performance analysis tools in order to optimize its performance. The physical problem being solved is a free boundary seepage problem which is non-linear and whose free surface is unknown a priori. A fixed domain formulation of the problem is discretized and the parallel solution algorithm is of successive over-relaxation type. During the iteration process there is message-passing of data between the processors in order to update the calculations along the interfaces of the decomposed domains. A key theoretical aspect of the approach is the application of a projection operator onto the positive solution domain. This operation has to be applied at each iteration at each computational point.

The VAMPIR and PARAVER performance analysis software are used to analyze and understand the execution behavior of the parallel algorithm such as: communication patterns, processor load balance, computation versus communication ratios, timing characteristics, and processor idle time. This is all done by displays of post-mortem trace-files. Performance bottlenecks can easily be identified at the appropriate level of detail. This will numerically be demonstrated using example test data and comparisons of software capabilities that will be made using the Blue Horizon parallel computer at the San Diego Supercomputer Center.

Keywords: Performance analysis tools; Finite element; Adaptive mesh; Free boundary seepage; Parallel computing

1. Introduction

The problem studied is the free surface seepage problem shown in Fig. 1. The following assumptions are made: the soil in the flowfield is homogeneous and isotropic; capillary and evaporation effects are neglected;

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the flow obeys Darcy's Law; the flow is two-dimensional and at steady state. Because of the assumptions made, the problem is described by the velocity potential function, φ, whose governing differential equation and boundary conditions are also shown in Fig. 1. The relevant dimensions are taken to be: $x_1 = 40$, $y_1 = 10$ and $y_2 = 3$. In Fig. 1, Ω is the seepage region abdf. The location of the curve fd, $y = \bar{f}(x)$, is unknown a priori.

A fixed domain formulation for this problem can be obtained by using the Baiocchi method and transformation (see [2,10,11,3,6]). In this approach the a priori unknown solution region is extended across the free surface into a known region. The dependent variable is also continuously, similarly extended. Then a new dependent variable is defined using Baiocchi's transformation within these regions. The resulting problem formulation leads to a 'complementarity system' associated with its respective variational inequality formulation. This method has proven effective not only from the purely theoretical point of view, but also from the point of view of yielding new, simple, and efficient numerical solution schemes.

Fig. 2 shows the governing equations and boundary conditions that describe the fixed domain formulation of the problem presented in Fig. 1. D is the region abef. The variable w is the Baiocchi transformation of the extended potential function, i.e.,

$$w(x,y) = \int_y^{y_1} [\tilde{\varphi}(x,\bar{\eta}) - \bar{\eta}]\,\mathrm{d}\bar{\eta}, \tag{1}$$

where

$$\begin{aligned} \tilde{\varphi}(x,y) &= \varphi(x,y) \quad \text{in } \overline{\Omega}, \\ \tilde{\varphi}(x,y) &= y \quad \text{in } \overline{D} - \overline{\Omega}. \end{aligned} \tag{2}$$

The detailed derivations of these equations are given in [3].

The problem shown in Fig. 2 can be written as a 'complementary system' and its corresponding variational inequality formulation. Then the following theorem can be stated:

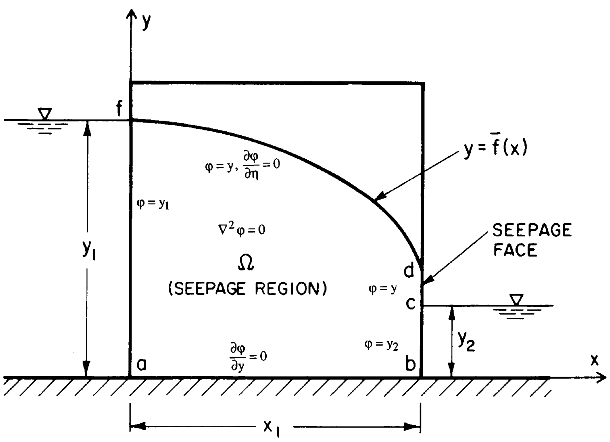

Fig. 1. The example physical problem (free boundary seepage).