KRISO KOREA RESEARCH INSTITUTE OF SHIPS & OCEAN ENGINEERING

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An Experimental Study for Global Performance of a FOWT using Real Time Hybrid Method

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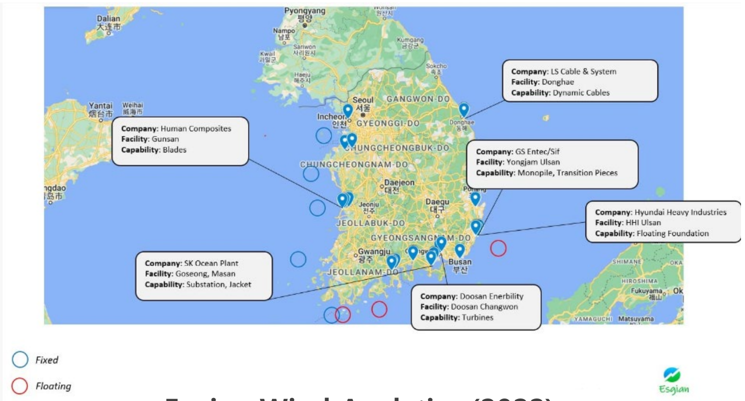
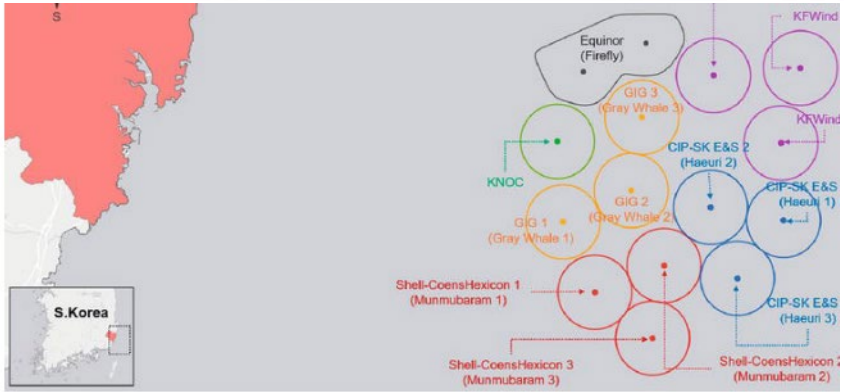
FOWT Projects in South Korea



Esgian Wind Analytics (2022)



Ryu et al. (2022)

Developer	Project	Capacity	Type	Site
SKecoplant & POSCO	-	1GW <	Floating (+Fixed Types)	Yeonggwang & Southestern
GIG/Total Energies/SKecoplant	BadaEnergy	1GW		Maenggol Channel & Geomun Island
GIG/Total Energies	BadaEnergy (Gray Whale)	1.512GW	Floating type	Ulsan
Equinor	Firefly	804MW		
CIP	Haeuri	1.563GW		
Shell/CoensHexicon	Munmubaram	1.26GW		
Korea Floating Wind	KFWind & East Blue Power	1.32GW		
KNOC/KOEWP/Equinor	Donghae	200MW		
TOTAL		8.659GW <		

Representative Guidelines for Model Test of FOWT

Document	Title
IEC61400-3-2	Wind energy generation systems-Part 3-2: Design requirements for floating offshore wind turbines
DNV-ST-0119	Floating wind turbine structures 2021
DNV-RP-0286	Coupled analysis of floating wind turbines 2019
ITTC-7.5-02-07-03.1	Floating Offshore Platform Experiments 2021
ITTC-7.5-02-07-03.2	Analysis Procedure for Model Tests in Regular Waves 2021
ITTC-7.5-02-07-03.5	Passive Hybrid Model Tests of Floating Offshore Structures with Mooring Lines 2021
ITTC-7.5-02-07-03.8	Model Tests for Offshore Wind Turbines 2021
ITTC-7.5-02-07-03.14	Analysis Procedure for Model Tests in Irregular Waves 2021

Track Record of KRISO for FOWT

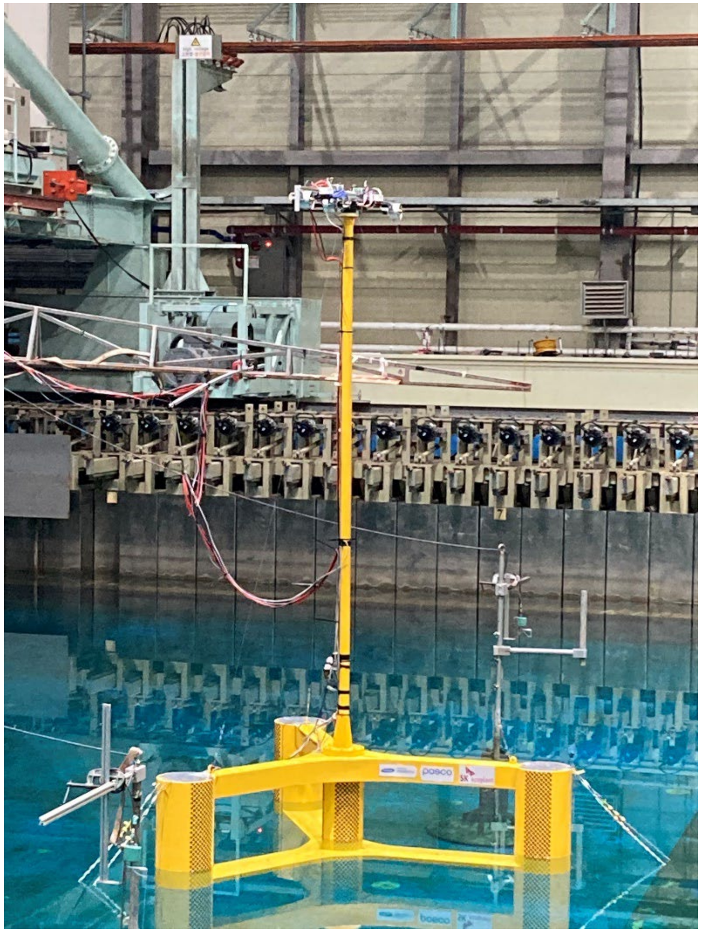
Project	Scale ratio	Platform & Mooring	Year	Model Test Technique
SHI-KRISO Joint Research	1/55	Spar Soft-spring	2012	Blade re-design
Wave-Offshore Wind Hybrid System	1/50	Semi. 12-Point & 8-Point Catenary	2014 & 2015	Equivalent Disk & Duct Fan
5MW Class FOWT	1/47	Spar 3-Point Catenary	2019	Blade re-design
10MW Class FOWT (HHI Platform)	1/35	Semi. 3-Point Catenary	2021	Real-Time Hybrid Method (Duct Fan)
15MW Class FOWT (KRISO Platform)	1/42.25	Semi. 3-Point Catenary	2022	
10MW Class FOWT (SKecoplant-POSCO)	1/36	Semi. 3-Point Catenary [Confidential]	2022	
8MW Class FOWT (HHI Platform & Doosan WT)	1/35	Semi. 3-Point Catenary [Confidential]	2023	
15MW Class FOWT (Hanwha Ocean (DSME))	-	- [Confidential]	2024 (planned)	
Gray Whale 3 project (Ulsan)	-	- [Confidential]	2024 (bidding)	
15MW Class FOWT (Government funded-project)	-	TLP	2024 (planned)	
KFWind & EBP project (Ulsan)	-	- [Confidential]	2024 (bidding)	

Model Setup

Experimental Model

Hydrostatics

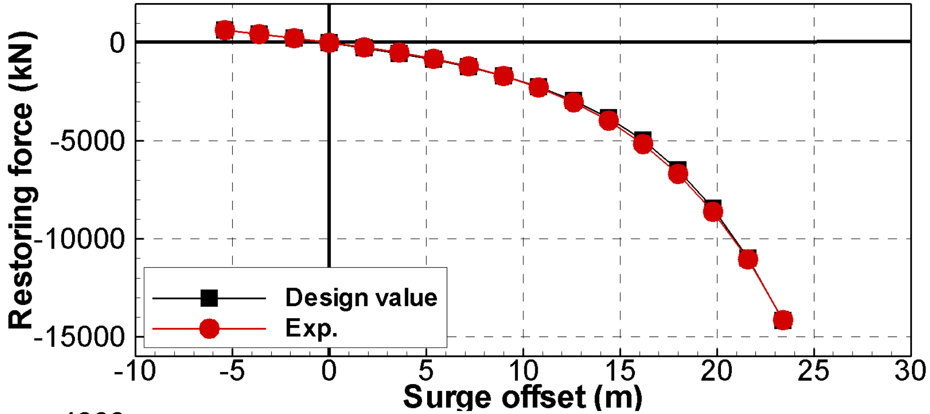
		Full scale (1:1)	Model scale (1:35)	Real scale (Measured)	Error
Water depth [m]		70.0	3.2	115.2	-
Draft (m)		Confidential			-
△ (kgf)					-
GM_T (m)					**2.8%**
GM_L (m)					**3.5%**
kxx [m]					**2.8%**
kyy [m]					**1.8%**
kzz [m]					-
Natural period [s]	Surge				-0.6%
	Sway				-5.9%
	Heave				-1.8%
	Roll				2.3%
	Pitch				1.7%
	Yaw				-7.0%

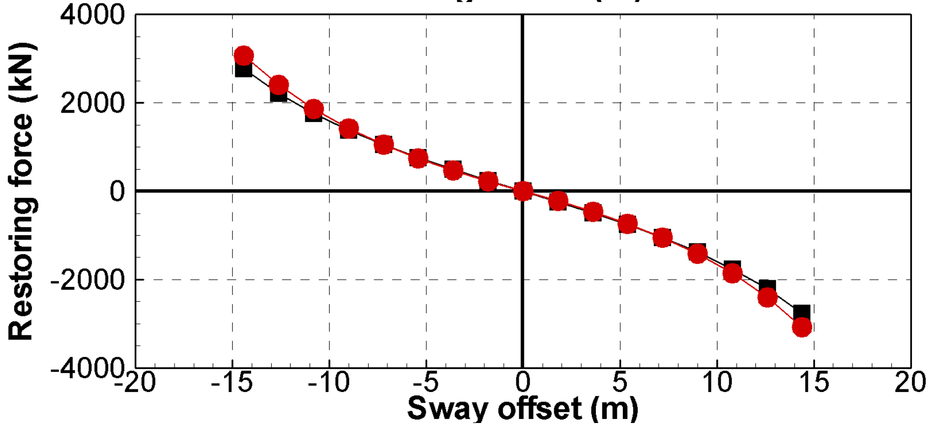


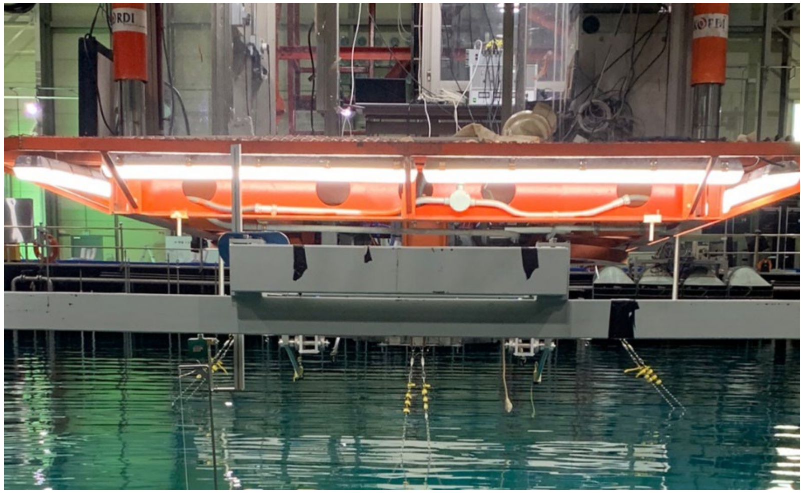
Model Setup

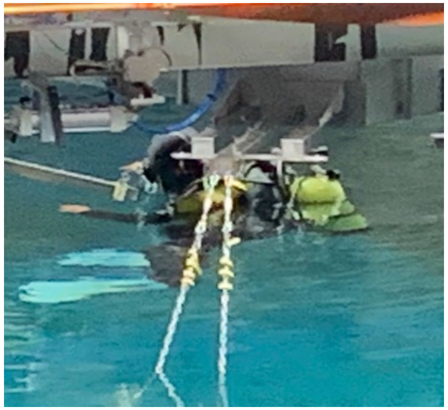
Experimental Model

Mooring lines (Extension method)





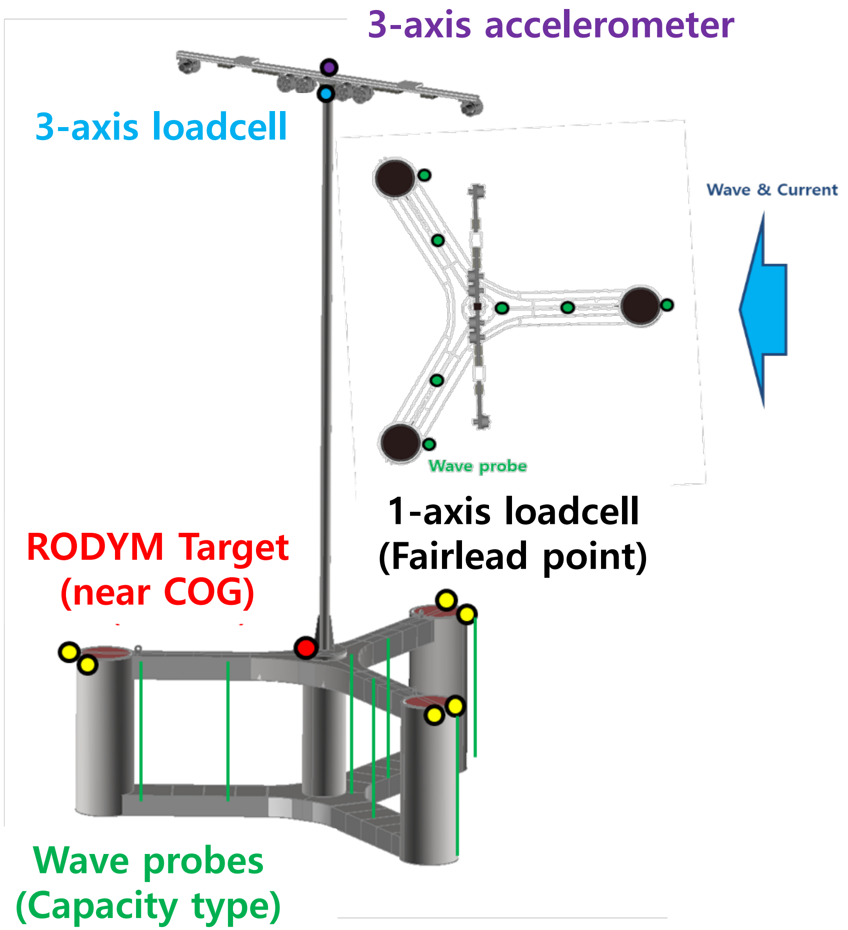


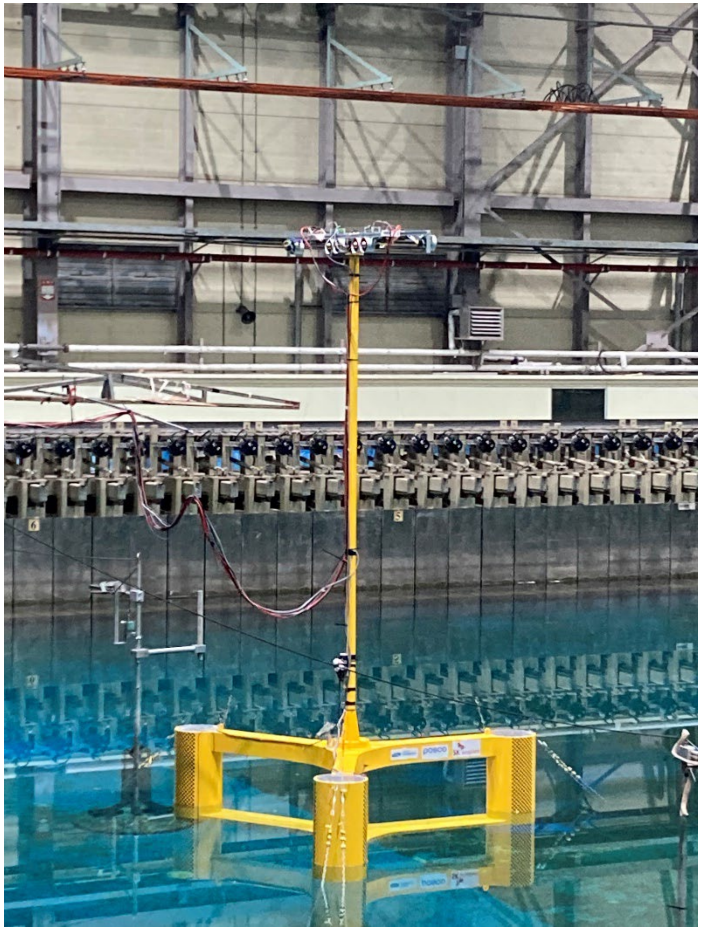


Model Setup

Experimental Model

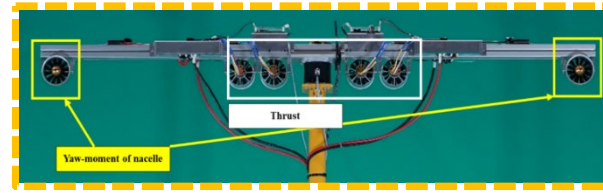
Measuring items

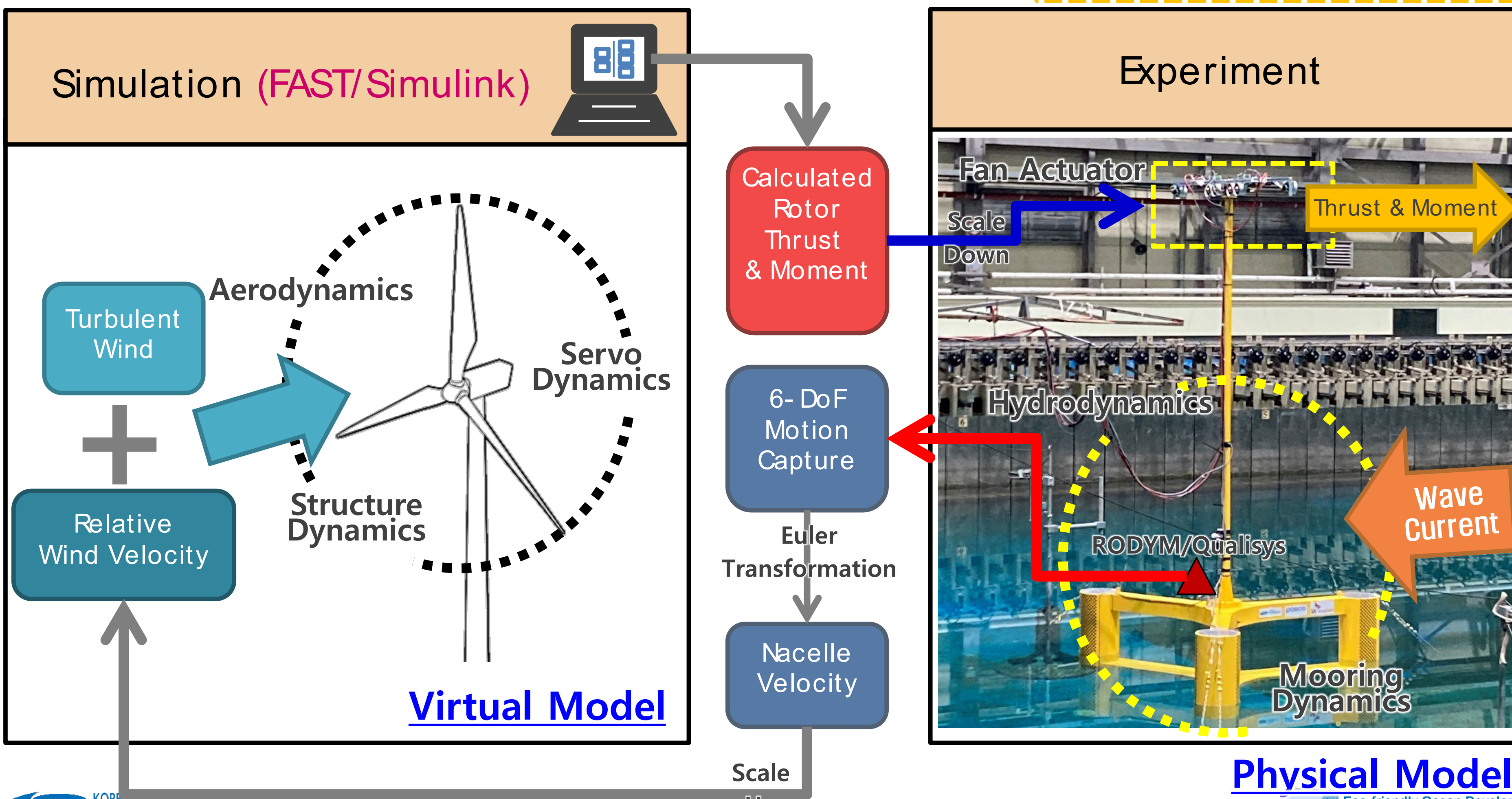




Real-Time Hybrid Method of KRISO

- KRISO MiLS(Model-in-the-Loop Simulation)



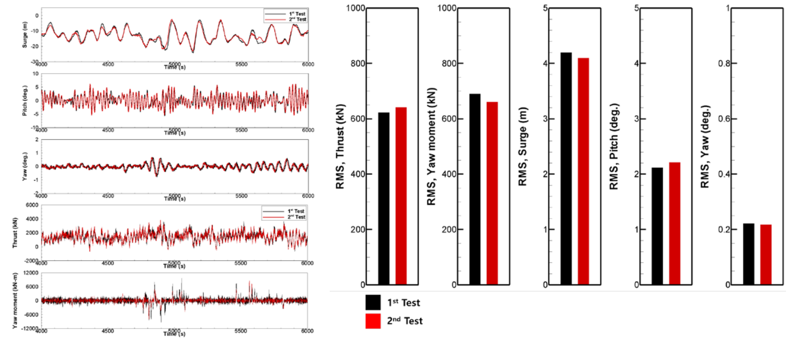


Validation of KRISO MiLS

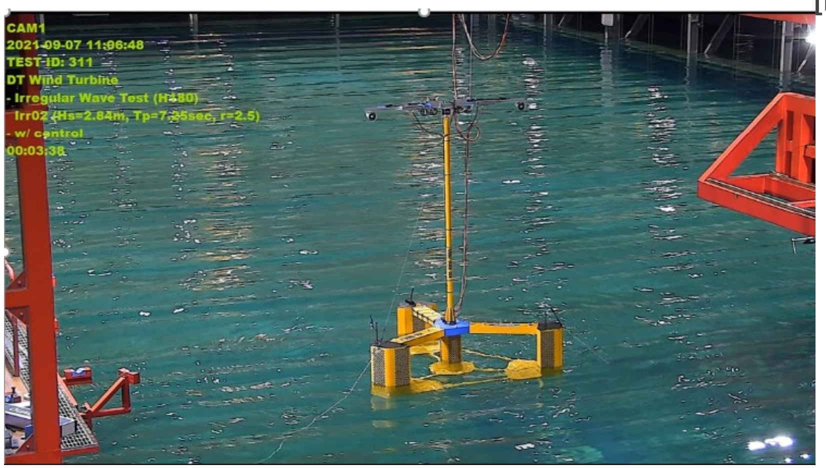
Validation of MiLS

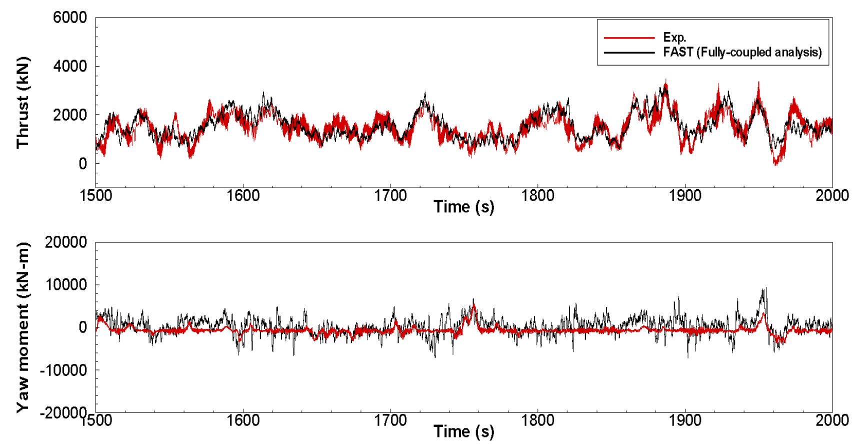
Evaluation of Performance between KRISO MiLS & Fully-coupled Analysis

- Comparison of MiLS and Fully-coupled Analysis (Ha et al. 2021, KWEA, Ha et al. 2023, OE)
  - Repeatability of FOWT global performance based on MiLS was confirmed with various wind and wave seeds.
  - Experimental results were validated with those of fully-coupled analysis(NREL FAST).



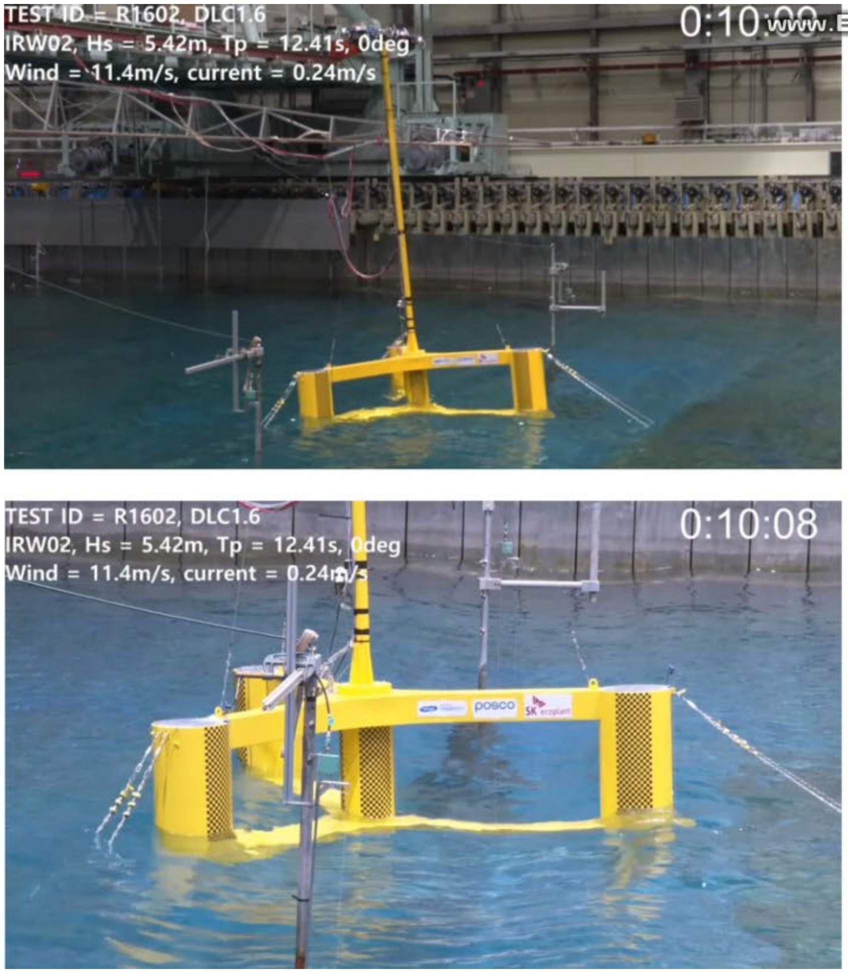
[Repeatability (Hs = 2.46m, Tp = 6.75sec, Vw = 11.4m/s (Turbulence))]



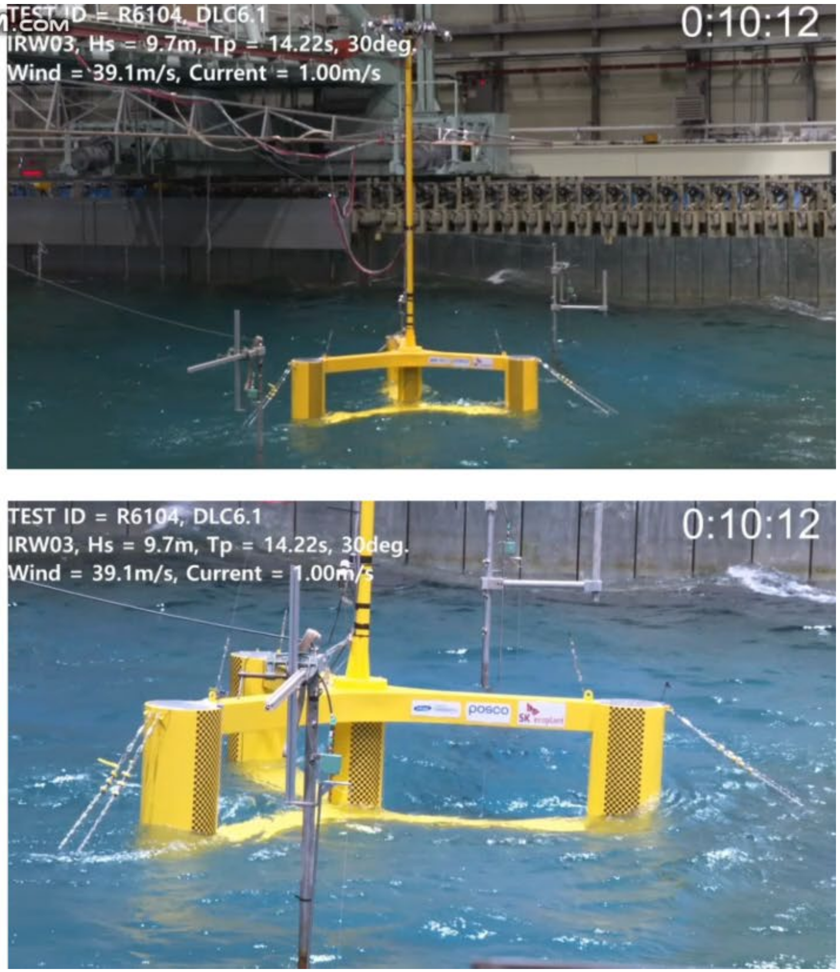


[Compared results for thrust & yaw-moment under operational condition (Hs = 2.46m, Tp = 6.75sec, Vw = 11.4m/s (Turbulence))]

Representative Results



DLC 1.6, Wind speed = 11.4m/s, Hs = 5.42m, Tp = 12.41s
Heading = 0deg., Current speed = 0.24m/s

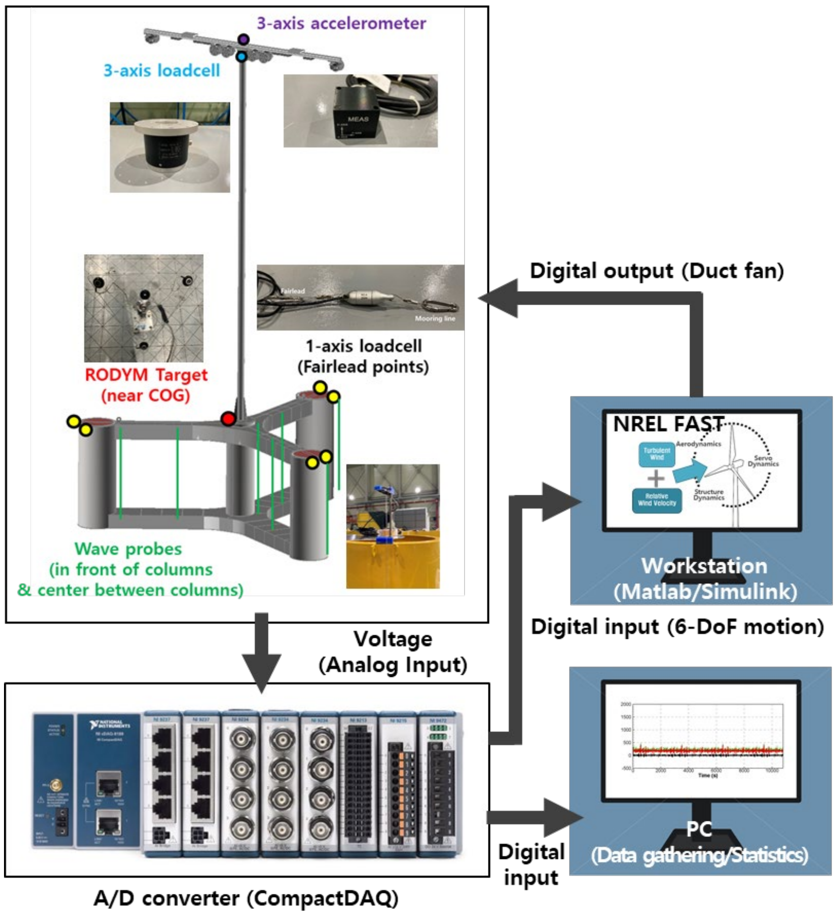


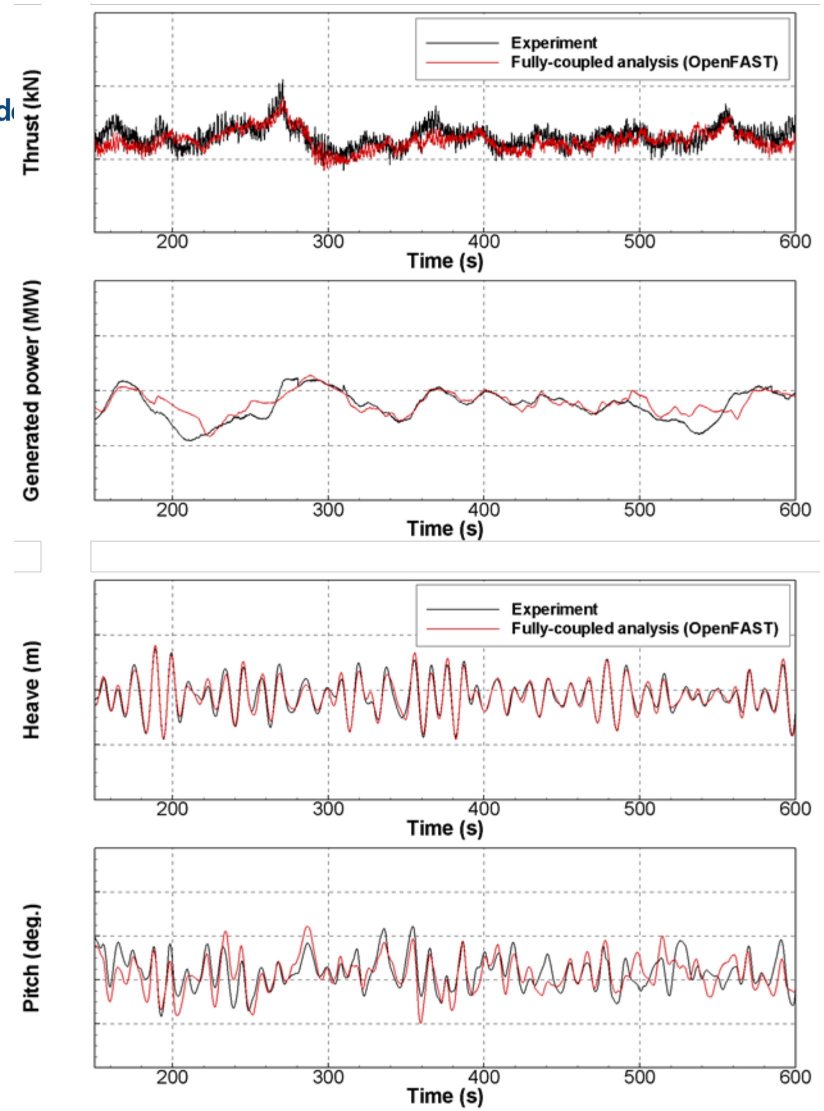
DLC 6.1, Wind speed = 39.1m/s, Hs = 9.70m, Tp = 14.22s
Heading = 30deg., Current speed = 1.00m/s

Representative Results

Validation

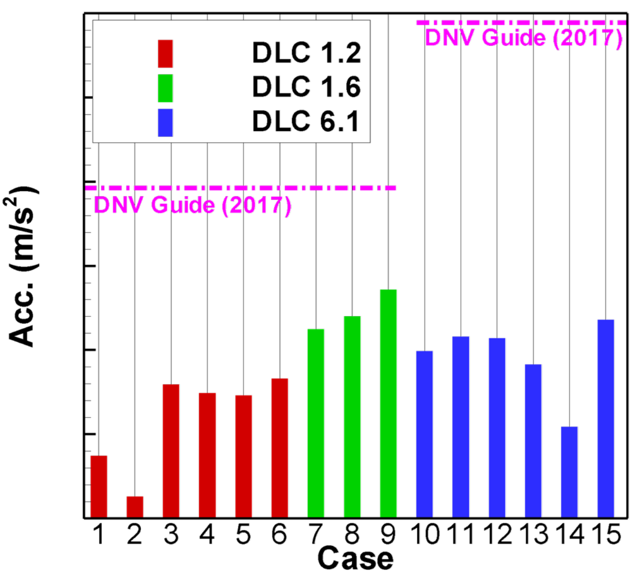
(DLC 1.6, Wind speed = 11.4m/s (rated), Hs = 5.42m, Tp = 12.41s, Heading = 0d

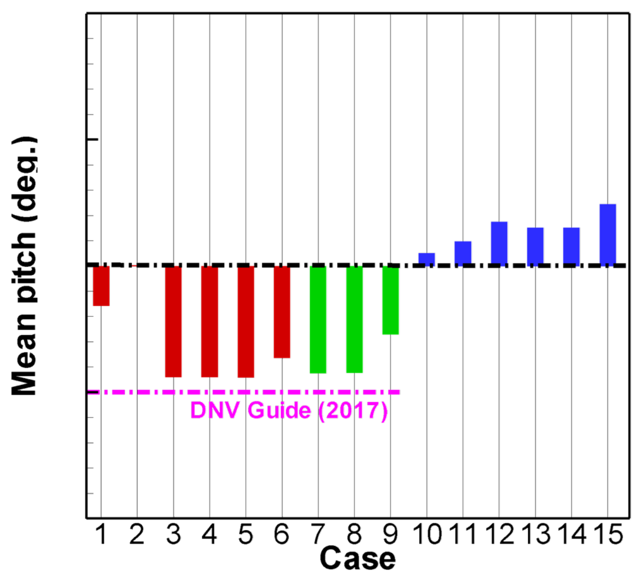


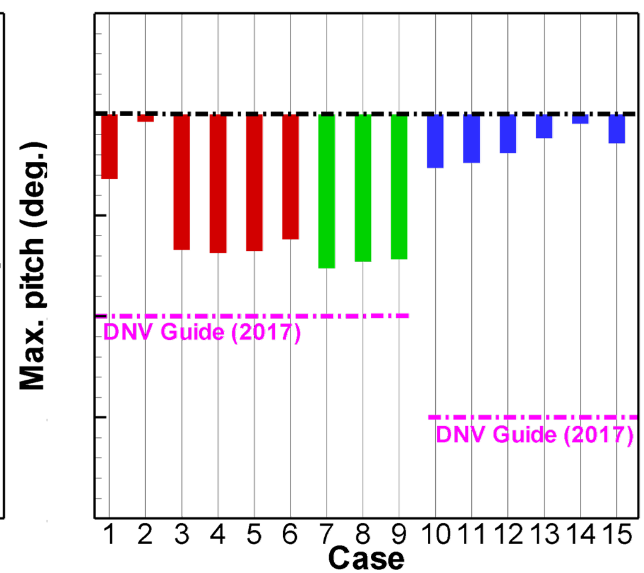


Representative Results

DLC	Case No.	Wind [m/s]		Wave Hs [m]	Wave Tp [s]	Curret [m/s]	Wind direction (deg.)	Wave direction (deg.)	Current direction (deg.)
1.2	1	5	0.833	0.5	5	-	-	0	-
	2	-	-	1.5	7	-	-	0	-
	3	11.4	1.9	1.5	7	-	-	0	-
	4	11.4	1.9	1.5	7	-	-	30	-
	5	11.4	1.9	1.5	7	-	-	60	-
	6	16	2.667	2.5	9	-	-	0	-
1.6	7	11.4	1.9	5.42	12.41	-	0	0	-
	8	11.4	1.9	5.42	12.41	0.30	0	0	0
	9	25	4.167	6.56	12.27	0.36	0	0	0
6.1	10	-	-	9.7	14.22	-	-	0	-
	11	39.1	6.517	9.7	14.22	-	0	0	-
	12	39.1	6.517	9.7	14.22	1.00	0	0	0
	13	39.1	6.517	9.7	14.22	1.00	0	30	0
	14	39.1	6.517	9.7	14.22	1.00	0	60	0
	15	39.1	6.517	9.7	14.22	1.69	0	0	0







Summary

Model Test Result

- **Model Setup**: Hydrostatic values have an error within 5%, and the natural frequency of low-frequency motions has an error within 10% (Experiment vs. Design value)
- **Mooring line**: Due to water depth limitations, the length of the model mooring lines has been extended; nevertheless, the restoring forces are a fairly good match with the design values
- **RTHM**: The model test results are a fairly good match with the results of the fully-coupled analysis
- **Performance**: As compared to the DNV guidelines, it can be found that a sufficiently stable FOWT has been designed

Future Work

- **FOWT industry**: This year, model testing related to the floating offshore wind power project in Ulsan, South Korea, is scheduled. We plan to enhance the RTHM technique to conduct high-precision model tests

"Thank you"

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