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Fundamental study of Fluid-Soil-Seepage flow coupled analysis by a particle method based on the mixed flow theory

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1. INTRODUCTION

In 2011, Tohoku-Kanto earthquake tsunami caused serious damage on the port structures such as breakwater and seawall. Damage mechanisms of these structures have been studied in the past, and there are mainly three causes; I. horizontal force due to the water level difference between the front and rear breakwater, II. soil scour and erosion behind the seawall during overflow and III. piping destruction associated with the decline of the bearing capacity by seepage flow.

Fluid-Structure-Soil coupling simulation is desired for a systematic comprehension of seawall collapse mechanism, and it may help to develop next disaster prevention method. In this study, a particle simulation tool based on the SPH has been developed to solve the different soil damage mechanisms; soil sour and seepage flow problem. These simulations should treat the Fluid-Soil and Fluid-Seepage flow interactions, and the particle simulation tool has been modified and improved to solve each interaction problem.

For the Fluid-Seepage flow interaction analysis, in this study, as a governing equation of Fluid-Seepage flow, Darcy-Brinkman equation[1] is introduced. This equation has been widely used to study flows in porous media in various contexts, and its derivation is based on the volume-averaging method, focusing on the underlying assumptions and on its relationships with the Navier-Stokes and Darcy equations. Using this equation, simultaneous analysis is carried out. These different simulations have been implemented by modifying the standard SPH method.

Finally, efficiency and adequacy of the proposed simulation technique has been validated through an application to one of experimental test done by Kasama. This numerical result shows a reasonable seepage flow behavior.

2. SEEPAGE FLOW ANALYSIS

For simplicity, this chapter explains only about Fluid-Seepage flow coupled analysis. In this study, as a first step, soil particles are fixed as porous media, and seepage flow particles are displayed on the soil particle. Therefore, it is sufficient only for Fluid and Seepage flow particles to be modelled. Both of them are generally described by Navier-Stokes equation and Darcy's law, however, in case water particles penetrate into soil mound and change surface flow to seepage flow, there needs to be a unified formula between them. So, in this research, as a governing equation of Fluid-Seepage flow, Darcy-Brinkman equation[1] is introduced and shown below.

$$\frac{\partial}{\partial t}\boldsymbol{v} + \boldsymbol{v}\cdot\nabla\left(\frac{\boldsymbol{v}}{\chi}\right) = -\frac{\chi}{\rho_l}\nabla p + \nu\nabla^2\boldsymbol{v} + \chi\boldsymbol{g} - \frac{\nu\chi}{k}\boldsymbol{v} \tag{1}$$

Here, χ is the liquid volume fraction (porosity) and k is the permeability. v is the liquid velocity in Fluid phase and Darcy velocity in Darcy phase (in soil mound). Where we solve the Darcy-Brinkman equation with changing porosity χ and permeability k, we can solve Navier-Stokes equation in the pure fluid and Darcy's equation in the porous matrix.

Fig.1 and Fig.2 show analysis result of its application to experimental test done by Kasama[2]. Here, the contour of each figure expresses respectively piezo water head and norm of velocity. From the figure, it can be confirmed that Darcy-Brinkman equation is good for Fluid-Seepage flow interaction problem.

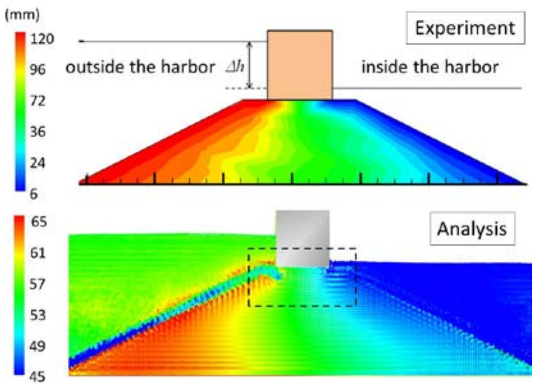

Fig.1 result of piezo water head

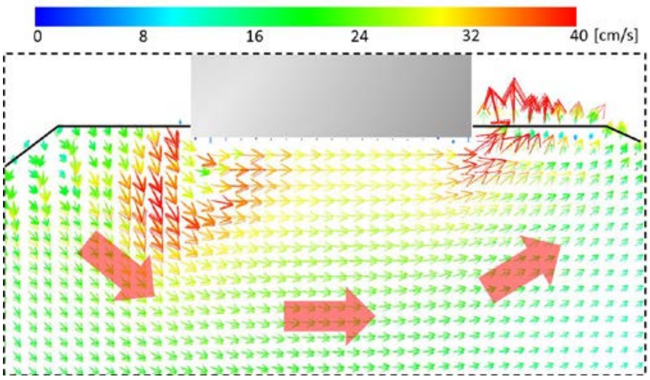

Fig.2 result of velocity vector and norm

3. CONCLUSION

In this study, Darcy-Brinkman equation has been used to Fluid-Seepage flow interaction problem with SPH method, and its analysis result is good from qualitative perspective. Finally, as a future work, developing Fluid-Soil-Seepage flow coupled analysis is our goal.

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