Experimental technique for visualization of aquitard compaction over aquifer caused by excess pumping

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Research background

Uncertainty of numerical modelling for subsidence due to excess pumping

- Uncertainty of modelling aquitard compaction
  - The compressibility of aquitard, caused by dissipation of pore water due to excess pumping form aquifer, is modelled for simulating aquitard deformation numerically, with no practical certainty of both **heterogeneity of the aquitard** and **complexity of geological settings** in the analyzed area.
- Uncertainty of inputting soil data
  - The soil data, obtained from in-situ and/or laboratory testing, may be **valid for input data after adopting interpretation of empirical correlations to obtain engineering properties in practice**.

Research Perspective

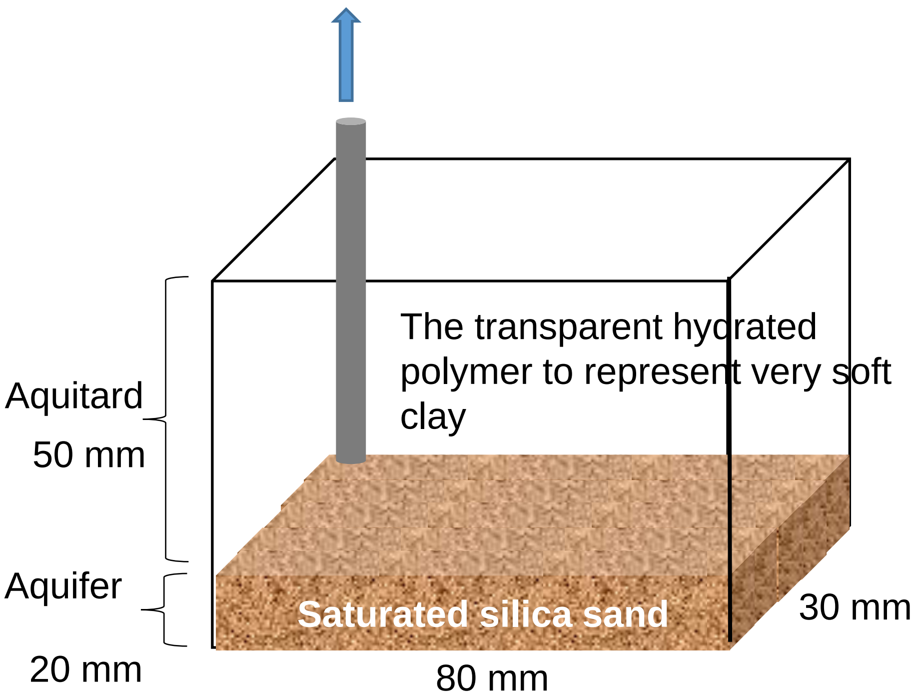
- Develop a method to confirm validity of numerical results to practical use by experimental results.
- This experimental method must enable to model heterogeneity of the aquitard and complexity of geological settings.
- Experimental method must be simple and inexpensive.

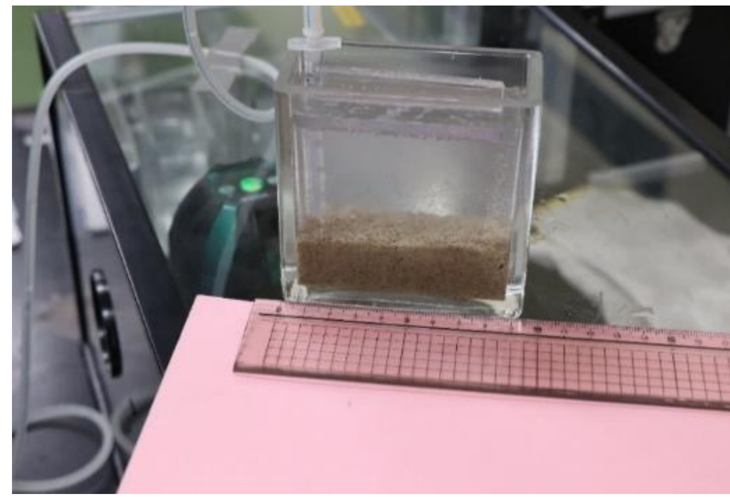
Purpose of This Research

- **Two layered soil model** was prepared by transparent hydrated polymer to represent aquitard over silica sand to represent aquifer.
- **Three dimensional poroelastic analysis** was conducted on the soil model to simulate deformation growth and distribution of porewater pressure within the transparent hydrated polymer after pumping from silica sand.
- **A visualization technique** was demonstrated to visualize inner deformation within the transparent hydrated polymer due to pumping.
- The numerical result was compared to the result of visualization technique.

Two layered soil model

A 5 mm- diameter tube pumped porewater from silica sand (12cc/5 mins)



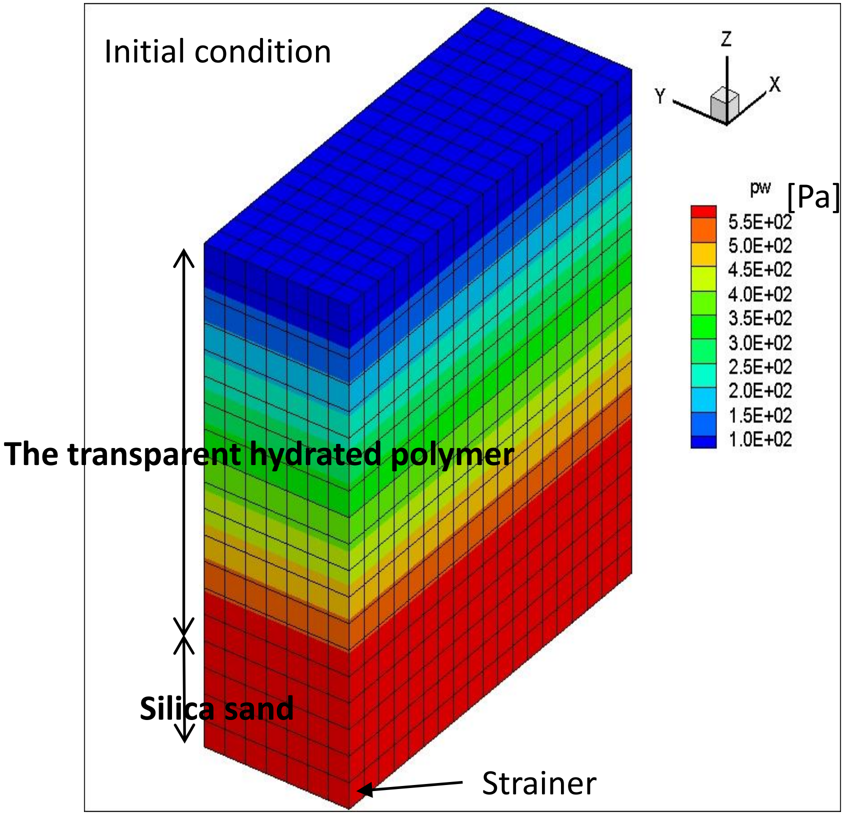


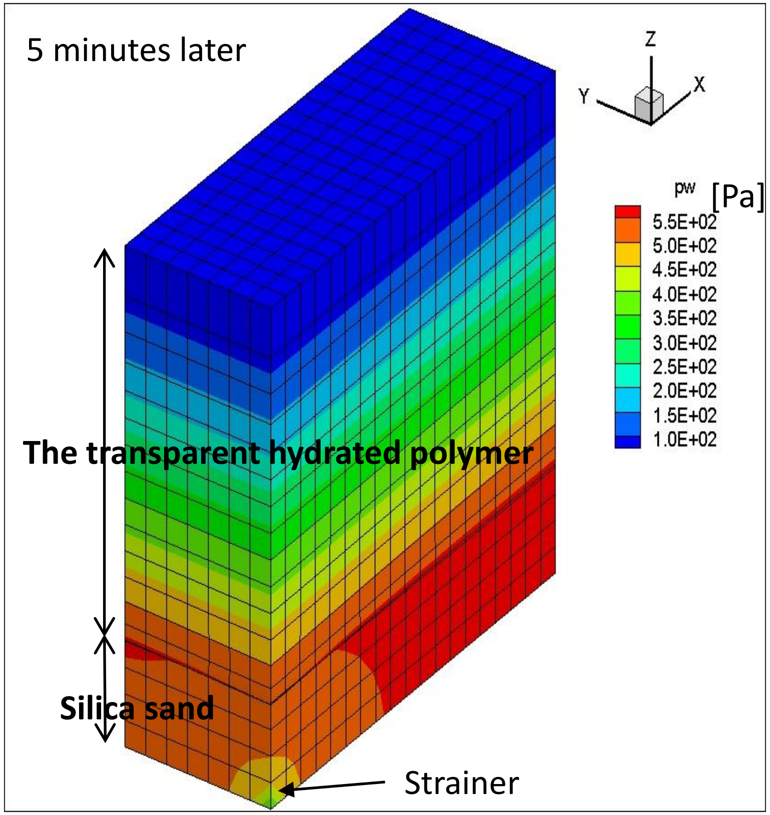
30mm width by 80mm length by 70mm height of glass tank filled with the transparent hydrated polymer to represent aquitard (saturated clay layer) over aquifer (saturated silica sand)

Input data of soil properties for three dimensional poroelastic analysis

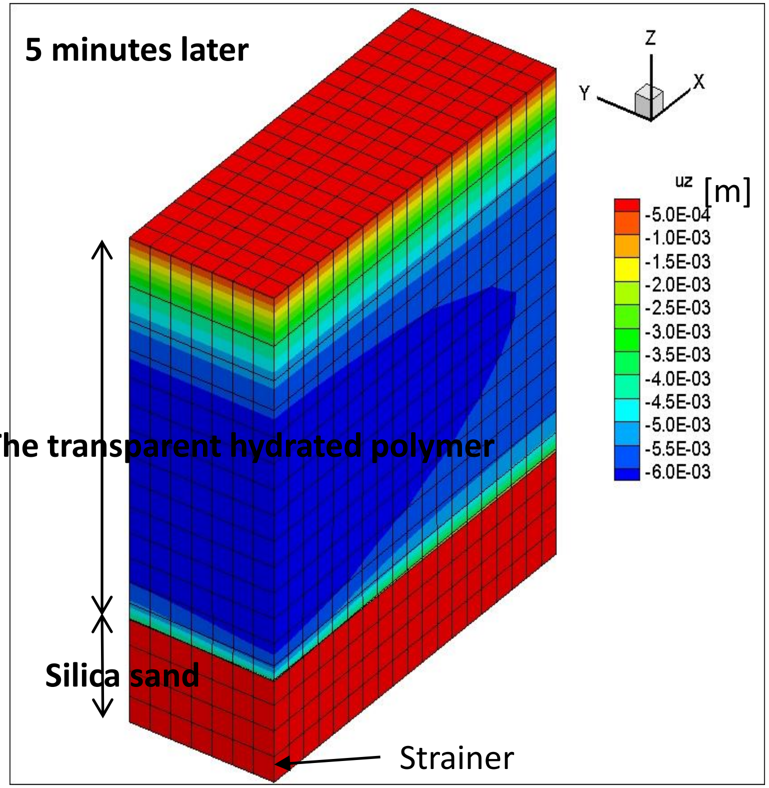
Soil properties	Input data of hydrated polymer	Input data of silica sand
Hydraulic conductivity (m/s)	10^{-5}	10^{-5}
Young`s Modulus (drained condition) (MPa)	0.00001	0.4
Poison`s ratio (drained condition)	0.25	0.25
Effective stress coefficient	1.0	1.0
Porosity	0.5	0.5

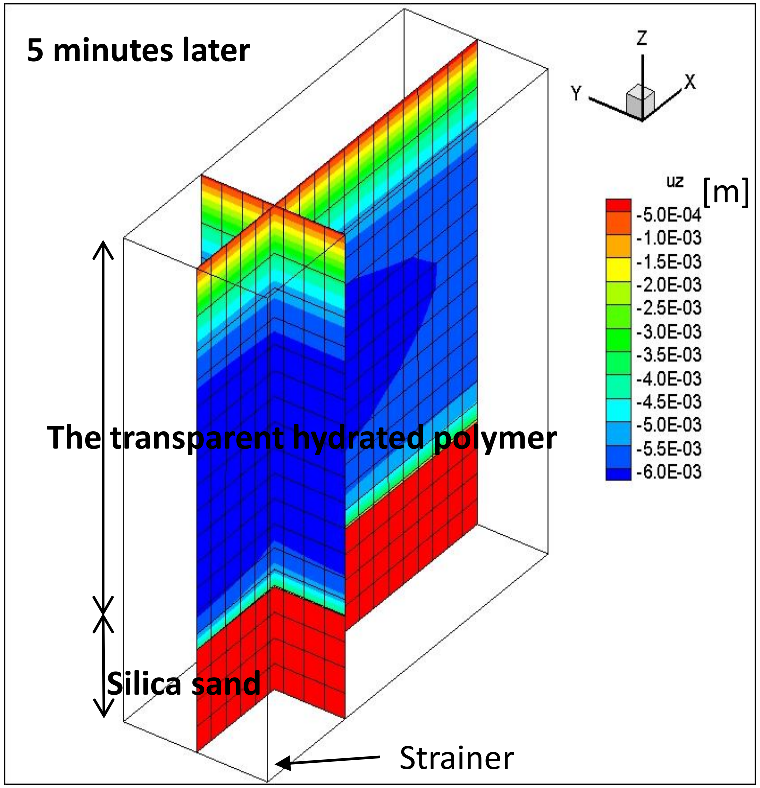
Numerical results
(distribution of porewater pressure)





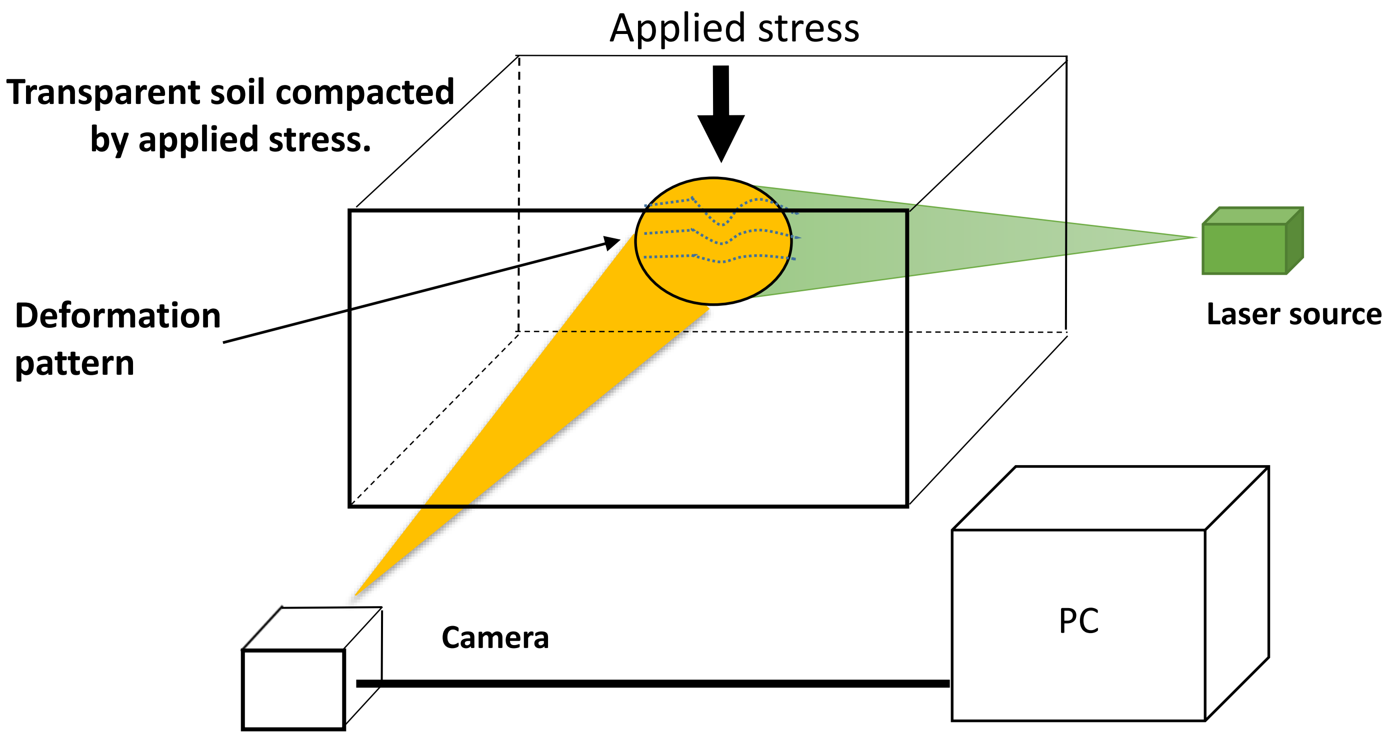
Numerical results
(distribution of deformation)





Visualization technique using transparent soil

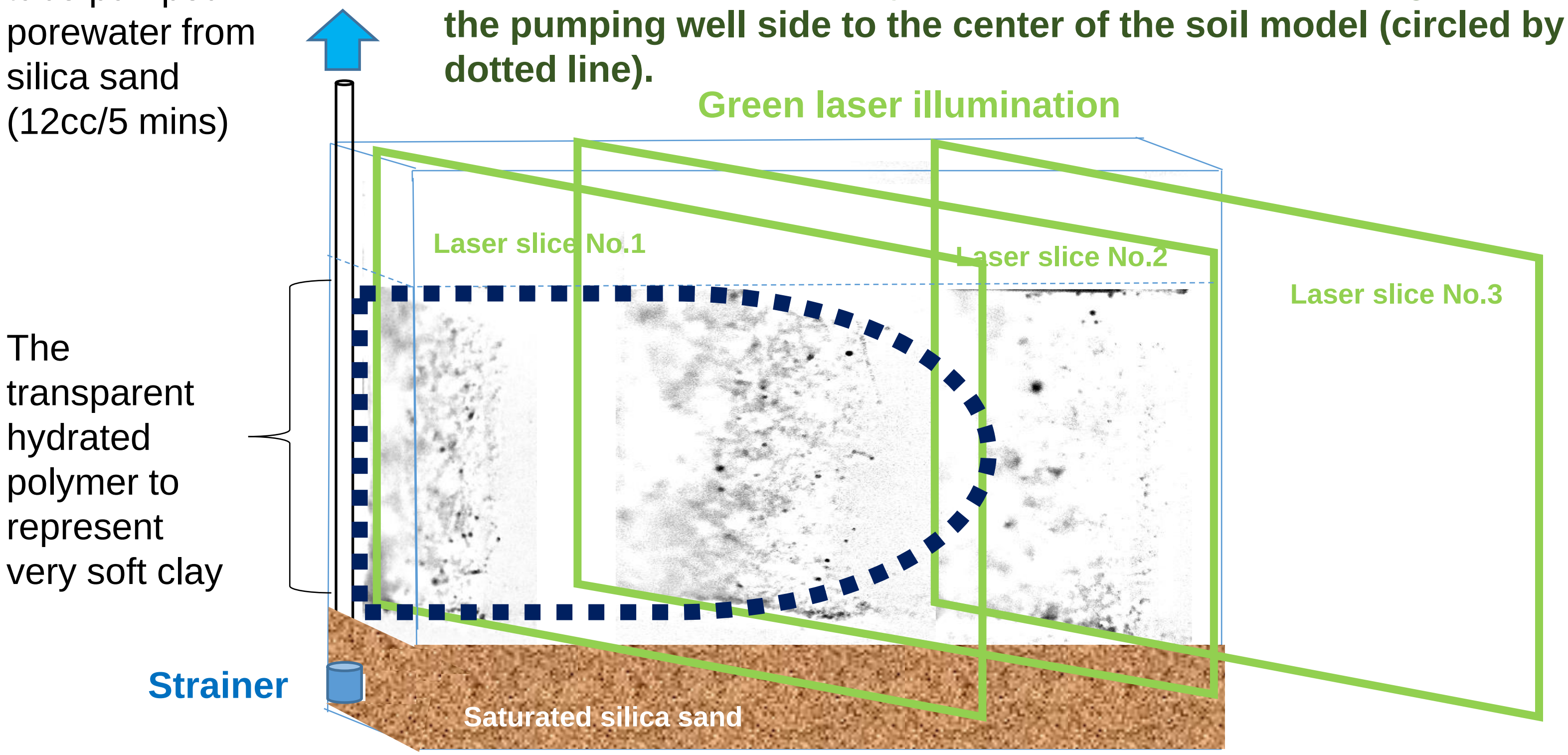
Transparent soils are developed as a physical modelling of macroscopic soil behaviors in geotechnical engineering aspect. Transparent surrogates with its index-matched fluid, called as transparent porous media or transparent soils, have been used for simulating geotechnical properties of natural soils.



Pseudo three dimensional picture using laser illumination

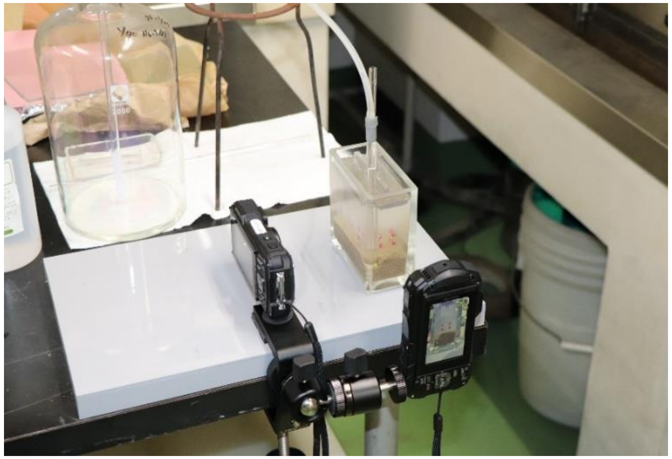
A 5 mm- diameter tube pumped porewater from silica sand (12cc/5 mins)

The deformation area in the transparent hydrated polymer is not uniform over the entire layer. Deformation was more significant from the pumping well side to the center of the soil model (circled by dotted line).

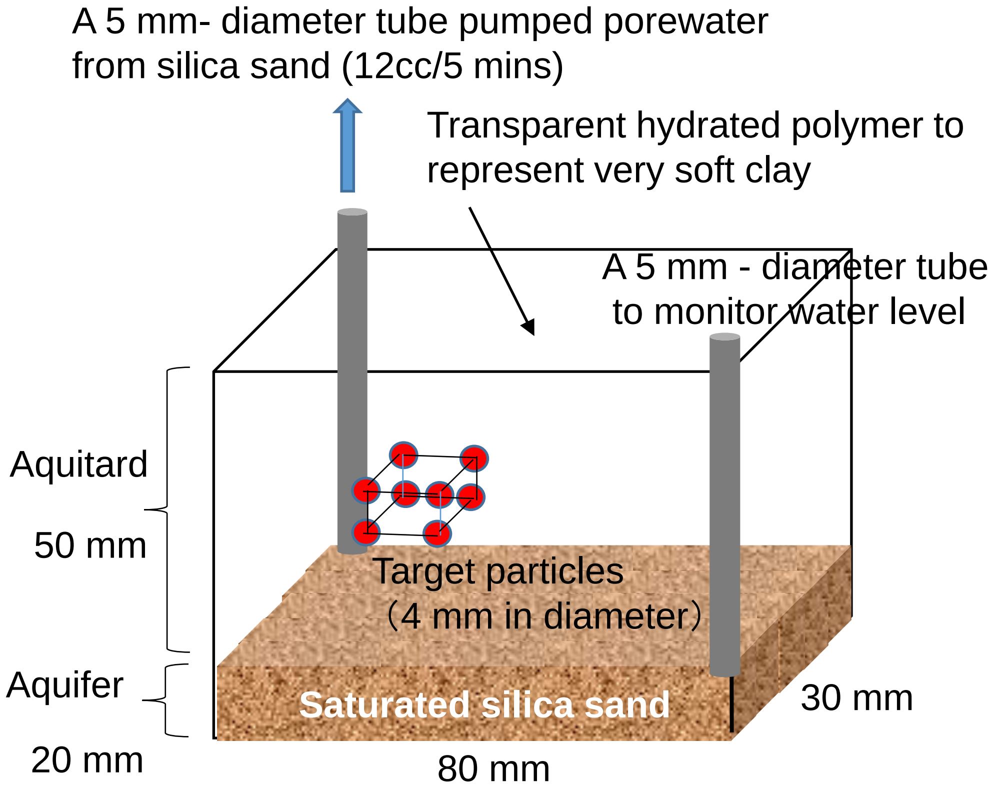


Visualization of deformation by target tracking method

In order to measure the displacement around the pumping well where the largest displacement was calculated by the analysis, a pumping experiment with target particles was conducted.

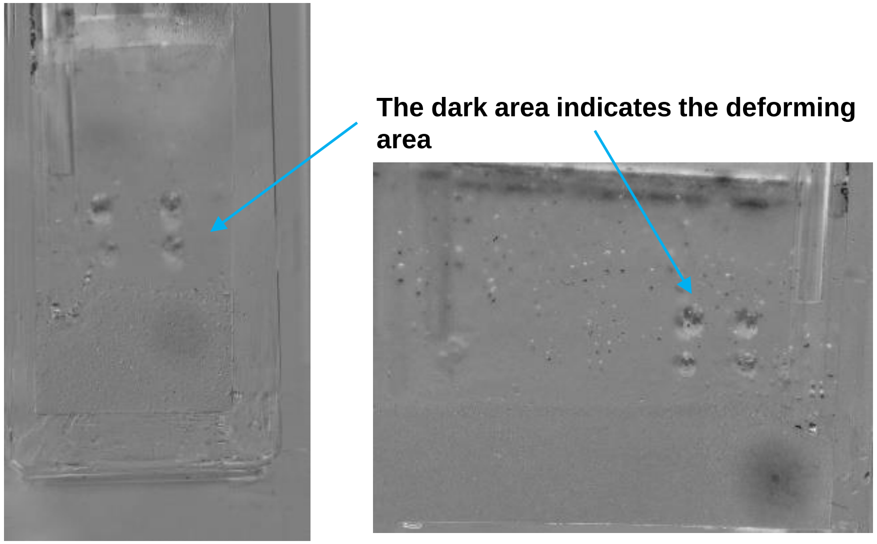


The movement of particle targets is captured with two digital cameras from both of the short side and the long side of the model, respectively.

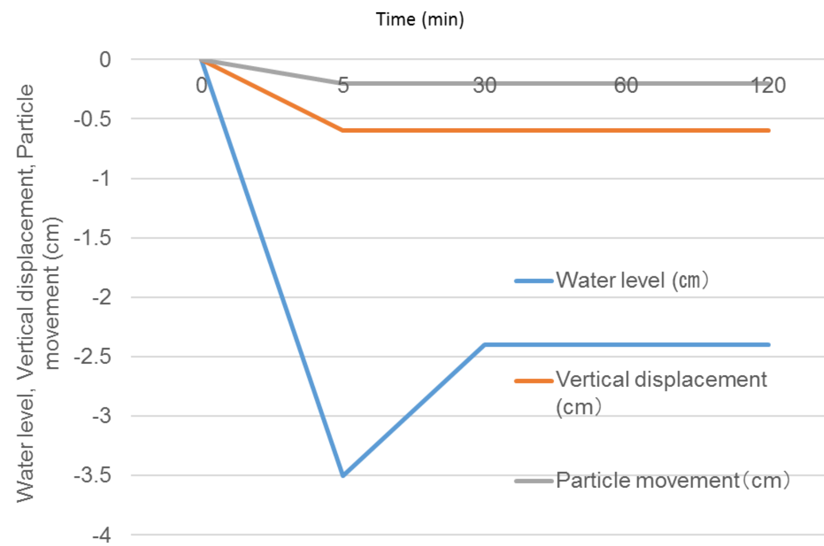


Two layered soil model

Movement of target particles in hydrated polymer and changes in observed water level



Difference image of photos at the start of the experiment and after 5 minutes (LHS: short side of the model, RHS: long side of the model)



Synthetic clay layer

- Five minutes after the start of pumping, the surface was submerged by 6 mm more than before the experiment. After that, the hydrated polymer continued to remain as it was.

Water level

- After 5 minutes from the start of pumping, it decreased by 35 mm compared to the initial water level. After 30 minutes, it recovered to 24 mm and then remained constant.

Target particles

- Five minutes after the start of pumping, it moved about 2mm vertically than the initial position. And then no movement was observed until 120 minutes later.

Movement of target particles with water level fluctuation confirmed that vertical displacement (contraction of the transparent hydrated polymer) occurred as the water level decreased, and that the synthetic clay layer remained contracted even after the water level recovered. In other words, it was suggested that the transparent hydrated polymer showed consolidation behavior.

Summary

- Three dimensional poroelastic analysis was conducted on a pumping test in 30mm width by 80mm length by 70mm height of glass tank filled with the transparent hydrated polymer to represent aquitard (saturated clay layer) over aquifer (saturated silica sand).
- The analysis quantitively illustrated that the transparent hydrated polymer was deforming due to vertical propagation of pore water pressure during the pumping test.
- This numerical simulation was compared to the result of experimental technique using transparent soil.
  - The pseudo three dimensional picture using laser illumination showed that deformation pattern captured in the transparent hydrated polymer was matched with the numerical illustration.
  - Movement of target particles with water level fluctuation confirmed that vertical displacement (contraction of the transparent hydrated polymer) occurred as the water level decreased, and that the transparent hydrated polymer remained contracted even after the water level recovered. In other words, it was suggested that the transparent hydrated polymer behaved in a consolidated manner.
- This experimental result showed good compatibility with the numerical result of three-dimensional porelastic deformation theory.
- The proposed visualizing technique, with polymer and water as index method fluids, is easy to conduct, non hazardous, and inexpensive.

Further studies

- Physical and consolidation properties of the transparent polymer need to be compared to the ones of natural soil.
- This technique has potentiality for simulating more complexity and heterogeneity of subsurface condition.

References and acknowledgement

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