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Comparison of applicability in dynamic response prediction by using engineering model and numerical water tank for barge platform

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Prediction of floater response for barge type floater

- The barge type floater has been installed expecting cost reduction.
- The accuracy of floater response prediction has been widely investigated for semi-submersible floater (Robertson et al. 2020, Ishihara and Zhang 2019)

Semi-submersible type

- Stable floater motion

Barge type

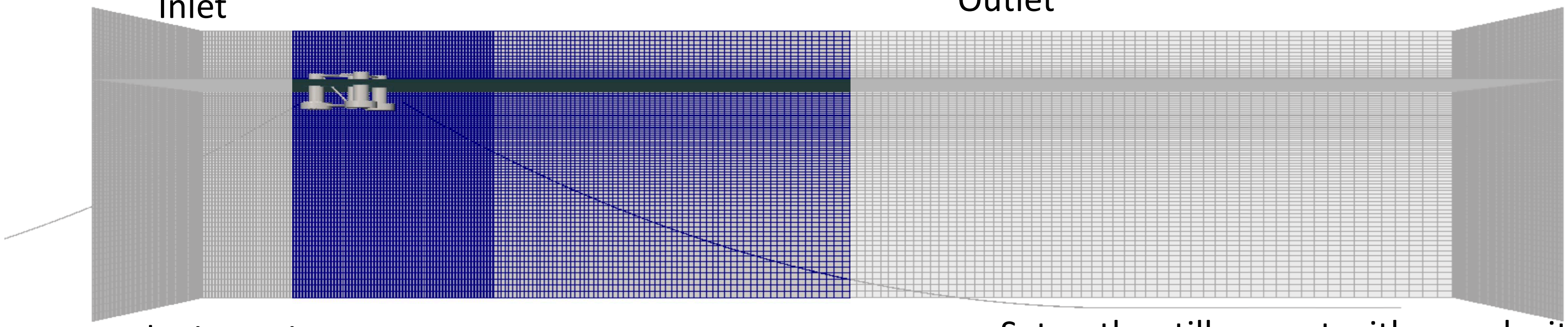
- Large water plane area
- Square panels, thin skirt → Strong non-linearlity

The prediction accuracy of floater motion for barge type floater is required

Layout of numerical water tank

- Floater motion prediction by using numerical water tank with Waves2Foam (Rivera-Arreba et al., 2019)
- Predicted floater motion in heave and pitch showed a good agreement with measurement.
- The optimum numerical layout setting was investigated for each case. It was suggested that the outlet zone length should be at least more than one wave length to avoid reflections from boundaries especially in heave resonance region.

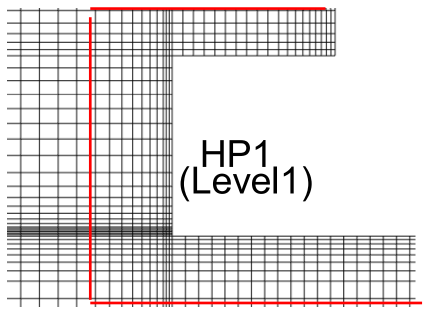
Layout for heave resonance case



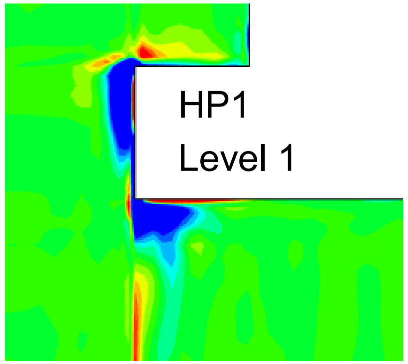
The sensitivity on numerical water tank layout on the floater motion needs to be investigated especially in surge direction

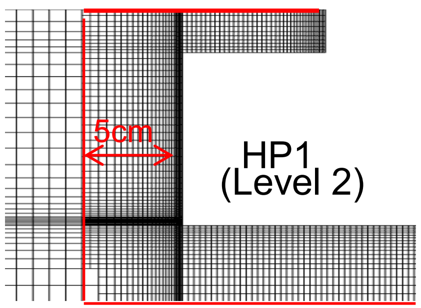
Prediction accuracy of drag force on heave plate

Drag force on heave plate for semi-submersible floater was predicted by using large eddy simulation (Pan and Ishihara, 2019)

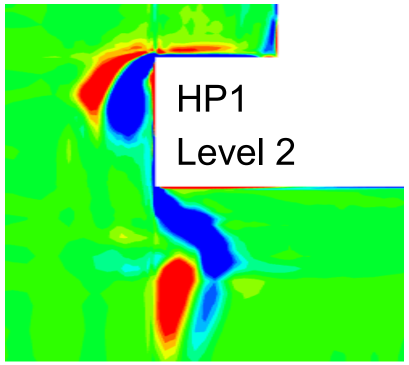


$h = 8mm$



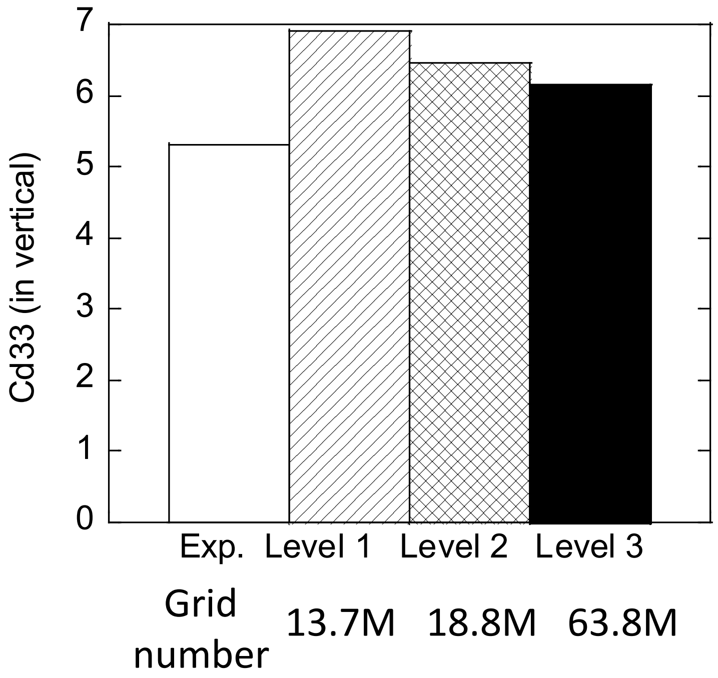


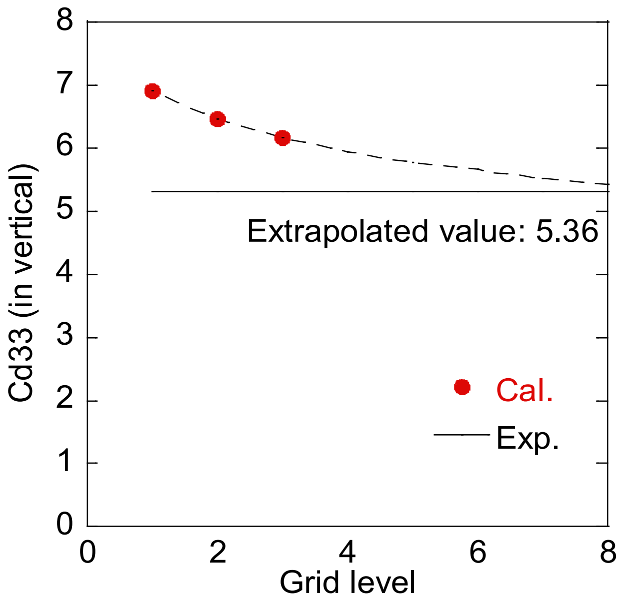
$h = 4mm$



Richardson Extrapolation method

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



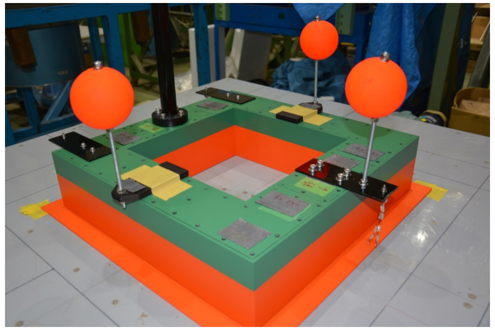


The extraordinary high calculation cost is required to get the accurate Cd

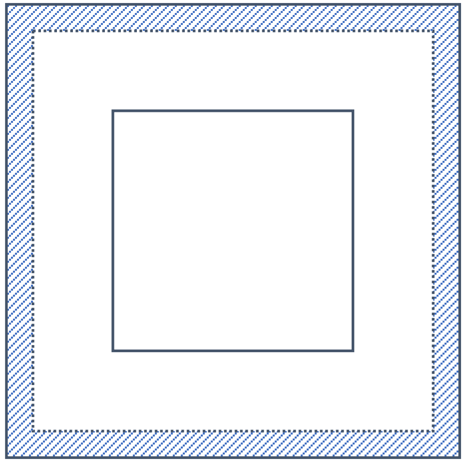
The distribution of drag force on skirt for engineering model

- Engineering model (FAST, Orcaflex) is necessary for design phase
- Nonlinear viscous-drag coefficient in vertical direction is important

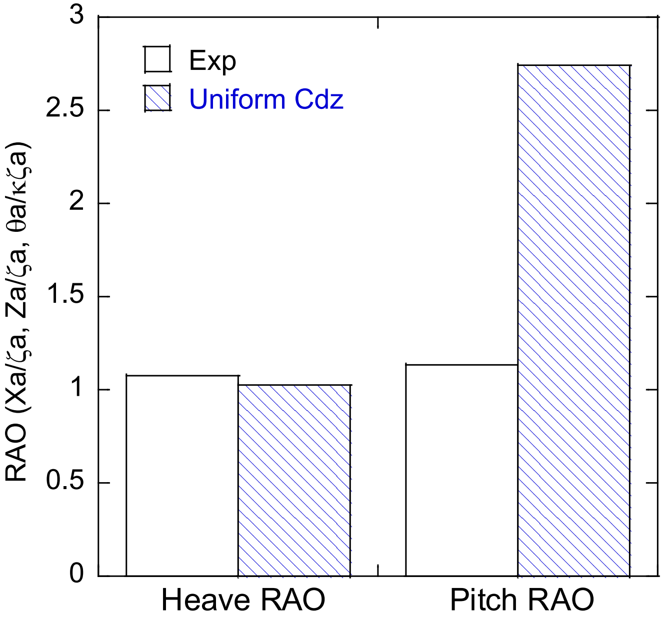
$$F_z = \frac{1}{2}\rho C_{dz} A_c |w - \dot{q_3}|(w - \dot{q_3})$$



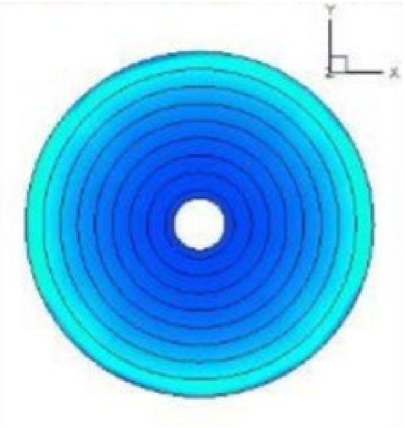
Bottom View of the floater



Uniform Cdz is adopted for the skirt



Pressure distribution on the skirt
Zhang and Ishihara (2018)



The uniform Cd on the skirt induces the overestimation of RAO in pitch direction

Objectives

1. Investigate the sensitivity of numerical water tank layout on the floater response in the surge direction

2. Evaluate the prediction accuracy of hydrodynamic force coefficient by forced oscillation simulation and clarify its effect on the floater motion prediction in numerical water tank

3. Analyze drag force distribution on the skirt by forced oscillation test in order to improve engineering model prediction

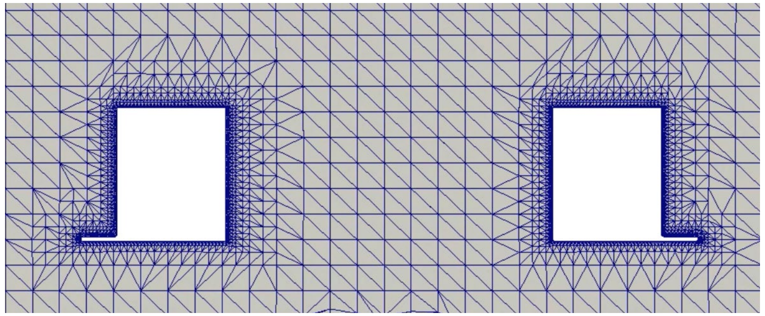
Numerical water tank setting

- OpenFOAM1606+ and Waves2Foam
- The volume of fluid (VOF) method
- Laminar simulation
- BlockMesh and snappyHexMesh for generating mesh

Numerical scheme (Ref.3)

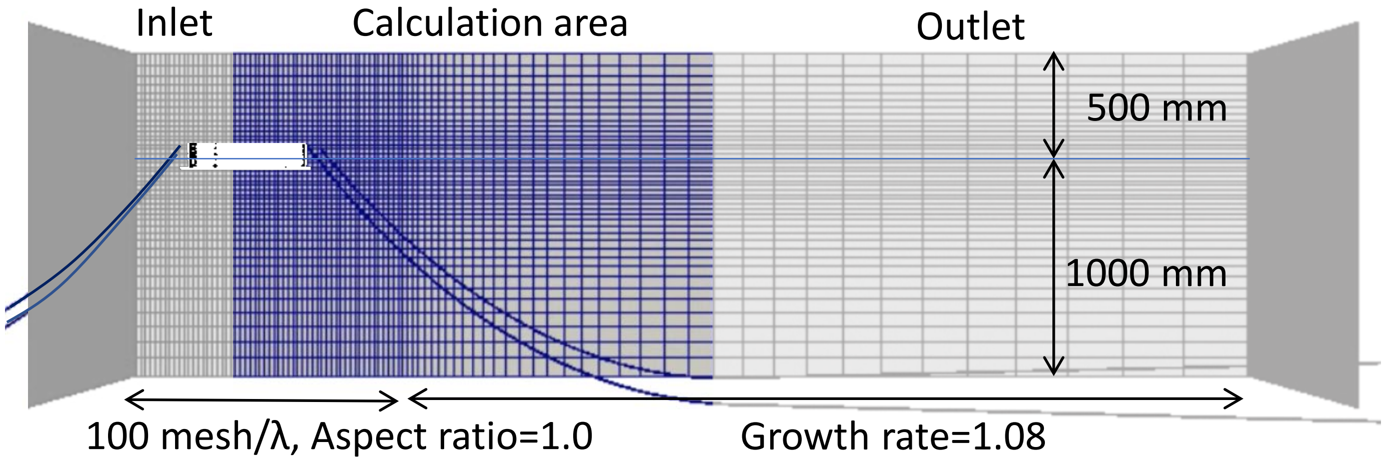
Temporal derivative	Euler's first-order	$\nabla \cdot (\Phi, \alpha)$	Gauss upwind
Gradient	Gauss linear	$\nabla \cdot (\rho \Phi_{rb}, \alpha)$	Gauss interface compression
Divergence	Gauss upwind	Laplacian	Gauss liner corrected

Navier-Stokes model



Global mesh size: 21mm (5.2 mesh/floater height)
Minimum mesh size: 1.3mm (2.8 mesh/skirt thickness)

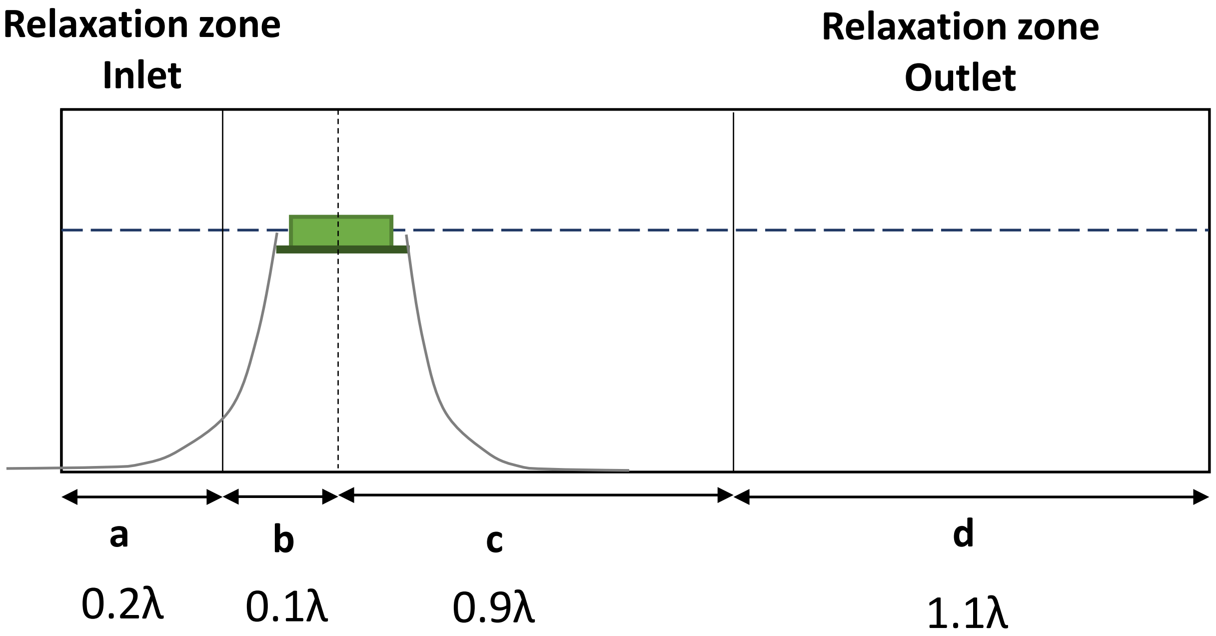
Numerical wave tank configuration in this study

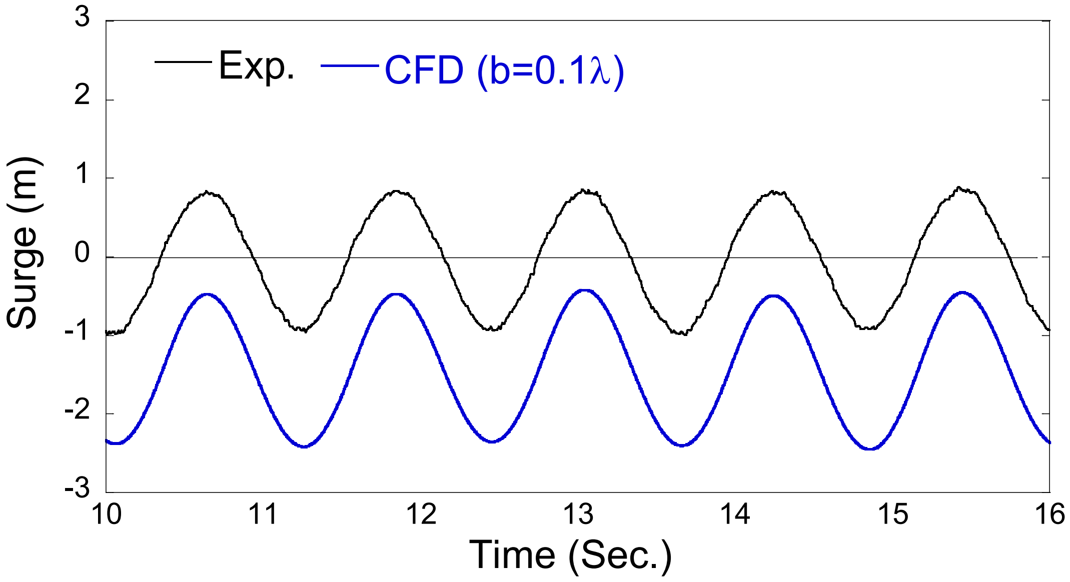


The numerical water tank is set for barge type floater

Prediction of surge dynamic response by numerical water tank

Significant wave height: 0.02 m, Wave period: 1.2 sec, λ means wave length

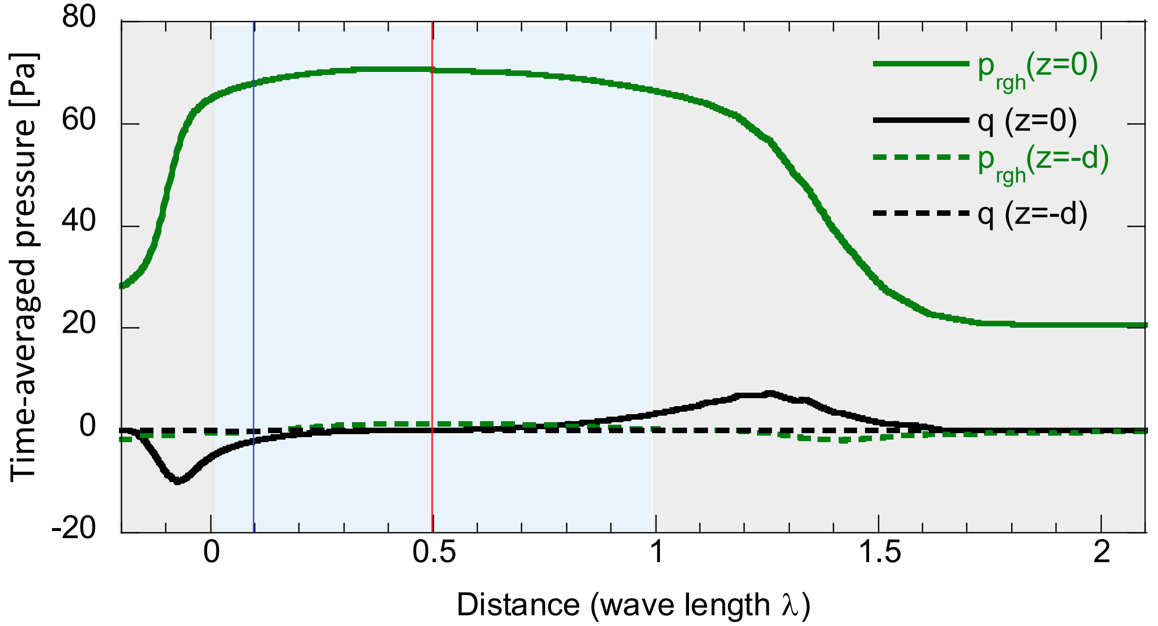


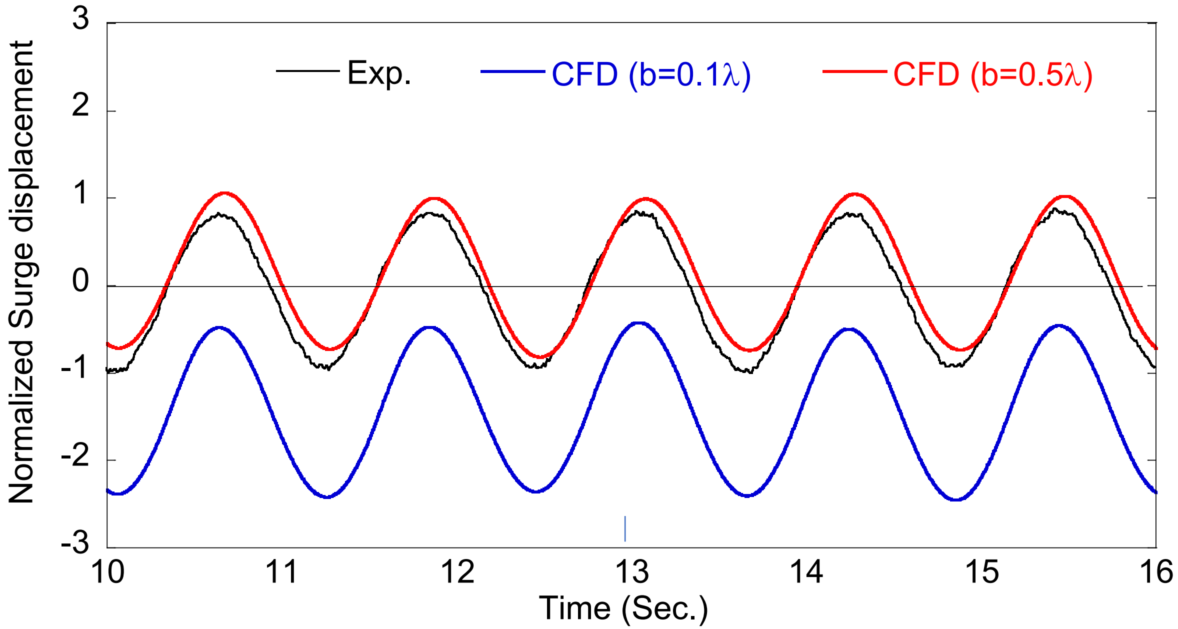


The drift occurred in surge direction when the floater is located near relaxation zone inlet

Pressure distribution in numerical water tank

- The difference of time-averaged pressure is observed on floater.
- Near the relaxation region, the pressure gradient is observed, which causes the negative pressure difference.
- λ=0.5 is chosen where the pressure gradient is constant.

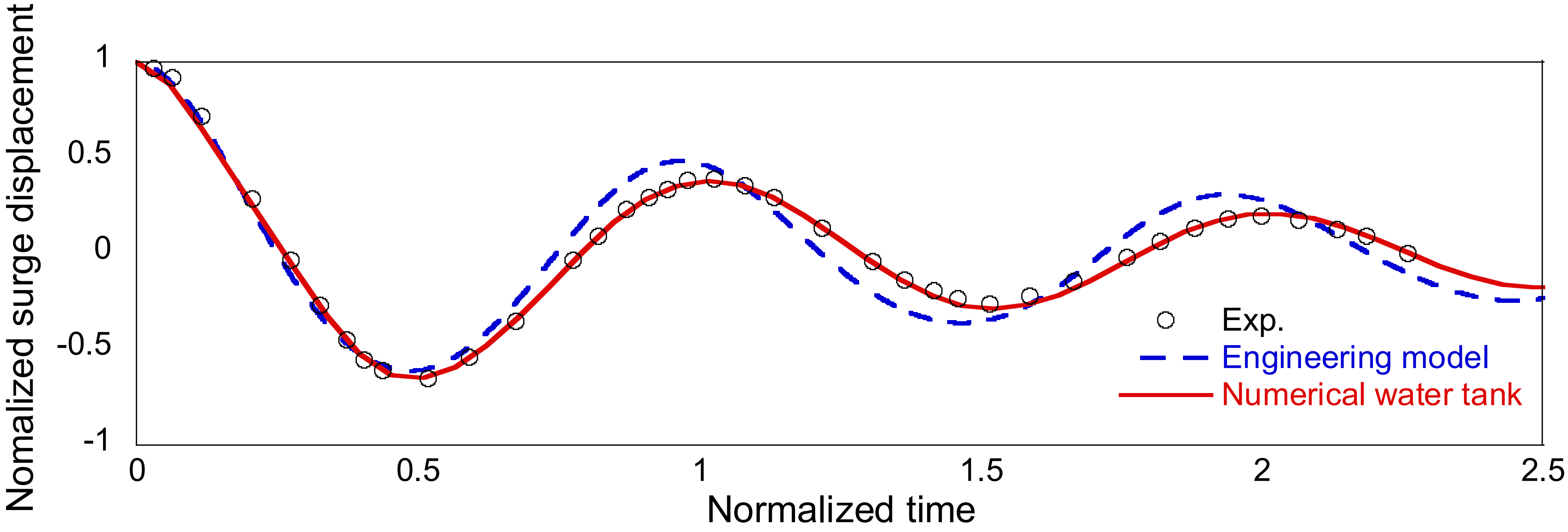




Pressure : $p_{rgh} = p - \rho g h$ Dynamic pressure : $q = 0.5\rho U_x|U_x|$

The region where the time-averaged pressure is constant needs to be selected for the numerical water tank simulation. The predicted RAO in surge direction agrees well with measurement.

Free-decay result in surge direction

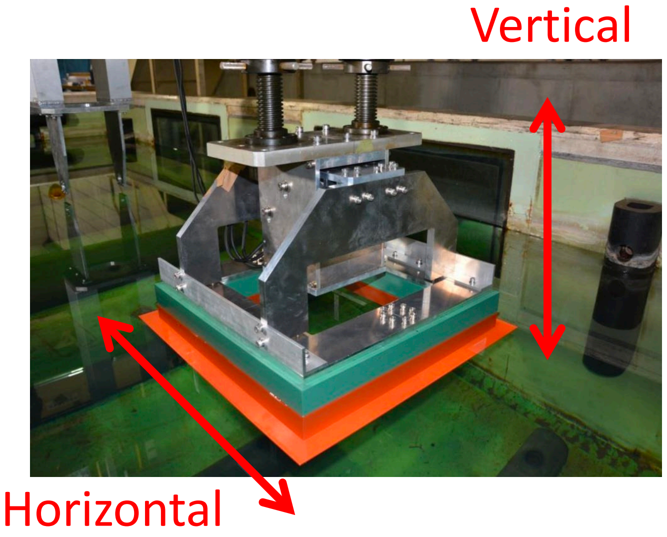


In surge direction, simulated free decay motion by numerical water tank shows a good agreement with experiment and its prediction accuracy is higher than that of engineering model. It is because amplitude dependency of hydrodynamic force is considered in numerical water tank.

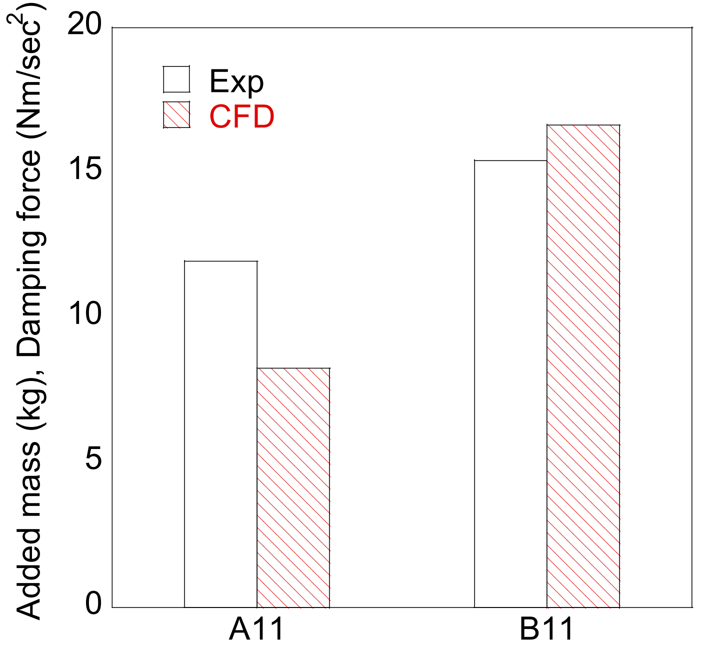
Hydrodynamic force prediction from forced oscillation test

Added mass and damping force are analyzed by forced oscillation test and CFD simulation by interDyMFoam tool in OpenFOAM with same mesh configuration

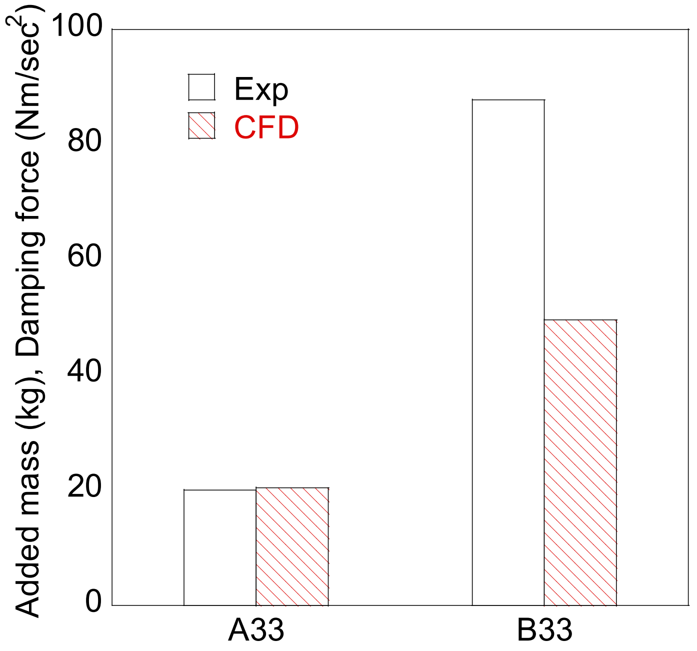
ω=1.2 sec.
Amplitude=0.02 m



Horizontal direction



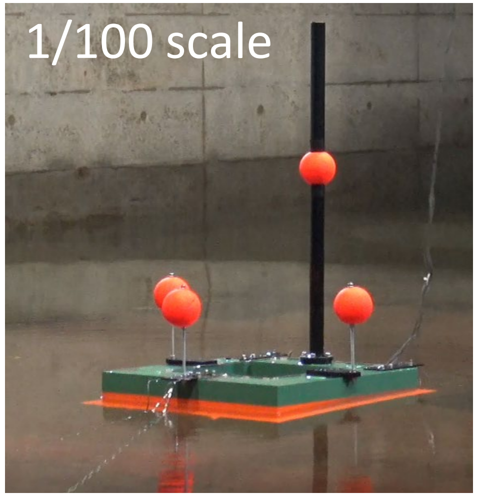
Vertical direction

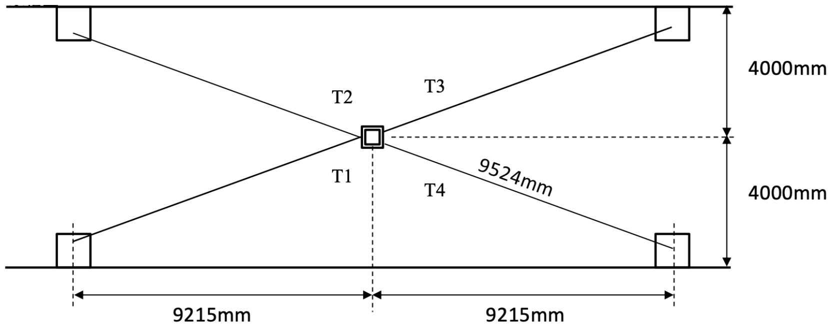


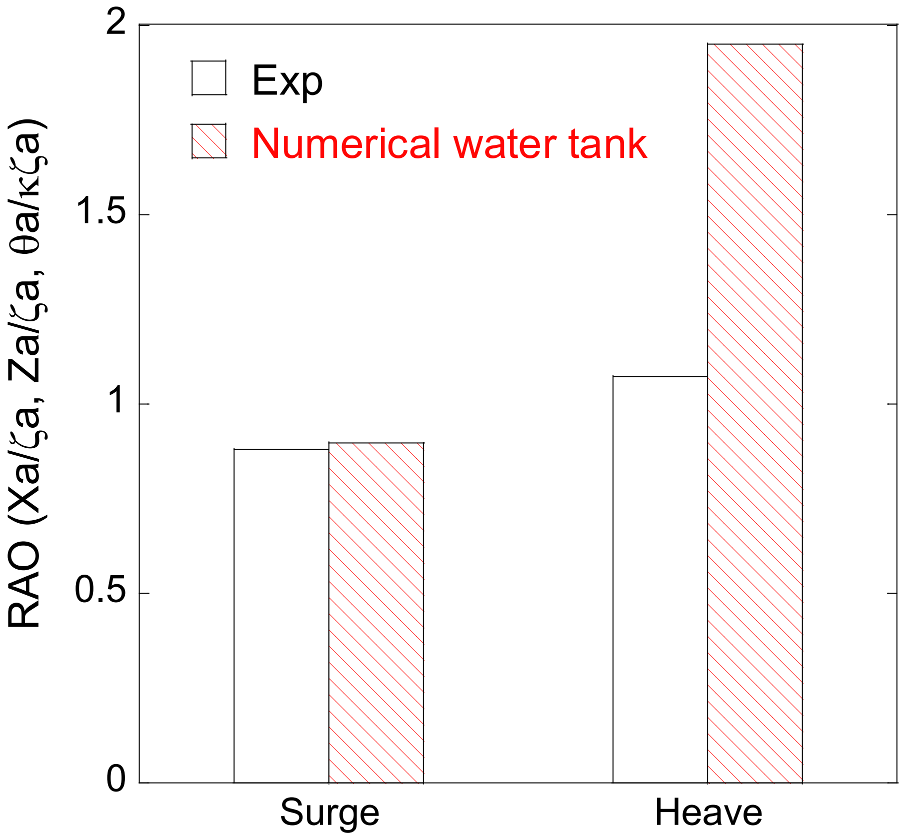
In horizontal direction, the predicted hydrodynamic force shows a good accuracy.
In vertical direction, the predicted added mass shows a good accuracy, but the predicted damping force highly underestimates the measurement.

Measured and simulated RAO by numerical wave tank

Regular wave case, Wave height: 0.02 m, Wave period: 1.2 sec





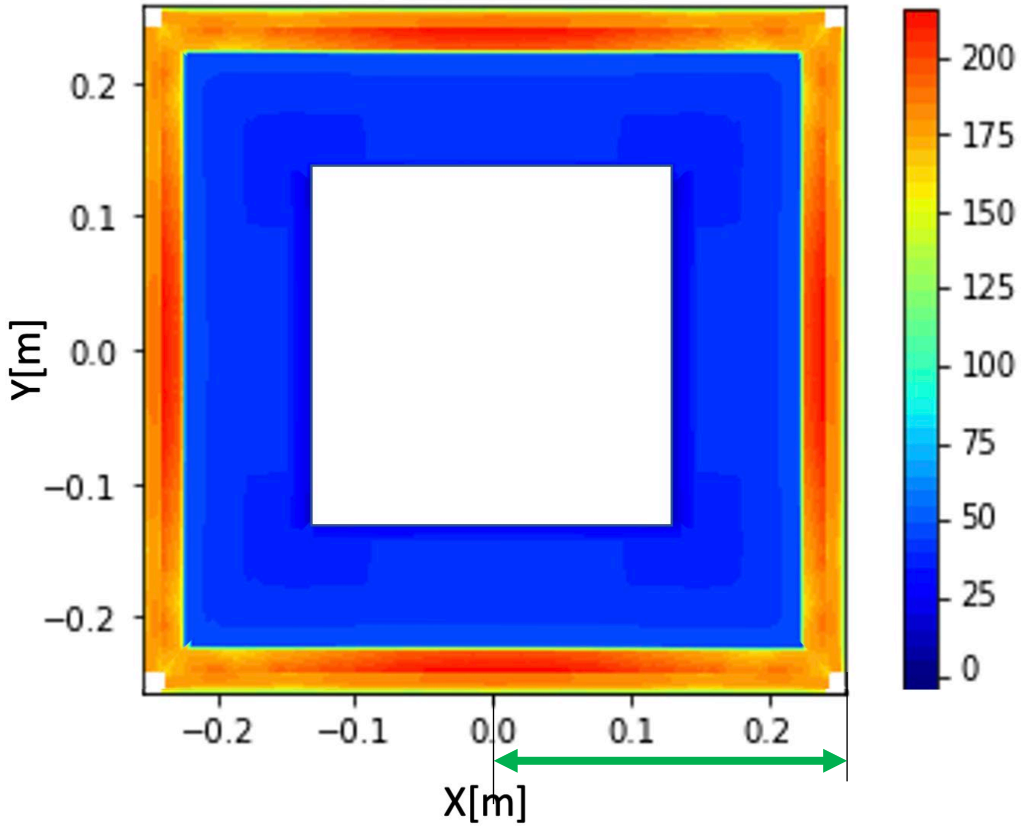


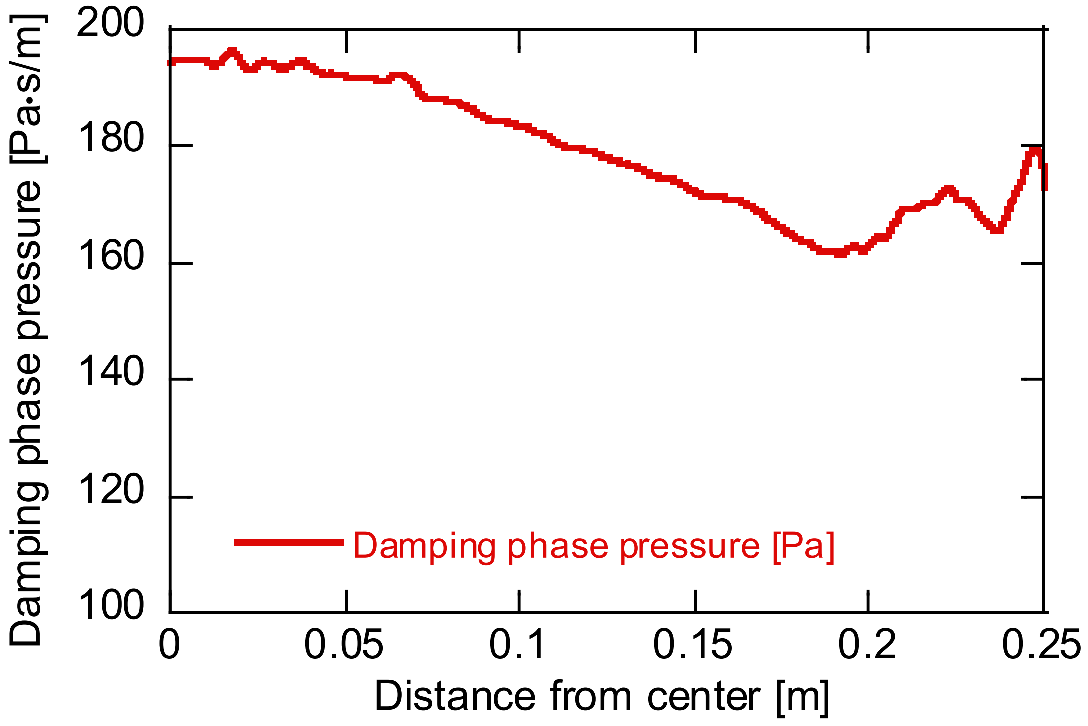
The predicted RAO in surge direction shows a good accuracy, but that in heave direction overestimates the measurement. The accurate prediction of damping force by mesh quality improvement is the next challenge.

Distribution of drag force coefficient on the skirt

Damping phase pressure is analyzed based on forced oscillation simulation.

Damping phase pressure $P_{dz}/\omega z_a$ [Pa·s/m]





Distribution of damping force on the skirt is quantitatively analyzed

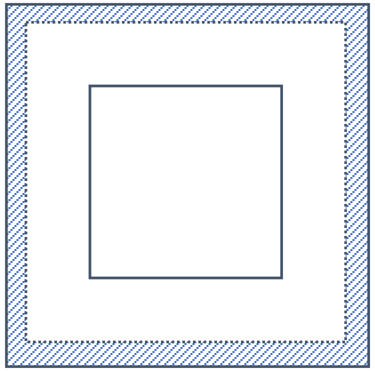
Engineering model considering Cd distribution on the skirt

RAO is estimated by using engineering model of FAST.

$\sum_i C_{d_{z},i} S_i = 1.18\ [m^2]$ (S_i: Area of Morison elements i)

Uniform Cdz

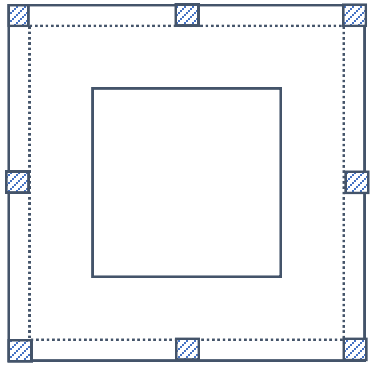
Bottom View of the floater



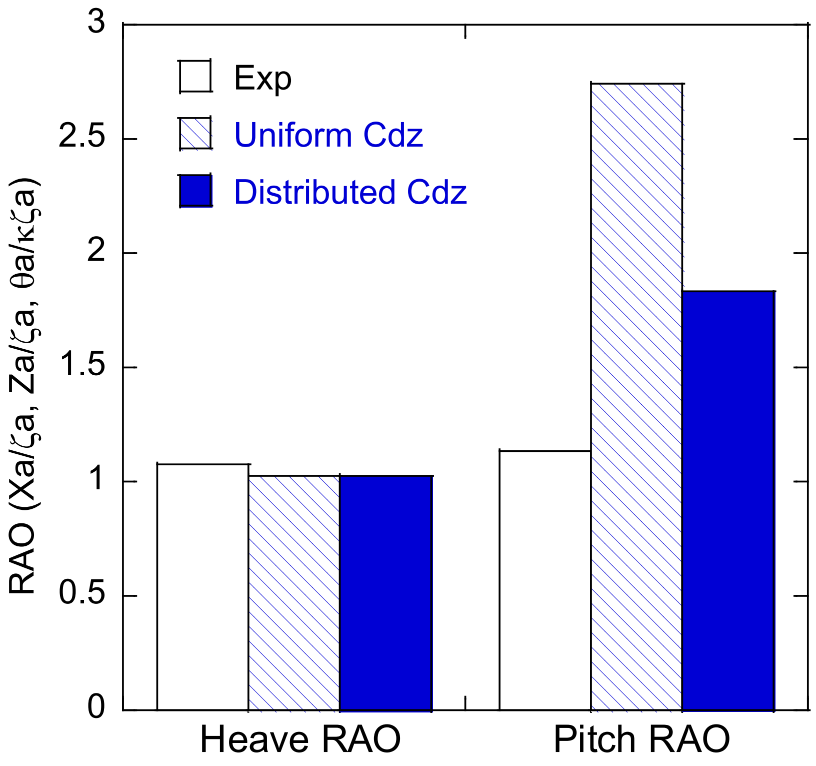
Cd_z distributed on skirt

Distributed Cdz

Bottom View of the floater



Cd_z distributed on maximal points



The prediction accuracy increases in pitch direction by considering the distribution. The prediction accuracy of wave exciting force needs to be investigated.

Conclusion

1. In regular wave simulation by numerical water tank, the drift is observed in surge direction when the floater is set near the relaxation zone. The pressure in numerical water tank is analyzed and it is found that the gradient is occurring near relaxation zone. The floater should be located where the pressure is constant.

2. The predicted floater motion in surge direction by numerical water tank shows a good agreement with measurement both in regular wave and free decay simulations. The predicted floater motion in heave direction overestimates measurement in regular wave simulation, because hydrodynamic damping force is overestimated.

3. The distribution of drag force is clarified by forced oscillation simulation. Engineering model considering pressure distribution on the skirt shows better agreement with measurement of floater motion in pitch direction.

Reference

1. A. Robertson et al., OC6 Phase I: Investigating the underprediction of low-frequency hydrodynamic loads and responses of a floating wind turbine, 2020 J. Phys.: Conf. Ser. 1618 032033
2. T. Ishihara and S. Zhang, Prediction of dynamic response of semi- submersible floating offshore wind turbine using augmented Morison's equation with frequency dependent hydrodynamic coefficients, Renewable Energy, Vol.131, pp.1186-1207, 2019.
3. I. Rivera-Arreba et al., Modeling of a semisubmersible floating offshore wind platform in severe waves, J. Offshore Mech. Arct. Eng. 141(6), 2019.
4. J. Pan and T. Ishihara, Numerical prediction of hydrodynamic coefficients for a semi-sub platform by using large eddy simulation with volume of fluid method and Richardson extrapolation, J. Phys.: Conf. Ser. 1356, 2019.
5. N. Bruinsma et al., Validation and application of a fully nonlinear numerical wave tank for simulating floating offshore wind turbines, Ocean Engineering 147, 2018.
6. F. Borisade et al., Design study and full scale MBS-CFD simulation of the IDEOL floating offshore wind turbine foundation, J. Phys.: Conf. Ser. 753 092002 2016.
7. J. M. Jonkman and D. Matha, Dynamics of offshore floating wind turbines – analysis of three concepts, Wind Energy, 14, 557-569, 2011.
8. University of Vactoia, Hydrodynamic modelling of floating bodies with moon pools, https://www.uvic.ca/research/projects/wcwi/home/news/current/news-story-28.php
9. K. M.A. Kosasih, H. Suzuki, H.Niizato, S.Okubo, Demonstration Experiment and Numerical Simulation Analysis of Full-Scale Barge-Type Floating Offshore Wind Turbine, J. Mar. Sci. Eng. 2020, 8,880; doi:10. 3390/jmse8110880