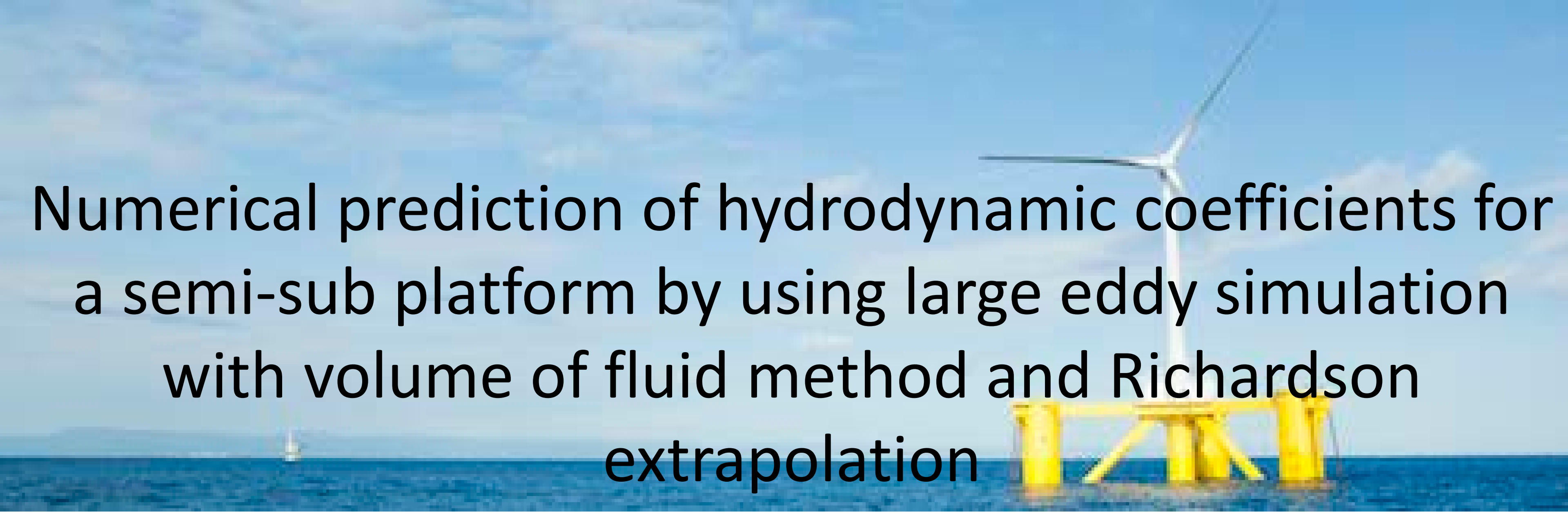

Numerical prediction of hydrodynamic coefficients for a semi-sub platform by using large eddy simulation with volume of fluid method and Richardson extrapolation

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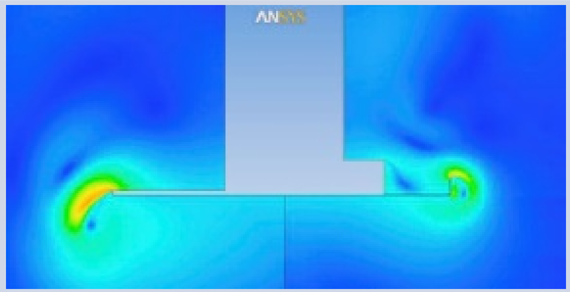
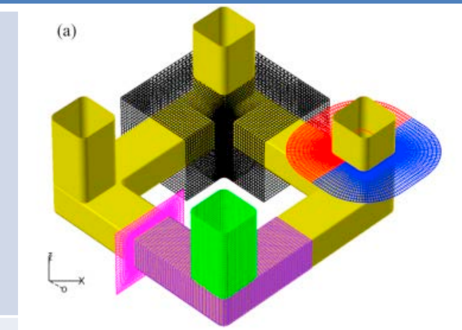
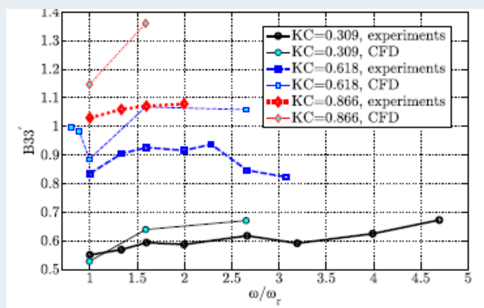
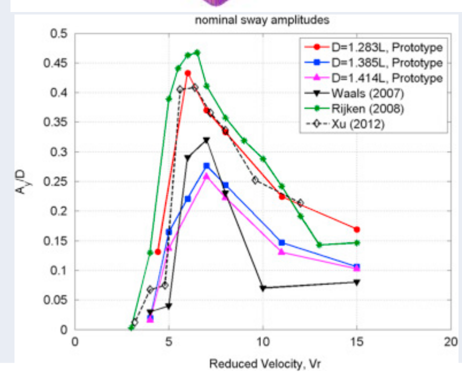
2019/01/17

Hydrodynamic coefficients (Ca & Cd)

Target structures 1. Heave Plate 2. Floater	L.Tao,2004; Lpoez-Pavon, 2015 (CFD) (Shear Stress Transport (SST) model)	Chia-Rong Chen, 2016(CFD) (No free water surface)
		
Accuracy		

C_a: Added mass coefficient; C_d: Viscous drag coefficient

Keulegan-Carpenter (KC) number: $KC = \frac{2\pi A}{D}$ (A: amplitude of motion; D: diameter of typical component)

- The effects of free water surface and of KC number on hydrodynamic coefficients of a semi-sub model predicted should be systematically investigated by LES with VOF .
- Accuracy of predicted hydrodynamic coefficients by CFD should be improved.

Objectives

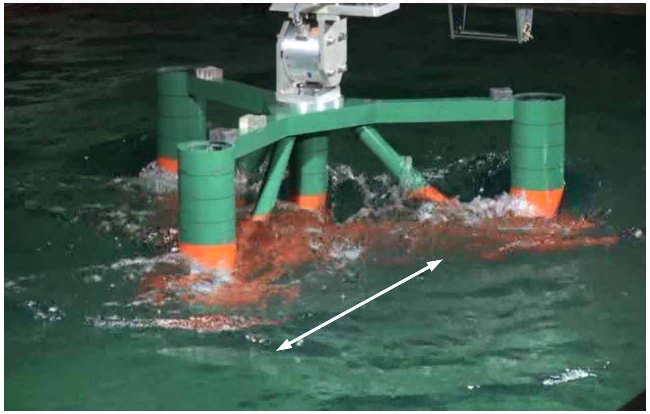
1. To improve accuracy of the predicted hydrodynamic coefficients by Richardson extrapolation method.

2. To study the effect of KC number and frequency on the hydrodynamic coefficients.

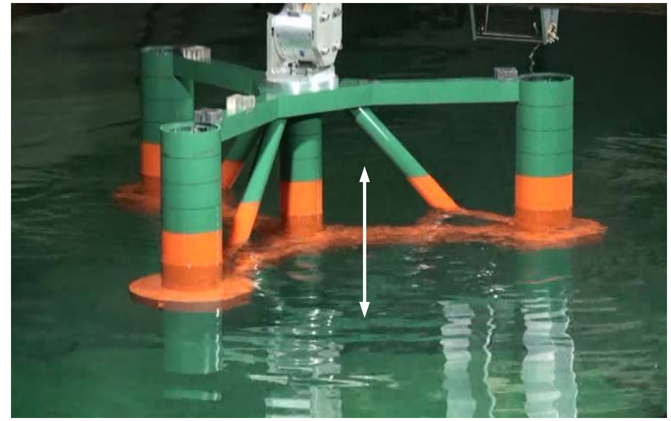
3. To investigate the importance of the free water surface on evaluation of hydrodynamic coefficients by LES with VOF.

Water tank tests

- Forced vibration tests in the horizontal and vertical directions



Horizontally forced oscillation



Vertically forced oscillation

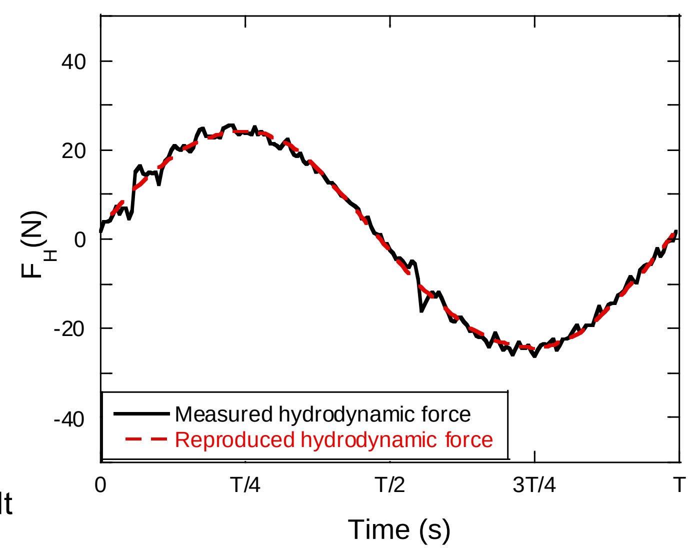
- KC number $KC = \frac{V_{max}}{D_i f} = \frac{\omega a}{D_i f} = \frac{2\pi a}{D_i}$

- Definition of hydrodynamic coefficients Ca and Cd

$$F_H(t) = F(t) - F_b - F_I(t) - F_K(t) \qquad F_H(t) = -C_a M\ddot{x}(t) - 0.5\, C_d\, \rho_w\, A\, |\dot{x}(t)|\, \dot{x}(t)$$

$$C_a = \frac{\int_0^T F_H(t)\sin(\omega t)dt}{\rho_w \nabla\, a\, \omega^2 \int_0^T \sin^2(\omega t)dt} = \frac{1}{\pi\omega a \rho_w \nabla}\int_0^T F_H(t)\sin(\omega t)dt$$

$$C_d = -\frac{\int_0^T F_H(t)\cos(\omega t)dt}{\frac{1}{2}\rho_w A(\omega a)^2 \int_0^T |\cos(\omega t)|(\cos(\omega t))\cos^2(\omega t)dt} = -\frac{3}{4\rho_w A\omega a^2}\int_0^T F_H(t)\cos(\omega t)dt$$



Large eddy simulation (LES) with volume of fluid (VOF))

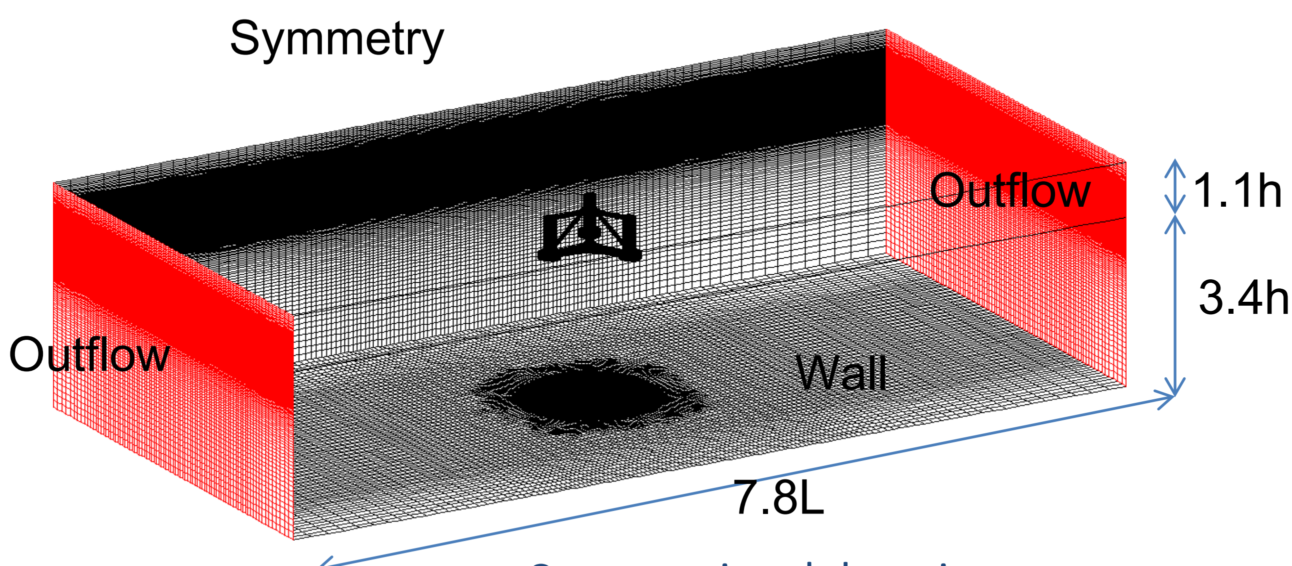
- Governing equation

$$\frac{\partial \tilde{u}_i}{\partial x_i} = 0$$

$$\rho\frac{\partial \tilde{u}_i}{\partial t} + \rho\frac{\partial \tilde{u}_i \tilde{u}_j}{\partial x_j} = -\frac{\partial \tilde{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i}\right)\right] - \frac{\partial \tau_{ij}}{\partial x_j}$$

- Continuity equation for the volume fraction of water

$$\frac{1}{\rho_w}\left[\frac{\partial}{\partial t}(\alpha_w \rho_w) + \nabla(\alpha_w \rho_w \vec{v}_w)\right] = 0$$



Computational domain

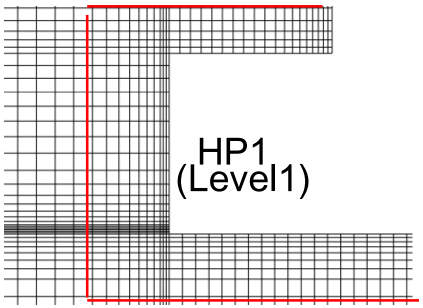
S.N.Zhang, T.Ishihara : Numerical study of hydrodynamic coefficients of multiple heave plates by large eddy simulations with volume of fluid method, Ocean Engineering, Vol.163, pp.583-598, 2018.

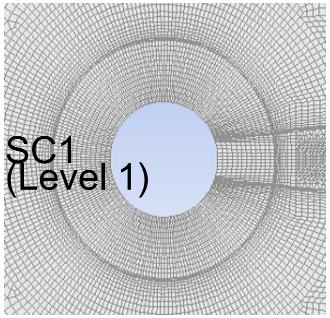
Numerical simulation by grid refinement

☐ Grid refinement

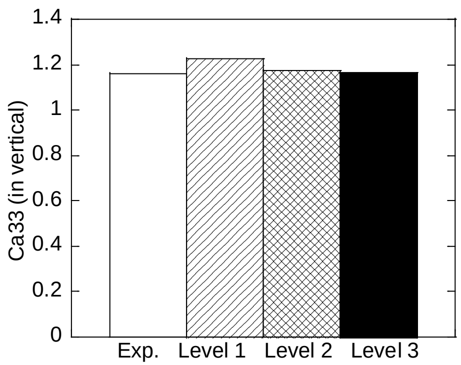
In the vertical : Refined area in a region of 5cm near Hp, Hp-C, Pntn
In the horizontal : Refined area in a region of 5cm near SC, CC

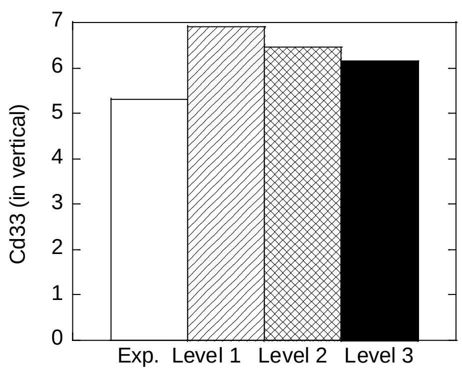
Grid level	1	2	3
Grid size	$h_1 = 8mm$	$h_2 = 4mm$	$h_3 = 2mm$
Grid number	13.7 million	18.8 million	63.8 million

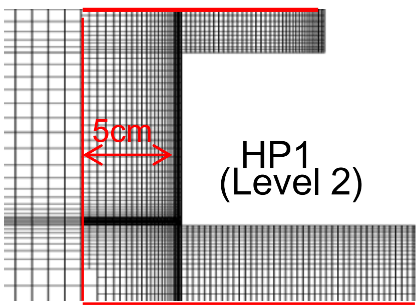


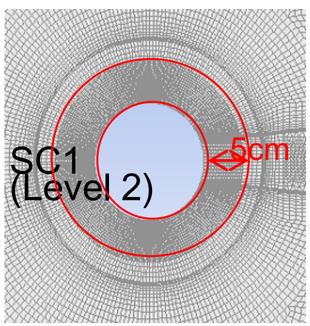


☐ Predicted Ca & Cd by refined grids









- The accuracy of predicted Cd by using grid refinement is not enough.

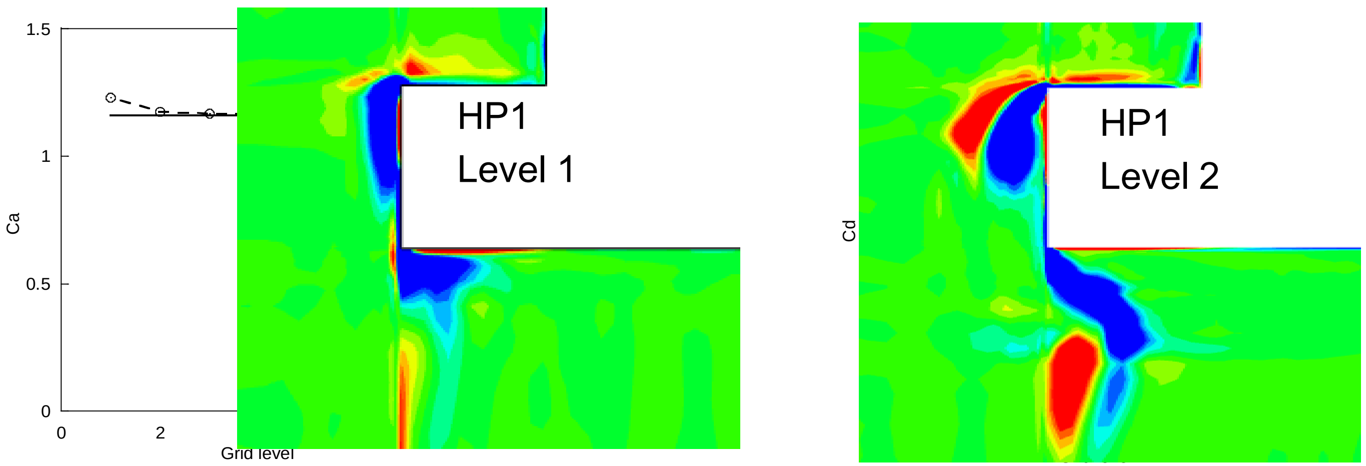
Richardson Extrapolation Method

Richardson Extrapolation Method

The exact solution $$\Phi = \phi_h + \varepsilon_h = \phi_{h_i} + \alpha h_i^{\,p} + H$$

where $$p = \frac{\log((\phi_{h_2} - \phi_{h_1})/(\phi_{h_3} - \phi_{h_2}))}{\log \lambda}, \quad \alpha = \frac{\phi_{h_3} - \phi_{h_2}}{h_3^{\,p}\left(\lambda^p - 1\right)} = \frac{\phi_{h_2} - \phi_{h_1}}{h_2^{\,p}\left(\lambda^p - 1\right)}, \quad \lambda = h_1 / h_2 = h_2 / h_3$$

$$p = 0.47 \quad \Rightarrow \quad \Phi = \phi_h + \varepsilon_h = \phi_{h_2} + \frac{\phi_{h_2} - \phi_{h_1}}{\left(\lambda^p - 1\right)}$$

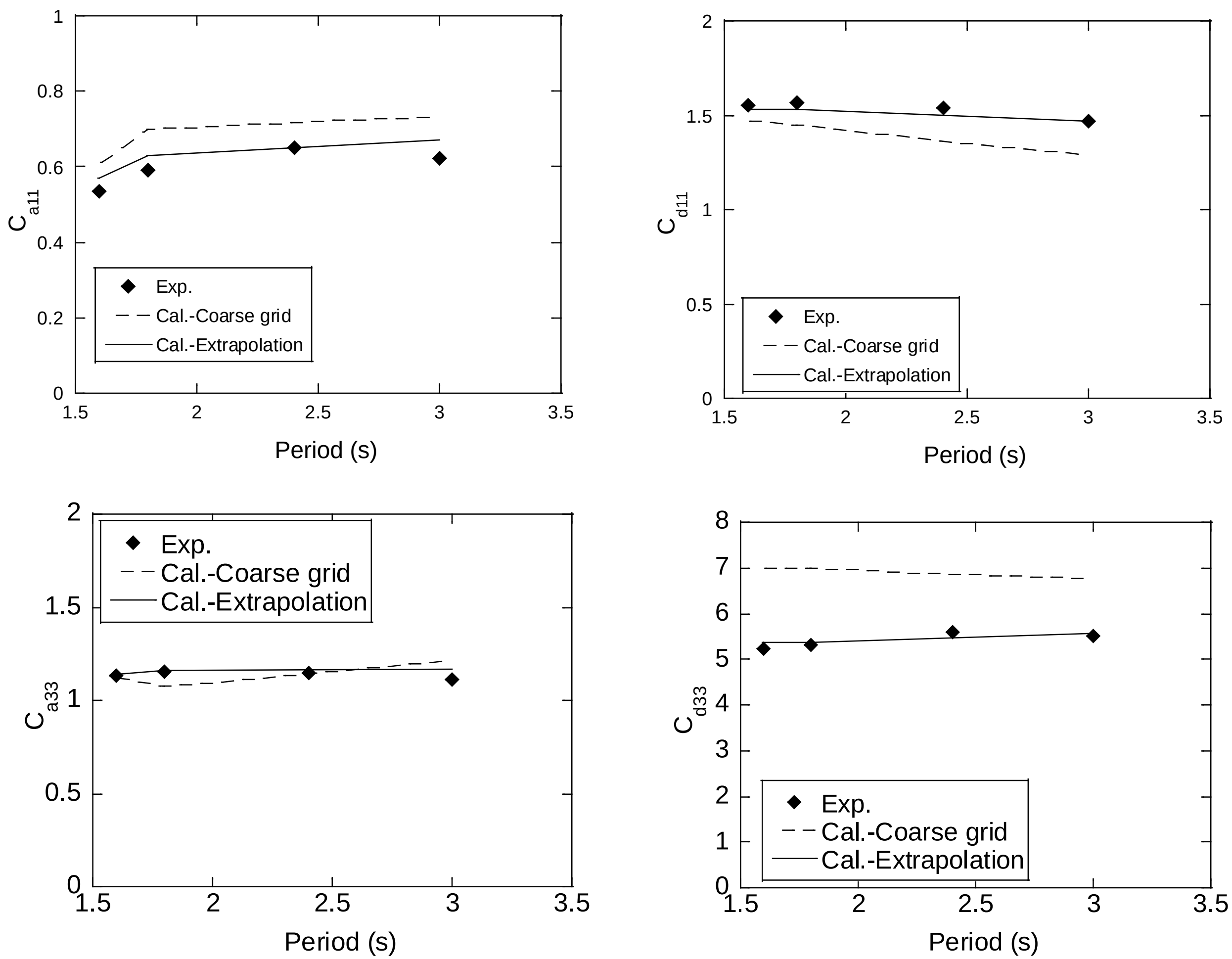


Fine grid is required to accurately simulate the vortex shedding.

Error:
29.9%
0.9%

- Richardson Extrapolation Method on the finest grid is applied and validated.

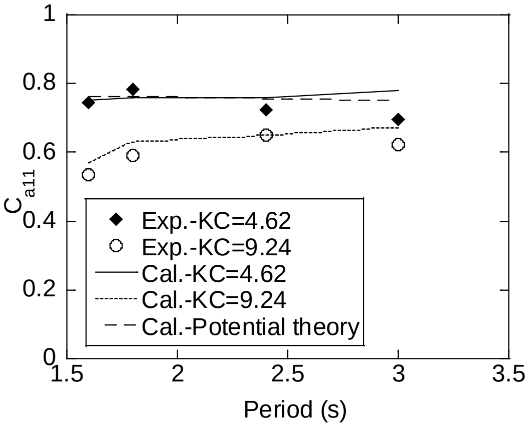
Effect of grid refinement

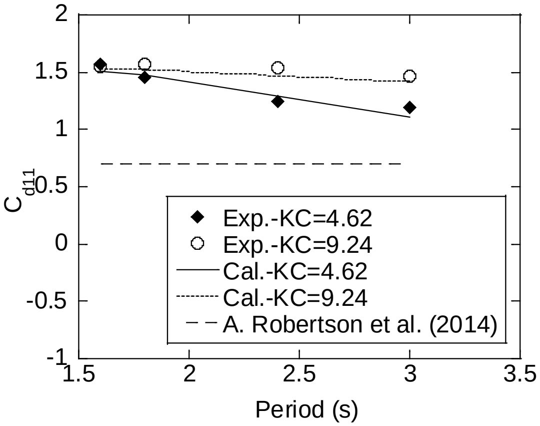


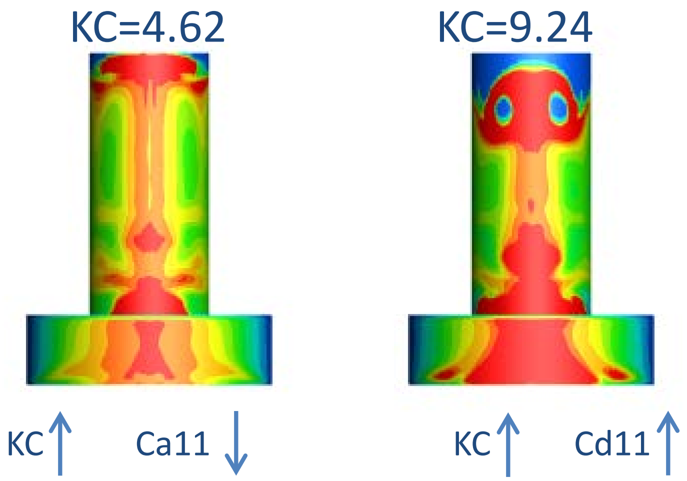
- The predicted hydrodynamic coefficients by using LES with VOF method agree well with the experimental data when Richardson extrapolation is performed.

Effect of KC number and wave frequency

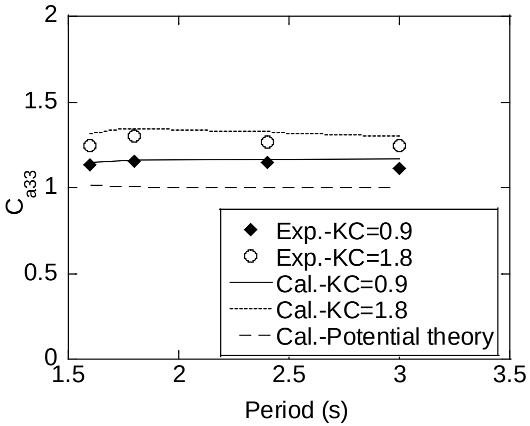
☐ In the horizontal direction

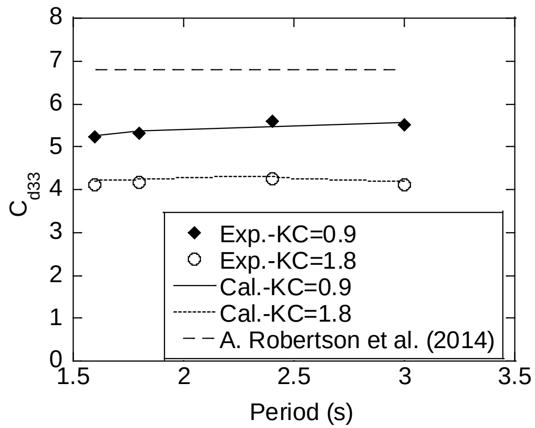


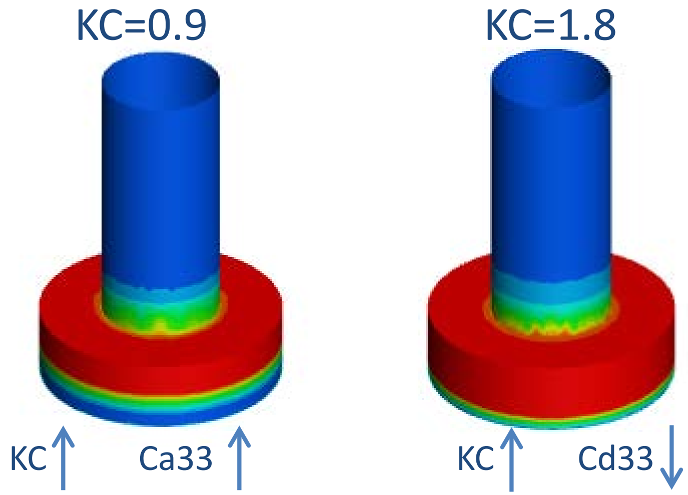




☐ In the vertical direction



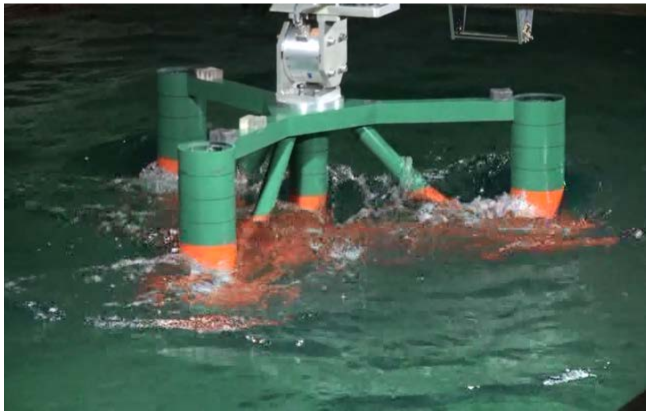




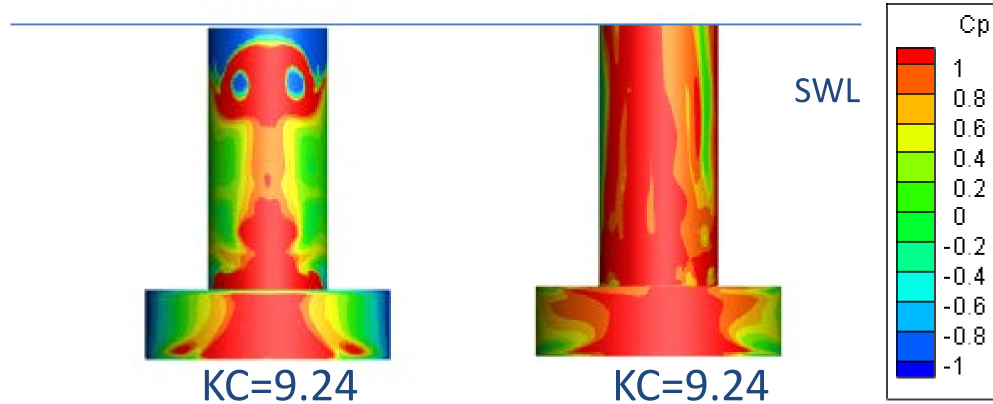
- Potential theory and database have limited accuracy for Ca and Cd, while LES model with VOF can accurately predict the Ca and Cd for different KC numbers and wave frequencies.

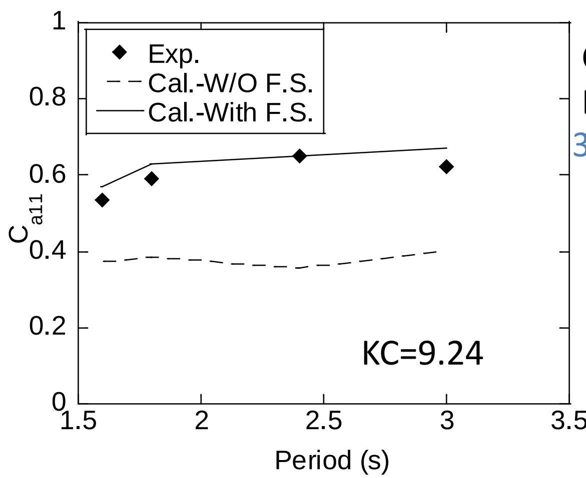
Effect of free water surface

☐ In the horizontal direction

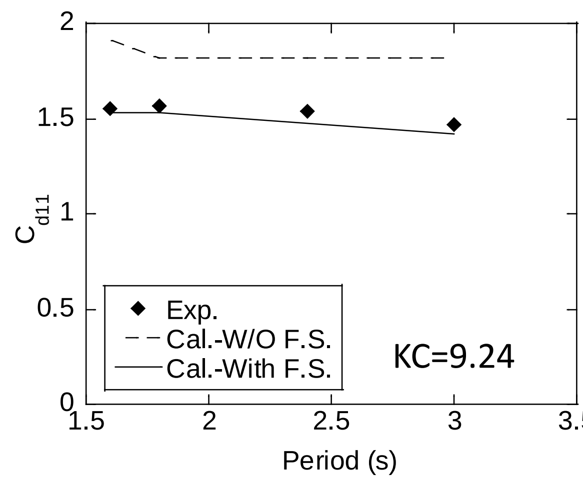


With free water surface W/O free water surface





Ca11
Error:
35.8%
8.0%

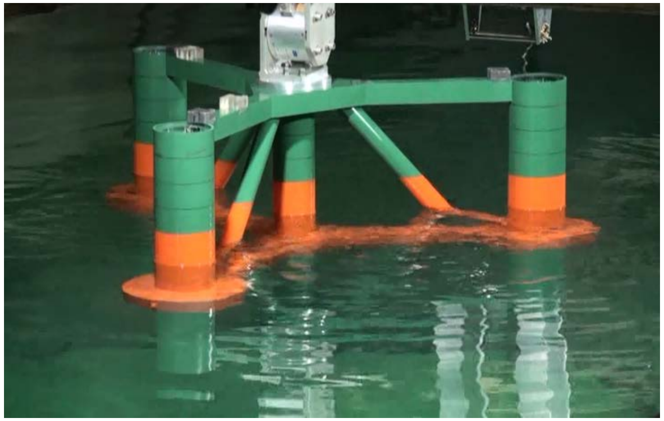


Cd11
Error:
25.2%
3.4%

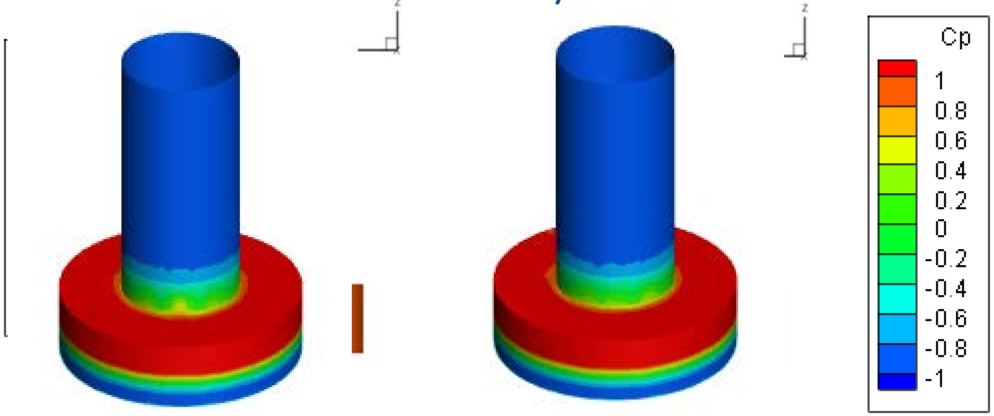
- The free water surface should be included to accurately predict hydrodynamic coefficients in the horizontal direction and can be captured by using LES with VOF.

Effect of free water surface

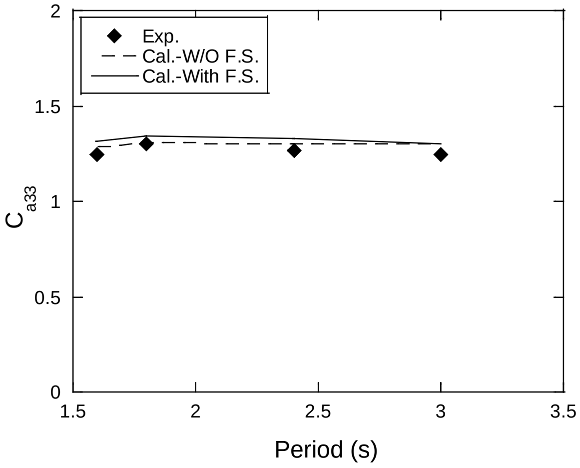
☐ In the vertical direction

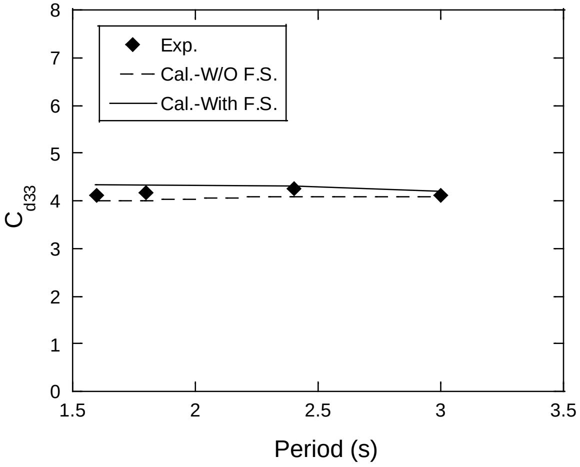


With free water surface / W/O free water surface



KC=1.8 / KC=1.8



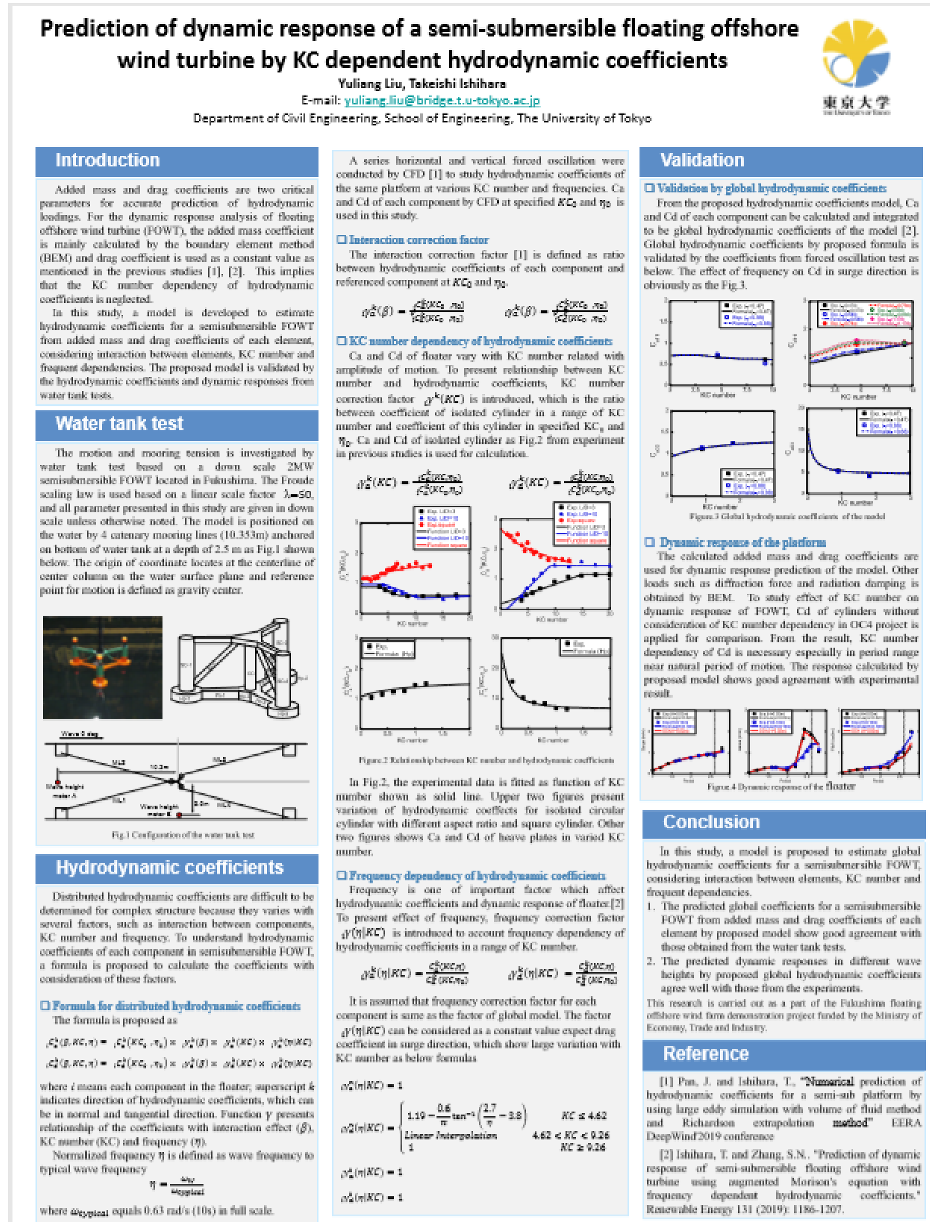


- The predicted Ca and Cd with and without free surface in the vertical direction coincide well with those from the water tank test, because the free surface has a limited effect on Ca and Cd in the vertical direction for the deep draft model.

Prediction of dynamic response

See the poster No.37

The predicted dynamic responses in different wave heights by proposed model show good agreement with those from the water tank tests.



Conclusions

1. The grid refinement can improve accuracy by capturing the vortex shedding near the model and the predicted drag coefficients by Richardson extrapolation method show good agreement with those from the water tank test.

2. LES model with VOF can accurately predict the KC number effect on the hydrodynamic coefficients in the horizontal and vertical directions, while potential theory and database have limited accuracy.

3. The hydrodynamic coefficients in the horizontal direction by LES with VOF show good agreement with the experimental data, while those predicted by LES without the free surface show significant differences.

Thank you for your attention!

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