ICCE 2018

36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

Baltimore, Maryland | July 30 – August 3, 2018

The State of the Art and Science of Coastal Engineering

Verification of seepage flow calculation based on fluid-ground weak coupling analysis model

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Contents

1.Introduction

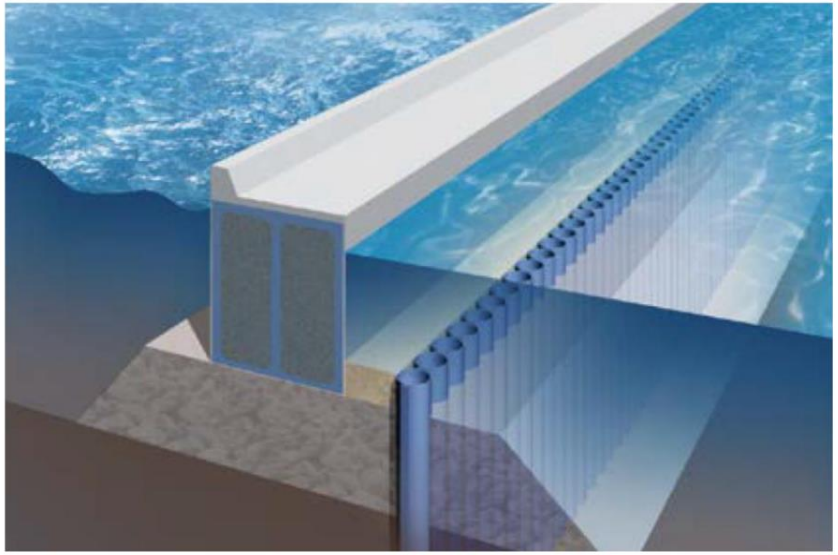
Introduction

It is essential to establish the coupled model of fluid analysis and ground analysis to evaluate destruction and deformation of structures with ground part such as coastal levees due to tunami and storm surge .

⇒ Since it is possible to consider the influence of seepage flow etc.

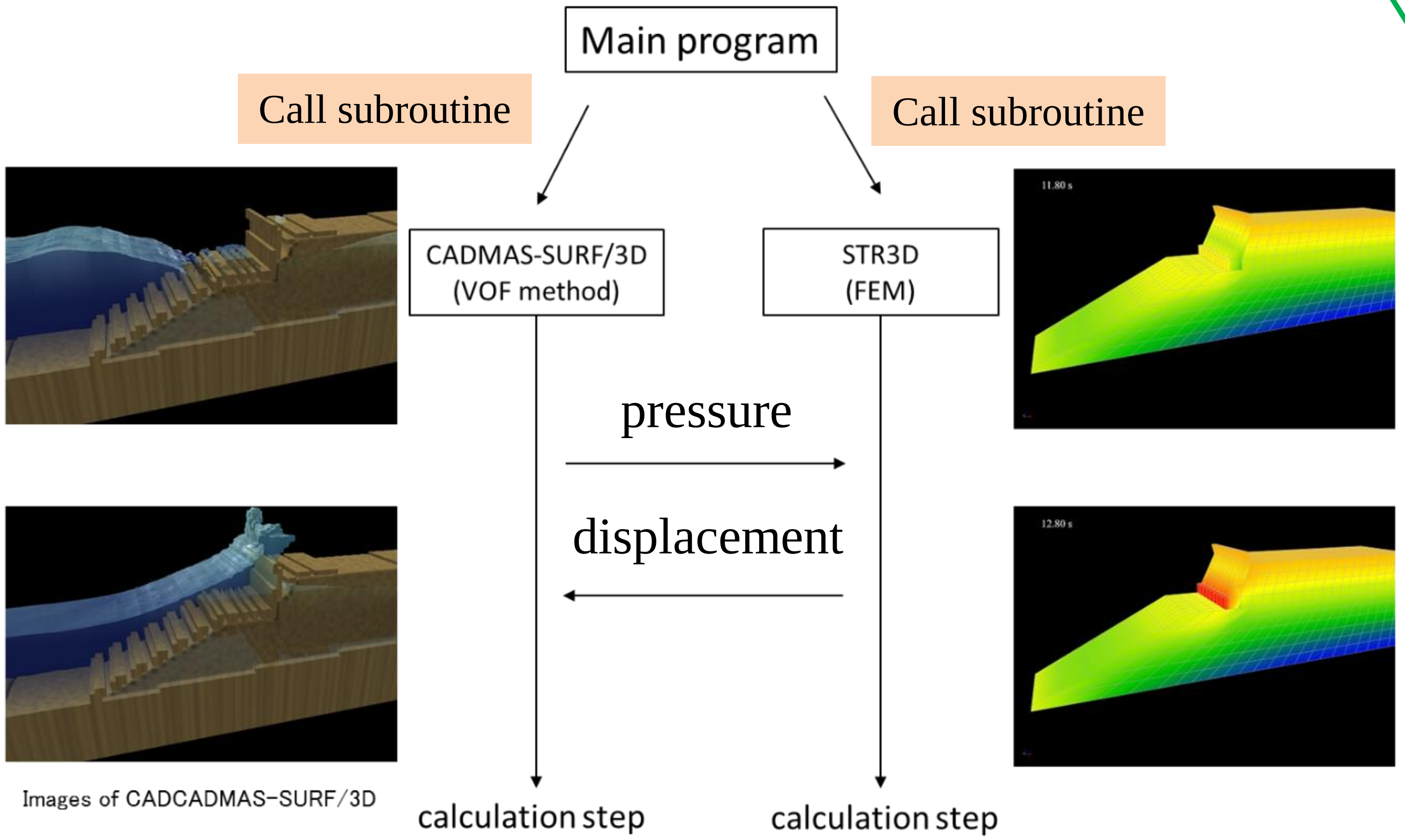
In *2009*, Arikawa *et al.* developed CADMAS-STR. This is a weak coupled model of fluid analysis and ground analysis.

http://www.ryowa-concrete.jp/sinsaihukou.html

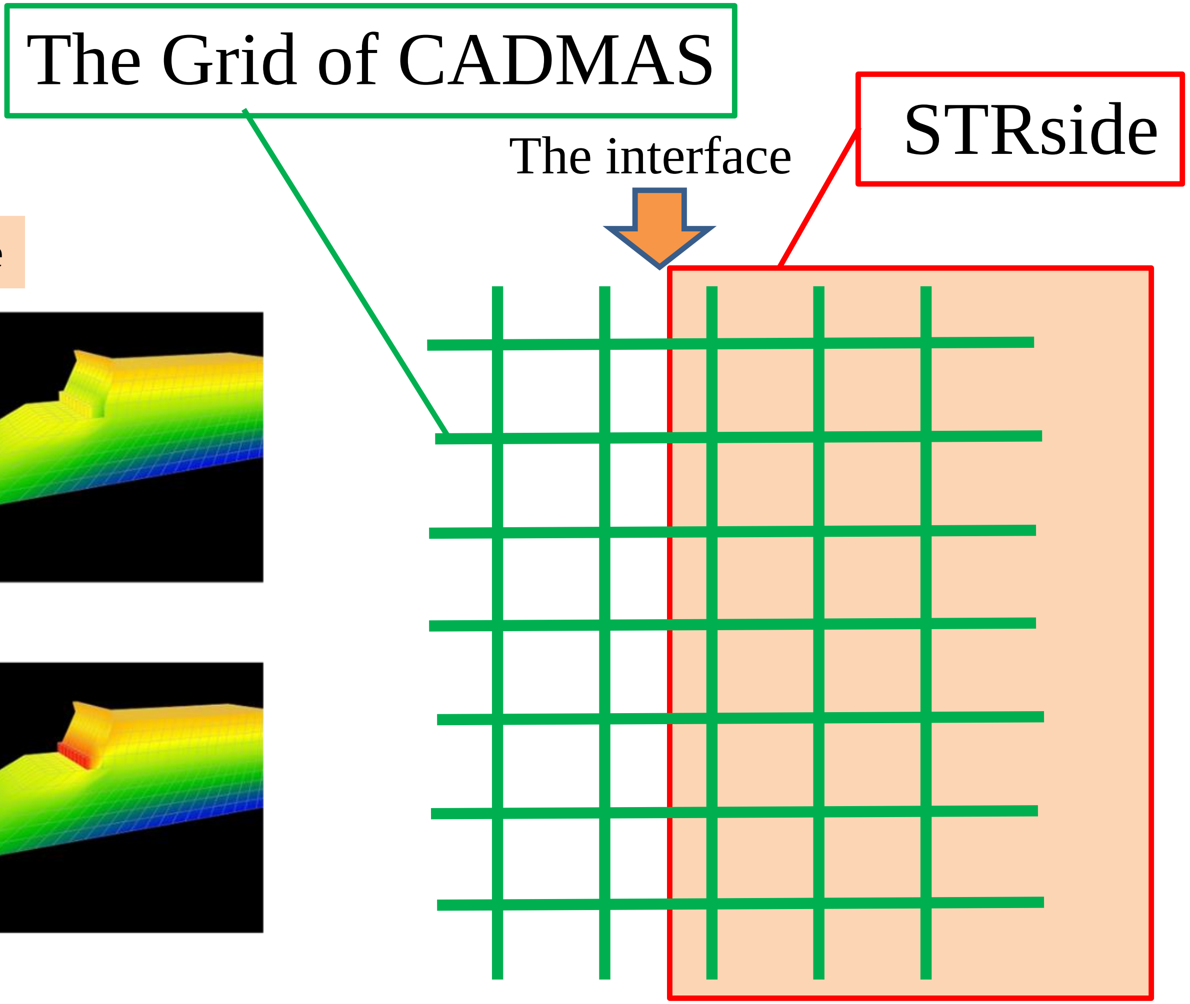


*Refer to Stability of the Breakwater with Steel Pipe Piles under Tsunami Overflow Arikawa et.al(2015)

Overview of CADMAS-STR



System of CADMAS-STR(Arikawa *et al.*2009)



- CADMAS sends the pressure at the interface between the structure and the fluid to STR
- STR sends the amount of displacement of the structure caused by the fluid pressure to CADMAS

About the ground analysis section

CADMAS side

CADMAS expresses the ground material by giving porosity, resistance coefficient to the ground region

STR side

STR conducts seepage flow analysis using Biot equation and Darcy resistance law

The seepage flow analysis of the ground region is calculated separately on both sides

However, in the CADMAS, there is no example examining the resistance coefficient when reproducing a material with small particle size such as ground.

Purpose of this research

① In order to model the ground, we examined the resistance coefficient of CADMAS

The Dupuit-Forchheimer's law was adapted to CADMAS.

We increased the consistency of water permeability between the CADMAS side and the STR side for CADMAS - STR.

② We reproduced the pore water pressure in the unsteady state

Flow of research

first

The experiment was conducted to measure the seepage flow velocity and the pore water pressure → The result of this experiment was gained

second

The resistance coefficient of CADMAS was examined → Dupuit-Forchheimer's law was found → The resistance coefficients of DF law was verified

third

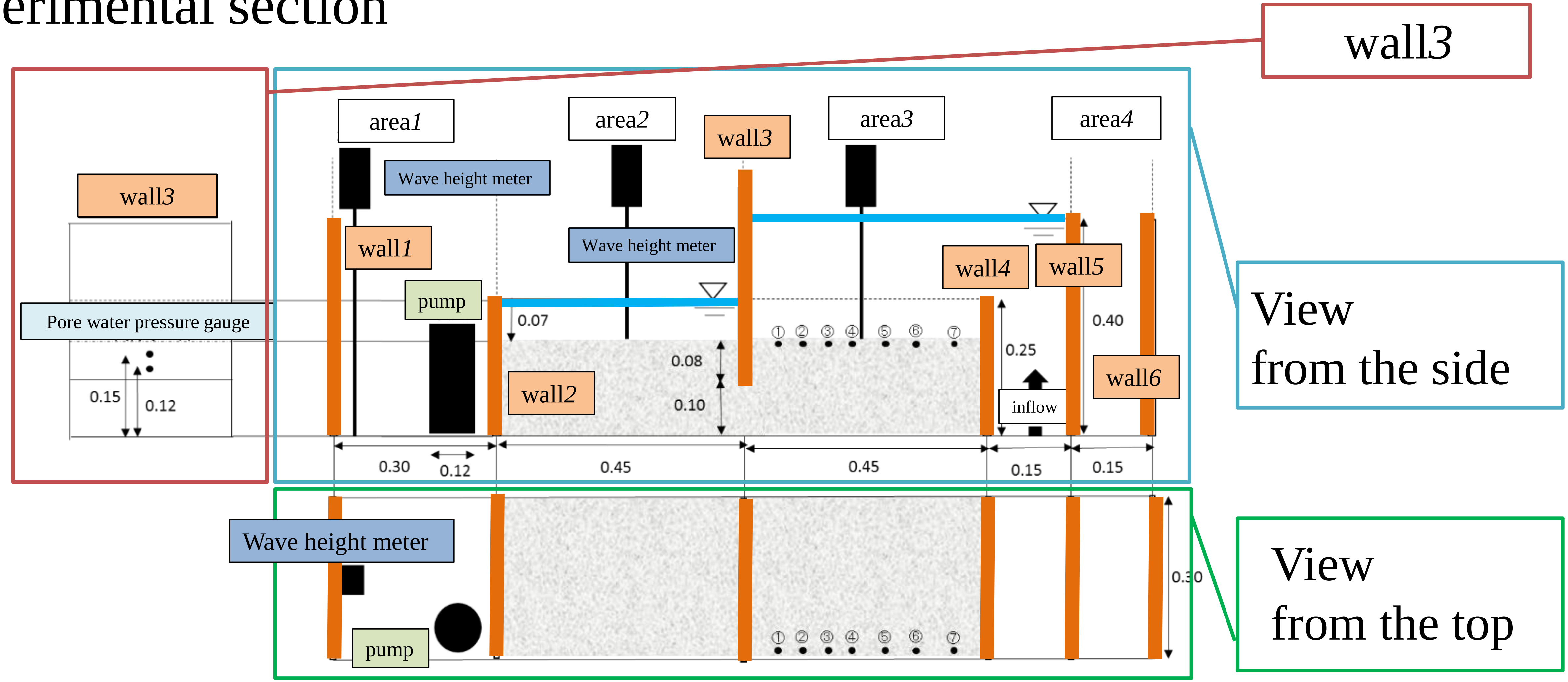
The seepage flow velocity of experiments and calculations were compared → The resistance coefficients of DF law was determined → The pore water pressure of experiments and calculations were compared

Result

The seepage flow velocity value and the pore water pressure value of the experiment were able to be reproduced roughly by adapting an expression of DF law to CADMAS

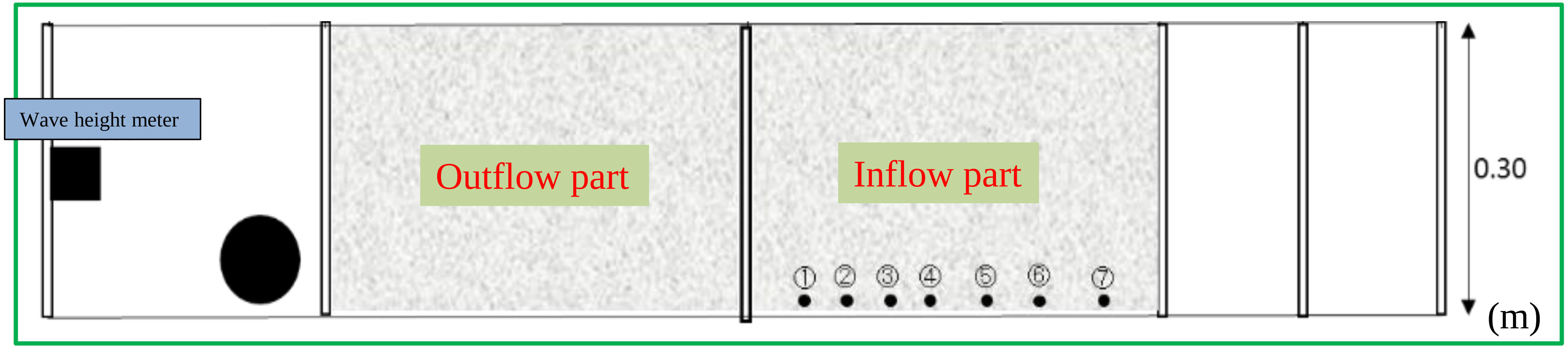
2.About the experiment

Experimental section



By installing the wall *5*, the water level difference was kept at *15* cm

Experimental measurement instrument

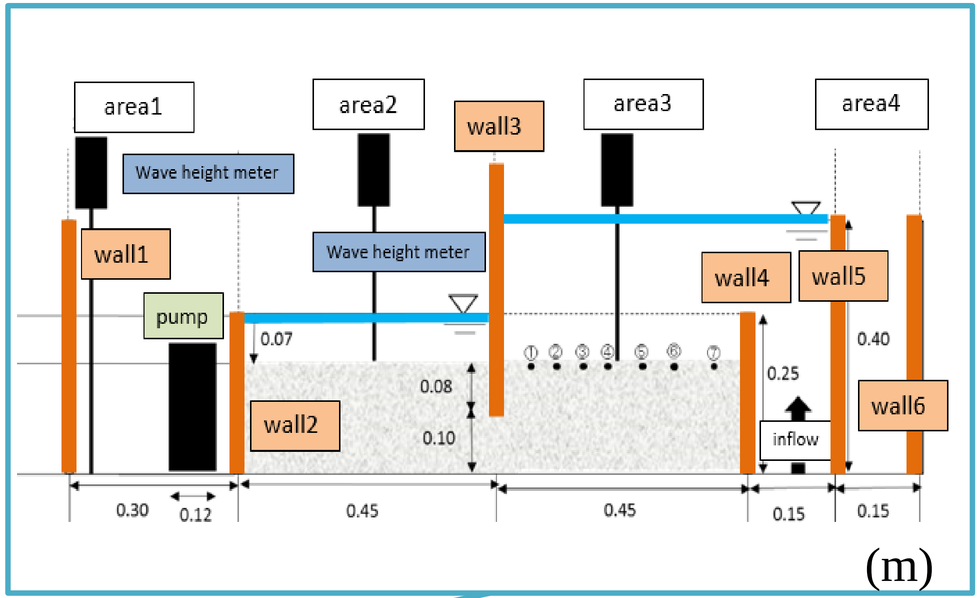


Outflow part

Inflow part

Two pore water pressures was installed on the inflow side and outflow side respectively. A total of four pore pressure gauges were installed.

Experimental video



Streamlines was visualized using dyes

The seepage flow velocity in the ground was obtained by image analysis.

3.About numerical calculation

About Dupuit-Forchheimer's law

Philip-Forchheimer (1901_hydraulik) 1852-1955

$$J = \left|\frac{\partial h}{\partial x}\right| = \alpha u_f + \beta {u_f}^2$$

The DF law is proportional to the first order of the flow velocity and the second order of the flow velocity.

This was applied to CADMAS

CADMAS equation

$$\lambda_v \frac{Du}{Dt} = -\frac{\gamma_v}{\rho} \nabla p + \gamma_v \nu_e \nabla^2 u - R_{x_i}$$

About resistance term

$$R_x = \alpha_1 u + \beta_1 u \sqrt{u_f^2 + v_f^2 + w_f^2}$$

Suzuki *et al.* (2003)

①The DF's law was adapted to CADMAS
② The flow velocity in the wave dissipating structure of the riprap was calculated
③The amount of scour was obtained

Kotoura *et al.* (2011)

①The DF's law was adapted to CADMAS
② The flow velocity in the wave dissipating structure of the riprap was calculated
③Resistance force was obtained

In past studies, there is no case that CADMAS examined a material with small particle sizes such as ground

About Dupuit-Forchheimer's law②

Dupuit-Forchheimer's law for CADMAS

$$R_x = \alpha_1 u + \beta_1 u \sqrt{u_f^2 + v_f^2 + w_f^2}$$

Several coefficients of α and β were studied in the past

①Ergun (1952_Fluid flow through packed colums)

$$\alpha = \frac{150\nu(1-\gamma_v)^2}{g{\gamma_v}^3{d_p}^2} \qquad \beta = \frac{1.75(1-\gamma_v)}{g{\gamma_v}^3 d_p}$$

②Kovacs (1981_Development in Water Science)

$$\alpha = \frac{144\nu(1-\gamma_v)^2}{g{\gamma_v}^3{d_p}^2} \qquad \beta = \frac{2.4(1-\gamma_v)}{g{\gamma_v}^3 d_p}$$

③Kadlec and Knight (1996_Development in Water Science)

$$\alpha = \frac{1}{k} = \frac{255\nu(1-\gamma_v)}{g{\gamma_v}^{3.7}{d_p}^2} \qquad \beta = \frac{2(1-\gamma_v)}{g{\gamma_v}^3 d_p}$$

④Sidiropoloulou (2007_Determination of Forchheimer equation coefficient a and b)

$$\alpha = 0.003333 D^{-1.500403} {\gamma_v}^{-0.060350}$$

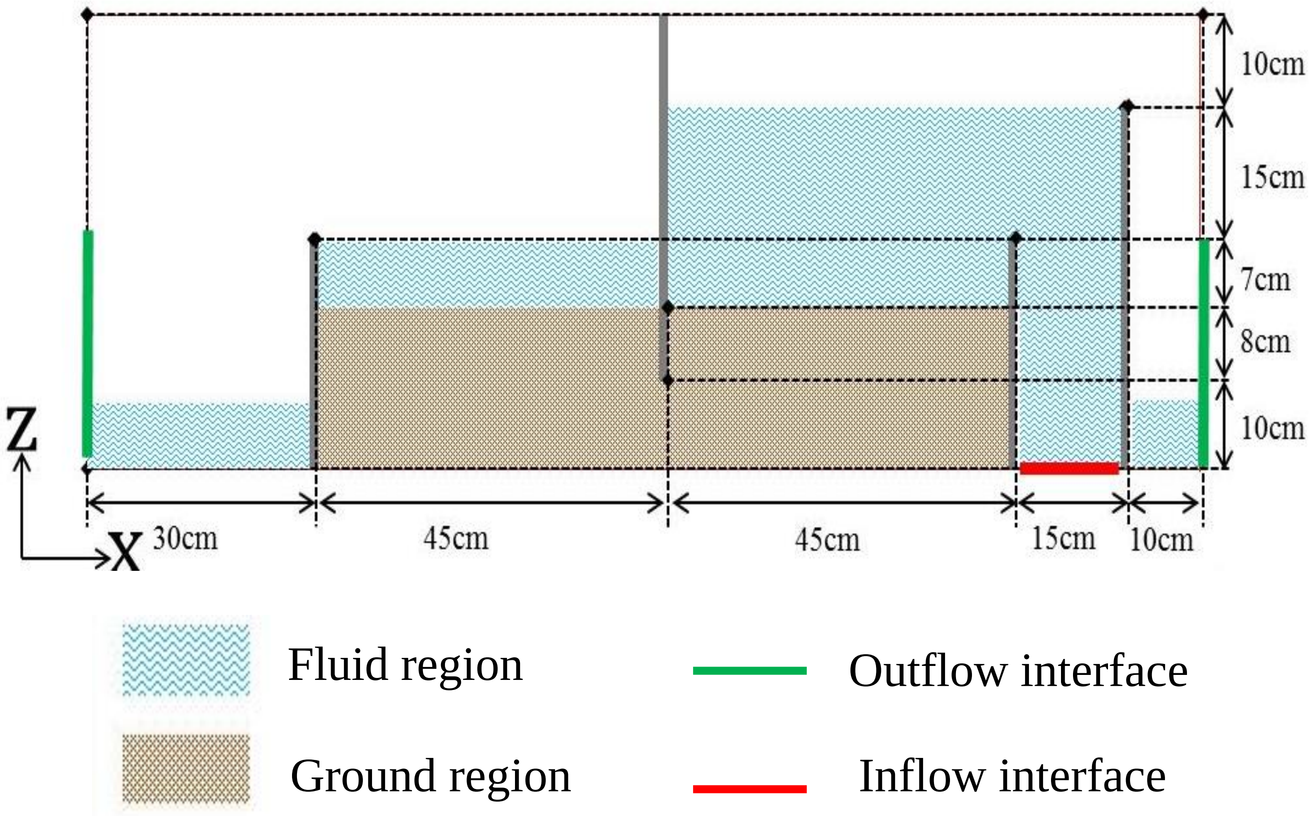
$$\beta = 0.194325 D^{-1.265175} {\gamma_v}^{-1.141417}$$

*Refer to Review on non-darcy flow in highly permeable porous media Yosioka et.al(2014)

⇨ some patterns were adapted to cadmas and examined this time.

Calculation condition

Calculation section



Input condition

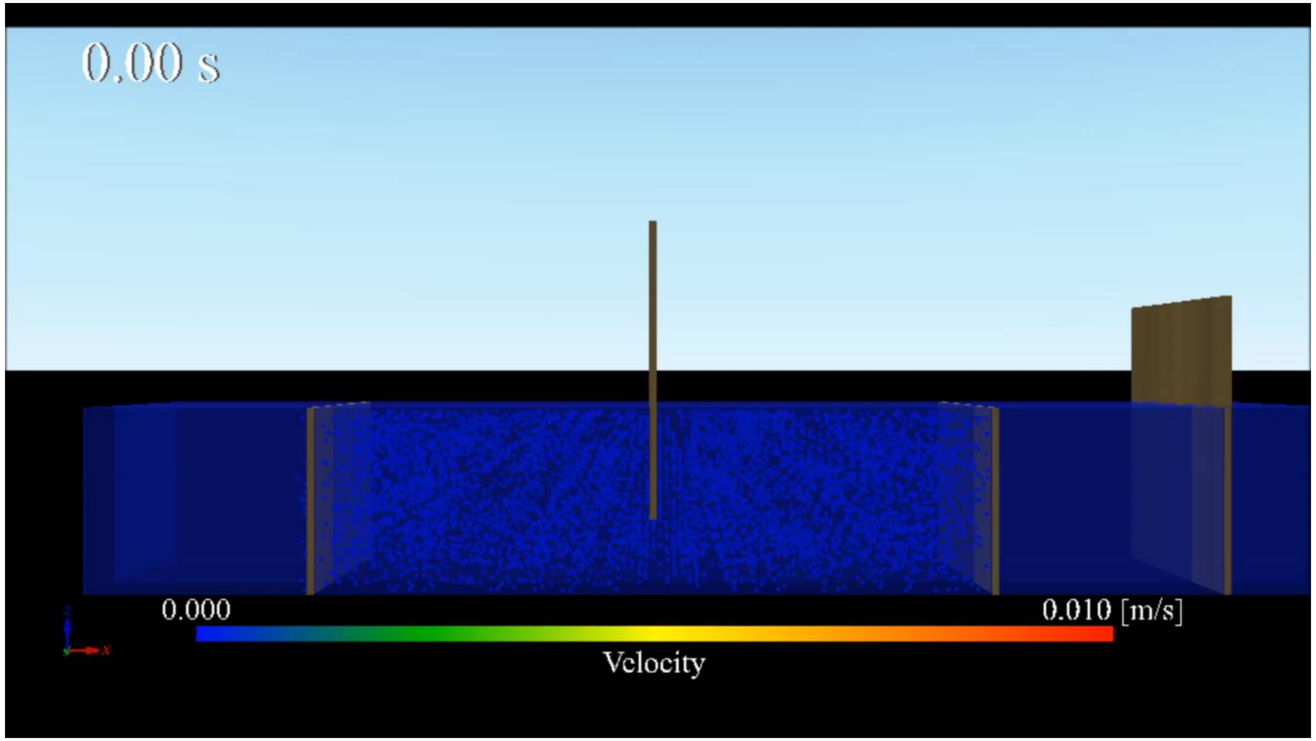
region	
x direction	0～135cm
y direction	0～1cm
z direction	0～50cm

grid size	
x direction	1cm
y direction	1cm
z direction	1cm

ground region(CADMAS)	
porosity	0.35
Kinematic viscosity coefficient	$1.0\times10^{-6}m^2/s$
Particle size	0.33mm

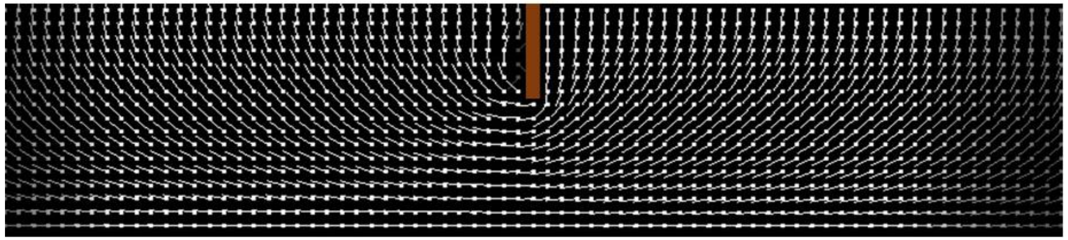
ground region(STR)	
porosity	0.35
coefficient of permeability	$7.14\times10^{-2}cm/s$
Particle size	0.33mm

The simulation video of the calculation

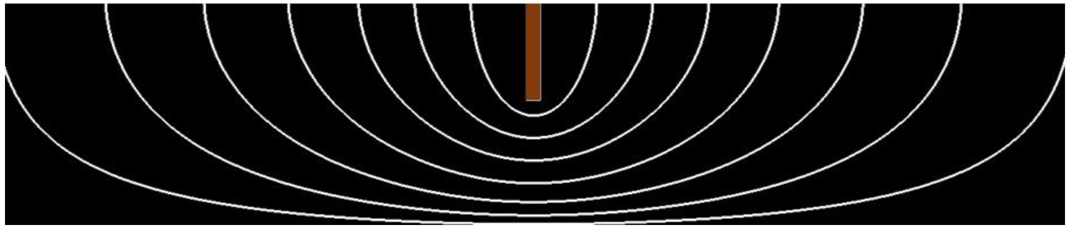


About streamlines

CADMAS-side



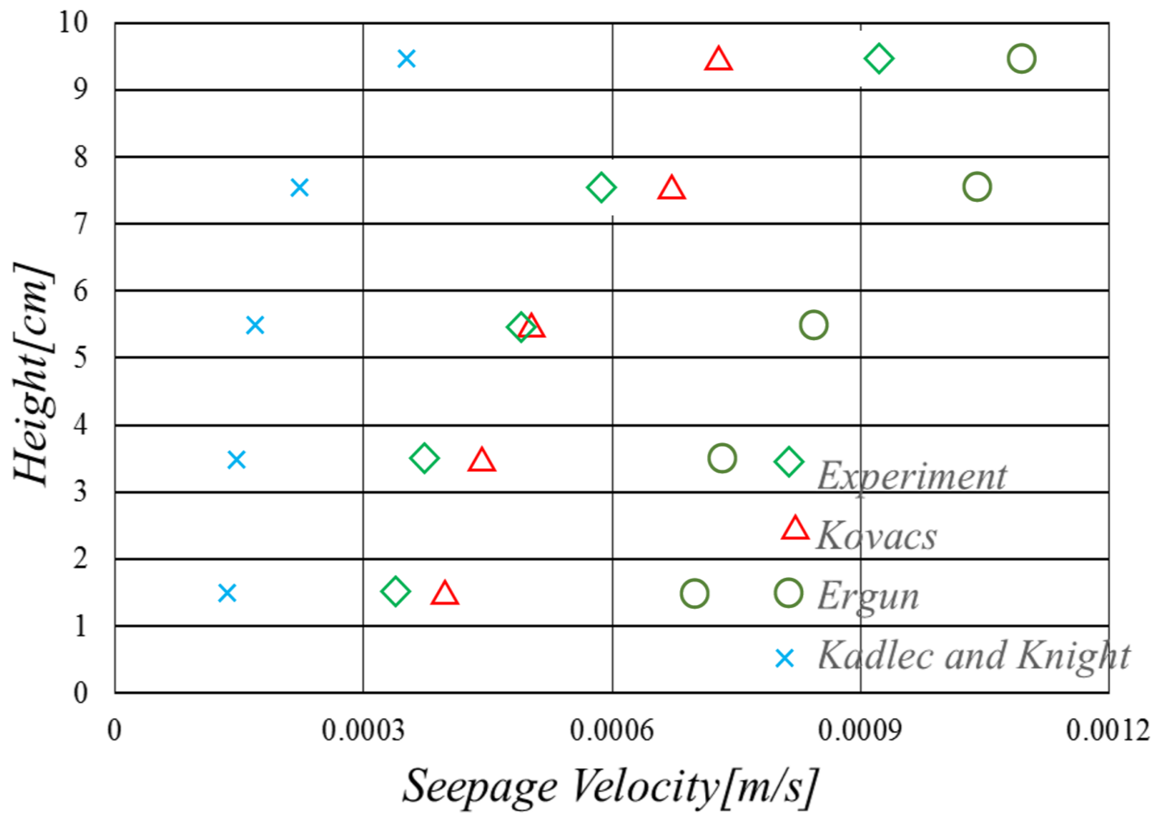
STR-side

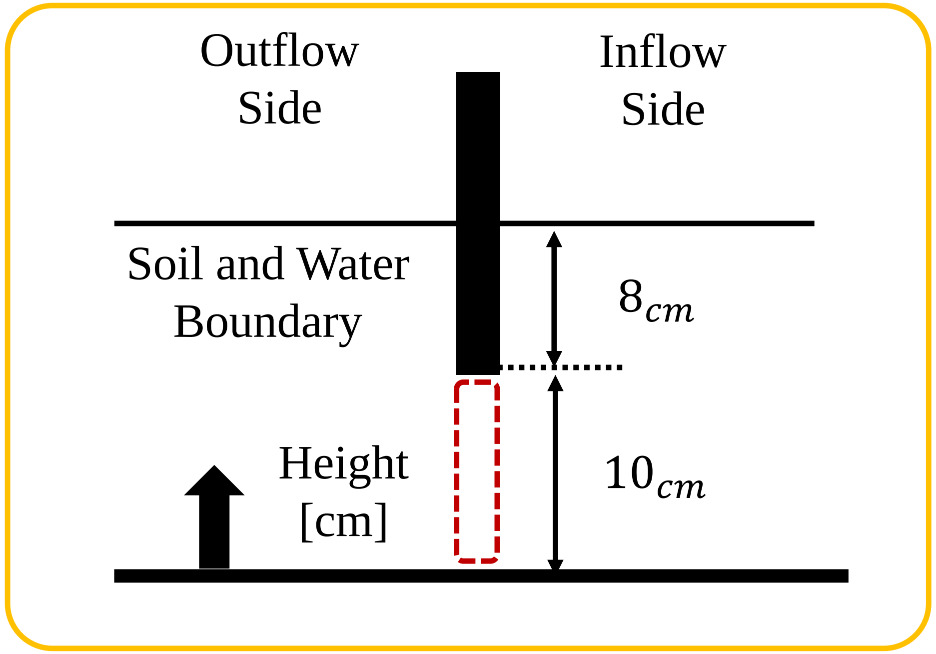


This animation was created to confirm the seepage flow velocity was occurred.

4.About the result

Comparison of coefficients of DF law



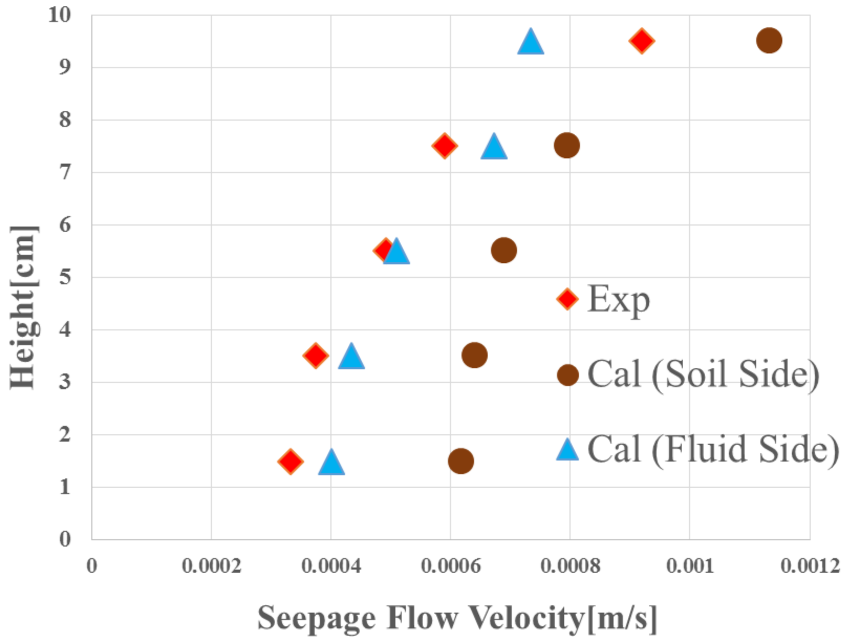


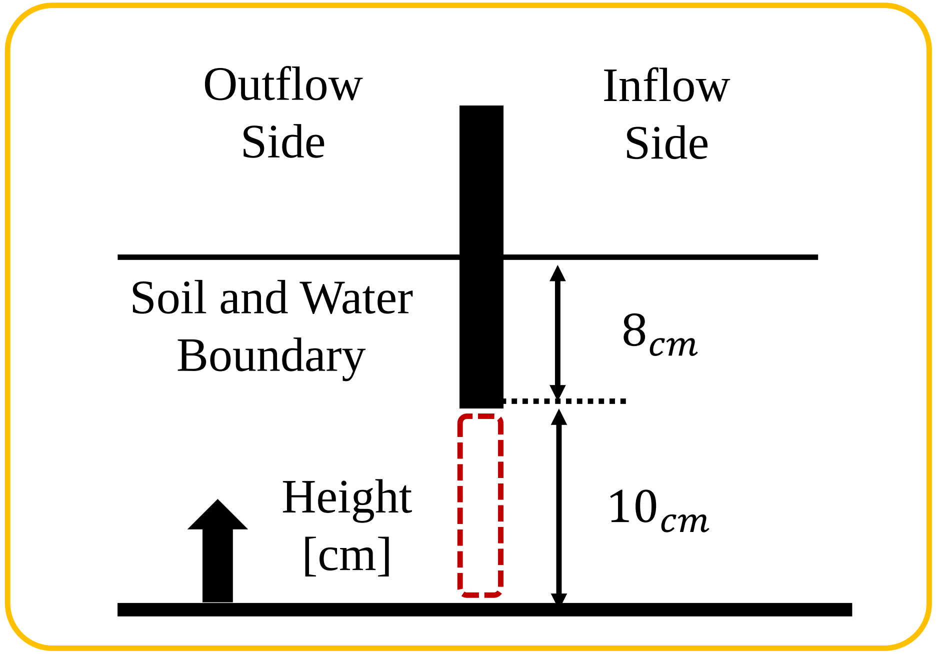
The expression of kovacs reproduced the experiment value most well.

Pore water pressures were compared this time using a model in which the expression of kovacs was adapted to CADMAS.

Investigation of seepage flow velocity

KOVACS expression was adapted to CADMAS





DF law(CADMAS side)

$$\frac{\partial h}{\partial x} = \alpha u + \beta u^2$$

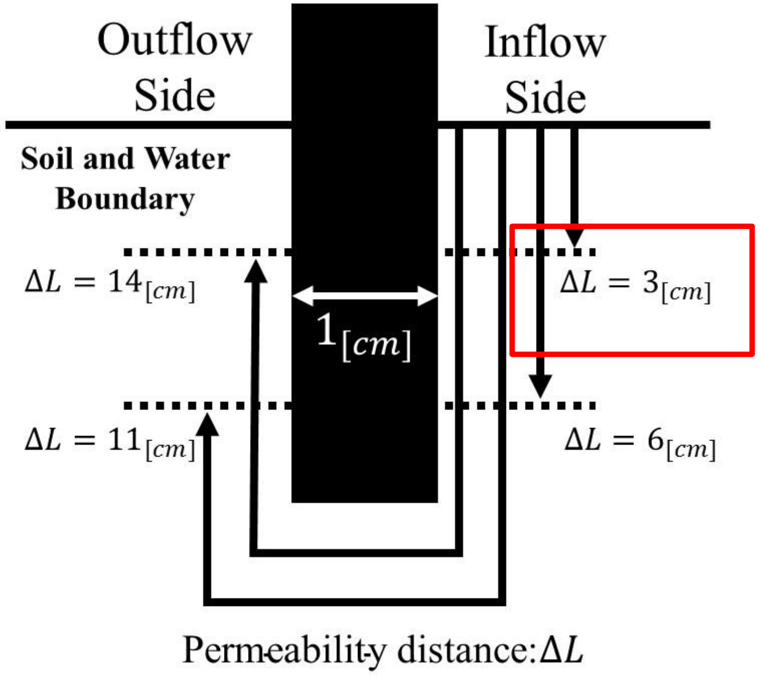
Darcy law(STR side)

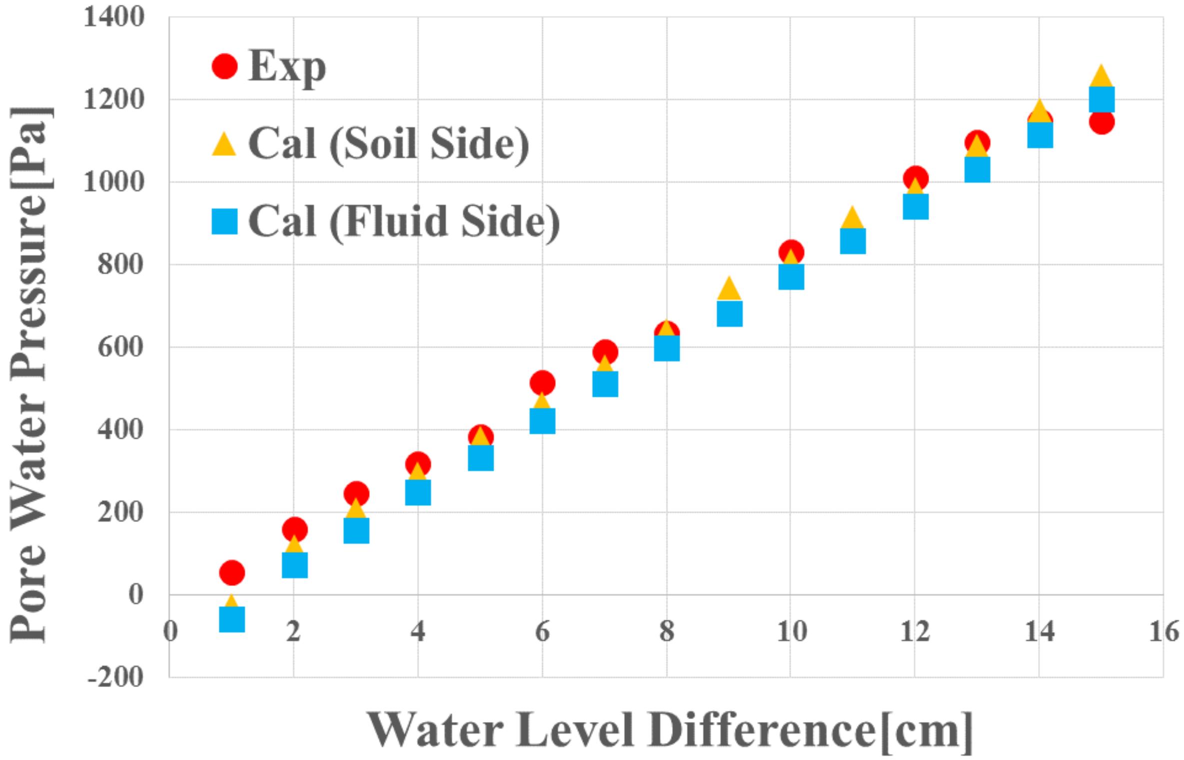
$$\frac{\partial h}{\partial x} = \frac{1}{k} u$$

- Three of the seepage flow velocity values were generally consistent
- Experimental values were reproduced well by CADMAS side

⇨ Experimental values were better reproduced by considering nonlinear terms.

Pore water pressure①

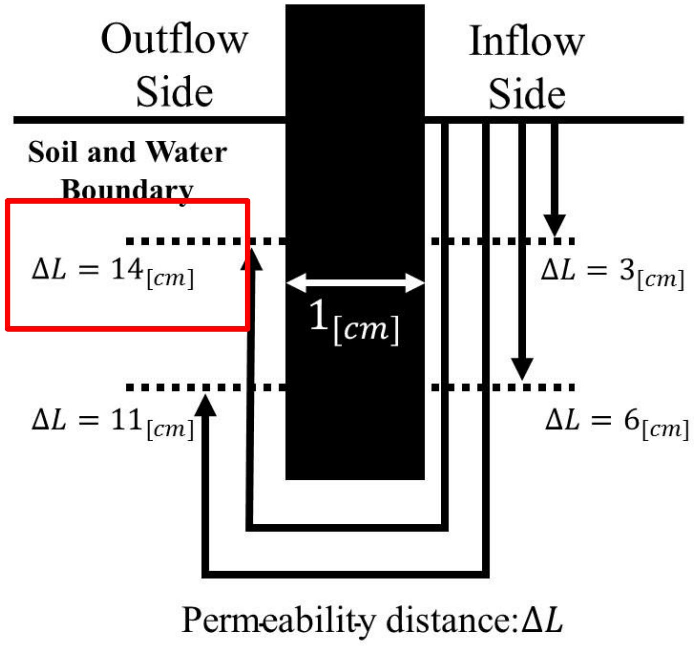


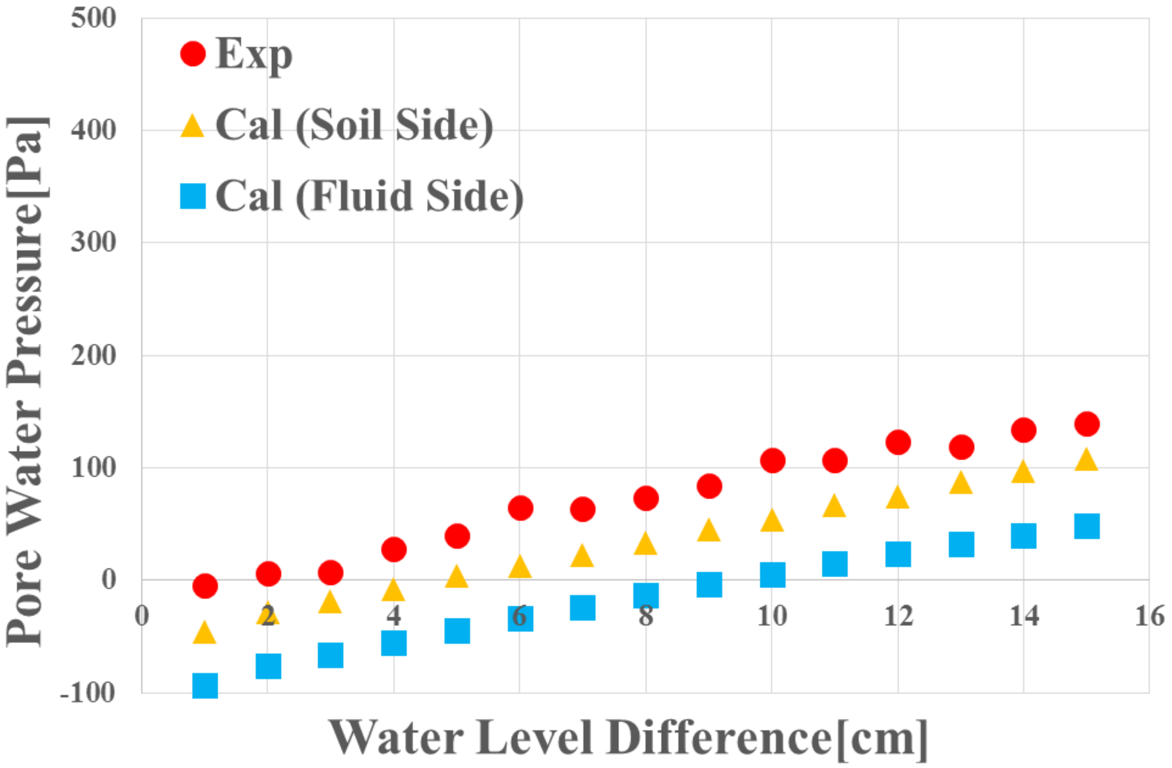


The consistent data was obtained between the experimental value and the calculated value.

⇔ Good results were obtained because the initial condition on the inflow side was able to be an appropriate value .

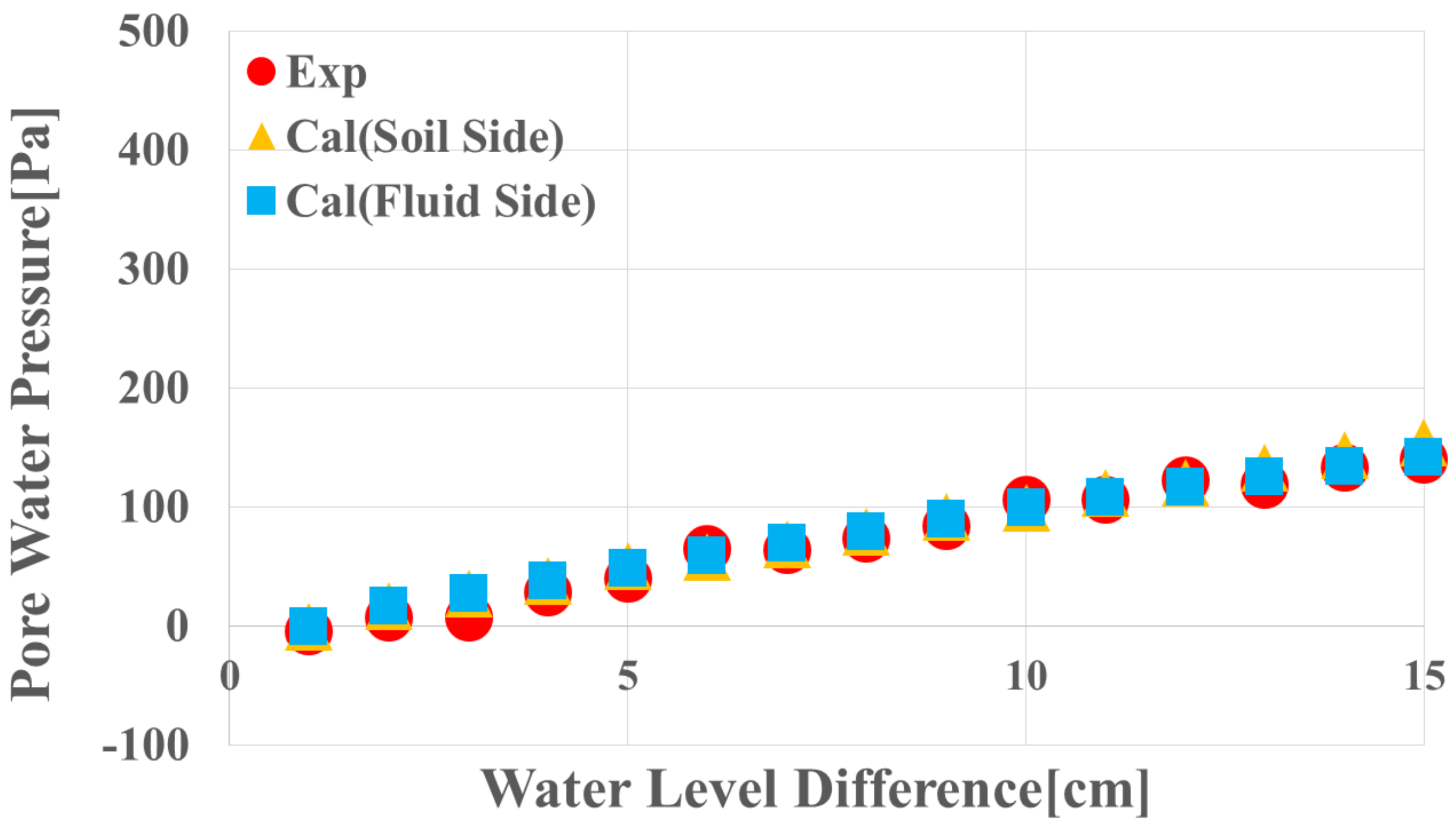
Pore water pressure②

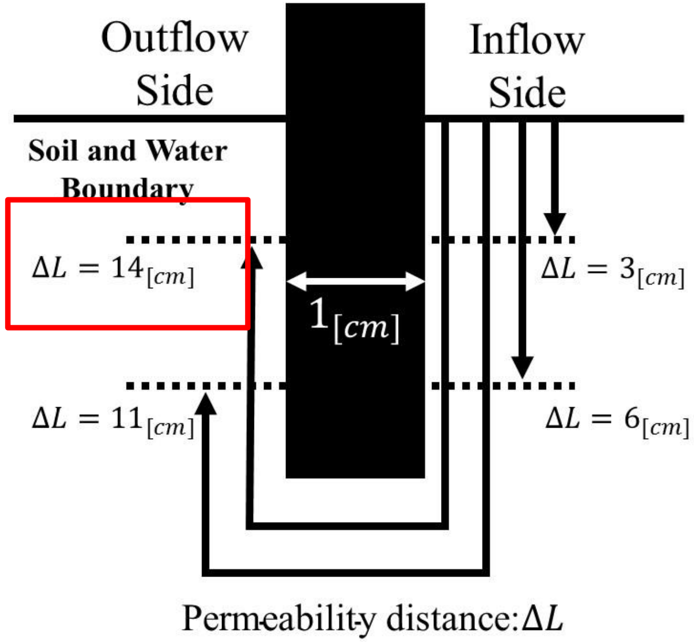




Almost the same result was obtained as the rising trend of the water level .
However the pore water pressure value takes a negative values at the initial stage.
⇔ This is because the water level was lower than the initial water level in the early stage of the analysis. We think that the ground subsides due to water pressure or that there is some cause, but this is a future task.

Pore water pressure②-1





- The data at *14*cm is organized based on a value of water level difference *1* cm.
- Data amount of change of the water level is generally match is obtained.

5.The Conclusion

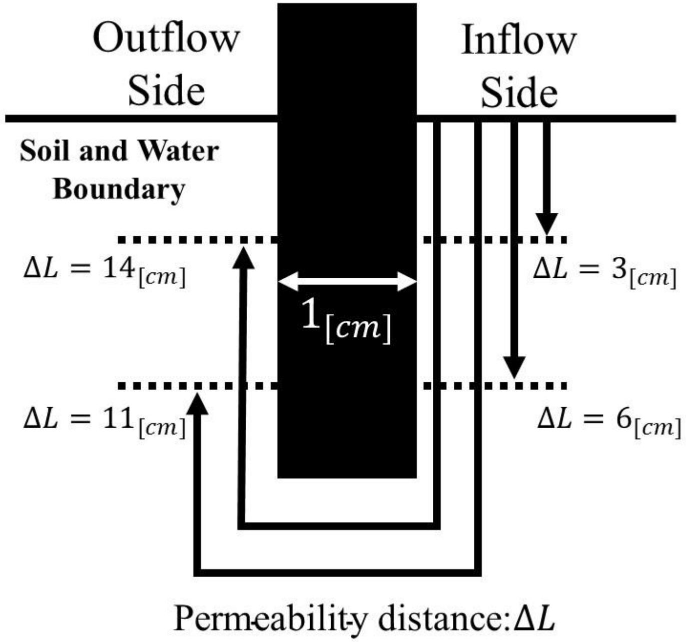
The Conclusion

(1)By applying the Dupuit-Forchheimer's law, reproducibility was confirmed for the seepage flow velocity at the steady water level. However, it is a future task that the seepage flow velocity on the STR side shows a larger value than the experimental value.

(2) We have confirmed that by applying the Dupuit-Forchheimer's law, we can evaluate the pore water pressure that changes with time on the STR results. In addition, we showed experimental results and good accuracy with regard to the pore water pressure on the CADMAS side.

(3)It was confirmed that the fluctuation amount of pore water pressure generally fit at *14* cm. However, investigating the cause of negative pressure at the initial stage is a future task

(4) The expression of KOVACS reproduced the experimental seepage flow velocity most.



Thank you for your attention.