Poro-elastic Deformation of a Heterogenous Geologic Medium due to Groundwater Withdrawal

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Land subsidence around coastal cities in the world have been recognized as a major concern due to risk of flooding from seawater. As an example, land surface near the Tokyo and surrounding regions in Chiba Prefecture in Japan have been subsiding at rates of few centimeters per year based on data from satellite observations and ground survey measurements. Such changes in land surface elevations may have caused due to subsurface fluid (water/methane) extraction from the Plio-Pleistocene sand reservoirs of the Kanto groundwater basin located in and around Tokyo and Chiba. Fluid removal from subsurface geologic medium can reduce pore fluid pressures underneath and subsequently strain the medium causing pore spaces to collapse. Stratigraphic and lithological interpretation of rocks exposed in outcrops from the Kujukuri region in Chiba showed alternations of sandstone-mudstone units and were characterized by transgressive-regressive cycles of vertical heterogeneity indicating a gradual transition of sediment size from coarse-grained sandstone to fine-grained siltstone/mudstone. The present research hypothesized that presence of local geological heterogeneities in a geologic medium can alter hydraulic properties of the medium affecting its deformation. The main purpose of this research was to determine effect of vertical heterogeneity on rock deformation and to predict land surface subsidence due to groundwater extraction. The research hypothesis was tested using a one-dimensional solution to equations for pore fluid mass conservation and Darcy’ s flow mechanics for a poro-elastic medium saturated with water. Porosity and permeability, both dependent upon clay content, were related by a modified form of Kozeny-Carman equation.

Simulations results for a hypothetical 130 m thick water-saturated porous medium under different geological conditions were compared to investigate heterogeneity effect on deformation. Results showed hydraulic strain in mudstone increased by orders of magnitude higher than less compressible and more diffusive sandstone. Simulation results also confirmed that geological heterogeneity would affect poro-elastic deformation by altering hydraulic diffusivity and bulk compressibility of a geologic medium. Moreover, model predicted land surface subsidence, using stratigraphic sections from the Kanto basin, were in good agreement with field deformation measurements from leveling survey. In addition, local heterogeneity can be more important for a geologic medium saturated with multiple fluids (methane/water) which will be addressed in future research.

Keywords: Poro-elastic modeling, Geological heterogeneity, Land subsidence