# Hydrodynamic research on flap-type WEC with high accuracy coupled SPH method

Shi Yingxuan
ZheJiang University

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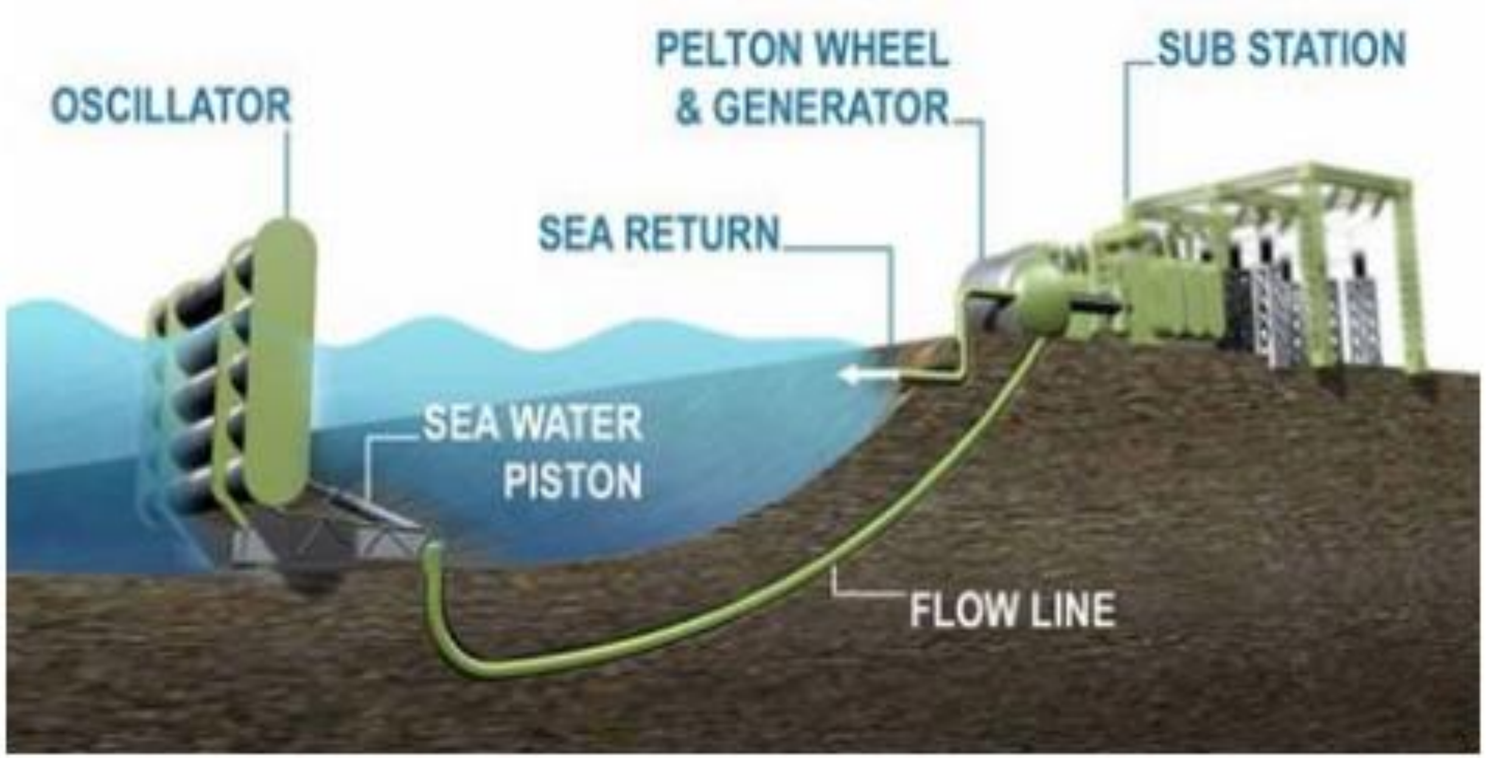
# Background

**Wave energy is important not only for alleviating energy crisis but also supplying the power for islands.**

**For improving efficiency of wave energy capturing, it is important to study hydrodynamic characteristics of floating.**



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# Methodology

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## Discrete governing equations

$$\begin{cases} \dfrac{D\rho_i}{Dt} = \rho_i \sum_j \left(\boldsymbol{u}_i - \boldsymbol{u}_j\right) \cdot \nabla_i W_{ij} V_j + \rho_{\delta i} \\ \rho_i \dfrac{D\boldsymbol{u}_i}{Dt} = -\sum_j \left(p_i + p_j\right) \cdot \nabla_i W_{ij} V_j + \rho_i \boldsymbol{g} + \boldsymbol{\tau}_i \\ \dfrac{D\boldsymbol{x}_i}{Dt} = \boldsymbol{u}_i \end{cases}$$

$$p_i = \left(\rho_i - \rho_r\right) c^2$$

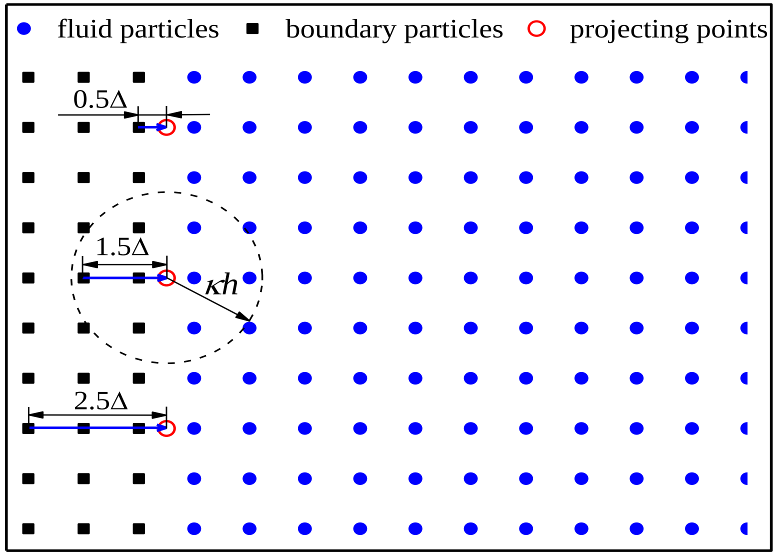
## δ-SPH model

$$\begin{cases} \rho_\delta = \delta h c_0 \sum_j \boldsymbol{\psi}_{ij} \nabla_i W_{ij} V_j \\ \boldsymbol{\psi}_{ij} = 2\left(\rho_i - \rho_j\right) \dfrac{\boldsymbol{x}_i - \boldsymbol{x}_j}{\left|r_{ij}\right|^2} - \left[\langle \nabla p \rangle_i^L + \langle \nabla p \rangle_j^L\right] \\ \langle \nabla p \rangle_i^L = \sum_j \left(\rho_i - \rho_j\right) L_i \nabla_i W_{ij} V_j \\ L_i = \sum_j \left(\boldsymbol{x}_i - \boldsymbol{x}_j\right) \otimes \nabla_i W_{ij} V_j \end{cases}$$

$$\boldsymbol{\tau}_i = \alpha h c \rho_0 \sum_j \frac{\left(\boldsymbol{u}_j - \boldsymbol{u}_i\right) \cdot \left(\boldsymbol{r}_j - \boldsymbol{r}_i\right)}{\left|\boldsymbol{r}_j - \boldsymbol{r}_i\right|^2} \nabla_i W V_j$$

$$\nu = \frac{\alpha h c_0}{2(d+2)}$$

## Boundary condition




### 1、Motionless walls

$$p_b = p_p - \rho_0 \boldsymbol{g} \cdot \boldsymbol{n}_b \eta \Delta$$

$$\begin{cases} u_b^{\boldsymbol{n}} = -u_p^{\boldsymbol{n}} \\ u_b^{\boldsymbol{\tau}} = u_p^{\boldsymbol{\tau}} \end{cases}$$

### 2、Moving boundary

$$p_b = p_p - \rho_0 \left[ \frac{D\boldsymbol{u}_b}{Dt} \cdot \boldsymbol{n}_b + \boldsymbol{g} \cdot \boldsymbol{n}_b \right] \eta \Delta$$

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## Wave-maker theory

$$x_{\text{piston}}(t) = \frac{s}{2}\sin(\sigma t)$$

$s=H/(kd)$

## Boundary force model

$$f_{ij} = \begin{cases} -\left(c_0 \dfrac{(\mathbf{u}_i - \mathbf{u}_j)\cdot \mathbf{n}_j W_{ij} h_{ij}^d \mathbf{n}_j}{|\mathbf{r}_{ij}\cdot \mathbf{n}_j|}\right) & (\mathbf{u}_i - \mathbf{u}_j)\cdot \mathbf{n}_j < 0 \\ 0 & (\mathbf{u}_i - \mathbf{u}_j)\cdot \mathbf{n}_j \geq 0 \end{cases}$$

## The motions of floating body

$$\begin{cases} \boldsymbol{F} = \sum\limits_{i\in solid} \dfrac{D\boldsymbol{u}_i}{Dt} \\ \boldsymbol{T} = \sum\limits_{i\in solid} \dfrac{D\boldsymbol{u}_i}{Dt}(\boldsymbol{x}_i - \boldsymbol{x}_{rot}) \end{cases}$$

$$\begin{cases} M\dfrac{d\boldsymbol{u}}{dt} = \boldsymbol{F} + M\boldsymbol{g} \\ I\dfrac{d\boldsymbol{\Omega}}{dt} = \boldsymbol{T} + M\boldsymbol{g}\cdot(\boldsymbol{x}_c - \boldsymbol{x}_{rot}) - k_d\cdot \boldsymbol{\Omega}_k \end{cases}$$

$$\frac{d\boldsymbol{x}_i}{dt} = \boldsymbol{u} + \boldsymbol{\Omega}\times(\boldsymbol{x}_i - \boldsymbol{x}_{rot})$$

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# Results& discussions

## 3.1 Standing Waves

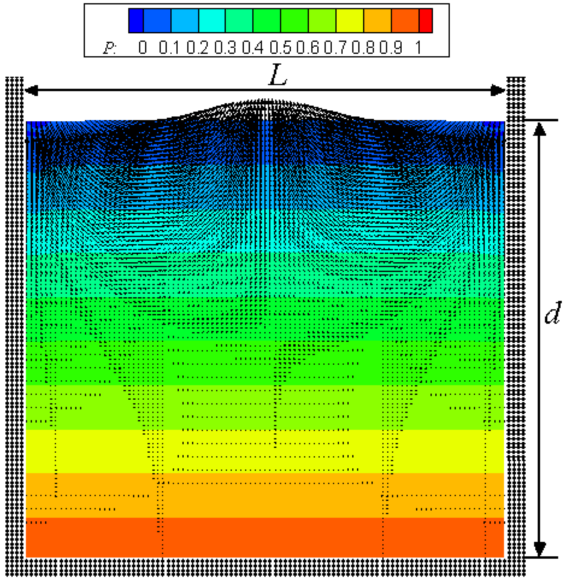
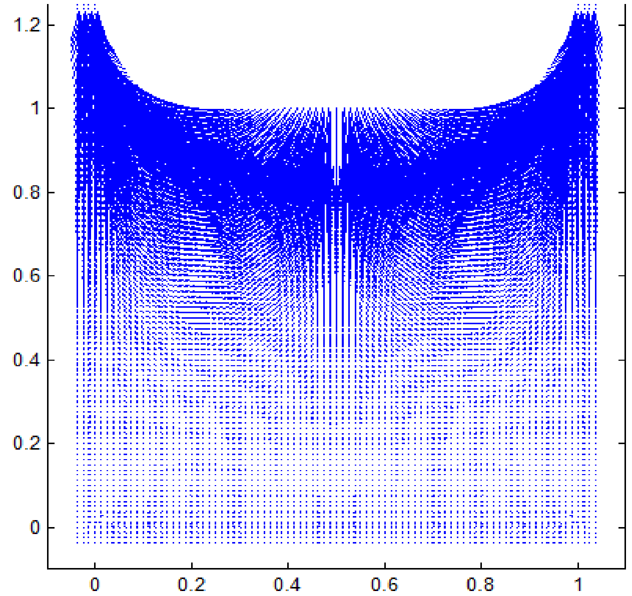



Fig.1 Tank model and its initial condition



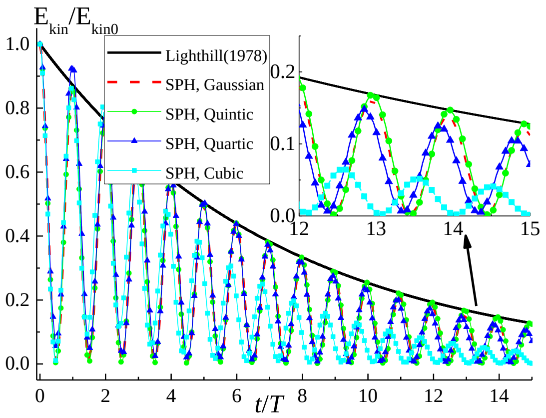



Fig.2 Effect of kernel functions on results

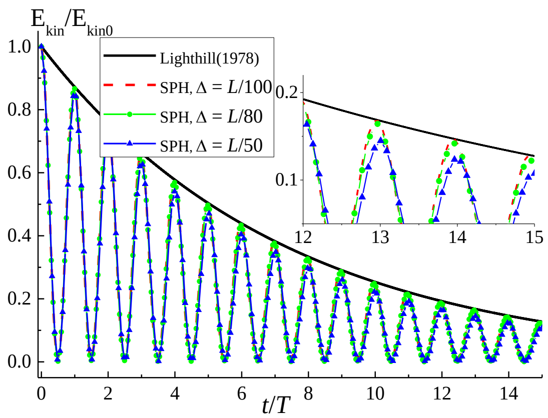



Fig.3 Effect of spacing resolutions (Gaussian)

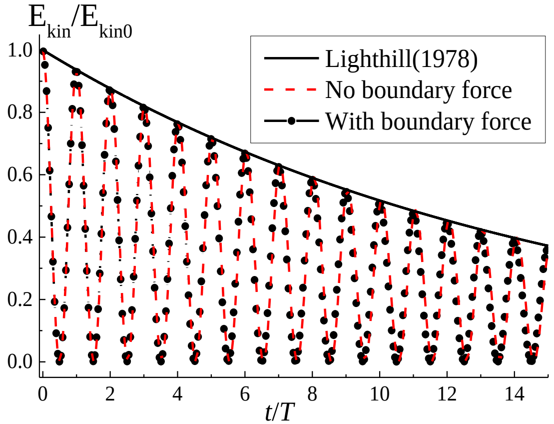



Fig.4 Effect of the boundary force model

Lighthill, Waves in Fluids, Cambridge University Press, New York, 2001.

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## 3.2 Wave tank

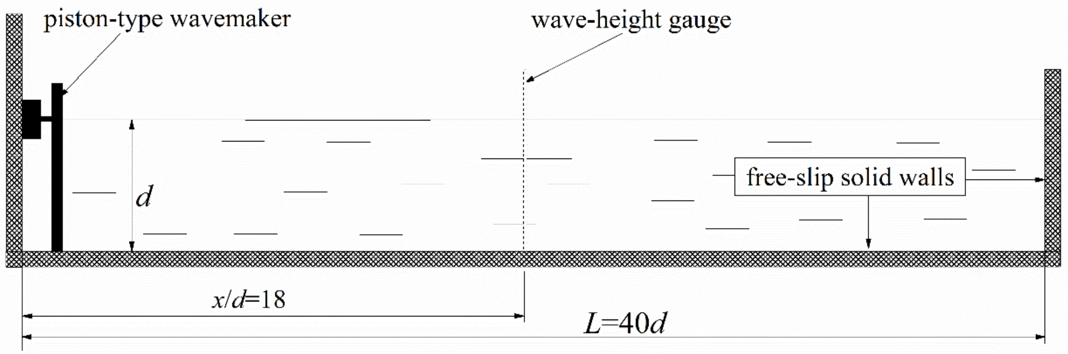
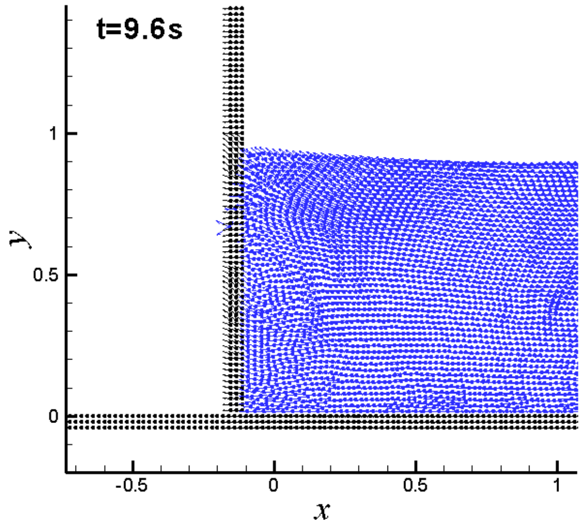



Fig.1 The sketch of numerical wave tank



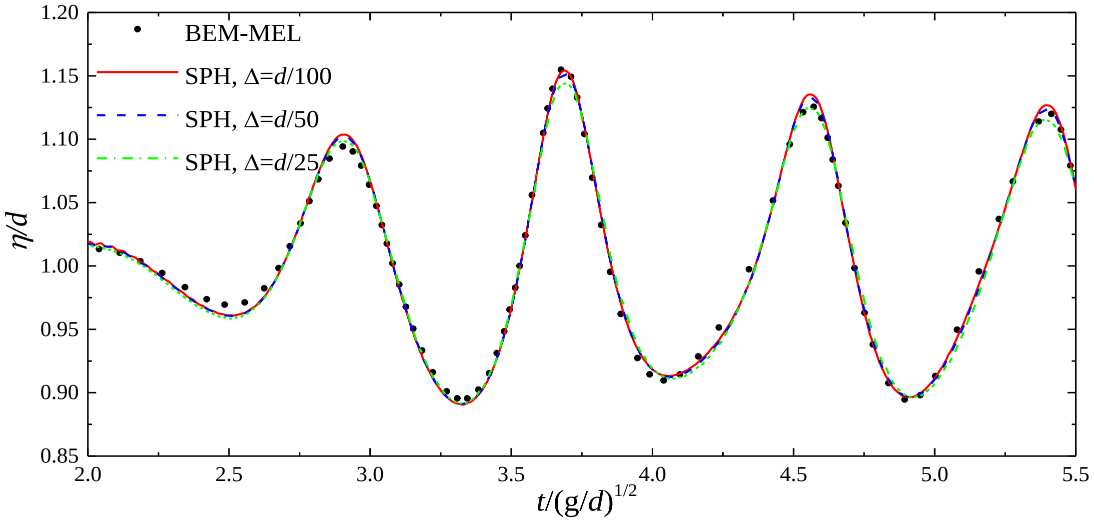




Fig.2 time profiles of water surface elevation predicted by different resolutions

Fig.3 particles penetrate across the wall boundary


Lugni, C., A study about the free-surface waves and the freely floating structure interactions (Ph.D. Thesis). University of Rome La Sapienza, 1999.

## 3.3 Interaction of Wave & Rigid Plate

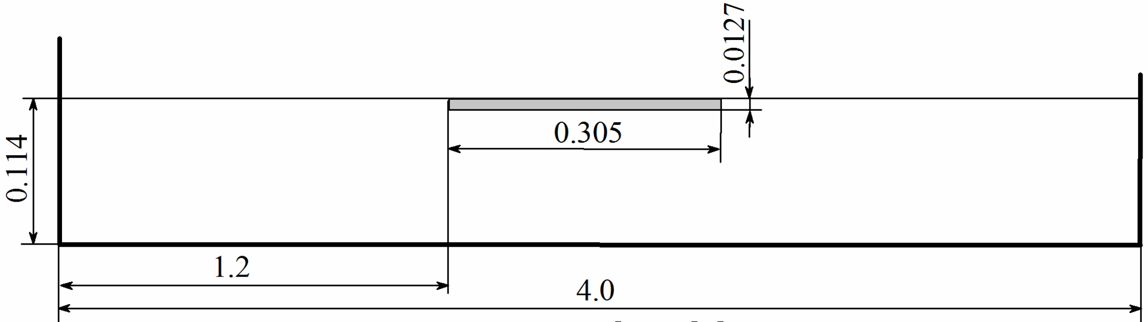
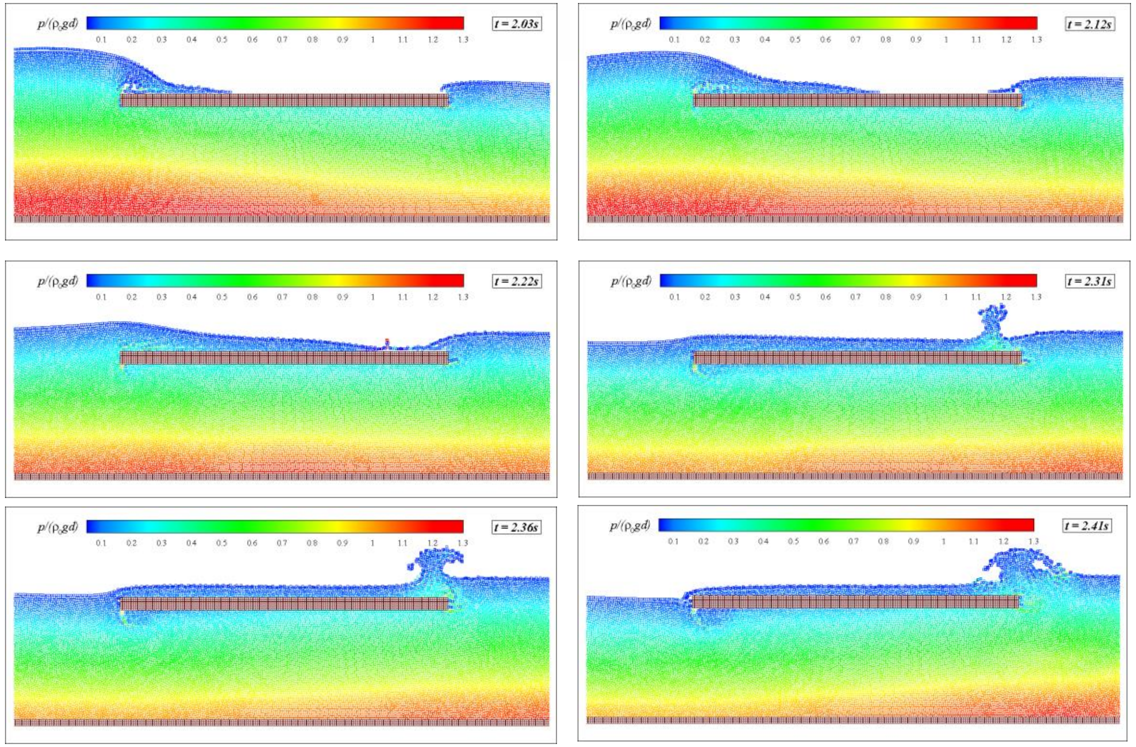



Fig.1 numerical model



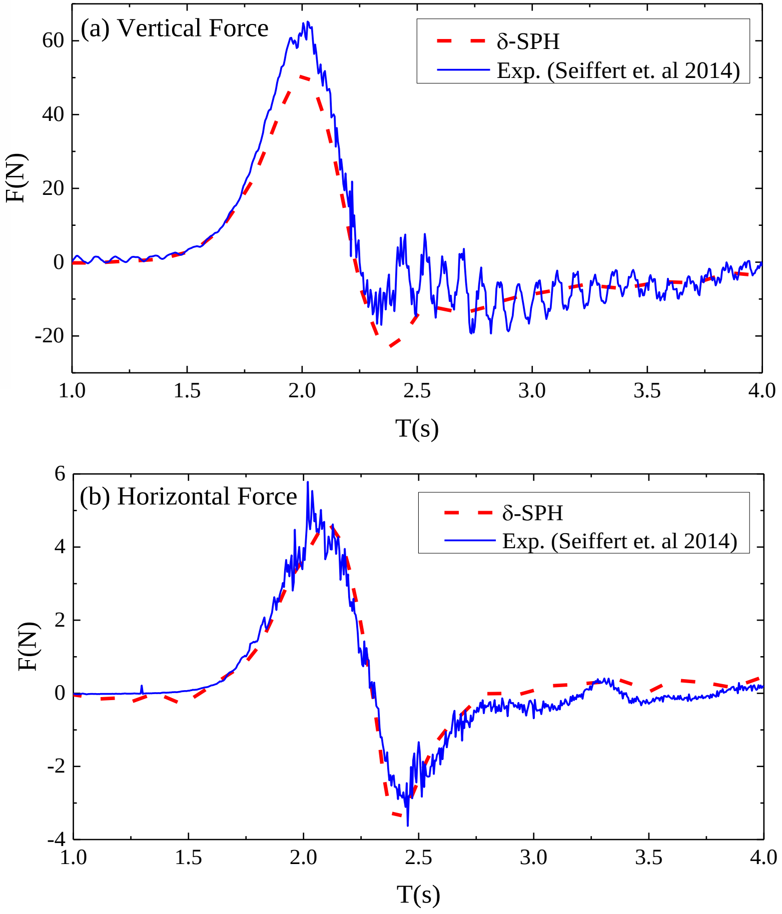




Fig.3 Comparison of the wave force on plate.
(Top: vertical force, Bottom: horizontal force.)

Seiffert, B., et al. Experiments and computations of solitary-wave forces on a coastal-bridge deck. Part I: Flat Plate. Coastal Engineering, 2014.

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## 3.4 Flap-type WEC of bottom-hinged pivot

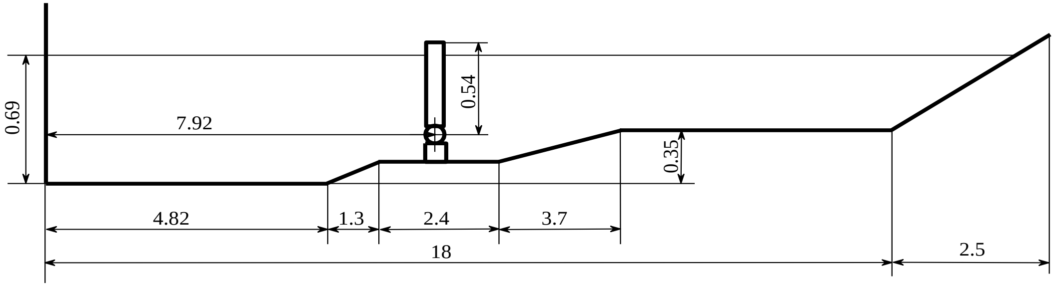


Fig.1 The schematic of bottom hinged Oscillating Wave Surge Converter

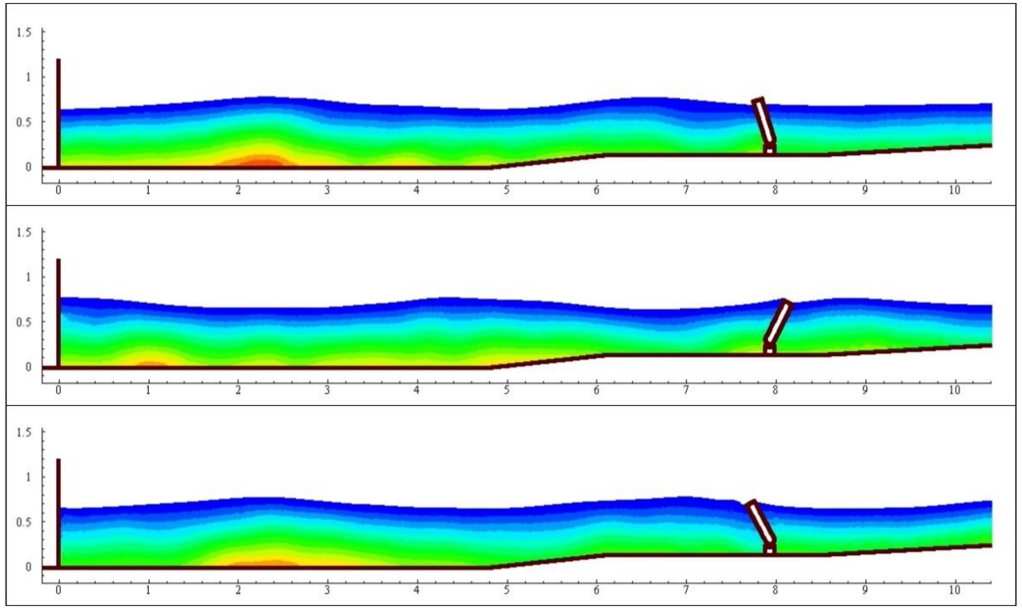

Fig.2 Pressure contours at different time.
(From top to bottom: t = 5s, t = 6s, t = 7s)

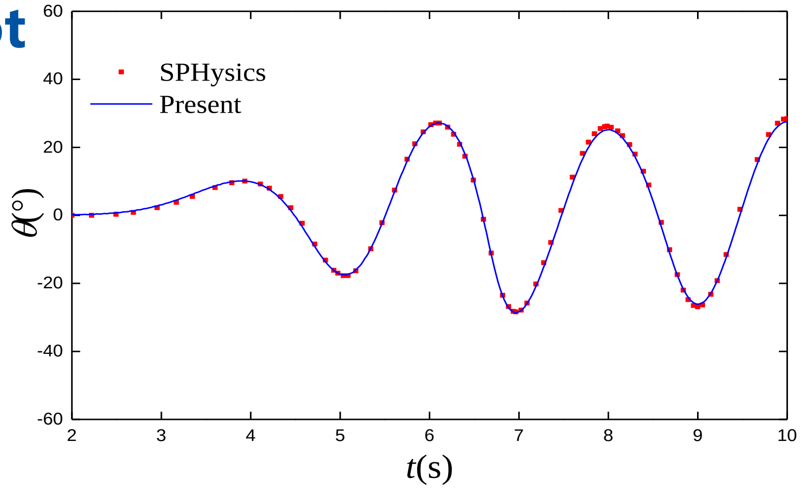


Fig.3a Time histories of the flap rotation angle (no damping)

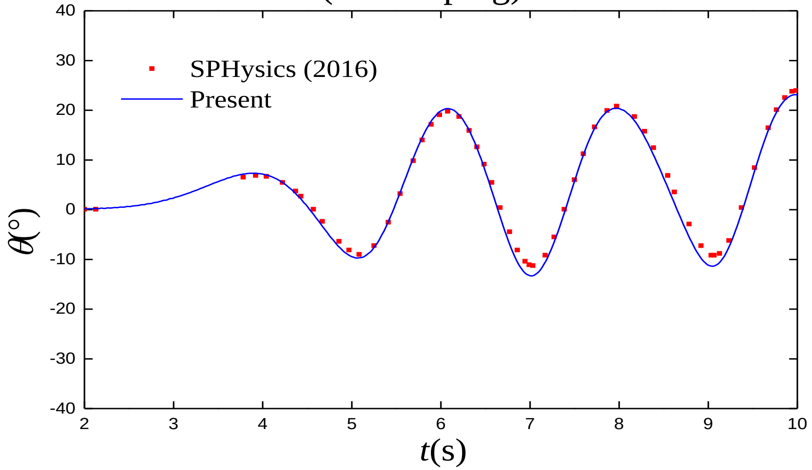


Fig.3b Time histories of the flap rotation angle (damping $k_d$ =35)


Brito, M., Canelas, R., Ferreira, R., Garc ía-Feal, O., Dom ínguez, J., Crespo, A., Neves, M., Coupling between DualSPHysics and Chrono-Engine: towards large scale HPC multiphysics simulations, 11th international SPHERIC workshop, Munich, Germany, 2016

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## 3.5 Flap-type WEC of land-hinged pivot

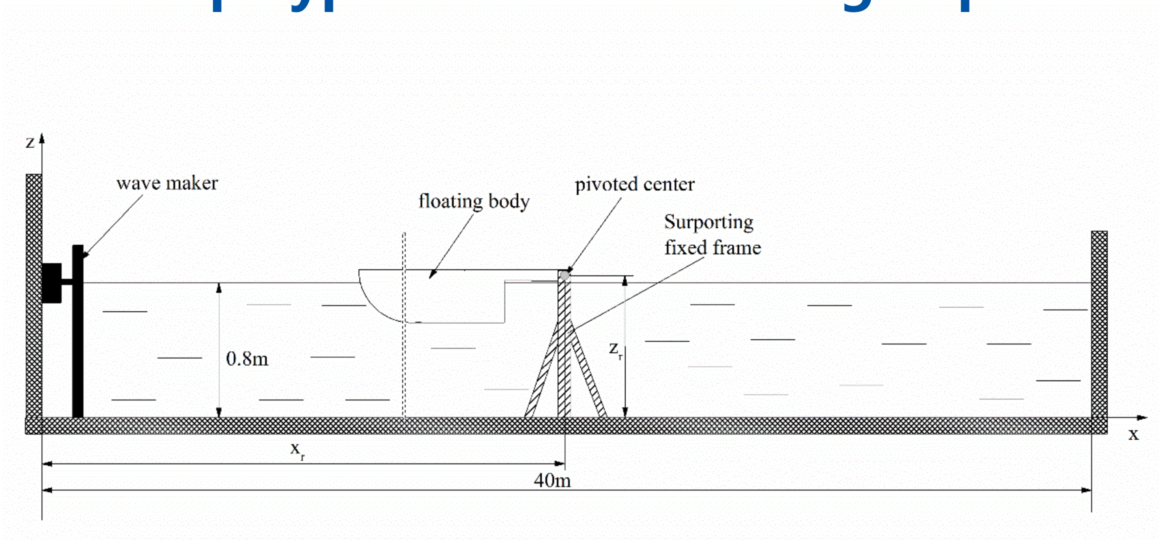



Fig.1 The schematic of land hinged Oscillating Wave Surge Converter.

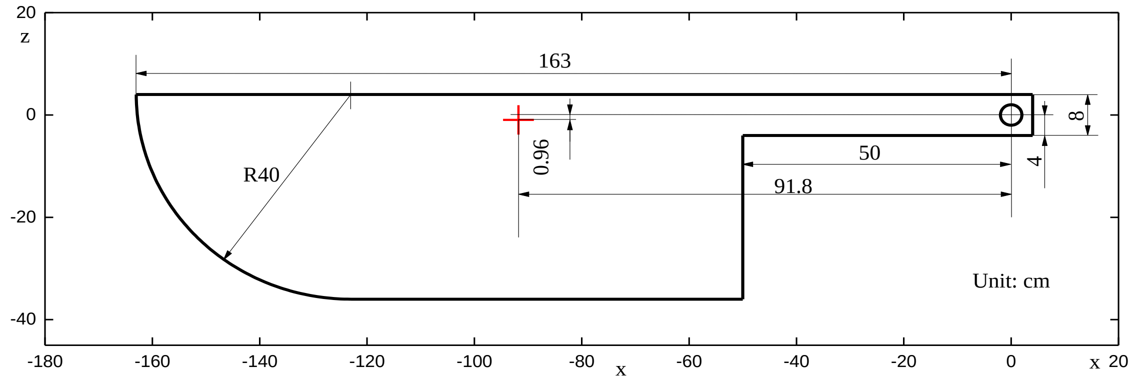
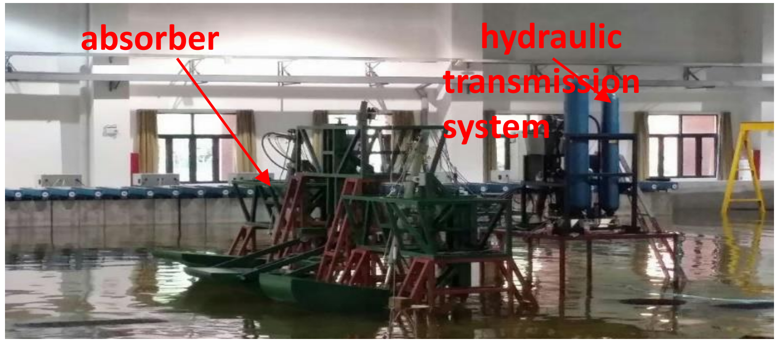
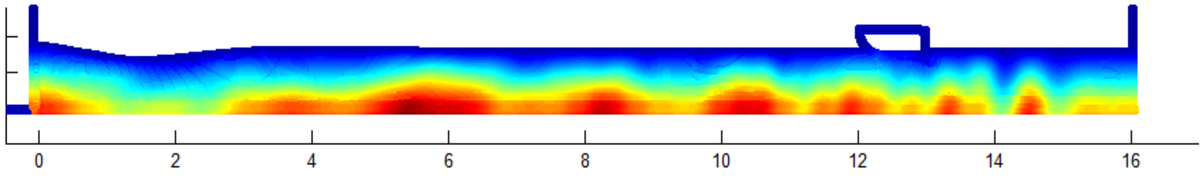



Fig.2 The sketch of pivoted absorber.




## 3.5.1 Single absorber



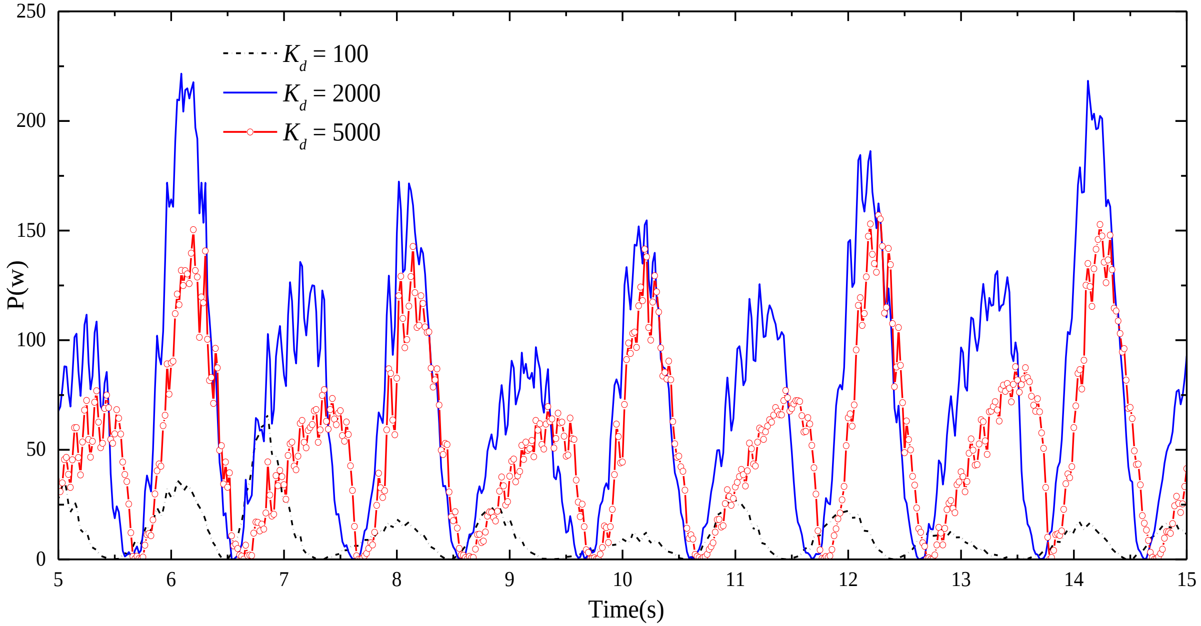




Fig.1 The instantaneous power of absorber with different PTO damping coefficients

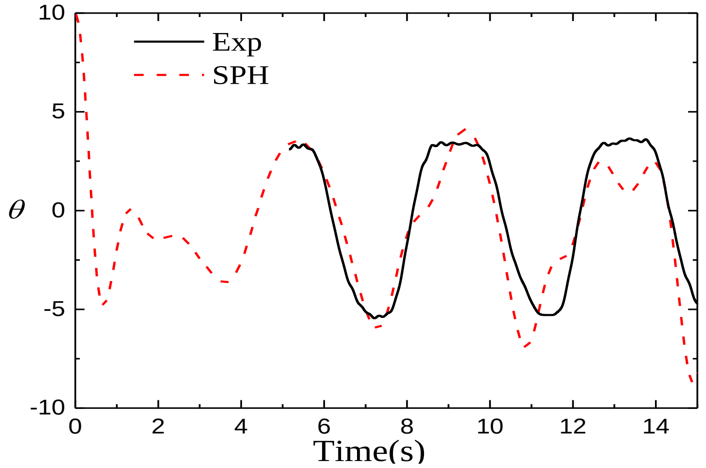



Fig.2 Comparision between SPH and experiment under period T=4s

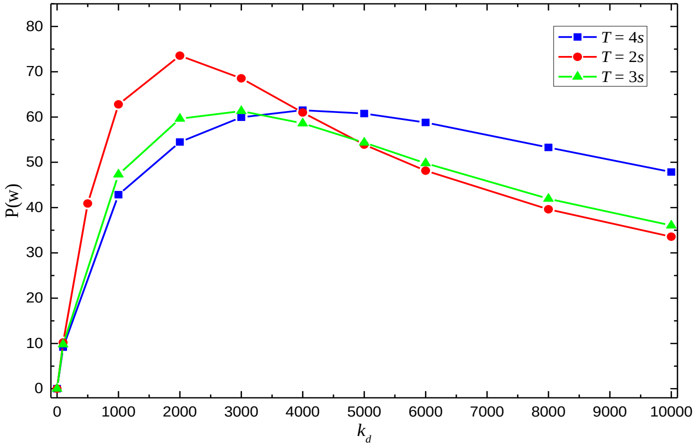



Fig.3 The active power of absorber with different PTO damping coefficients for different wave periods

## 3.5.2 Double absorber

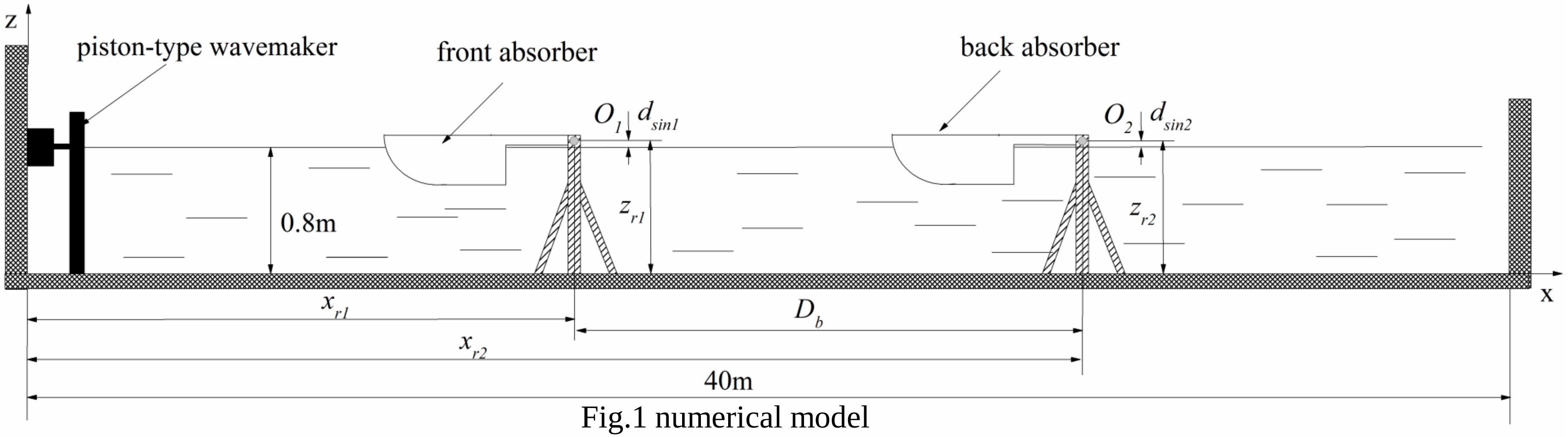



Fig.1 numerical model

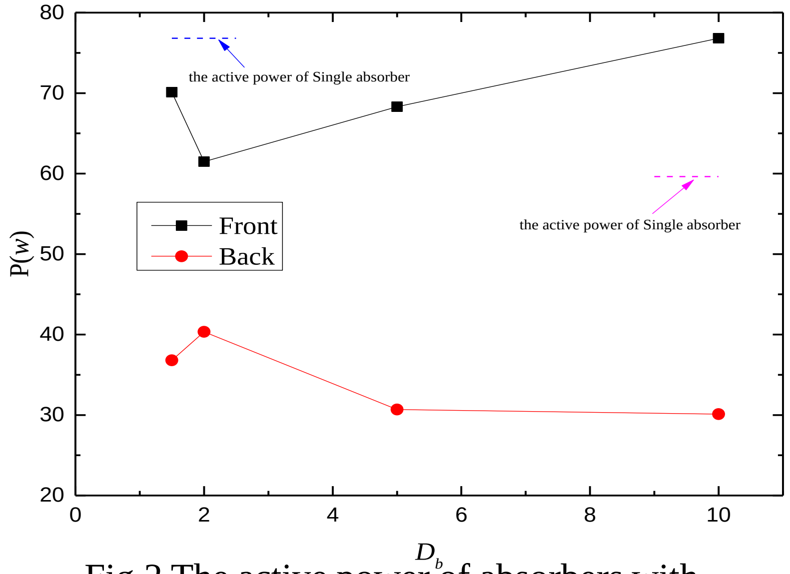



Fig.2 The active power of absorbers with different gaps

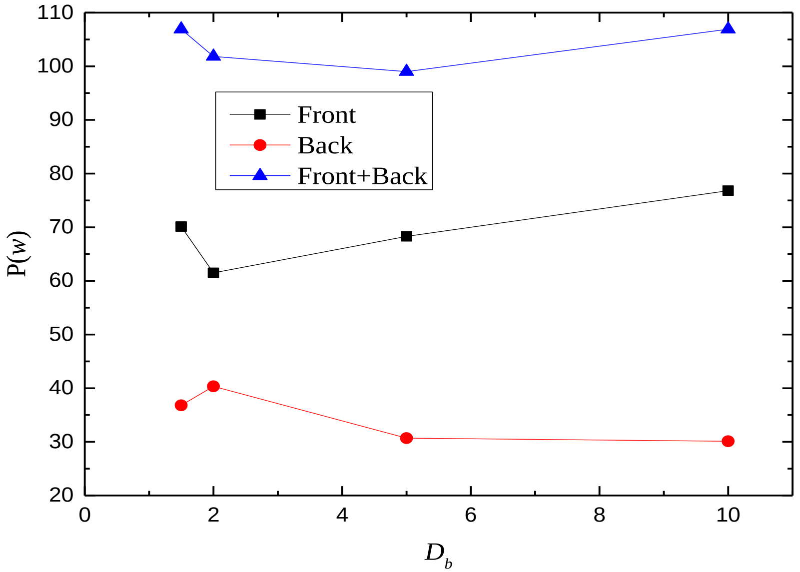



Fig.3 The total active power of absorbers

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# Conclusions

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## Conclusions

1. The selection of kernel function is critical for accuracy of SPH method. Gaussian kernel can be regarded as a proper kernel function for simulations of waves.

2. The PTO damping coefficients and the wave periods have important effect on active power, and there is the optimal damping coefficient for the fixed wave period.

3. The distance between two absorbers has large effect on energy capturing efficiency, and the maximal active power is obtained when the distance is large enough.

# Thanks for Your Attention

ZheJiang University

Shi Yingxuan