CIP based Liquefaction Induced Lateral Spreading Analysis

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INTRODUCTION

The behavior of soil during liquefaction induced lateral spreading has been studied based on case studies of historical earthquakes and experiments. Several researchers have also developed numerical methods in the framework of fluid dynamics using different schemes, such as the VOF (Volume of Fluid) scheme, to treat free boundaries and interfaces between fluids of different physical properties. This paper presents a numerical method for liquefaction induced lateral spreading analysis based on the CIP (Cubic Interpolated Pseudo-particle) scheme devised by Yabe [1]. We used the CIP method because it can correctly define the flow behavior at interfaces between multi fluids and can also be used as a unified scheme for both compressible and incompressible fluids. We improved the old version of the CIP based program by incorporating implicit calculation for pressure terms as well as the Bingham viscosity. The numerical method is validated and applied to shaking table tests of a liquefied slope and the simulation results were verified in comparison to experimental results by Hamada et al [3] and numerical results from another existing fluid dynamics code. The numerical method is found to reproduce a previously proposed similitude law for liquefied ground flow [3,4] and the time history of flow velocity.

NUMERICAL METHOD

The governing equations of fluid motion can be written in a form:

$$\frac{\partial \rho}{\partial t} + (u.\nabla)\rho = -\rho \nabla.u \qquad (1)$$

$$\frac{\partial u}{\partial t} + (u.\nabla)u = -\frac{\nabla p}{\rho} \qquad (2)$$

$$\frac{\partial p}{\partial t} + (u.\nabla)p = -\gamma p \nabla.u \qquad (3)$$

***Key words**: CIP, Lateral spreading, Similitude*

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where ρ is the density, **u** the velocity, **p** the pressure and γ the specific heat ratio. In the CIP method the above equations are split into Non-advection and Advection phases.

***Non-advection*:** In this phase only the right hand side is solved with a finite difference method as shown in eqs. (4) to (6). The superscript ^{n} stands for quantities at the present time step and * means one time step after the non-advection phase; and the quantities having * will be used in the advection phase. Because speed of sound in an incompressible fluid is very large, the term

$$\frac{\rho^* - \rho^n}{\Delta t} = -\rho^n \nabla.u^{**} \qquad (4)$$

$$\frac{u^{**} - u^n}{\Delta t} = -\frac{\nabla p}{\rho^n} \qquad (5)$$

$$\frac{p^{**} - p^n}{\Delta t} = -\gamma p^n \nabla.u^{**} \qquad (6)$$

related to pressure is solved implicitly. The quantities having ** are used to make this implicit calculation. In order to determine such implicit equation, we take the divergence of eq. (5) and substitute it into eq. (6). Then we obtain eq. (7).

$$\frac{\nabla^2 p^{**}}{\rho^n} = \frac{p^{**} - p^n}{\gamma p^n \Delta t^2} + \frac{\nabla.u^n}{\Delta t} \qquad (7)$$

Advection: After ρ^*, $\mathbf{u}^*$, $\mathbf{p}^*$ are obtained in the non-advection phase, the CIP solver devised by Yabe et al. is used to obtain ρ^{n+1}, $\mathbf{u}^{n+1}$ and $\mathbf{p}^{n+1}$. These two phases complete the numerical procedure and are repeated step by step.

METHOD VALIDATION

The numerical method is applied to dam break analysis and comparison is made with experimental results shown in Fig. 1. The calculated curve matches very well with results from experiment, therefore, the numerical method can be used for practical simulations.

NUMERICAL SIMULATIONS

The following equation was used to calculate the equivalent viscosity η' for the Bingham model.

$$\eta' = \eta + \frac{R_{min}.P}{\dot{\gamma}} \quad (8)$$

The lateral spreading experiment on liquefied sand in the inclined soil container on the shaking table by Hamada et al [3] is simulated. In the similitude analysis, model parameters were set as 1.0 Pa.s for the Bingham viscosity η and 0.011 for the maximum residual strength ratio R_{min}; and 1.0 Pa.s and 0.018 in the velocity time history analysis. The velocity to liquefied layer thickness relations obtained from experiment and the CIP based numerical method, for 3% ground slope are shown on Figures 2. It can be seen that the numerical method has reproduced the proposed simulated law, which states flow velocity is proportional to the square root of liquefied subsoil layer thickness. Figures 3 and 4 show time history of the flow velocity from the CIP based numerical method and an existing fluid dynamics code, respectively. From these two figures it can be seen that the CIP based numerical method has reproduced the time history of flow velocity of the liquefied subsoil but with a slightly higher maximum velocity.

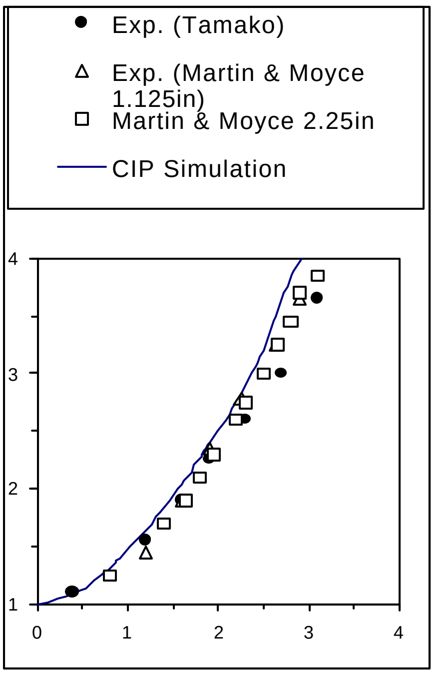

Fig. 1. Dam break analysis

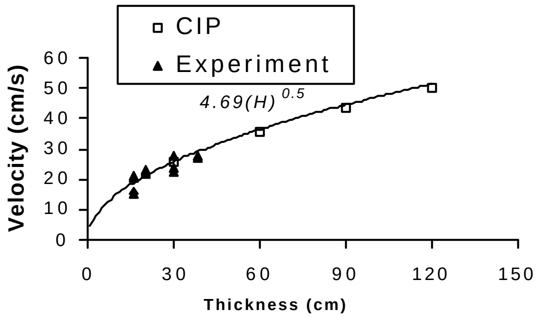

Fig. 2 Similitude Law

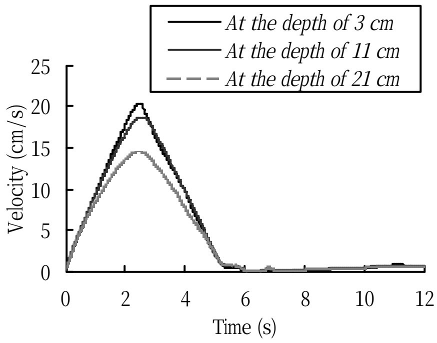

Fig. 3 Velocity time history curve, CIP

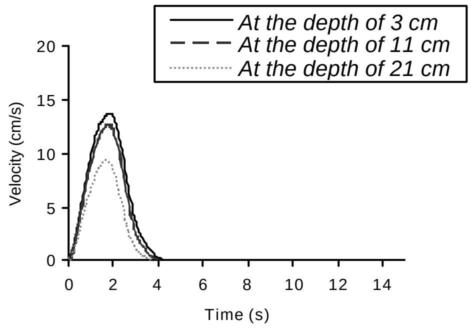

Fig. 4 Velocity time history curve, existing code

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