SIMULATION OF FLOWS OF GROUNDWATER AND CONTAMINANTS AROUND LANDFILL SITES

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Abstract. A simulation system to compute groundwater flow fields and convection-diffusion of contaminants around landfill sites is presented. This computational study of groundwater flows around landfill sites is intended to facilitate construction of a high-resolution simulation system for groundwater flow and leachate leakage, and assessment of areas influenced by leachate accidents.

1 INTRODUCTION

In recent years, many research efforts have investigated underground flows for various objectives including water supply management, assessment of nuclear and solid hazardous waste management, and others[2]. CFD techniques are anticipated to play a particularly important role for groundwater flow analyses because of the invisibility of the flows. The objective of this study is to develop a simulation system to compute the groundwater flows around landfill sites situated in mountainous regions. Landfill sites in Japan are located in mountainous regions, because the large Japanese population resides in limited flat areas. Therefore, landfill locations in Japan necessarily coincide with water supply areas, which is the main reason for the importance of assessment of influences of leachate accidents. In this paper, we present the outline of our model and some simulation results.

2 MATHEMATICAL MODEL

2.1 Governing equations

This study adopts Navier-Stokes equations with a drag force proportional to fluid velocity to represent three-dimensional groundwater flows.

\[
\frac{\partial u}{\partial t} + \rho (u \cdot \nabla) u = -\nabla (\varepsilon p) - \nabla \cdot \tau_v + \rho \varepsilon g - \frac{|g|}{K} u, \quad (1)
\]

where \( u \) is superficial velocity of water, \( p \) is pressure, \( \varepsilon \) is porosity, \( K \) is permeability and \( \rho \) is density. It is noteworthy that the equation reduces to Darcy’s equation by neglecting unsteady,
advection and viscosity terms. The conservation of mass is represented as

$$\varepsilon \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0,$$

(2)

where density \(\rho\) is represented using saturation \(S\):

$$\rho = \rho_w S + \rho_a (1 - S).$$

(3)

Saturation \(S\) is a volume ratio of water in the pore space of porous media. Conservation of leachate mass is represented using the convection-diffusion equation

$$\frac{\partial C}{\partial t} + (\mathbf{u} \cdot \nabla) C = \kappa \nabla^2 C + \Phi,$$

(4)

where \(C\) is the concentration of leachate, \(\kappa\) is the diffusion coefficient, \(\Phi\) is a source of leachate, and \(\mathbf{u}\) is the velocity of groundwater flow. These governing equations are solved simultaneously with suitable initial and boundary conditions.

2.2 Unsaturated flow

In the unsaturated region, there exists many meniscuses which bring about capillary pressure. Larger pressure gradient is needed to make a flow in unsaturated regions. A lot of formulations have been proposed for representation of relative permeability. In this study, a relationship between saturation and relative permeability

$$K(S) = S^{2+\alpha}$$

(5)

is adopted, which has been proposed by Brooks and Corey[1].

3 NUMERICAL METHODS

The numerical model is discretized using finite-difference method. A generalized coordinate system is utilized to represent the complex geometry around landfill sites in mountainous regions. Figure 1 shows a finite-difference mesh around a test landfill site. A surface mesh is generated from numerical map data. The physical space \((x, y, z)\) is transformed to computational space \((\xi, \eta, \zeta)\), in which one coordinate surface coincides with the land surface. All spatial derivatives, except for advection terms, are approximated by second-order central differences. The advection term is approximated by the third-order upwind scheme[3]. The Generalized Product-type Bi-Conjugate Gradient Method (GP-BiCG)[7] with a preconditioner by incomplete LU factorization is employed for solving the Poisson equation for the pressure. The computational code is parallelized to achieve a high performance on parallel computers using the standard message passing interface (MPI) library.
4 NUMERICAL RESULTS

Figures 2 and 3 show the expected processes of leachate convection-diffusion in the event of a leachate leaking accident in different conditions. The leachate source is presumed to be at the bottom of the landfill. It can be seen that the leachate is convected and diffused in the groundwater flow.
Figure 3: Convection-diffusion of leachate (2)
5 CONCLUSIONS

This study constructed a simulation system to elucidate groundwater flows and to evaluate the convection-diffusion of leachate around landfill sites using test computations. The resulting simulation system is applicable to planning, arrangement, and assessment of new landfill site construction. It also facilitates optimization of effective countermeasures for leachate leakage accidents.

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