



# 36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

Baltimore, Maryland | July 30 – August 3, 2018

*The State of the Art and Science of Coastal Engineering*

## WAVE ENERGY CONVERTER WITH WAVE ABSORBING CONTROL

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### **Dr. Shogo Miyajima**

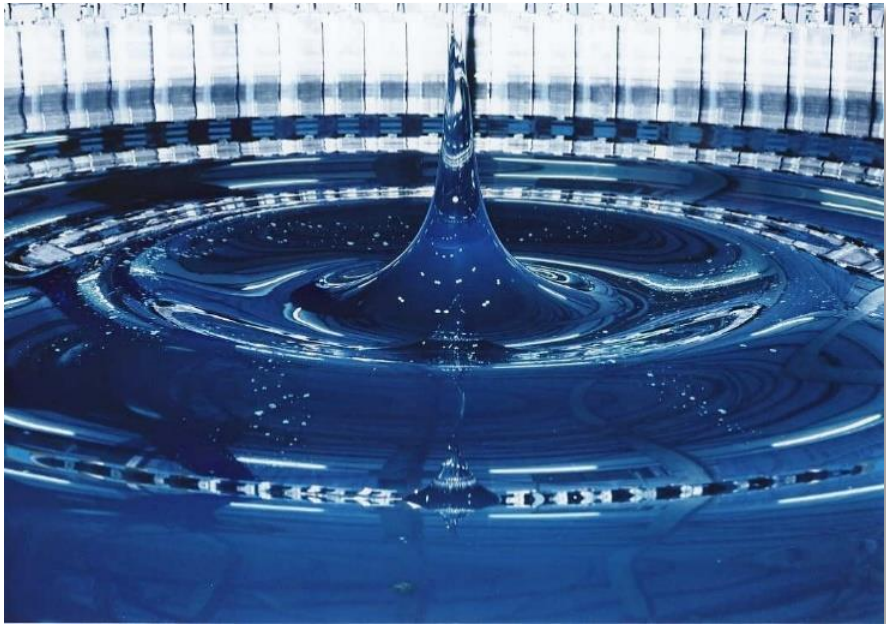
Akishima Laboratories (Mitsui Zosen) Inc. Tokyo, Japan

### **Dr. Taro Arikawa**

Department of Civil and Environmental Engineering, Chuo University Tokyo, Japan



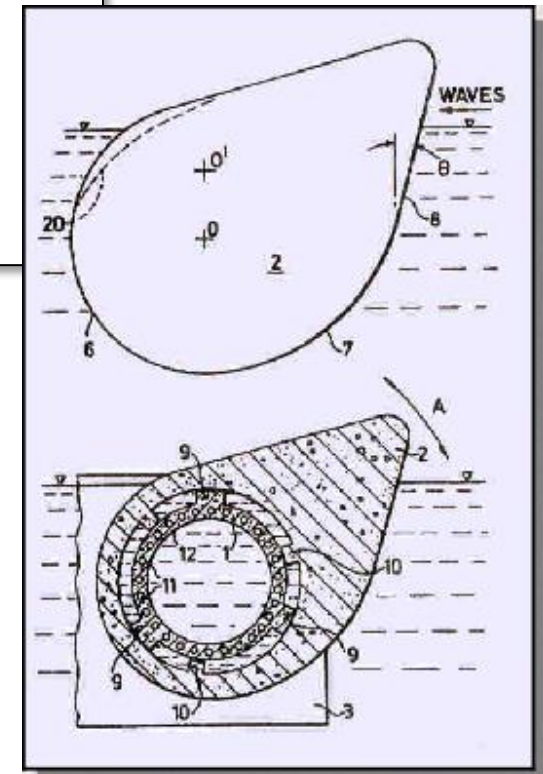
# Inspired by Salter Duck of Edinburgh Univ. in 1982



Stephen Salter .  
dept Mechanical Engineering  
Mayfield Road  
Edinburgh 9,

## APPLICATION OF A PISTON-TYPE ABSORBING WAVEMAKER TO IRREGULAR WAVE EXPERIMENTS

*Hiromaru Hirakuchi*<sup>1</sup>  
*Ryoichi Kajima*<sup>2</sup>  
*Takashi Kawaguchi*<sup>3</sup>

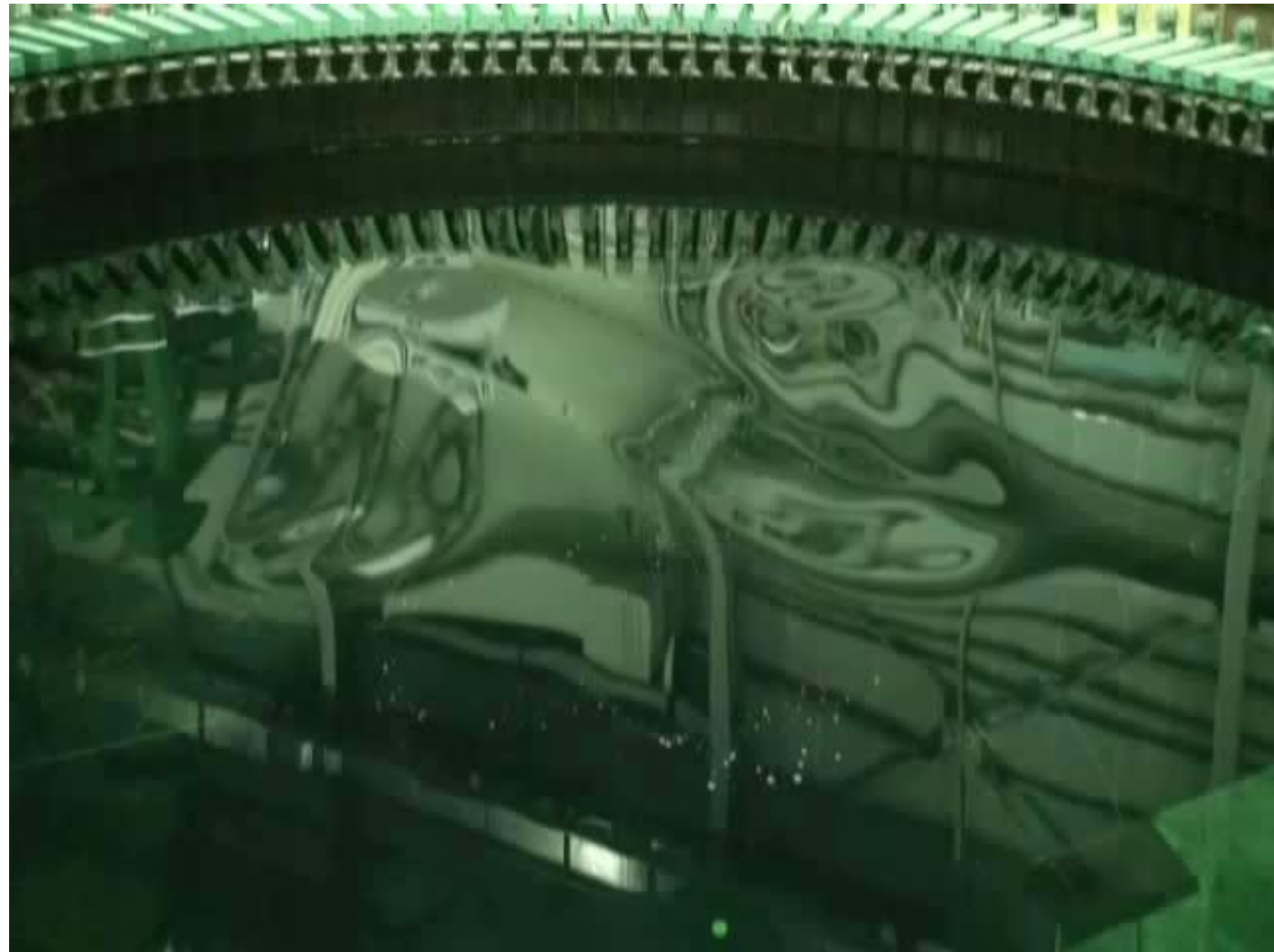


# Waves made by absorption wavemaker

[https://www.nmri.go.jp/news/toics/wave\\_art.html](https://www.nmri.go.jp/news/toics/wave_art.html)



Flap type wavemaker  
Reflection factor: **97%**  
Energy absorption: **85%**  
( $0.80 \text{ s} < T < 2.53 \text{ s}$ )



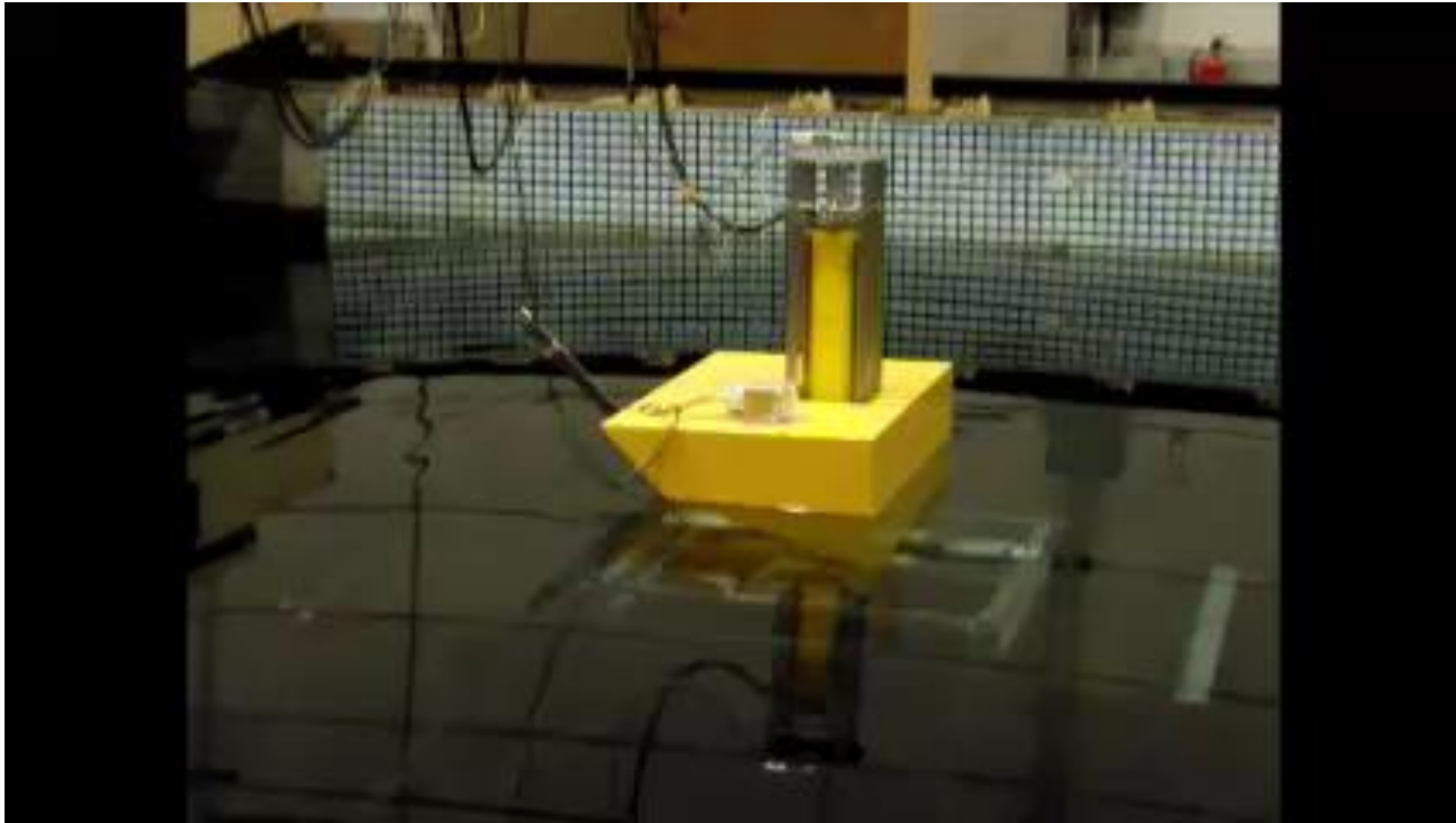
**National Maritime Research Institute, Tokyo, Japan**



# Wave absorption with Plunger Float (1)



# Wave absorption with Plunger Float (2)



# ABSORPTION vs. RESONANCE

## Absorption

If you start with **velocity potential theory**, your goal may be absorption.

$$\Phi = \frac{-ga \cosh k(z+h)}{\omega \cosh kh} \sin(\omega t - kx)$$

=

## Resonance

If you start with **forced oscillation theory**, your goal may be resonance.

$$M\ddot{X} + C\dot{X} + KX = f \cos(\omega t - kx)$$



# Wave Generation & Absorption by Surging Plate

## <Wave Generation>

When generating the waves :

$$\eta_R = a_R \cos(\omega t - k_0 x + \varepsilon_R)$$

Plate motion is to be:

$$X = S_R \sin(\omega t + \varepsilon_R)$$

$$\dot{X} = S_R \omega \cos(\omega t + \varepsilon_R)$$

## <Wave Absorption>

When absorbing the waves :

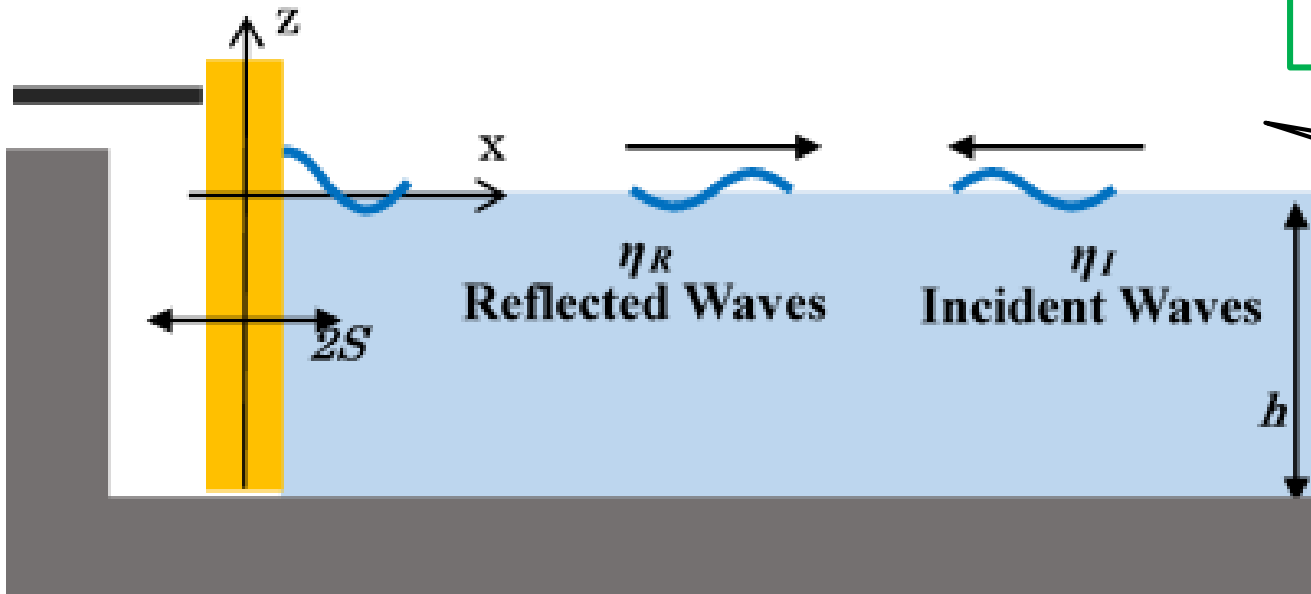
$$\eta_I = a_I \cos(\omega t + k_0 x + \varepsilon_I)$$

Plate motion is to be:

$$X = -S_I \sin(\omega t + \varepsilon_I)$$

$$\dot{X} = -S_I \omega \cos(\omega t + \varepsilon_I)$$

$$\dot{X} = -\omega / \bar{A} \cdot \eta_{I,x=0}$$



$$S_R = a_R / \bar{A} \quad S_I = a_I / \bar{A}$$

$\bar{A}$ : Response Amplitude Operator

Velocity potential theory



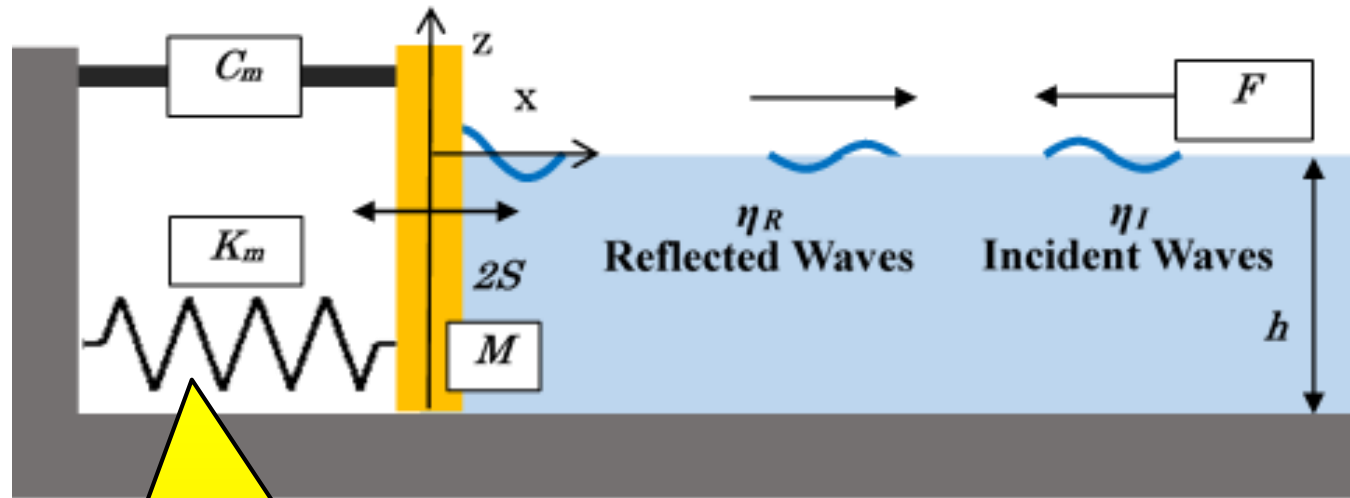
# Resonance by surging plate

$$M\ddot{X} + C_m\dot{X} + K_m X = -F$$



$$\dot{X} = -F / C_m$$

$$= -\omega / \bar{A} \cdot \eta_{I,x=0}$$



**MASS  
SPRING  
DAMPER  
SYSTEM**

virtual spring force  
*K<sub>m</sub>* for resonance.

**Forced Oscillation theory**





# Wave Generation & Absorption by Heaving Body

## <Wave Generation>

When generating the waves :

$$\eta_R = a_R \cos(\omega t - k_0 x + \varepsilon_R)$$

Body motion is to be:

$$Z = -S_R \sin(\omega t + \varepsilon_R)$$

$$\dot{Z} = -S_R \omega \cos(\omega t + \varepsilon_R)$$

## <Wave Absorption>

When absorbing the waves :

$$\eta_I = a_I \cos(\omega t + k_0 x + \varepsilon_I)$$

Body motion is to be:

$$Z = S_I \sin(\omega t + \varepsilon_I)$$

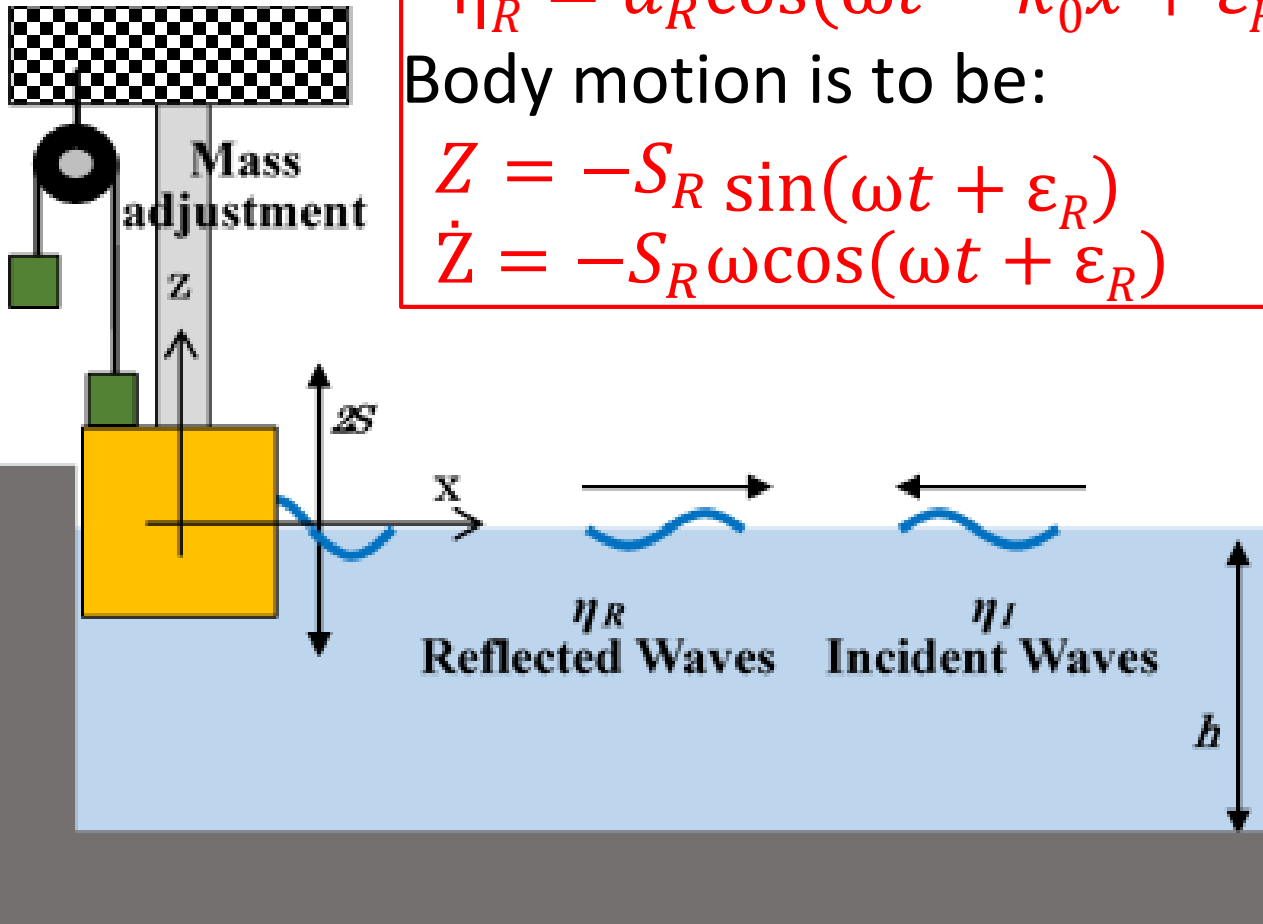
$$\dot{Z} = S_I \omega \cos(\omega t + \varepsilon_I)$$

$$\dot{Z} = \omega / \bar{A} \cdot \eta_{I,x=0}$$

$$S_R = a_R / \bar{A} \quad S_I = a_I / \bar{A}$$

c: Response Amplitude Operator

Velocity potential theory



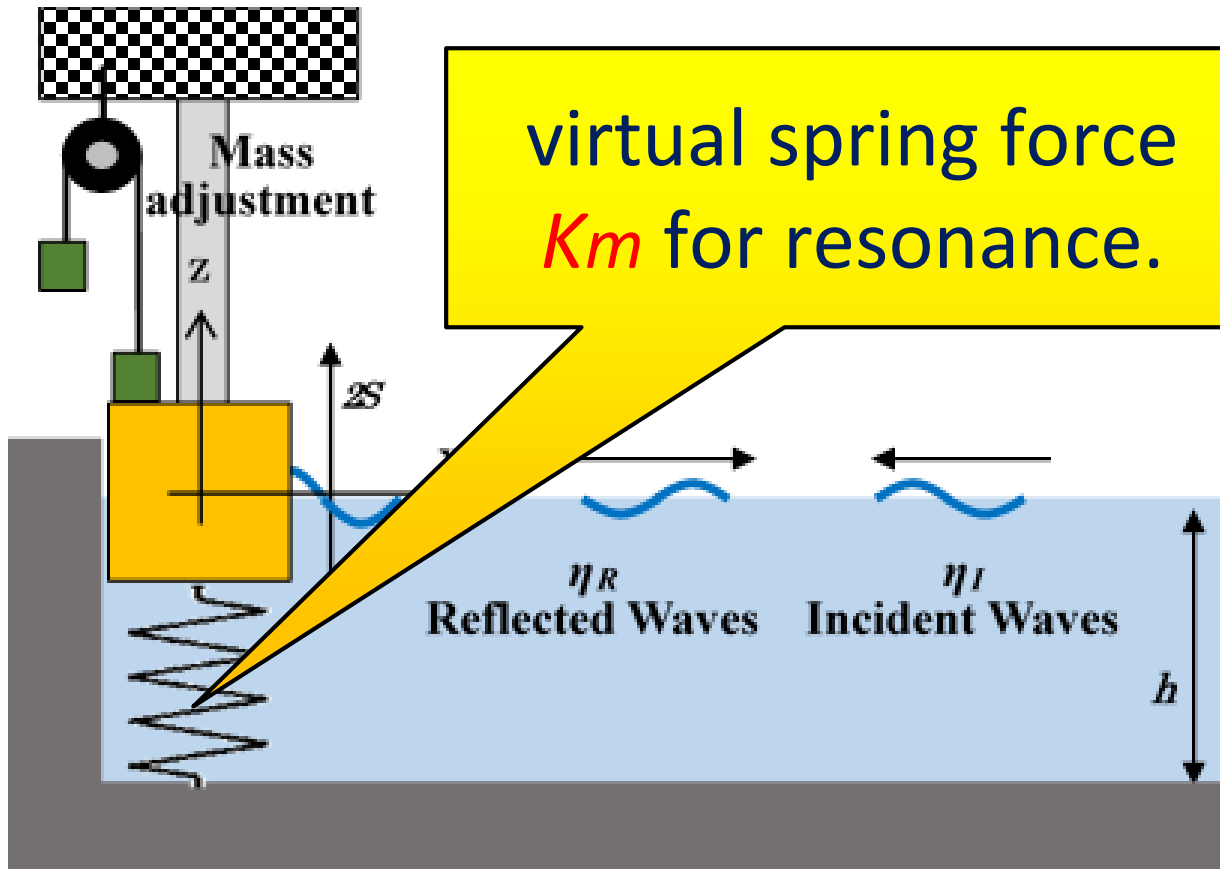
# Resonance by heaving body

$$M\ddot{Z} + C_m\dot{Z} + (K + K_m)Z = F$$



$$\dot{Z} = F / C_m \\ = \omega / \bar{A} \cdot \eta_{I,x=0}$$

virtual spring force  
 $K_m$  for resonance.



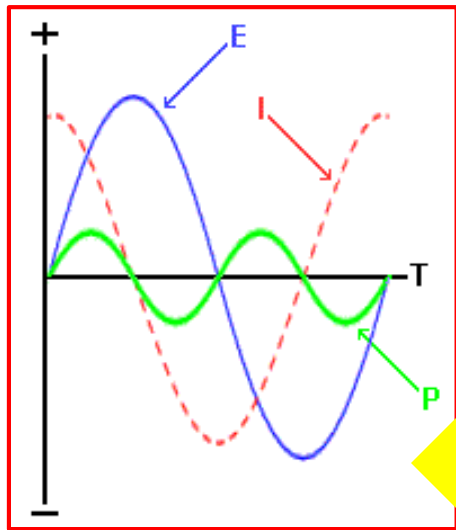
MASS  
SPRING  
DAMPER  
SYSTEM

Forced Oscillation theory

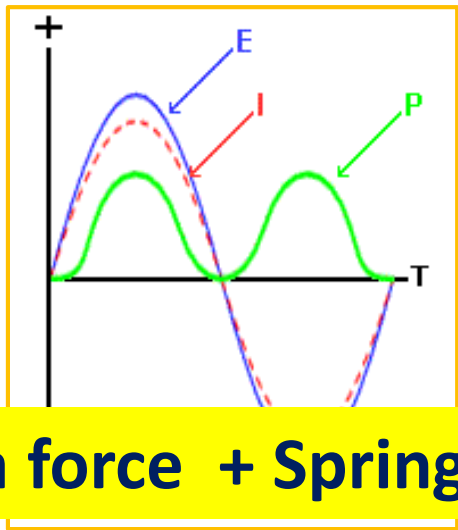
**CIVIL**: in a **C**apacitor the **I** (current) leads **V**oltage, **V**oltage leads **I** (current) in an inductor **L**.

**Forced Oscillation theory  
Four Quadrant Drive**

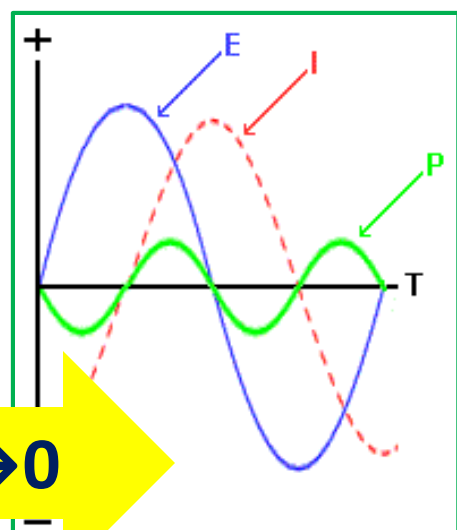
**INERTIA FORCE**  
 $M\ddot{X} \propto \text{Acceleration}$



**DAMPING FORCE**  
 $(N+C_m)\dot{X} \propto \text{Velocity}$



**SPRING FORCE**  
 $KX \propto \text{Displacement}$



**Inertia force + Spring Force → 0**

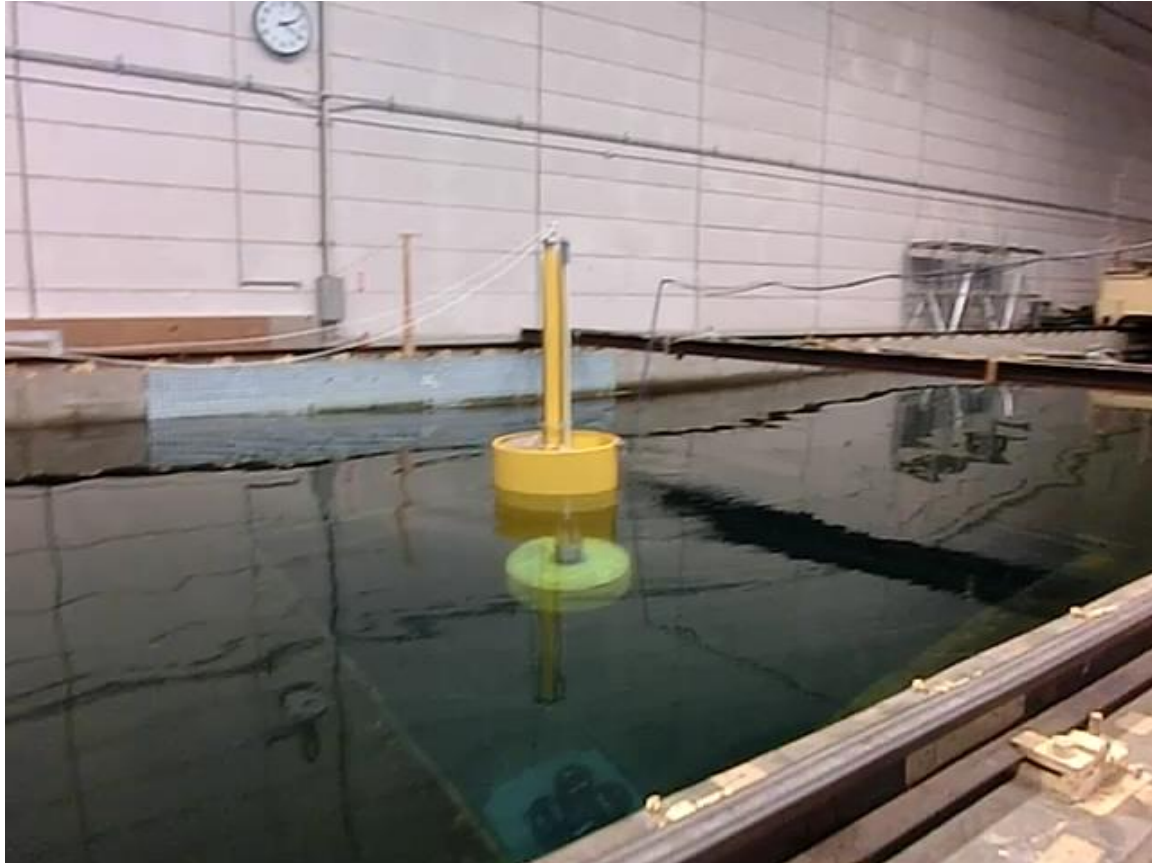
**Reactive power**  
I leads V. (Capacitor)  
Force leads Velocity.

**Real power**  
I & V in-Phase. (Resistor)  
Force & Velocity in-Phase.

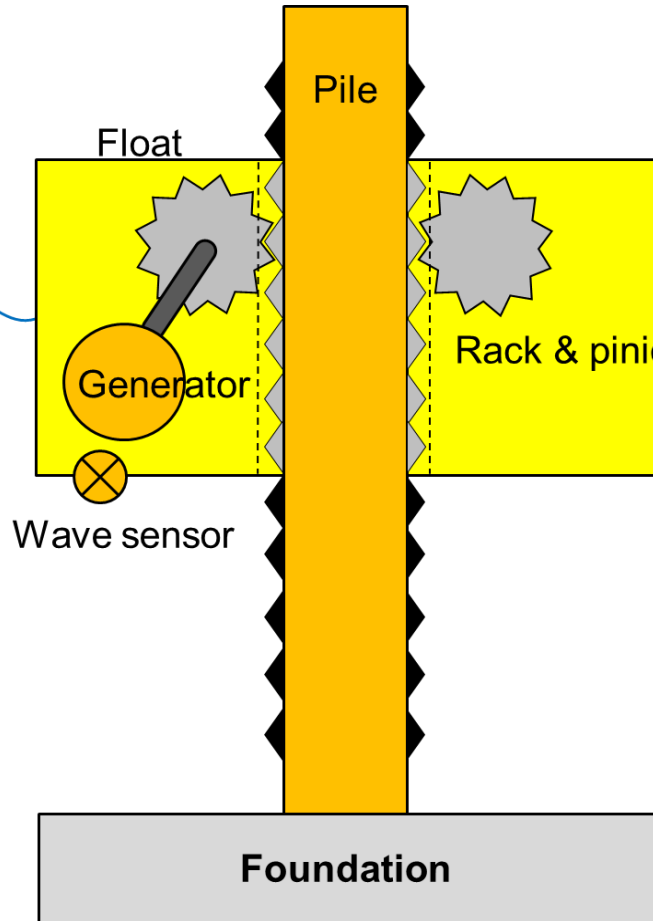
**Reactive power**  
V leads I. (Inductor)  
Velocity leads Force.



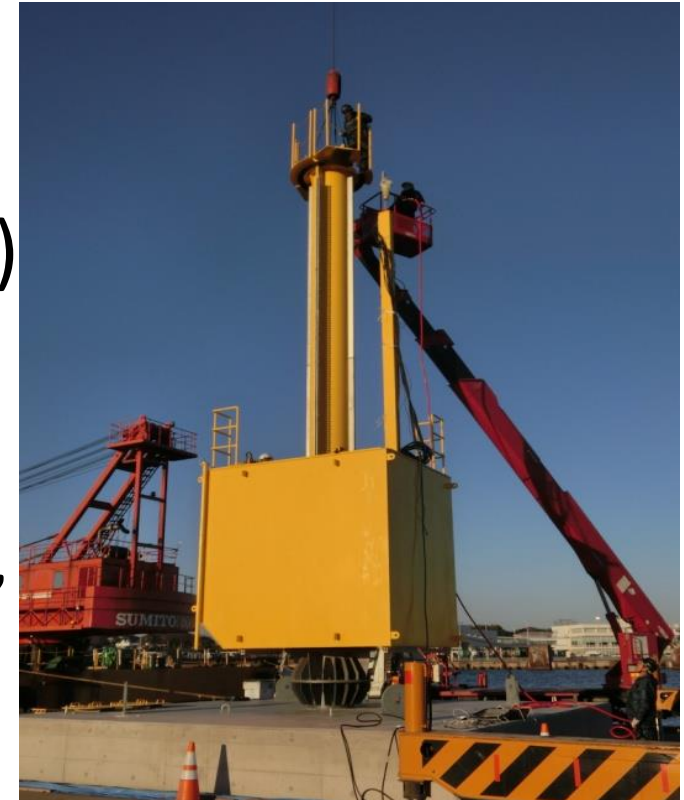
# Tank & Sea Test with Cylindrical Float



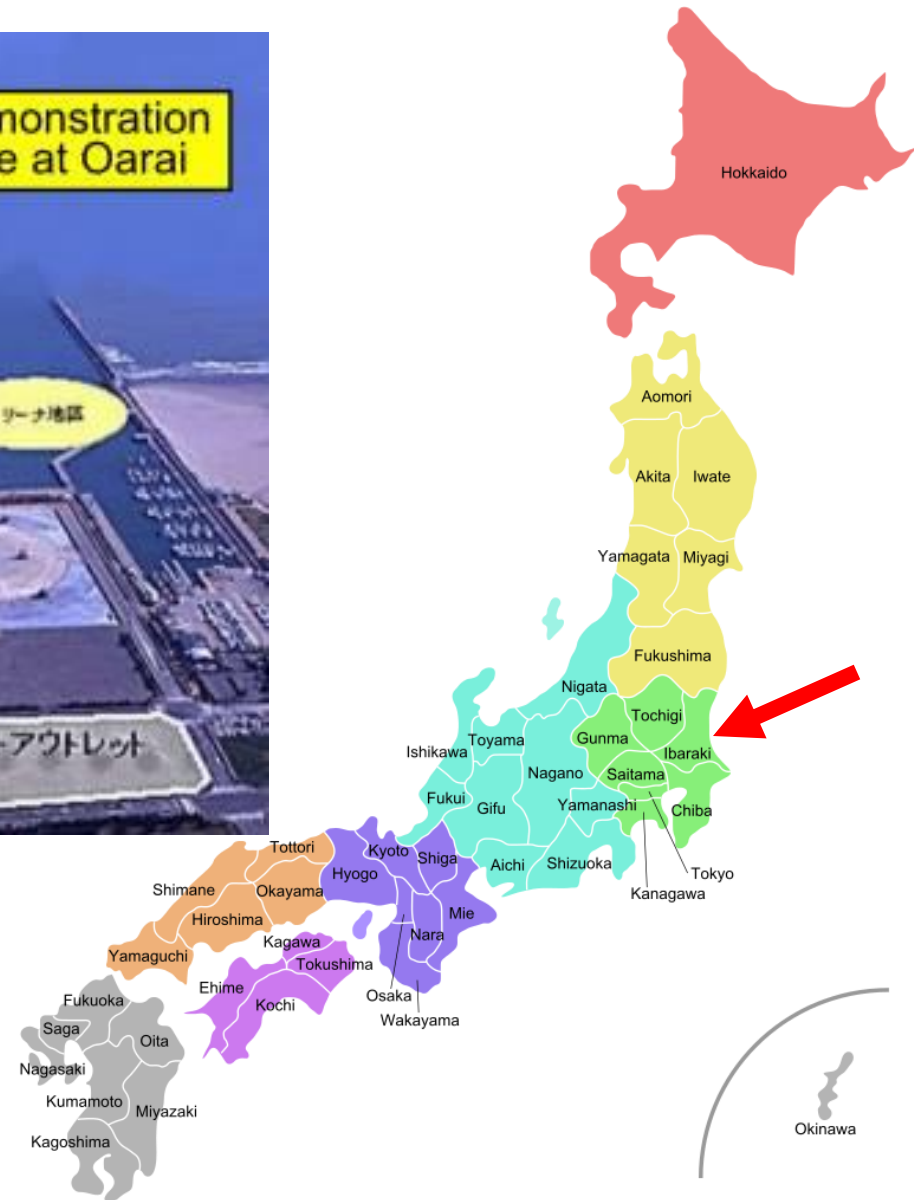
# 20kW WEC Prototype



Considering manufacturing cost, cubic float was selected instead of cylinder. (2.5mW, 3.2mD, 3.0mH)  
Tank testing shows the cubic float are not inferior to the cylinders, in performance.



# Demonstration Site: Oarai, Ibaraki, Japan



# 20kW Prototype with Cubic Float



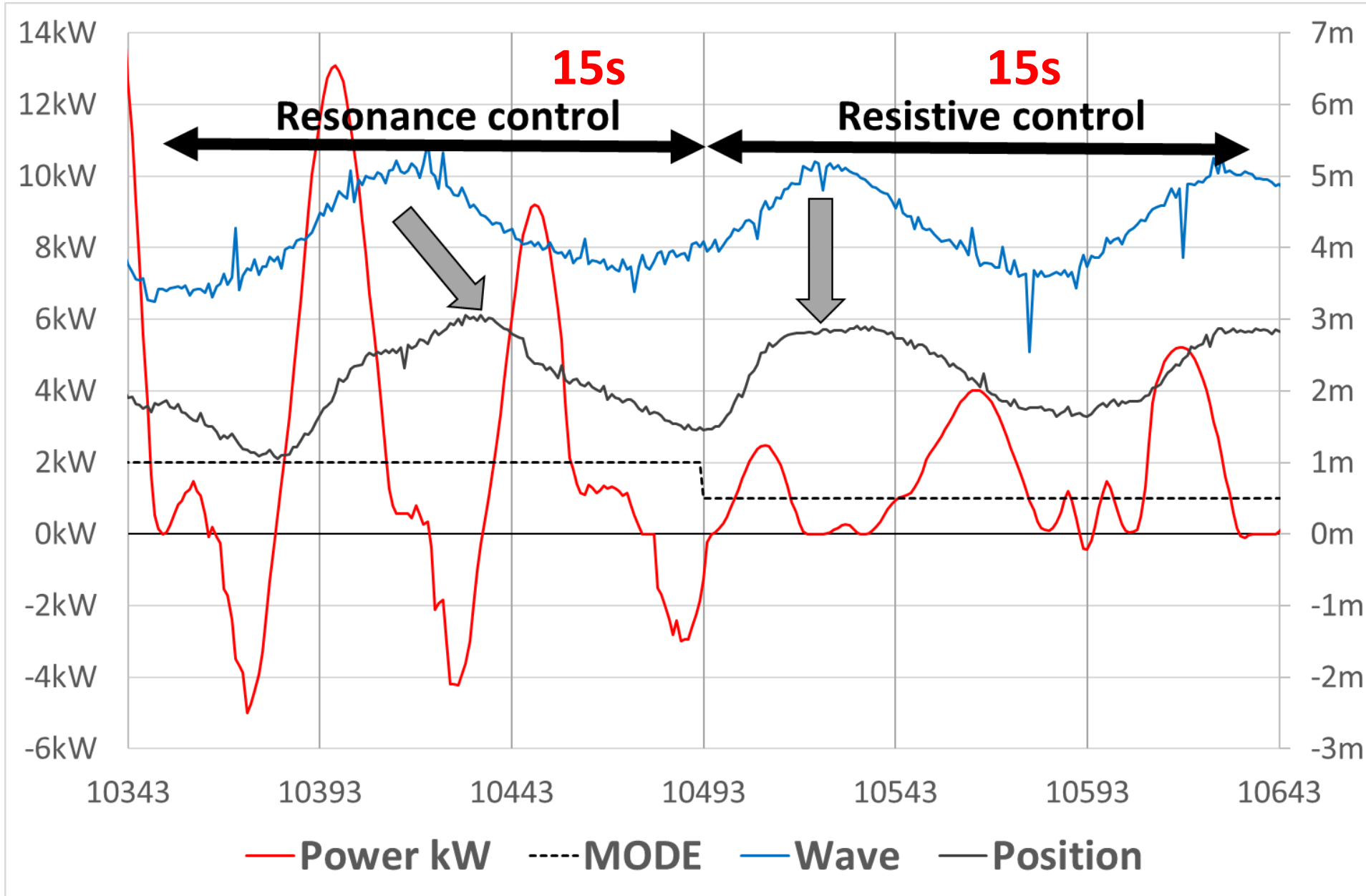
# 20kW Prototype with Cubic Float

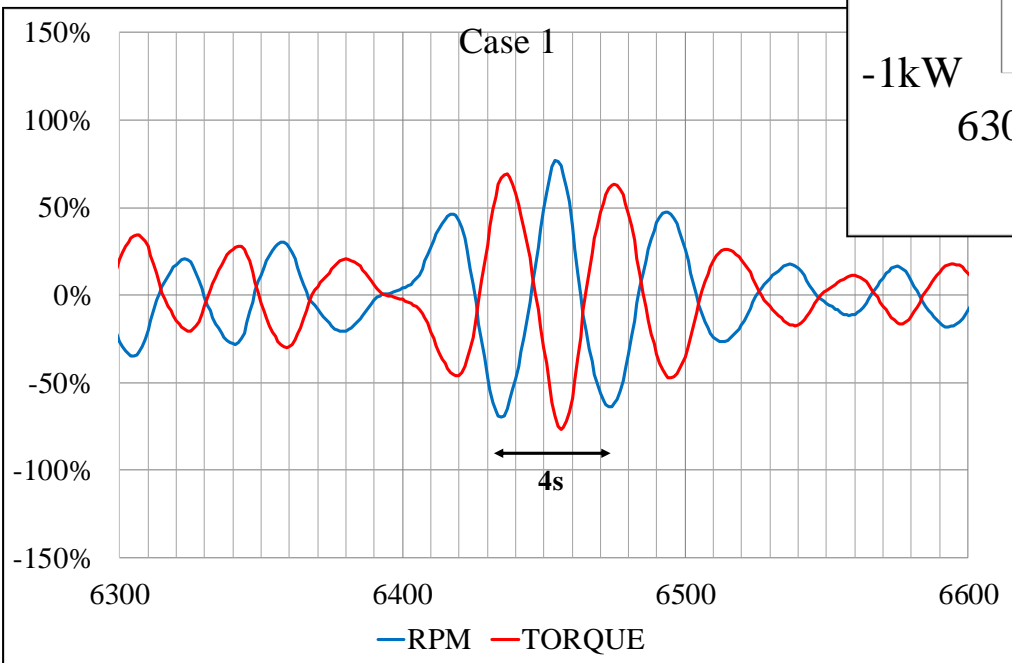
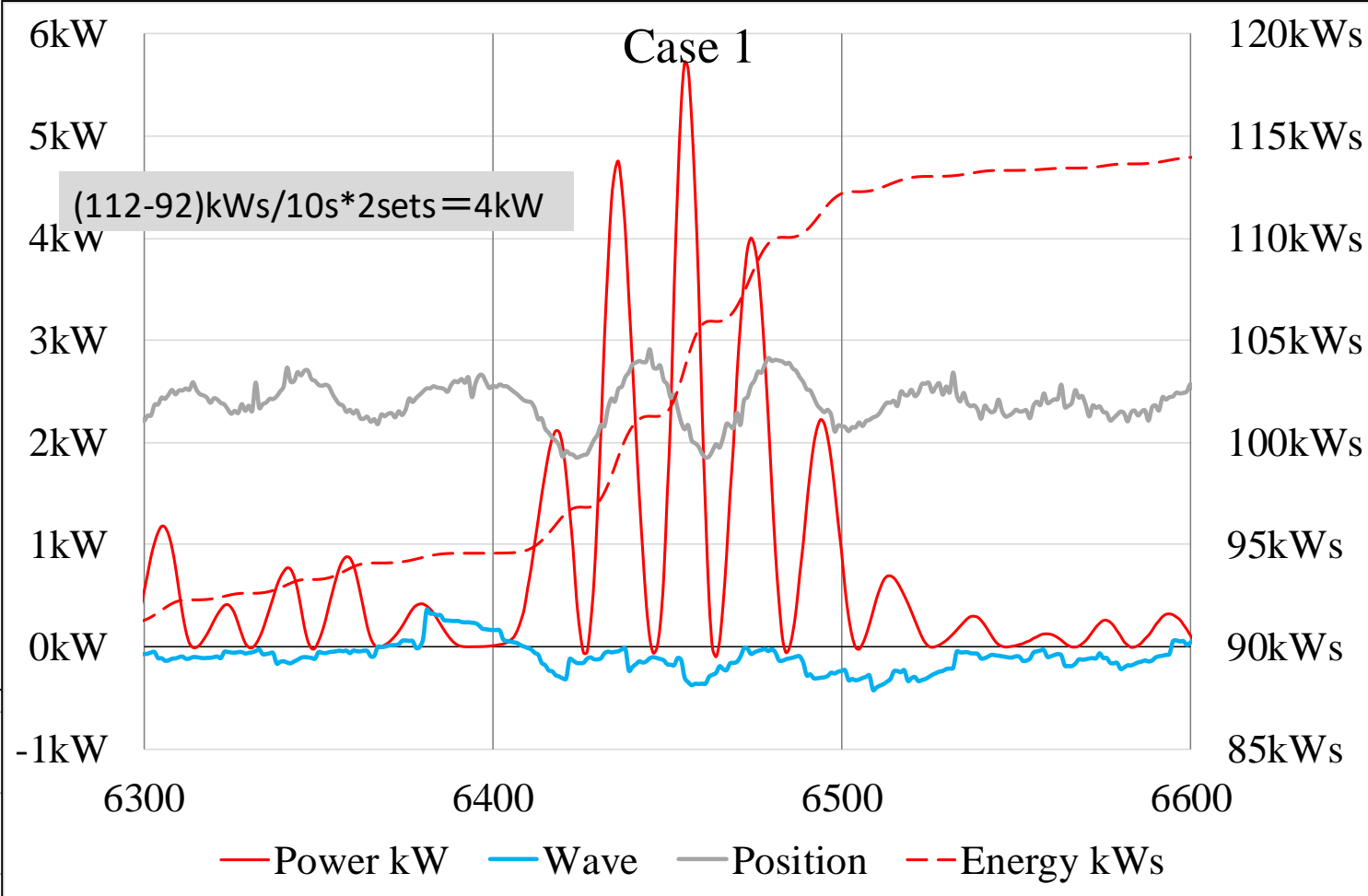
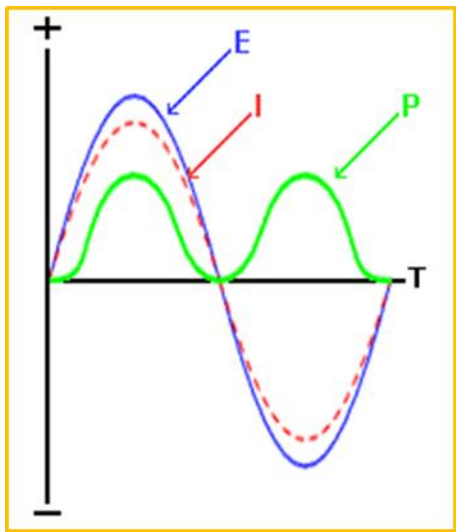
The float sinks to the bottom during a storm.



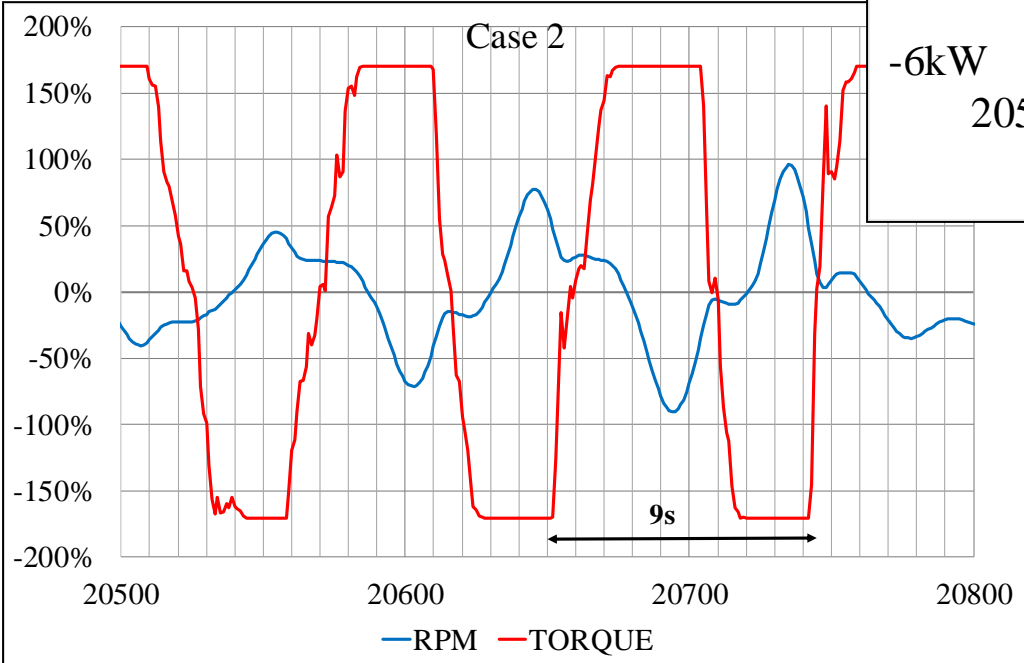
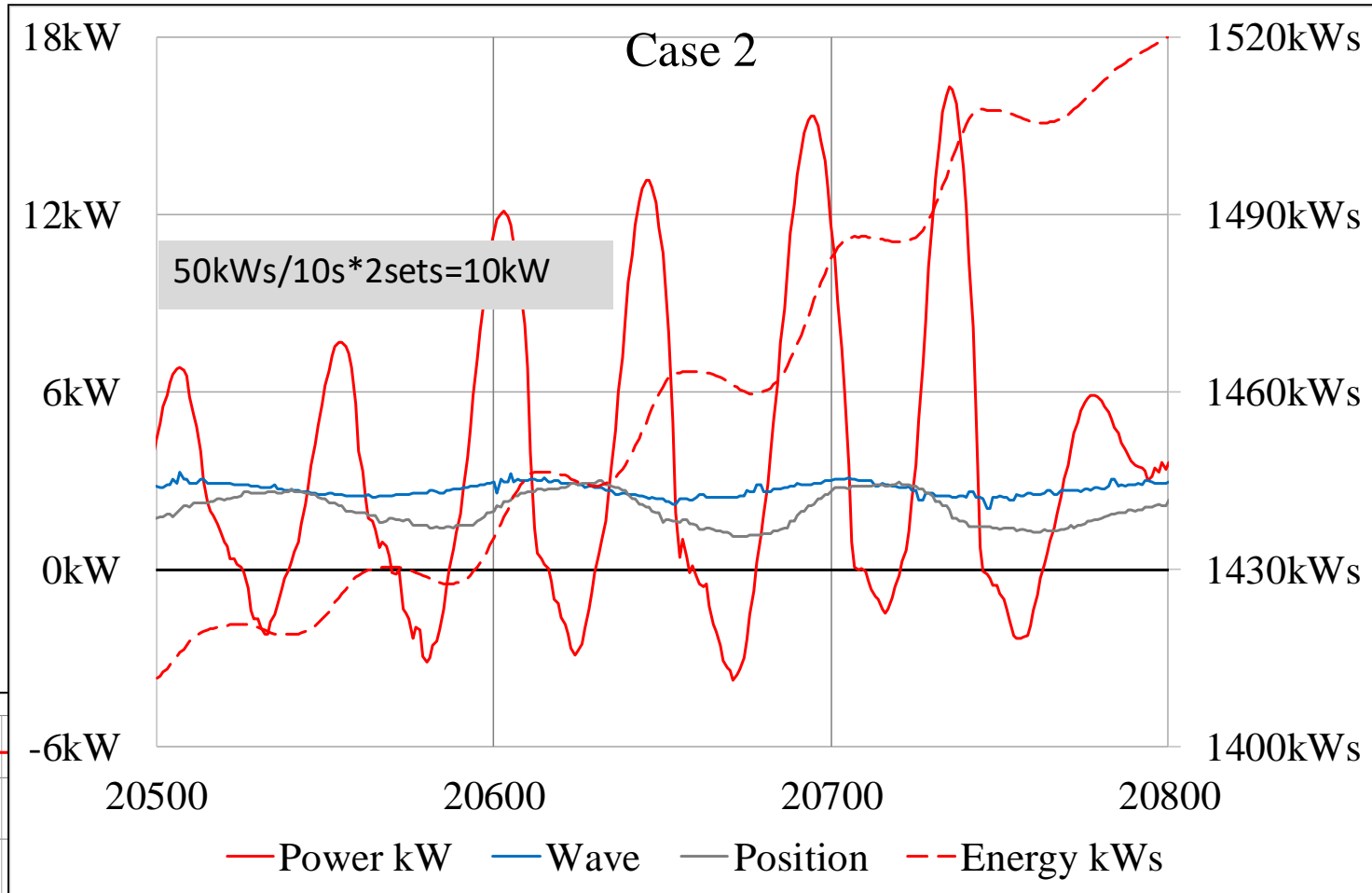
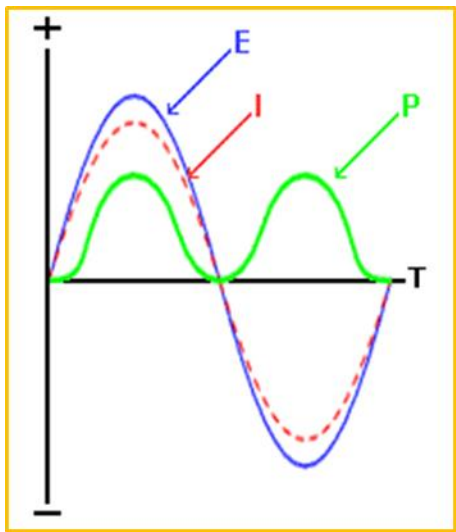


# Case0 $T \approx 10s$ , $H \approx 1.5m$





**Case1  $T \approx 4.2\text{s}$ ,  $H \approx 0.5\text{m}$**



**Case2  $T \approx 9s$ ,  $H \approx 0.55m$**

# *Thank you!*

## Absorption

If you start with **velocity potential theory**, your goal may be absorption.

=

## Resonance

If you start with **forced oscillation theory**, your goal may be resonance.

***Resonance means Absorption!***

