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Numerical analysis to evaluate the change in degree of saturation considering diffusion and dissolution process on partially saturated soil.

Keywords: Numerical analysis, Diffusion, Degree of saturation

o Narayan Marasini, Mitsu Okamura & Ryota Kasatani
Ehime University

1. Introduction

Desaturation by air injection is an innovative countermeasure technique especially for the existing structure founded on liquefiable soil. The reliability of this technique is depends on the sustainability of the injected air in the soil pore. Previous study qualitatively revealed that the lowered degree of saturation by artificially injected air will sustained for a decades or longer. But still there is no proper prediction method that has been developed to foresee the change of degree of saturation with time. To evaluate the change in degree of saturation (which ensures the longevity of injected air) at different seepage flow pressure on partially saturated sand, experiments were conducted in the laboratory (Kasatani and Okamura, 2014). In this study laboratory experiments were numerically simulated with considering advection and the molecular diffusion process of mass transfer by using the multiphase flow simulation model (TOUGH2) based on the finite difference method (FDM).

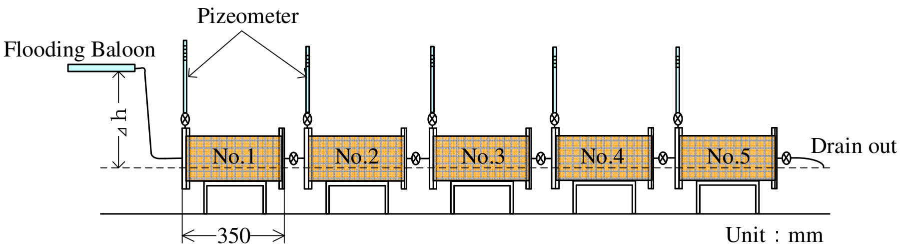

Figure 1: Experimental set up

2. Experiment Conditions

Figure 1 schematically illustrates the experimental set-up adopted to observe the change in degree of saturation. It consisted of five Plexiglas cylindrical tube with an inner diameter of 10cm and length 35cm. Five cylinders connected in-line by a thin tube simulated the change in degree of saturation on 1. 75m long column at one dimensional flow condition. The soil used for the model preparation was Toyoura sand with relative density 90% and initial degree of saturation before the flow of water initiated from the flooding balloon was about 93%. The water used for the seepage flow was de-aired at -100kPa pressure for more than 12 hours to remove all dissolve air in the water. The flow of de-aired water was supplied through the flooding balloon with keeping three different hydraulic head of 0.66m, 0.43m and 0.12m as a case 1, case 2 and case 3, respectively. The change in degree of saturation was measured by measuring the change in mass of each cylinder. In addition, piezometers were installed in each cylinder to measure the permeability during the continue seepage flow condition. Experimental conditions are shown in Table 1.

Table 1: Experiment condition

Experiment case	Sample	Flow water	Relative density Dr(%)	Initial degree of saturation (%)	Hydraulic gradient
case1	Toyoura sand	Deared water	90%	92～94%	0.66
case2					0.43
case3					0.12

3. Numerical methods

We use a multiphase flow simulator of TOUGH2 (Pruess et al., 1999) considering the molecular diffusion process also due to the concentration gradient to describe a saturation process and to examine an applicability of the model if replicating the experimental measurements.

In TOUGH2, a mass balance may be expressed in integral form for arbitrary sub-volume, Vn, bounded by a surface area of Γ_n given as,

$$\frac{d}{dt}\int_{V_n} M^k dV_n = \int_{\Gamma_n} F^k .nd\Gamma_n + \int_{V_n} q^k dV_n , \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where κ denotes the component, M^κ is the amount of component κ with a dimension of mass per volume, F^κ is the flux of component κ, n is the outward unit vector normal to the volume surface, q^κ is the rate of generation of component κ within the volume.

Air erosion in unsaturated soil at occluded air phase is due to water flow when there is water head difference, and is due to diffusion when there is concentration difference of dissolved air (Fredlund and Rahardjo, 1993). Both the diffusion and advection process of mass transfer has been considered to evaluate the change in degree of saturation by the equation of state 3 (EOS3, air and water flow) under TOUGH2 simulator using PetraSim5 interface model.process of mass transfer has been considered to evaluate the change in degree of saturation by the equation of state 3 (EOS3, air and water flow) under TOUGH2 simulator using PetraSim5 interface model. The simulated domain has one dimensional flow in X-direction compatible to Fig. 1. The water pressure exerted at injection cell (First cell) is fixed to the pressure equivalent to hydraulic head of 0.66m, 0.43m and 0.12m compatible with the experiment. The material parameter used in the analysis are listed in Table2.

Table 2. Parameter used for simulation

Relative Permeability (Van Genuchten model)		
Parameter		
λ		0.889
Air entry value P_0 (kPa)		4.47
Residual liquid degree of saturation(S_{lr})		0.155
Maximum liquid degree of saturation(S_{ls})		1.0
Residual air degree of saturation (S_{gr})		0.06
Diffusion Coefficient		
Parameter	Gas	Liquid
Water	1.0E-5	1.0E-9
Air	1.0E-5	1.0E-9

4. Comparison between experiments and simulations

Time histories of flow rate (discharge) in case 1 and case 2 from laboratory experiment and numerical simulation are depicted in Figure 2. Experiment and numerical simulation results on change in degree of saturation are depicted in Figure 3. In case 1, flow rate of water continuously increases and reached constant after 27hr of seepage flow in both the experiment and numerical simulation as shown in Figure 2. This 27hr is the time elapsed to reach the degree of saturation 100% as depicted in Figure 3. In case 2 discharge increases till 48hr of continue flow and then remains constant as depicted in Figure 2. In this case also 48hr is the time elapsed to reach the degree of saturation 100% in both the experiment and numerical simulation. The increase pattern of degree of saturation is also comparable in both the experiment and numerical simulation. In the experiment, just after the first soil column reached Sr= 100% the second soil column started to increase in. In case 3, the hydraulic head is comparatively lower than case 1 and case2, so the degree of saturation increase rate is pretty slow in both experiment and simulation and can't achieve 100% degree of saturation throughout the model even after 100hr of continue seepage flow as depicted in Figure 3.

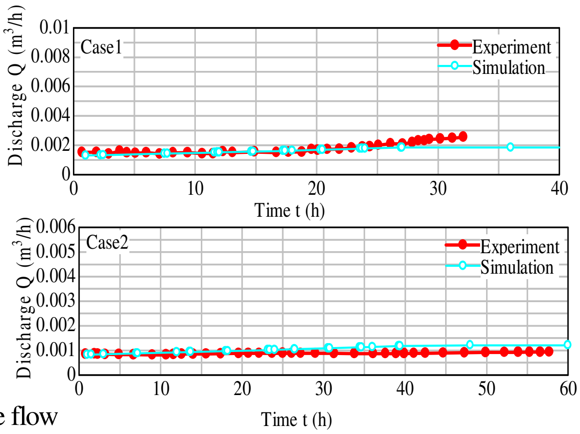

Figure 2. Time history of discharge

5. Conclusion

In this study, numerical simulation was performed to validate the experiment test to predict the changes in degree of saturation at continue seepage flow in different hydraulic head considering the advection and diffusion process of mass transfer. Results were quite comparable with the test results for all the three cases of laboratory experiment. This study indicates, simulator may be capable of predicting the saturation process after the degree of saturation lowered by air injection technique under arbitrary conditions, and be applicable to field problems to predict the longevity of artificially injected air as flow characteristics are identified.

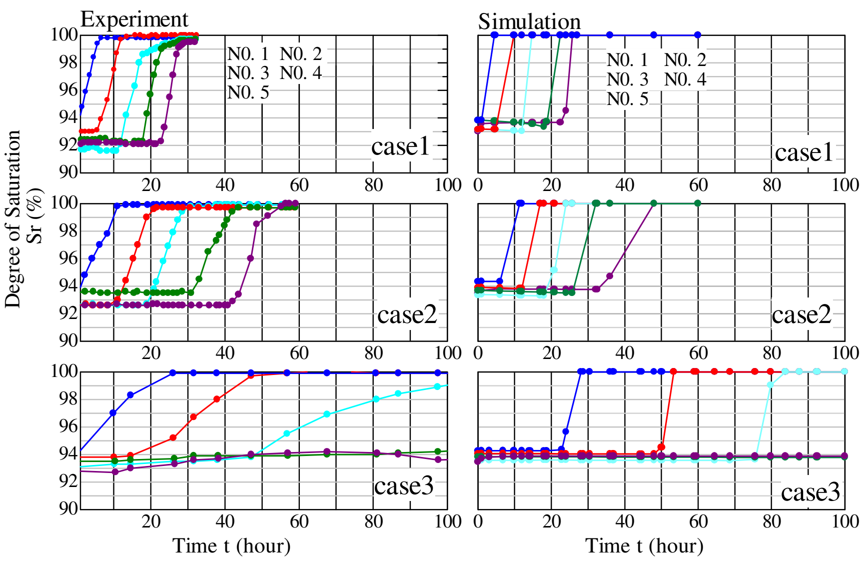

Figure 3. Degree of saturation (Sr) change with time

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