Applicability of a Toroidal Hull Structure for Floating Wind

Kurt Delpeche

Pacifico Energy K.K.

Offshore Wind

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Self Introduction

- Mr Kurt Delpeche
    - Pacifico Energy K.K., Offshore Wind, Japan
    - Foundations Package Manager

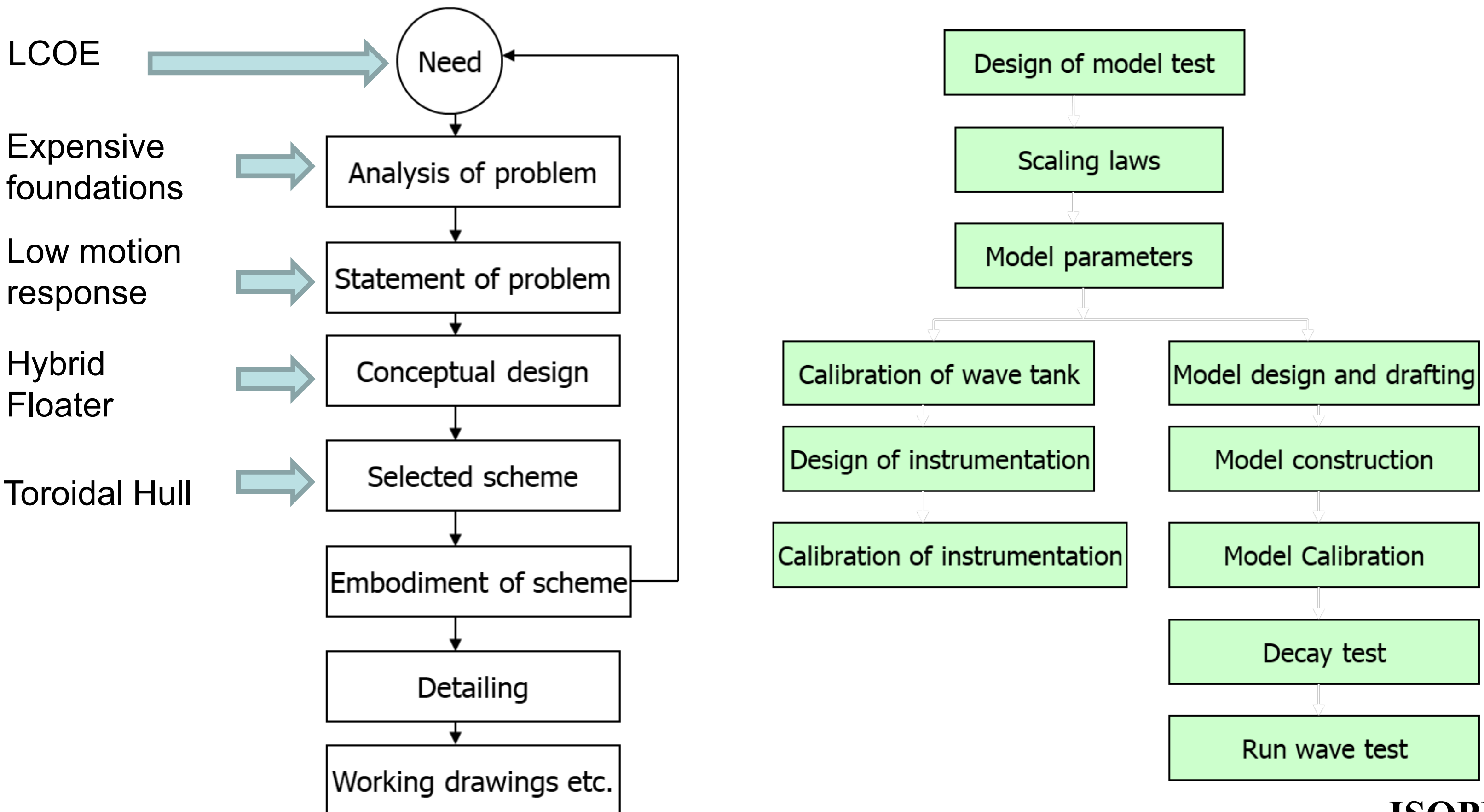
    - MSc in Offshore Engineering, 2008
    - Newcastle University, UK, Marine department
    - Hydrodynamic and Experimental Analysis on a Novel Hybrid Floating Offshore Renewable Energy Structure

Outline

- Background
  - Context
  - Historical concepts
  - Current concepts
  - Toroidal hull concept
- Design and hydrodynamics
- Experimental setup
- Results

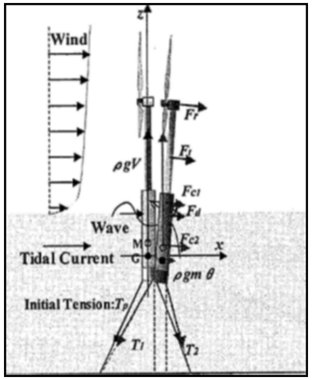
Background

- Context – Design and Modelling Process

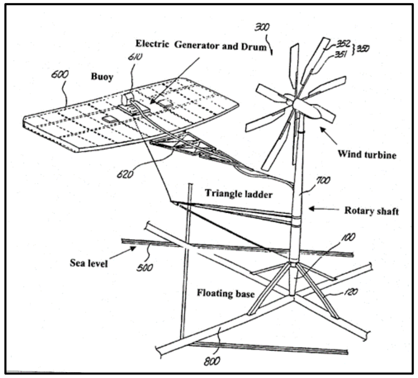


Background

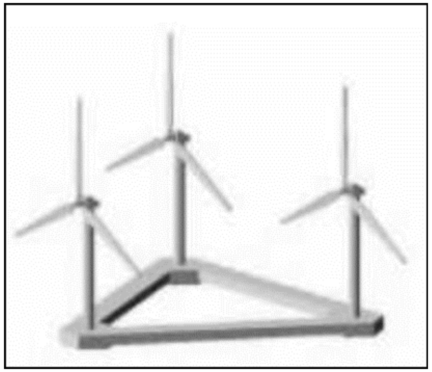
- Historical concepts



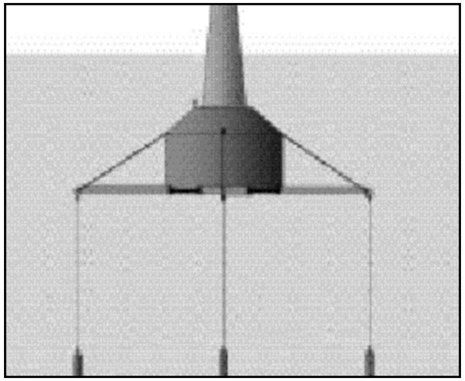
Taut moored SPAR (Susuki et al)



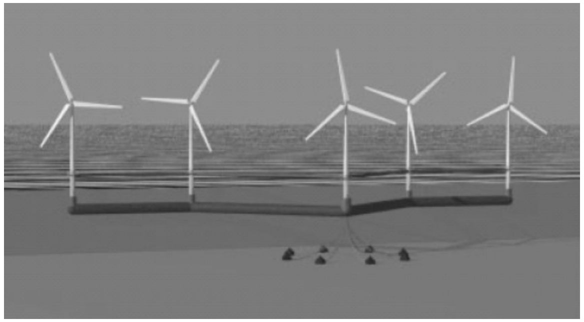
Shim wind-wave device (Cho and Shim, 1999)



Box girder (Ohta et al, 2003)



TLP concept (Musial et al, 2004)



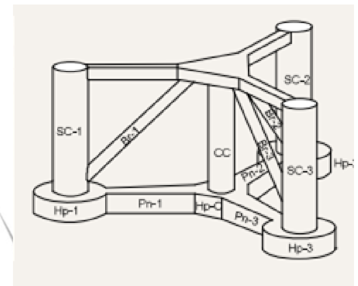
Multi-turbine floater (Henderson, 1997)

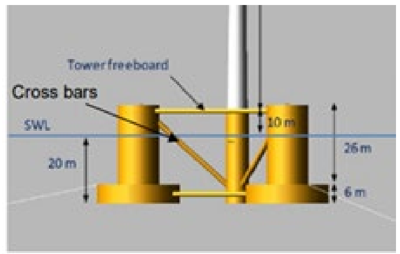
Hywind concept, (Equinor, 2005)

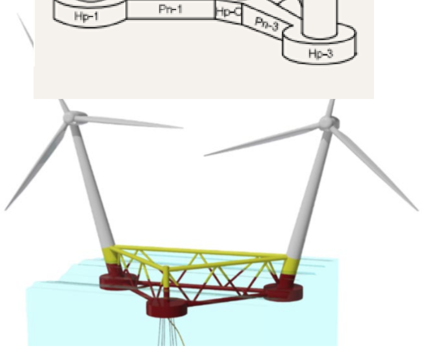
Background

- Current concepts

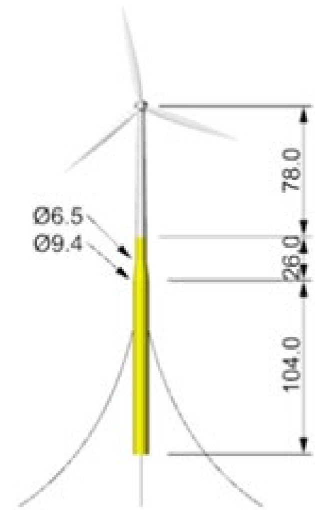
Semi-sub





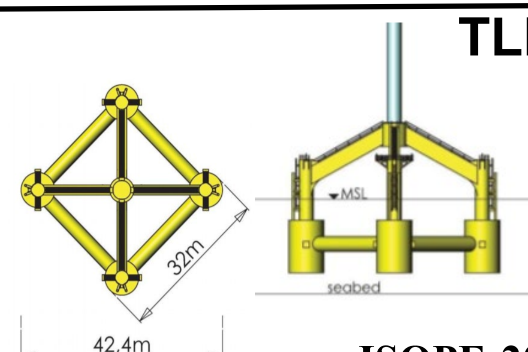


Spar-buoy



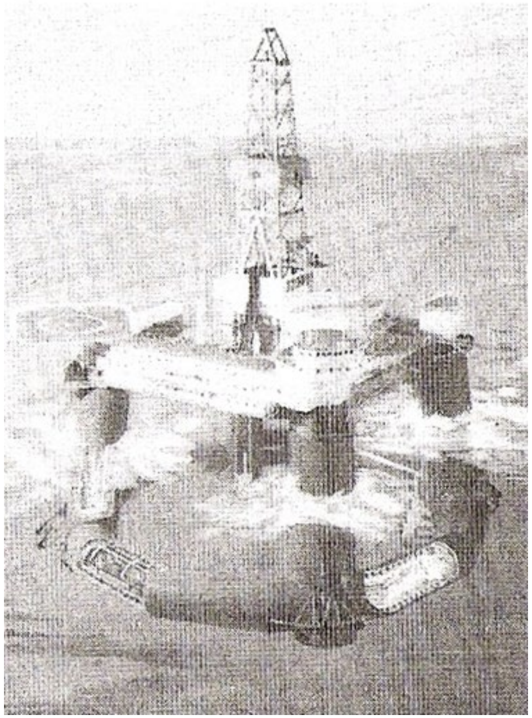
Other Variations

TLP



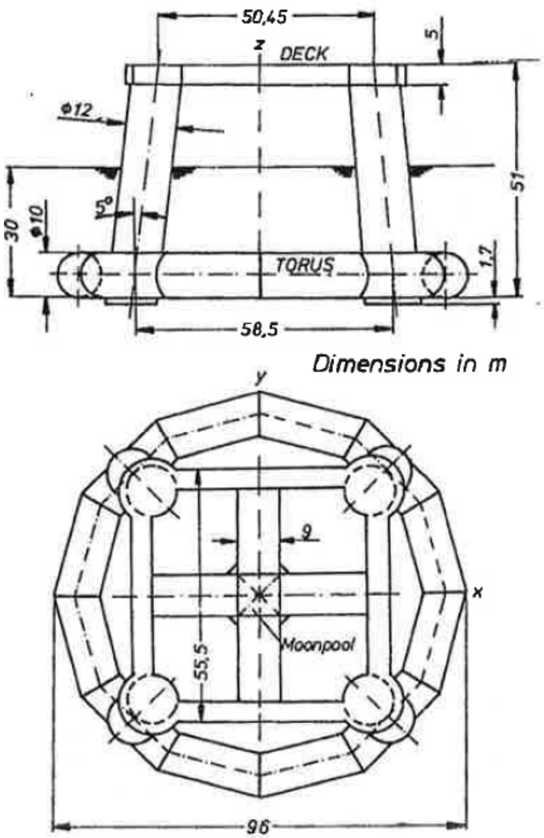
Background

- Toroidal hull – a historical concept
  - ❑ The toroidal hull concept was first suggested by ERNO Raumfahrttechnik GmbH and partners as a new design of semi-submersible called the RS 35 for rough weather operation (Source: The naval architect, 1980)
  - ❑ The symmetrical arrangement is said to give good motion characteristics and eliminated the need for cross bracing.
  - ❑ The toroidal form was suggested for the design of underwater missile launches and an underwater space station (Ross, 2005)



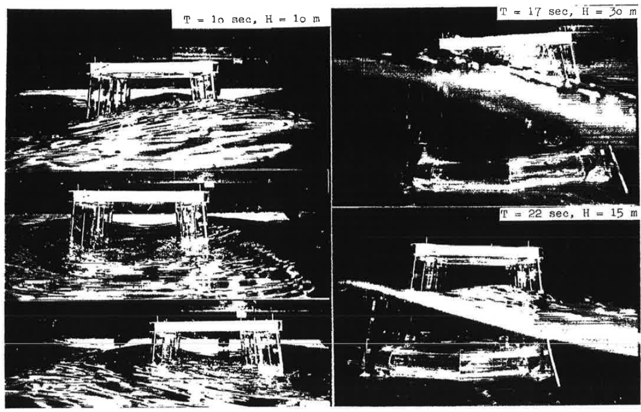
Background

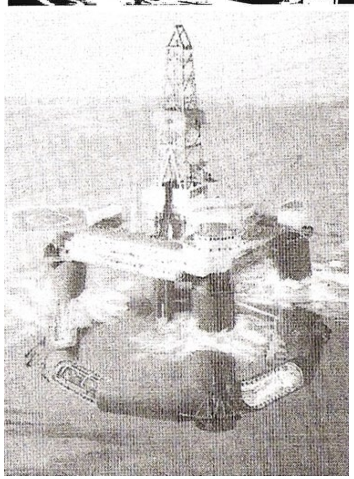
- Toroidal hull – scale of the structure
  - ❑ Ring-hull: overall diameter of about **100 m**
  - ❑ Tubular sections: diameter of about **10 m**
  - ❑ Vertical columns: diameter of about **12 m**
  - ❑ In its operational mode the ring-hull is submerged to a depth of about **20 m**



Background

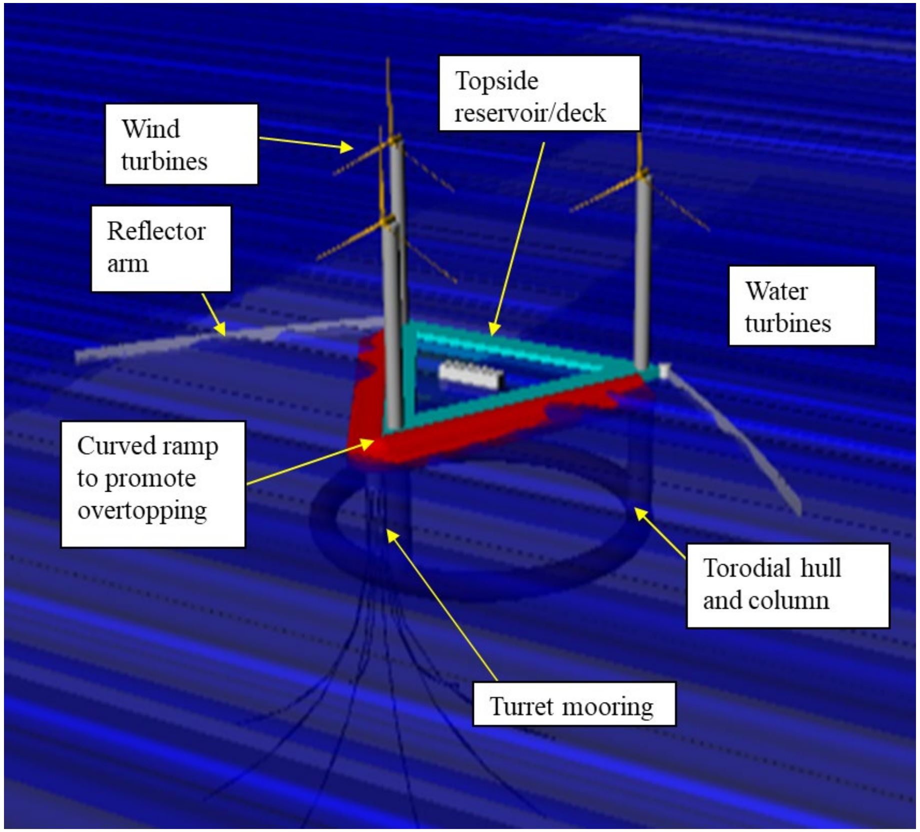
- Toroidal hull – historical results of seakeeping tests
  - The transfer function of **heave, surge** and **pitch** prove the **excellent response characteristics of this design**
  - In the period range of 5-12 **the platform motions** are **extremely small** since **<u>the forces acting on the submerged torus are nearly cancelled by the forces on the columns</u>**.
  - The **drag resistance** of the ring structure is about **half of the transverse resistance** of a comparable twin hull semi-submersible.





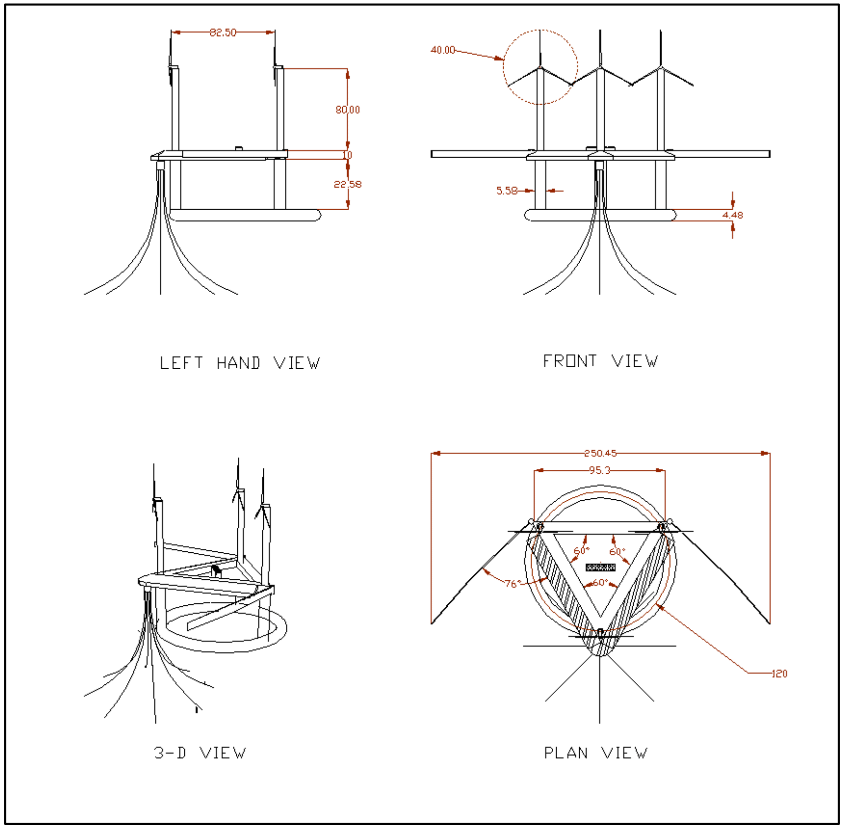
Design and Hydrodynamics

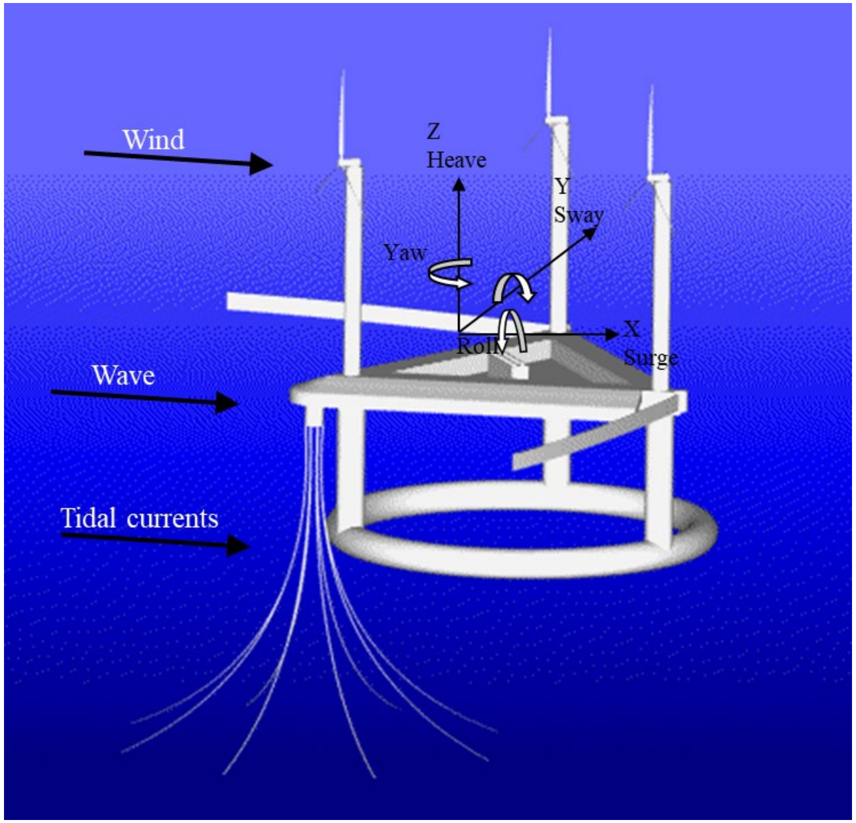
- Toroidal hull applied to a hybrid wind and wave energy structure



Design and Hydrodynamics

- Specifications, Motions and Forces





Design and Hydrodynamics

- Forces
  1. The variation in **pressure** due to the passage of the wave – the **Froude-Krylov force**
  2. **Inertia forces** due to the effects of the acceleration of the particles within the wave on the **added virtual mass** of the body

○ Surface wave→ $y = \zeta_0 \cos(kx - \omega t)$, where $\zeta_0 = 0.5H_w$

○ Heave response → $(M + M_{AVM,y})\ddot{y} + c\dot{y} + ky.y = F_{WAVE}$

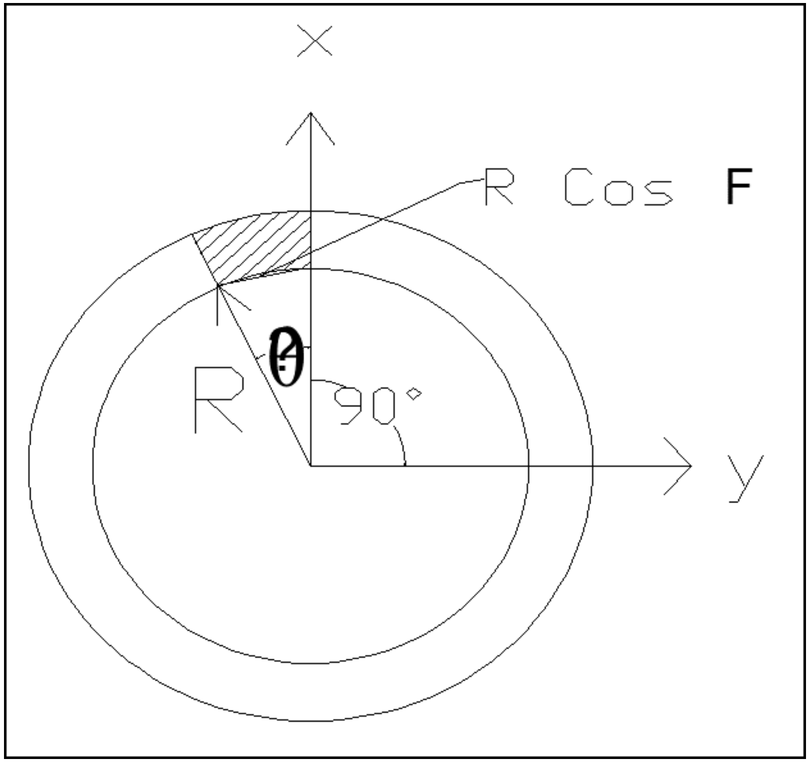
○ Solution→

$$y = \frac{\left(F_{wave}/K_{,y}\right)\cos(\omega t + \phi)}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left(\frac{2\omega}{\omega_n}\omega_d\right)^2}}$$

$$RAO(\omega) = \frac{F(\varpi)}{-m.\varpi^2 + k}$$

Design and Hydrodynamics

- Torus
  - ❑ The **added mass** and **drag coefficients** are two critical parameters for accurate prediction of hydrodynamic forces on the floater.
  - ❑ The added mass can be deduced from a simple strip theory, as the product of the two dimensional added mass and the circumference of the torus.



Design and Hydrodynamics

- Evaluation of Added-Mass and Forces on a Torus

$$b_{33} \cong \pi c B_{33}$$

$$m_{33} \cong 2\pi c M_{33} \cong \left[\frac{(1-4)}{(3\pi K a) m} \right]$$

$$F_{hull} = -2\pi R.\omega^2.\zeta_0.e^{-kz}.[\cos(KR.\cos.\theta)]$$

$$J_0(Z) = \frac{1}{2\pi} \int_0^{2\pi} \cos(Z \cos\theta) d\theta$$

$$J_1(Z) = \frac{1}{2\pi} \int_0^{2\pi} \cos\theta \sin(Z \cos\theta) d\theta$$

Experimental Set-up

- Modelling Criteria
  - **Using Froude's law** and the sale as **λ (1:200)**

VARIABLE	UNIT	SCALE FACTOR	REMARKS
Length	L	λ	Any characteristic dimension of the object
Displacement	L	λ	Position at rest is considered as zero
Natural Period	T	$\lambda^{1/2}$	Period at which inertia force = restoring force
Force	MLT^{-2}	λ^{3}	Action of one body on another tend to change the state of motion on the body
Wave Height	L	λ	Consecutive crest to trough distance
Density	ML^{-3}	λ	Mass per unit volume

Experimental Set-up

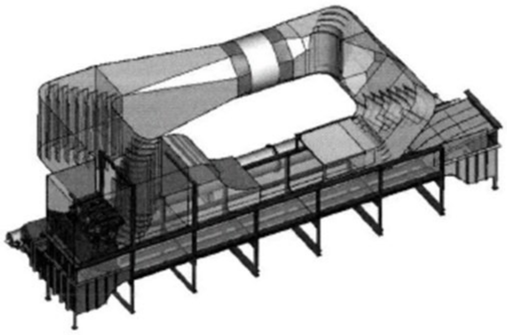
- Scaled components

Item	Geometry	Prototype Dimension [m]	Model Dimensions [m]
Pontoon	Diameter 1	120	0.600
	Diameter 2	4.48	0.022
Column	Diameter	5.58	0.028
	Height	22.58	0.113
Deck	Length	95.3	0.477
	Height	10	0.050
Tower	Length	80	0.400
	Diameter	5	0.025
Turbine	Rotor Diameter	40	0.200

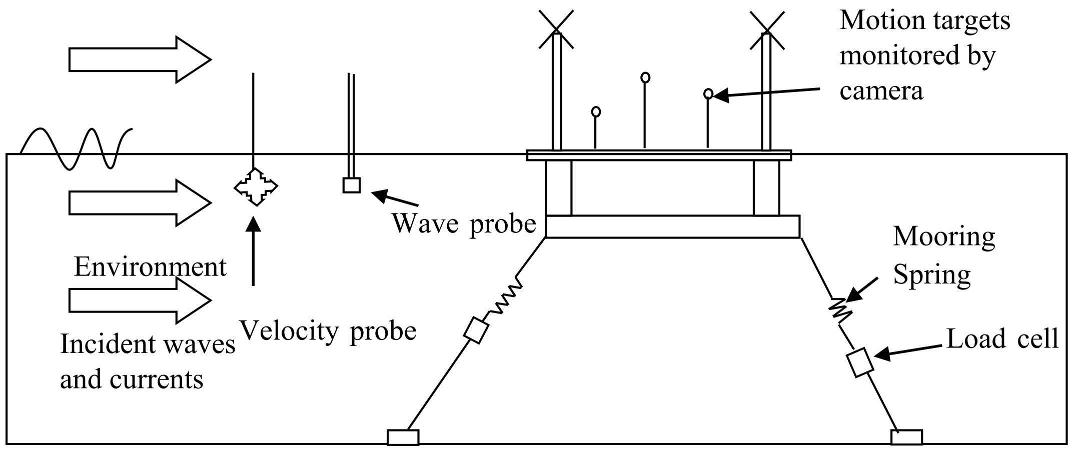
Experimental Set-up

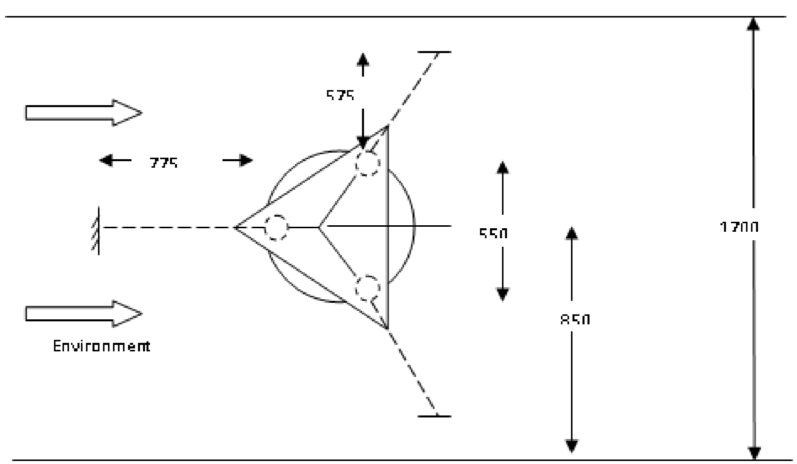
❑ Specifications

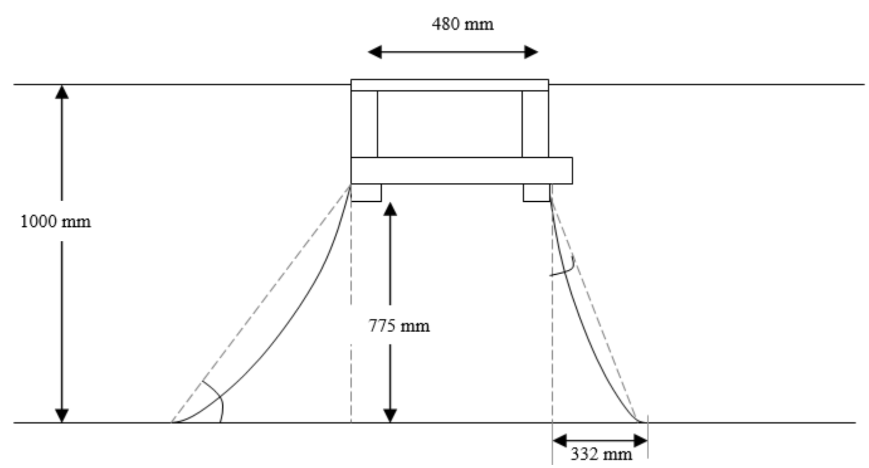
Flume length	11 m
Width	1.8 m
Water depth	1 m
Air Clearance	1 m
Central measurement section	3 m
Water velocity	1 m/s
Wind velocity	20 m/s
Period Range	0.8 – 4 sec
Wave height	0.02 -0.2m (Period Dependent)



Experimental Set-up







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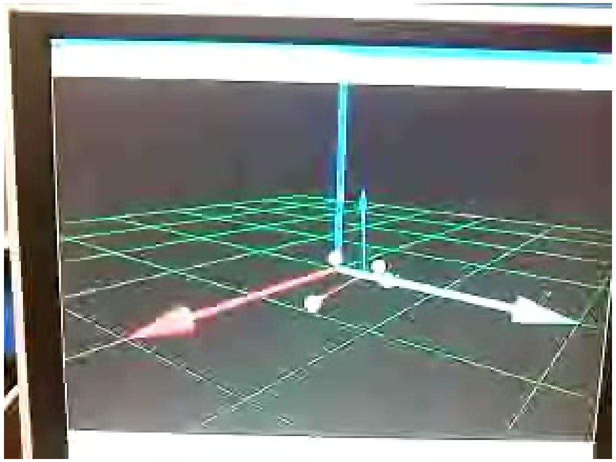
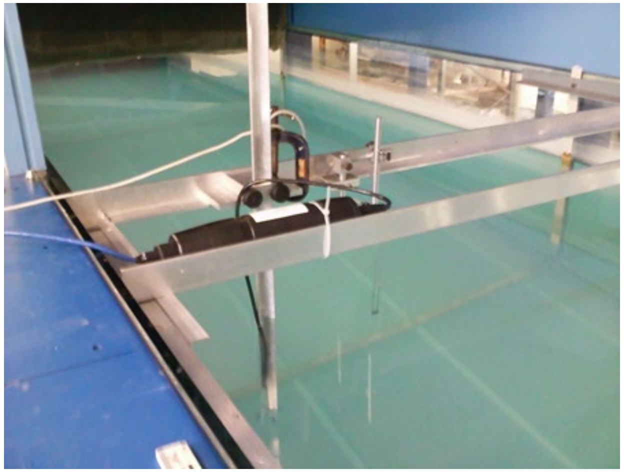
Experimental Set-up

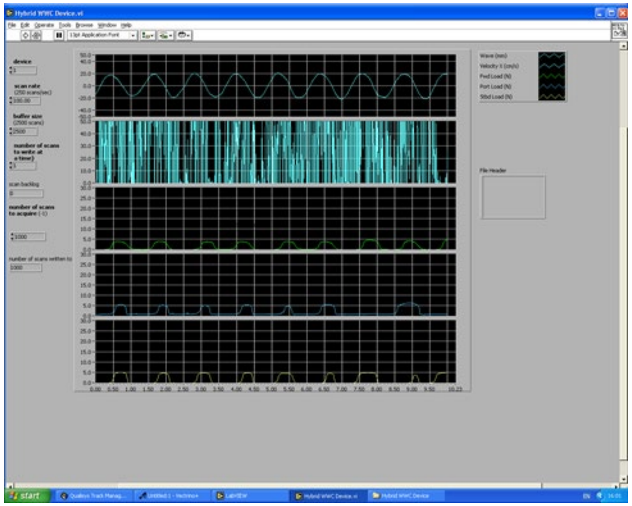
- Instrumentation
  - ❑ QUALYSIS motion tracking system
    - ➢ Displacement
  - ❑ Ventrino+ velocity probe
    - ➢ Water particle velocity
  - ❑ Capacity probe
    - ➢ Wave motion





Experimental Set-up

- Instrumentation
  - ❑ Load cells
  - ❑ Data acquisition system- LabView



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Results

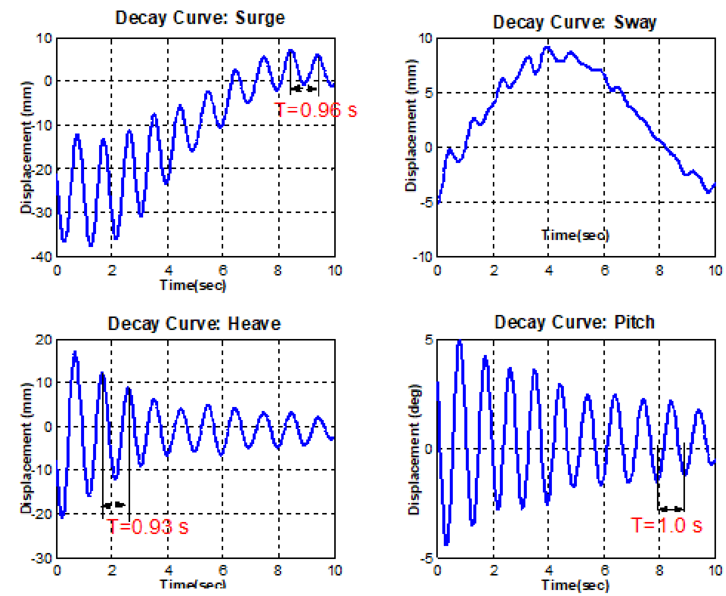
- Decay test
  - ❑ Computation of the damped frequency motion
  - ❑ Extinction curve for the structure in heave
  - ❑ Added mass and damping

$$m = -\xi\omega_N$$

$$\omega_d = \omega_N\sqrt{1-\xi^2}$$

$$\xi = 0.0468$$

$$\omega_N = 6.75 rad/\sec$$



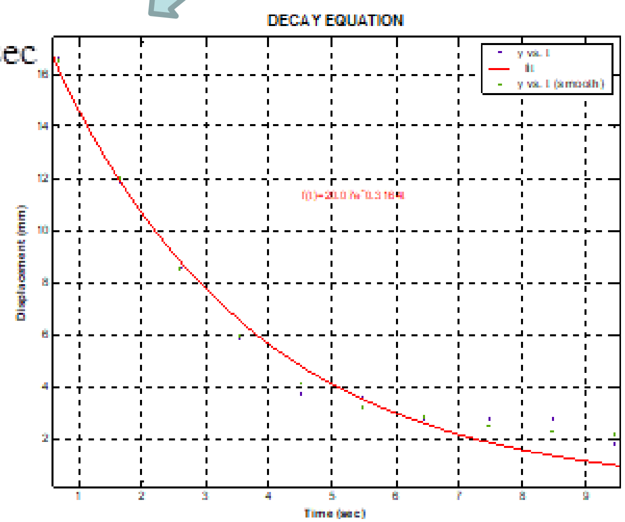
$$M_{am} = M - M_0 = \frac{k}{\omega_N^2} - M_0$$

$$= 28.6kg$$

$$C = 2M\xi\omega_N$$

$$= 2(15.17)(0.0468)(6.75)$$

$$= 9.58kg\_rad/\sec$$



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Results

Low waves, long period

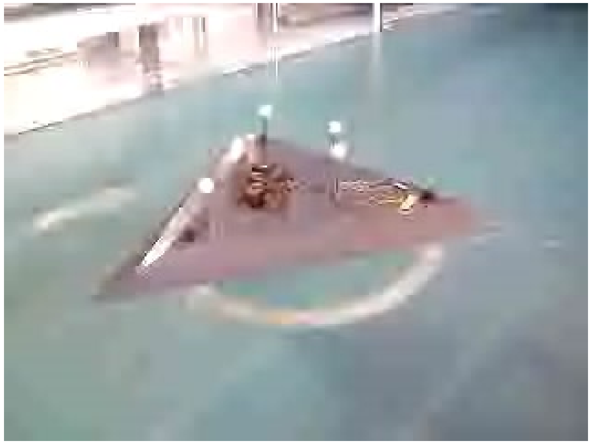
High waves, short period

Medium current only

Medium waves, long period

High waves, long period

Low current only



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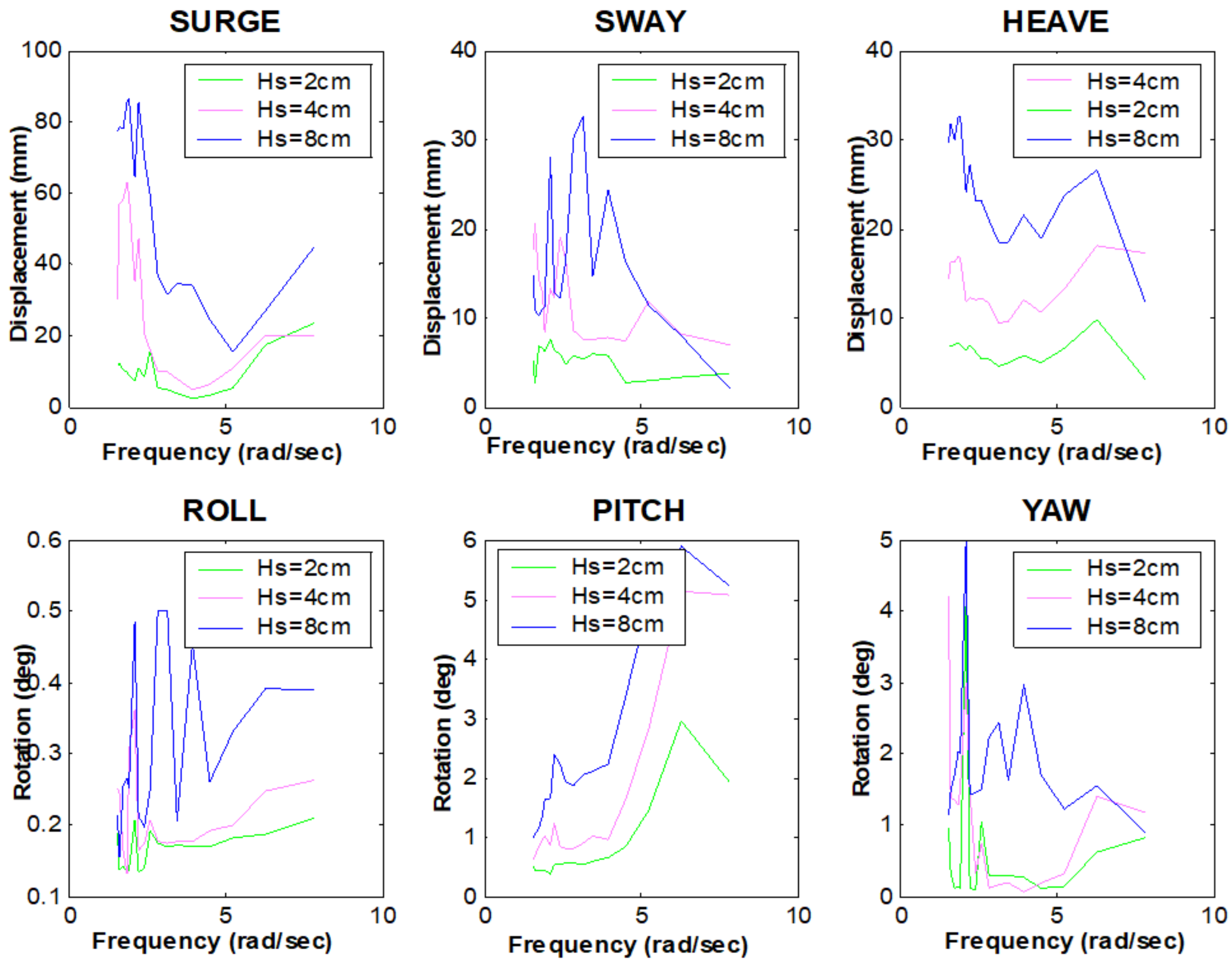
Results



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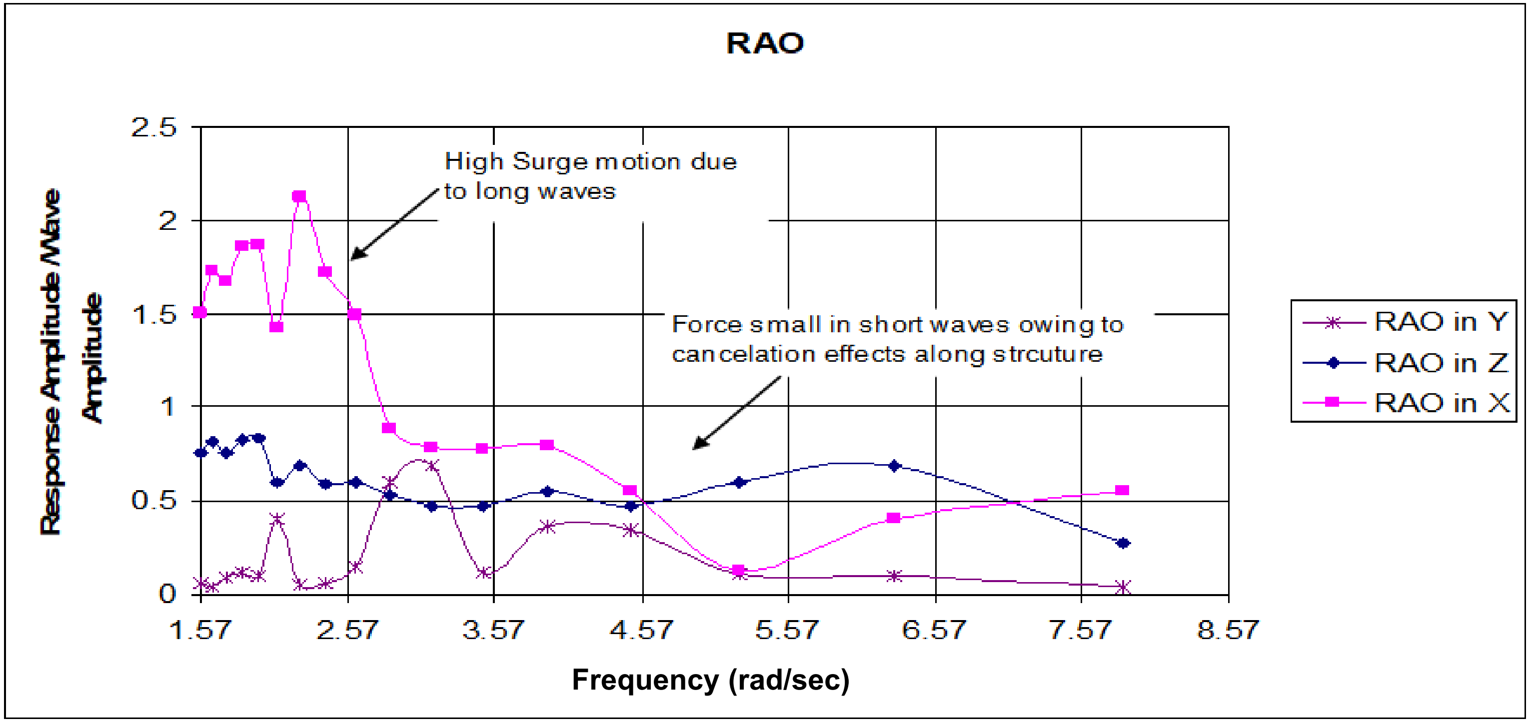
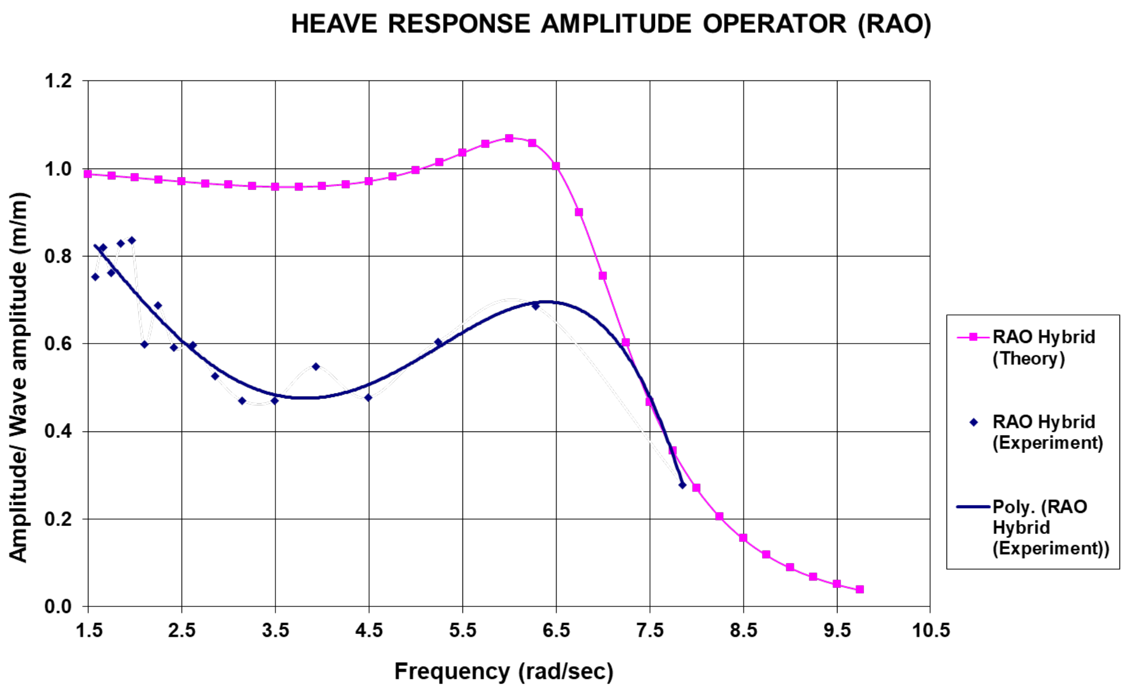
Results

- RAOs (Heave, Surge, Pitch)



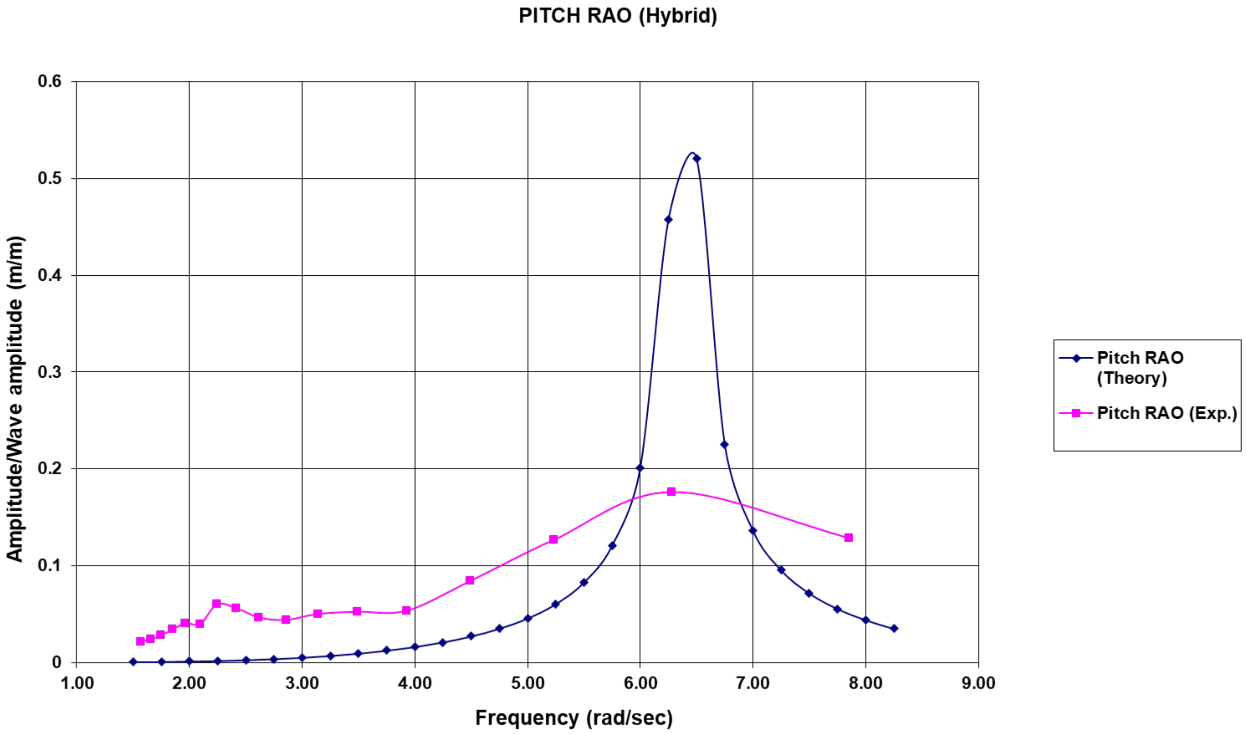
Results

- Heave RAO



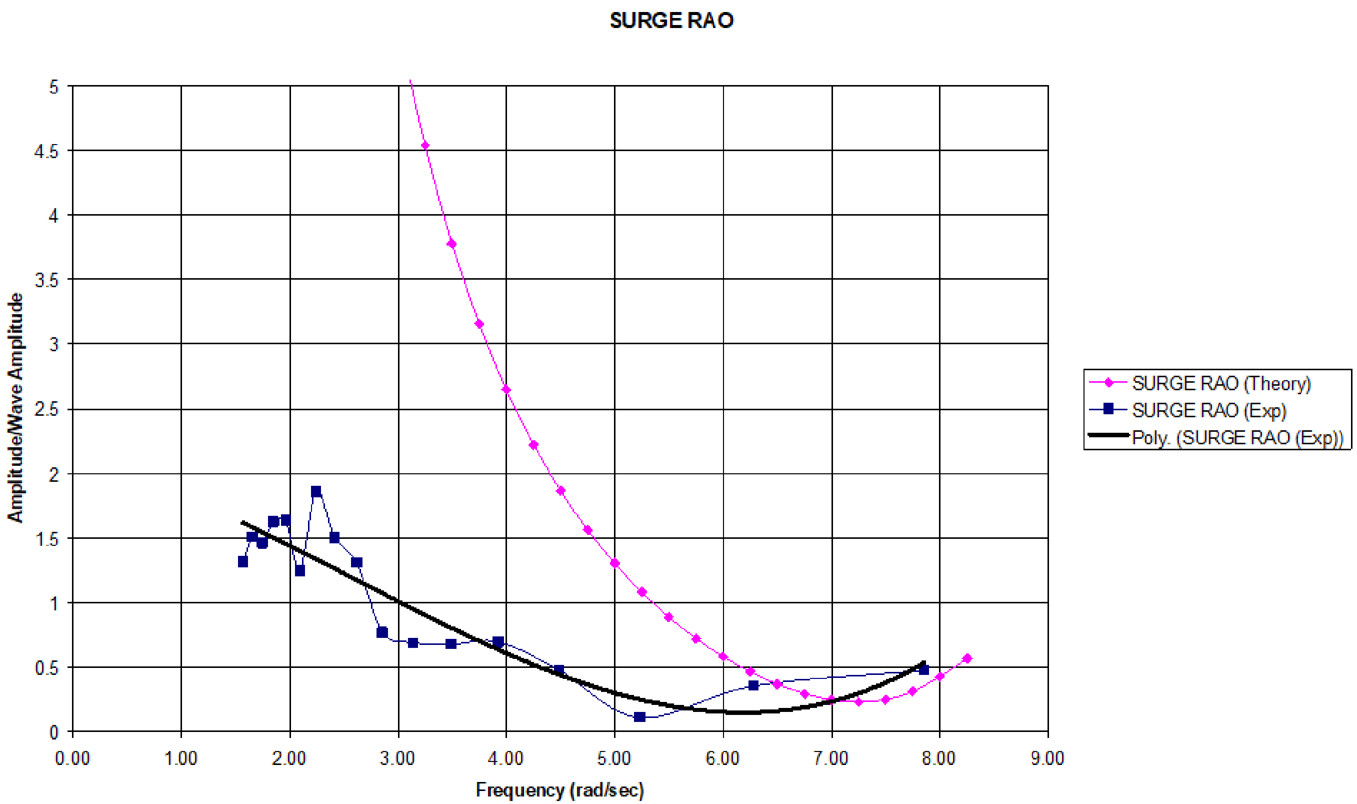
Results

- Pitch RAO



Results

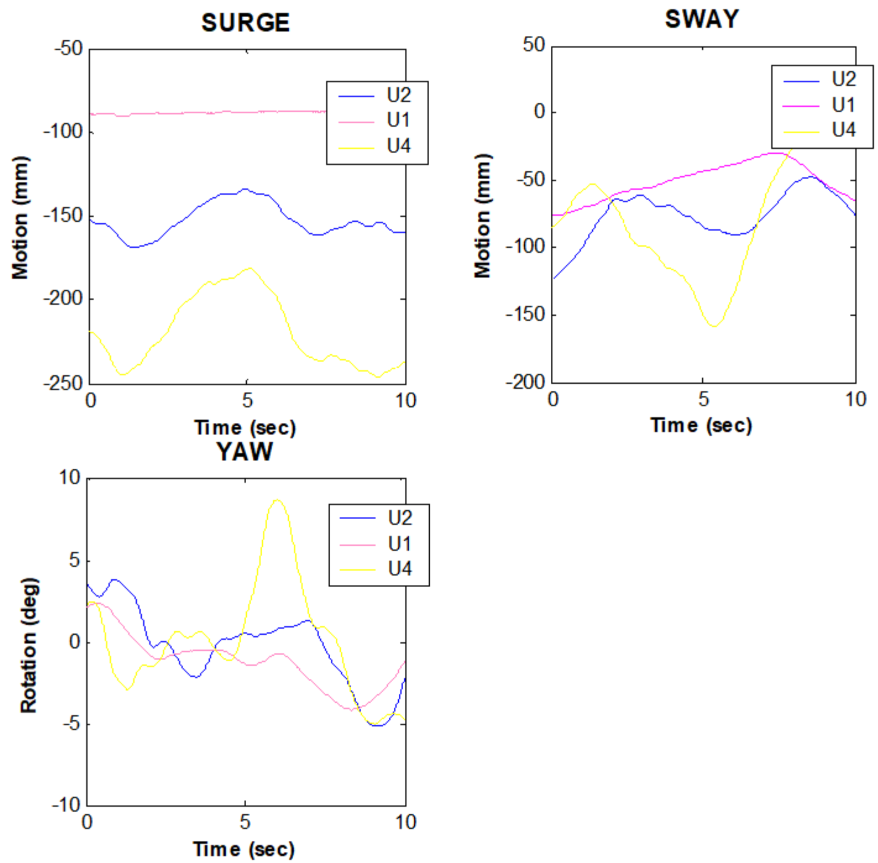
- Surge RAO



Results

- Motions with current only

Test number U	Test speed (m/s)
1	0.2
2	0.365
3	0.42
4	0.45



Conclusion

- The torus is unique in several aspects.
- The results gives an overview of the hydrodynamic properties of the deep submerged toroidal displacement structure with its circular cross section combined with a barge type structure.
- Possible application with large renewable energy structures such as floating islands as well as using VAWT.
- Detailed numerical modelling is required including the combined wind turbine dynamics and a comparison with other floater types.

Thank you for your time!

Kurt Delpeche

Pacifico Energy K.K.

Roppongi Grand Tower 37F,
3-2-1 Roppongi, Minato-ku, Tokyo 106-0032, Japan
Tel： +81-3-4540-7838 (Direct)
Mobile: +81-80-2301-7553
Email： kdelpeche@pacificoenergy.jp