2025 IERE-TPC Taipei Net-Zero Workshop

Performance Evaluation of Three Semi-Submersible Floating Offshore Wind Turbine Designs for the Taiwan Strait

Heng SU and Shiu-Wu CHAU

Department of Engineering Science and Ocean Engineering
National Taiwan University
2025/5/27

Motivation

OWF Demo Project
2 WFs, 238 MW, 2021 (C)

OWF Potential Sites
11 WFs, 5.5 GW, 2025 (C?)

OWF BD Phase I
7 WFs, 3000 MW, 2022/12/30 (A)
5 WFs, 2335 MW, 2023/8/31 (S)

OWF BD Phase II
5 WFs, 2700 GW, 2024/8/5 (A)
5 WFs, 2700 GW, 2025/2 (S?)

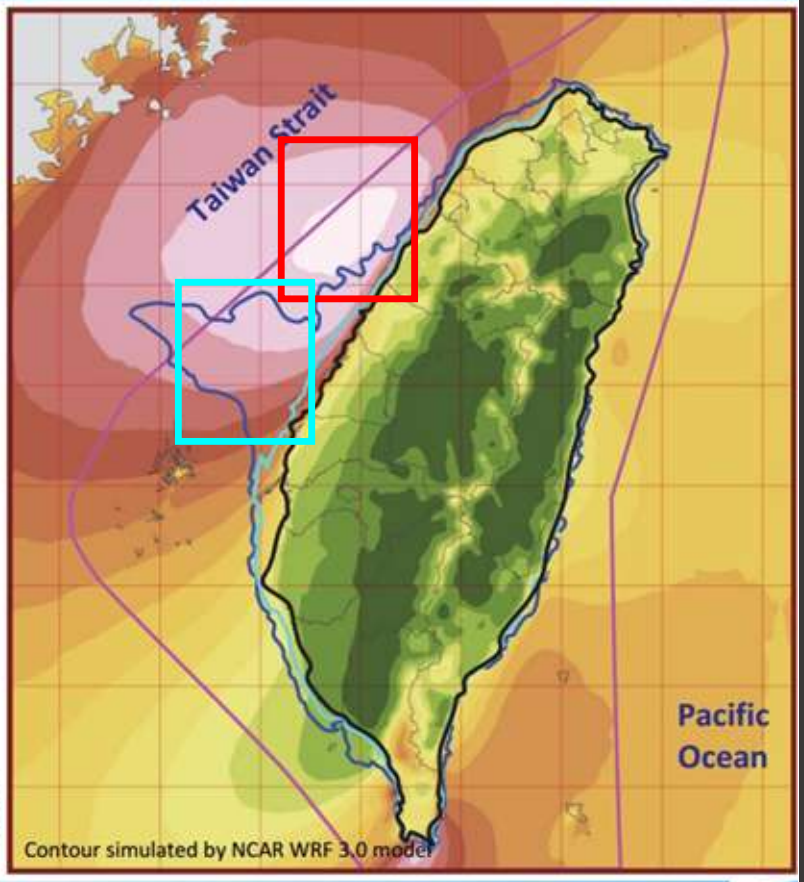
Bottom Fixed → Floating?

Taiwan Offshore Wind Potential

Shallow Water (5-20 m)
- **Area:** 1,779.2 km²
- **Potential:** 9 GW
- **Feasible:** 1.2 GW

Deep Water (20-50 m)
- **Area:** 6,547 km²
- **Potential:** 48 GW
- **Feasible:** 5 GW

Deeper Water (> 50 m)
- **Potential:** 90 GW
- **Feasible:** 9 GW



Wind Power Density(W/m2)

< 100	400 - 500	800 - 900	1,200 - 1,300
100 - 200	500 - 600	900 - 1,000	1,300 - 1,400
200 - 300	600 - 700	1,000 - 1,100	1,400 - 1,500
300 - 400	700 - 800	1,100 - 1,200	> 1,500

工業技術研究院

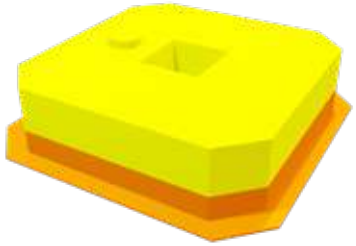
Ref. "Wind Resource Assessment Handbook," ITRI, 2011

Floating Platform Design

Disk-type

Column-type

Barge-type



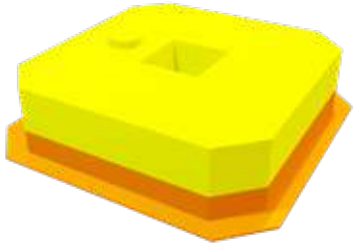
Platform Type	Disk	Column	Barge
Platform Mass (t)	33869		
Displacement (m^3)	35000		
Draft (m)	39.9	27.19	7.24
Overall CM above SWL (m)	-23.46	-10.91	5.90
Roll Inertia (10^{10} kg·m^2)	6.49	6.75	3.99
Pitch Inertia (10^{10} kg·m^2)	6.49	6.75	4.07
Yaw Inertia (10^{10} kg·m^2)	3.27	5.70	2.58

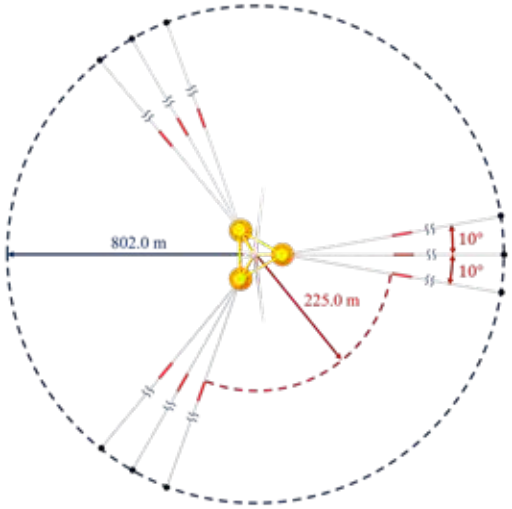
Mooring Line Design

Disk-type

Column-type

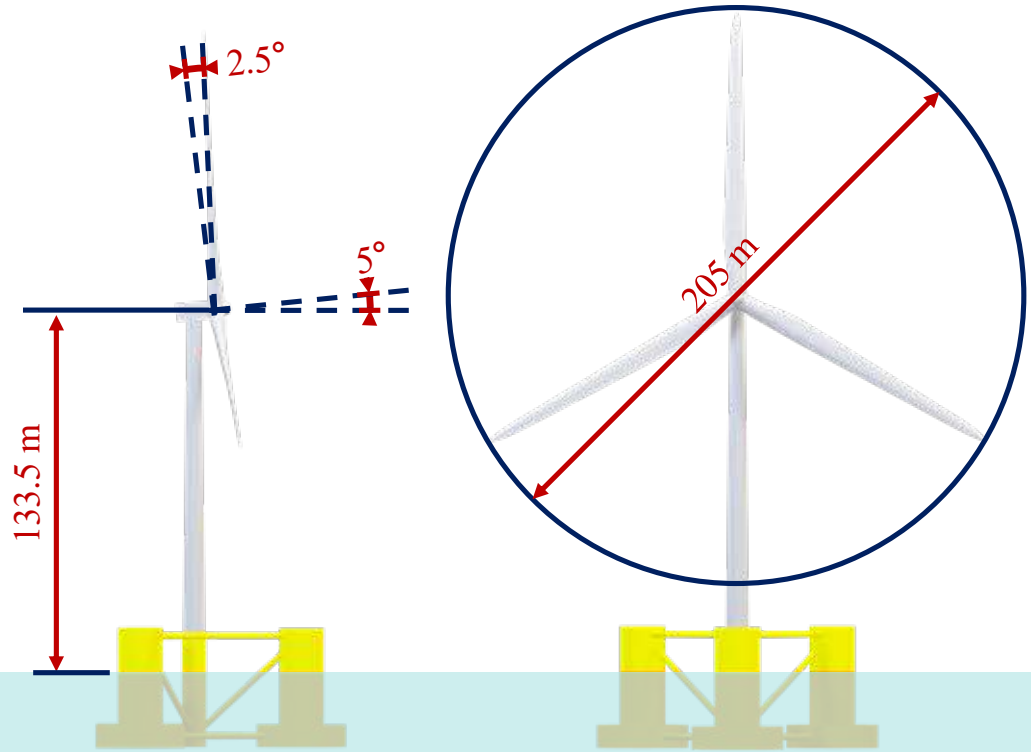
Barge-type

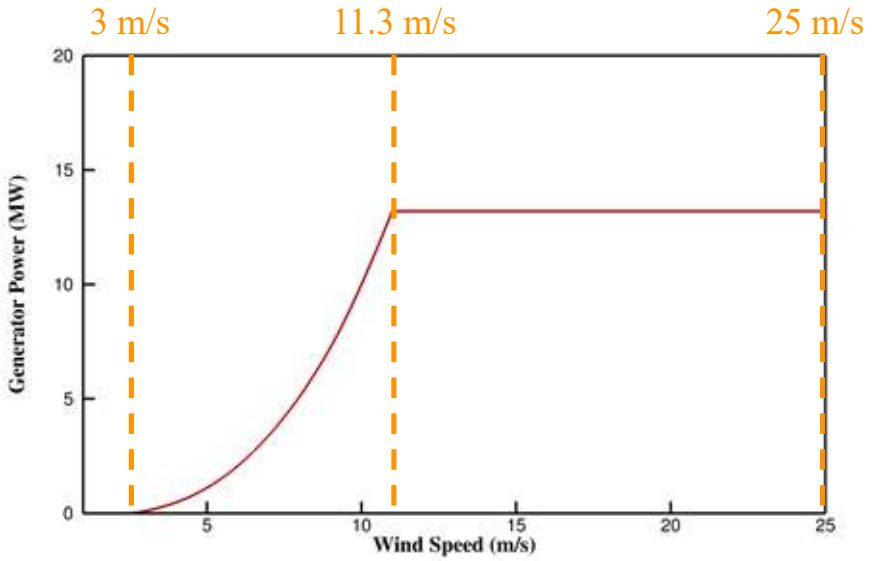




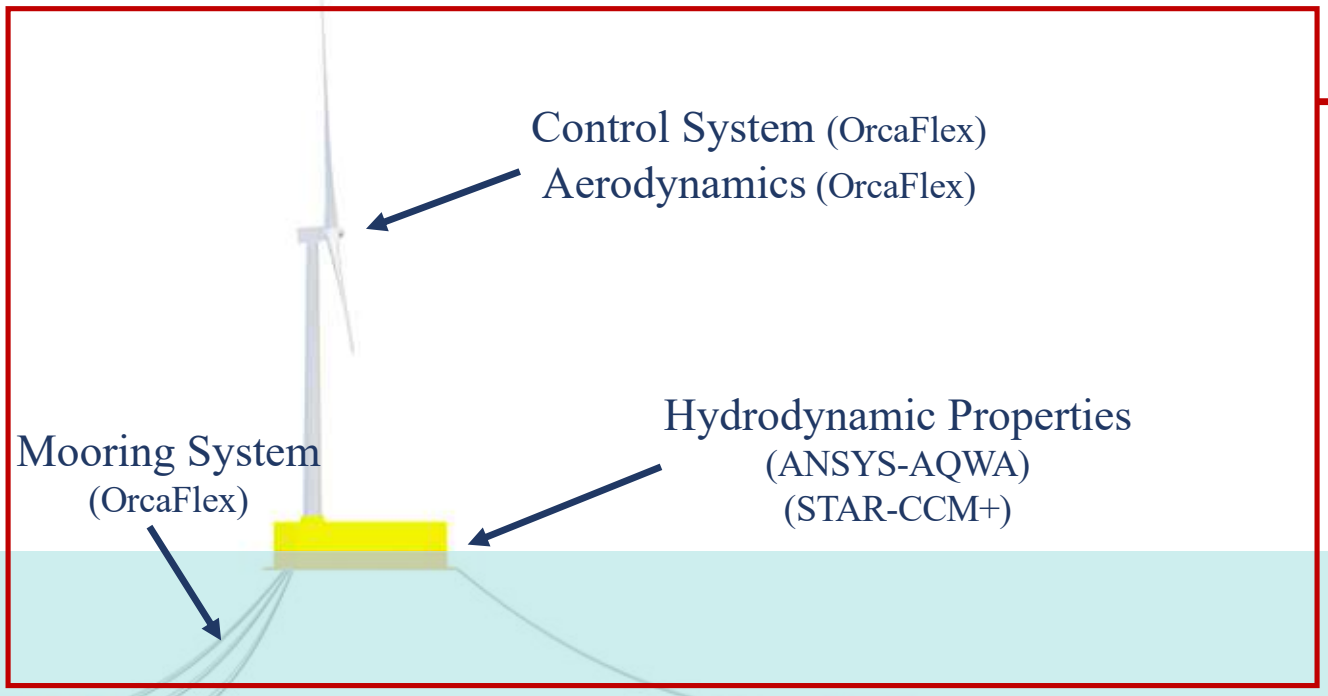
Mooring Pattern	3x3
Chain Grade	R4s
Chain Diameter (mm)	165
Clump Weight Number	10
Weight of Clump Weight (t)	5
Mass Density (kg/m)	545
Break Load (MN)	25.49

Wind Turbine Design





Numerical Framework



Equations of Motion
(OrcaFlex)

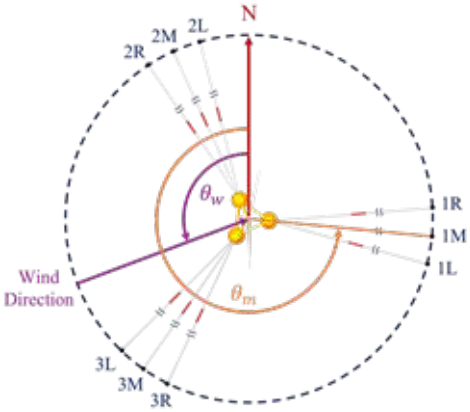
Motion Responses
Generator Power
(OrcaFlex)

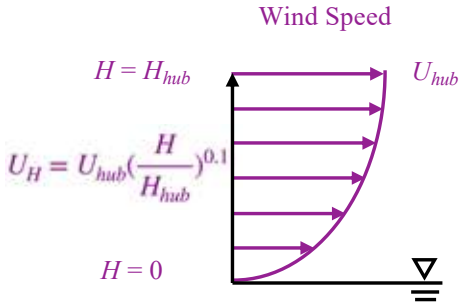
Cases Description

P_{H_S,T_Z} (%)

H_S (m) / T_Z (s)	0.30	0.40	0.65	0.95	1.25	1.70	2.50	3.50	4.50
3.50	4.14	5.56	5.73	3.67	0.59				
4.50	5.48	8.65	8.90	9.33	8.21	4.04	0.08		
5.50	0.49	1.86	2.57	3.61	5.63	11.36	5.46	0.06	
6.50		0.11	0.23	0.22	0.37	0.86	1.84	0.63	0.02
7.50			0.01	0.03	0.04	0.06	0.09	0.07	0.05

Wind Direction = Wave Direction





P_{θ_w}(%)

θ_w (°)	45	135	225	315
P (%)	13	22	13	52

Wave

JONSWAP Spectrum

$$S_J(f) = \frac{\alpha g^2}{16\pi^4} f^{-5} \exp\left[-\frac{5}{4}\left(\frac{f}{f_m}\right)^{-4}\right]\gamma^b \qquad \gamma = 2.08$$

Wind

API Spectrum

$$S_A(f,z) = U_z^2 I_z^2 f_p^{-1}\left[1 + 1.5\left(\frac{f}{f_p}\right)\right]^{-5/3}$$

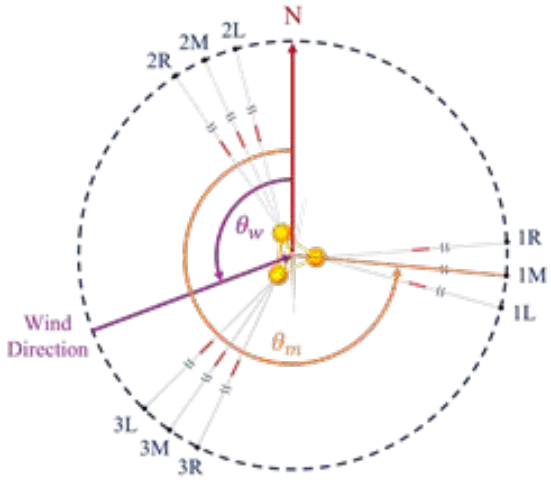
Gust Model

$$U_t = U_z(1 - K \cdot g(t))$$

Cases Description

P_{H_S,T_Z} (%)

T_Z (s) \ H_S (m)	0.30	0.40	0.65	0.95	1.25	1.70	2.50	3.50	4.50
3.50	4.14	5.56	5.73	3.67	0.59				
4.50	5.48	8.65	8.90	9.33	8.21	4.04	0.08		
5.50	0.49	1.86	2.57	3.61	5.63	11.36	5.46	0.06	
6.50		0.11	0.23	0.22	0.37	0.86	1.84	0.63	0.02
7.50			0.01	0.03	0.04	0.06	0.09	0.07	0.05



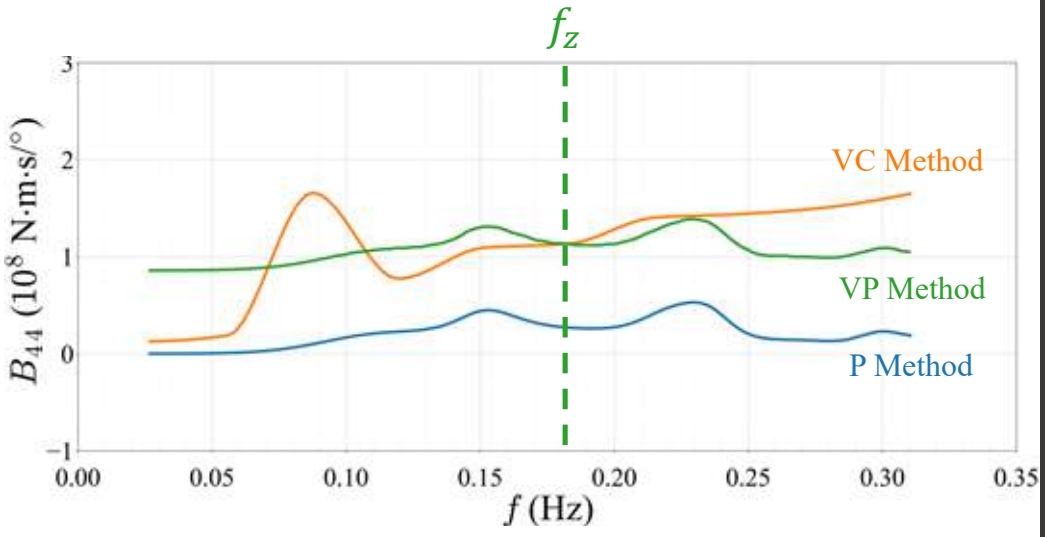
Wind Direction:
$\theta_w = 45°, 135°, 225°, 315°$

Mooring Line Arrangement:
$\theta_m = 15°, 45°, 75°, 105°$

Rated Wind Speed Condition (RC)

Sea State: $H_s = 1.70$ m, $T_z = 5.50$ s

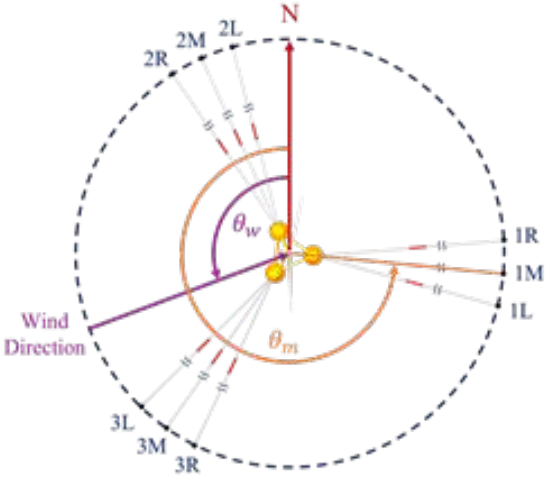
Turbine Status: Operating



Cases Description

P_{H_S,T_Z} (%)

T_Z (s) \ H_S (m)	0.30	0.40	0.65	0.95	1.25	1.70	2.50	3.50	4.50
3.50	4.14	5.56	5.73	3.67	0.59				
4.50	5.48	8.65	8.90	9.33	8.21	4.04	0.08		
5.50	0.49	1.86	2.57	3.61	5.63	11.36	5.46	0.06	
6.50		0.11	0.23	0.22	0.37	0.86	1.84	0.63	0.02
7.50			0.01	0.03	0.04	0.06	0.09	0.07	0.05



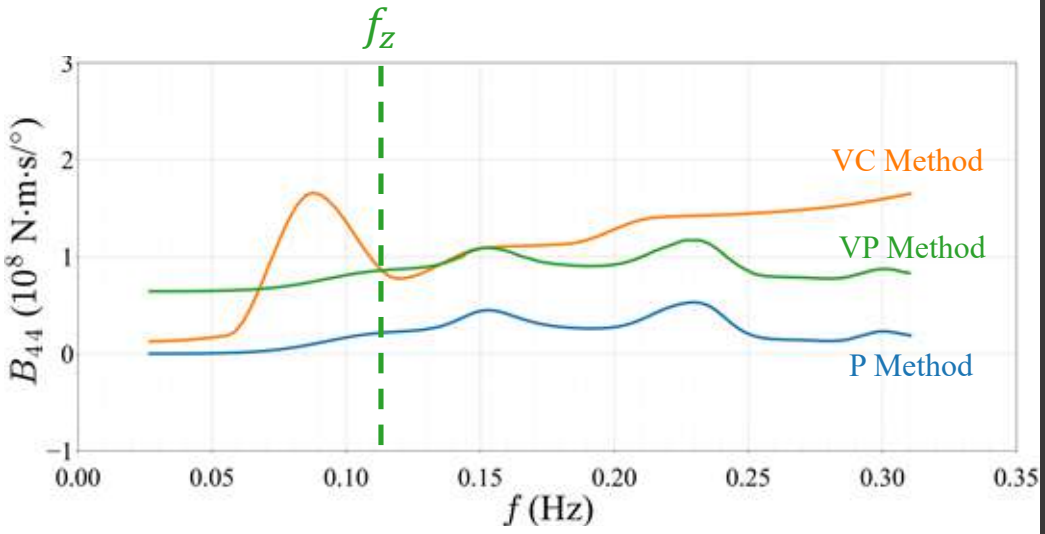
Wind Direction:
$\theta_w = 45°, 135°, 225°, 315°$

Mooring Line Arrangement:
$\theta_m = 15°, 45°, 75°, 105°$

50-Year Return Period Wind Speed Condition (50C)

Sea State: $H_s = 12.72$ m, $T_z = 8.83$ s

Turbine Status: Parked



Cases Description

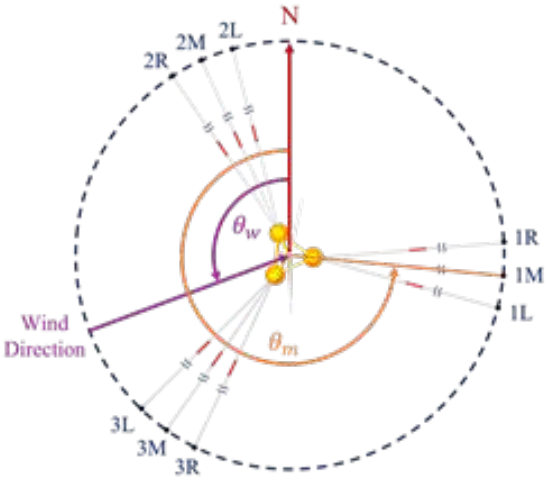
P_{H_S,T_Z} (%)

T_Z (s) \ H_S (m)	0.30	0.40	0.65	0.95	1.25	1.70	2.50	3.50	4.50
3.50	4.14	5.56	5.73	3.67	0.59				
4.50	5.48	8.65	8.90	9.33	8.21	4.04	0.08		
5.50	0.49	1.86	2.57	3.61	5.63	11.36	5.46	0.06	
6.50		0.11	0.23	0.22	0.37	0.86	1.84	0.63	0.02
7.50			0.01	0.03	0.04	0.06	0.09	0.07	0.05

Long-Term Condition (LTC)

Sea State: All

Turbine Status: Operating

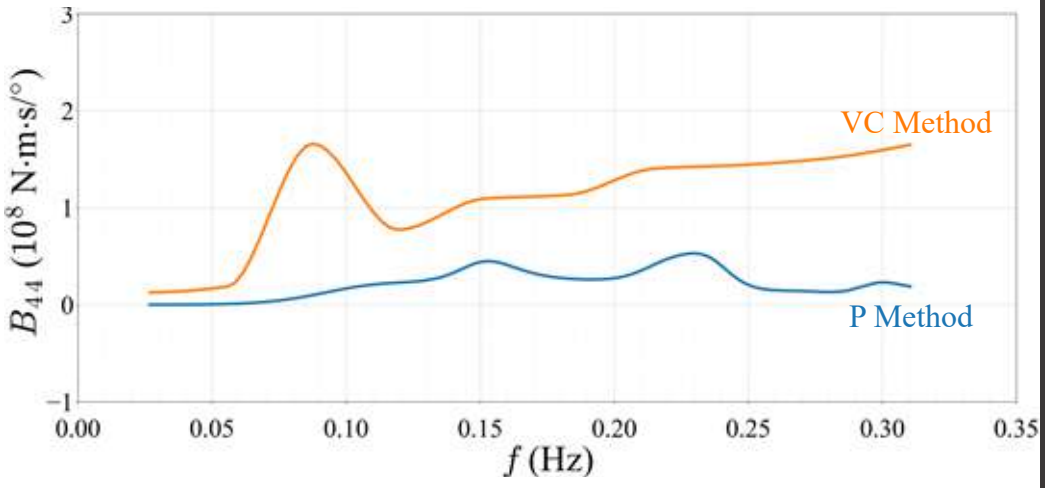


Wind Direction:

$\theta_w = 45°, 135°, 225°, 315°$

Mooring Line Arrangement:

$\theta_m = 15°, 45°, 75°, 105°$



Capacity Factor

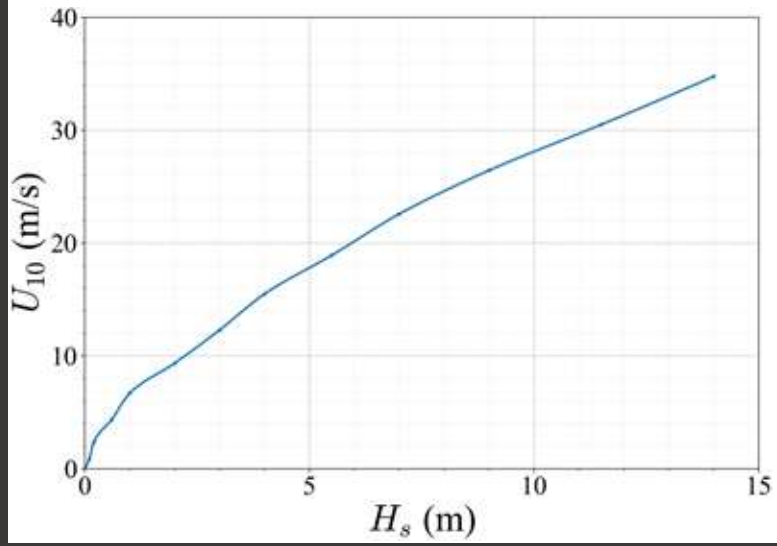
CF_S (Simulated Capacity Factor)

$$CF_S = \frac{\sum P_g^m \times P_{H_s,T_z} \times P_{\theta_w}}{P_{g,rated}}$$

CF_T (Theoretical Capacity Factor)

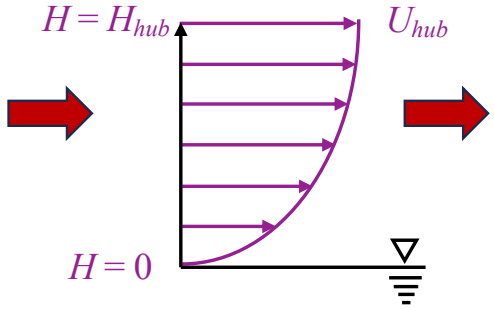
$$CF_T = \frac{\sum P_{g,t} \times P_{H_s,T_z} \times P_{\theta_w}}{P_{g,rated}} = 0.4646$$

Beaufort Scale

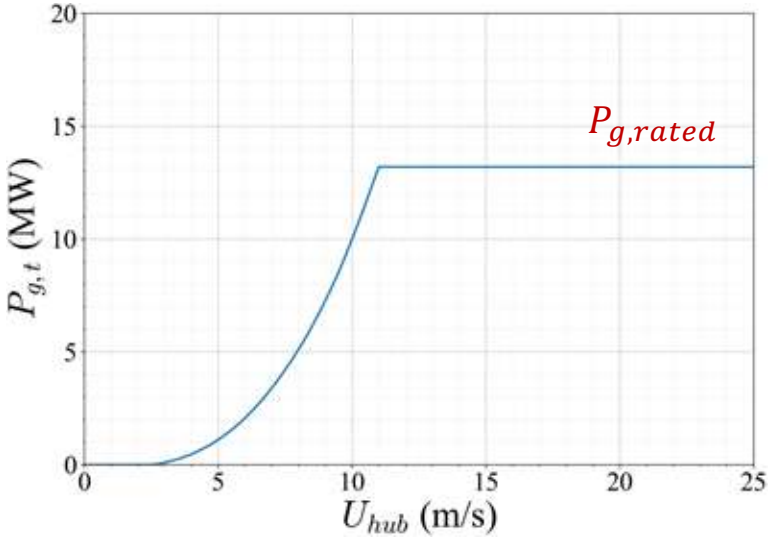


Wind Profile

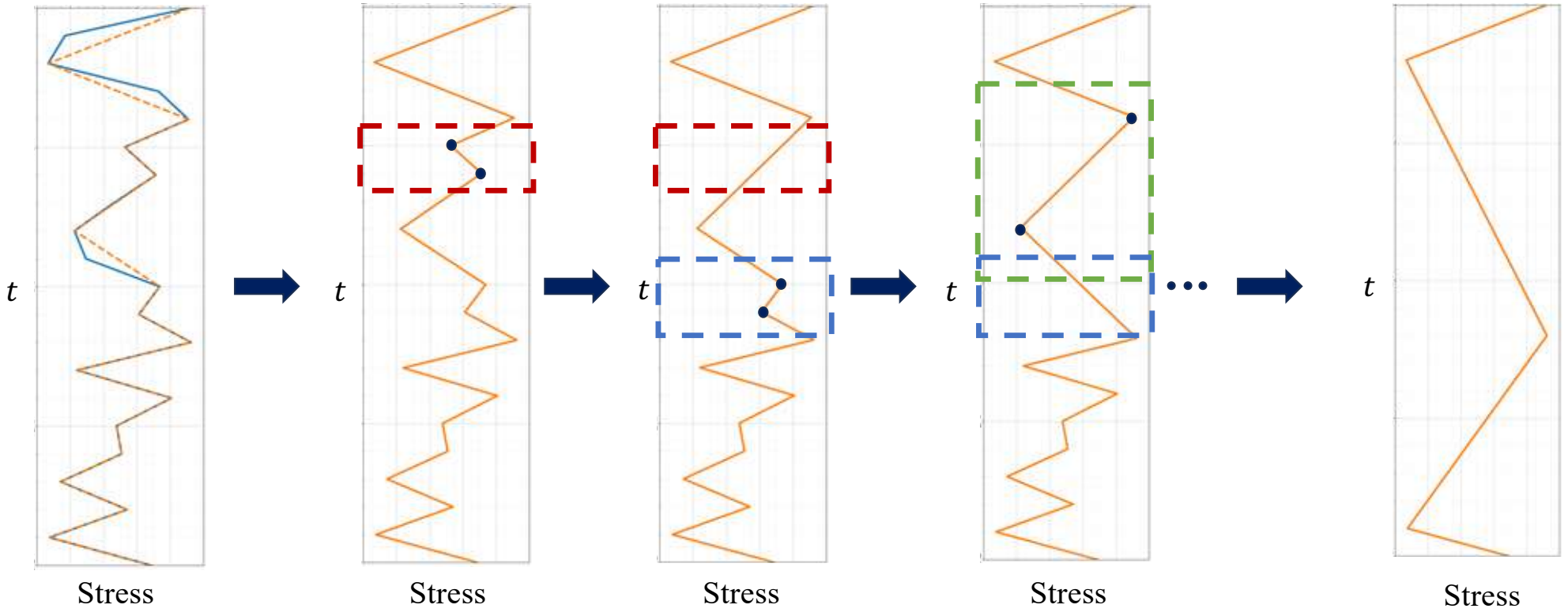
$$U_H = U_{hub}\left(\frac{H}{H_{hub}}\right)^{0.1}$$



Power Curve



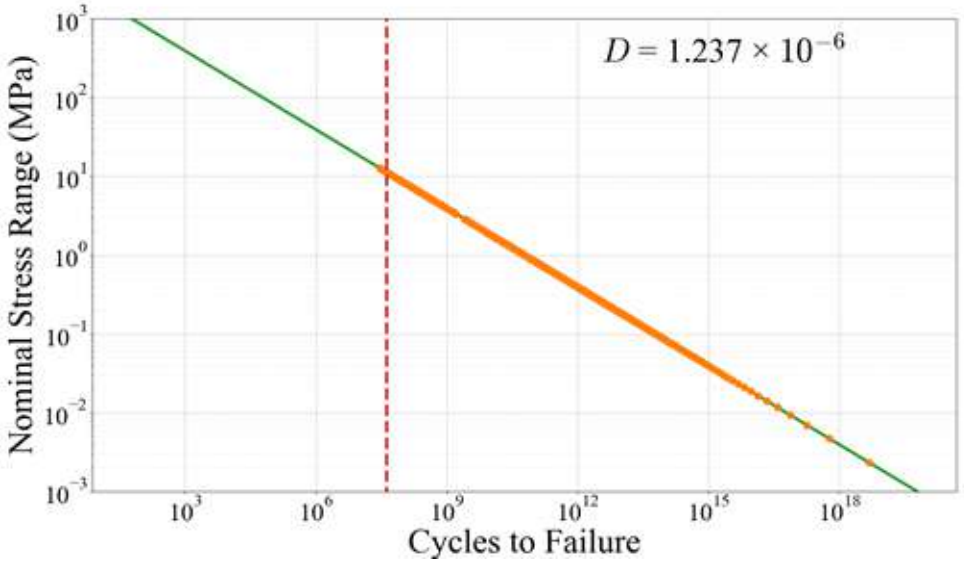
Fatigue Damage Assessment



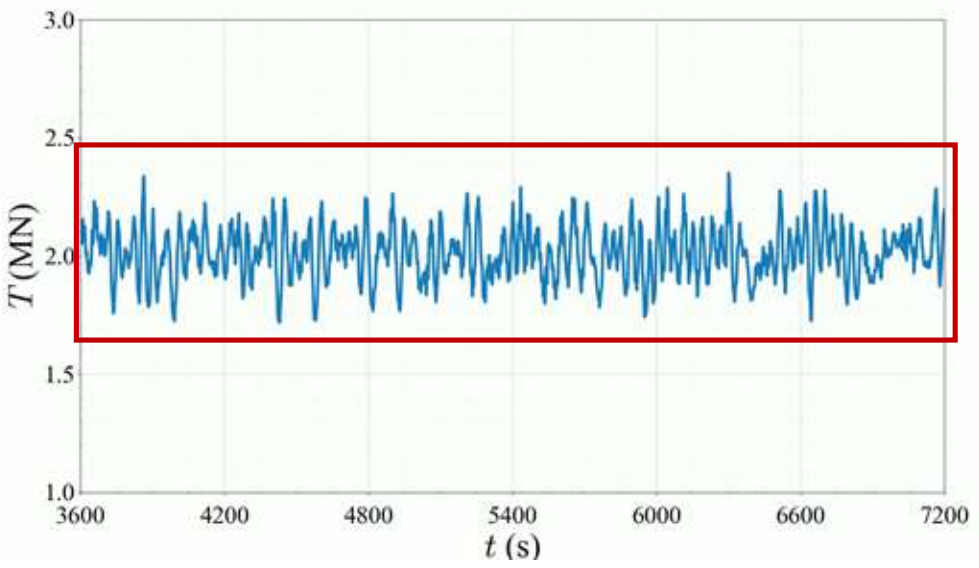
Fatigue Damage Assessment

$$D_{25}^{T}\ (25\text{−year total fatigue damage}) = \sum D\times 25\times 365\times 24\times P_{H_s,T_z}\times P_{\theta_w}$$

S-N Curve

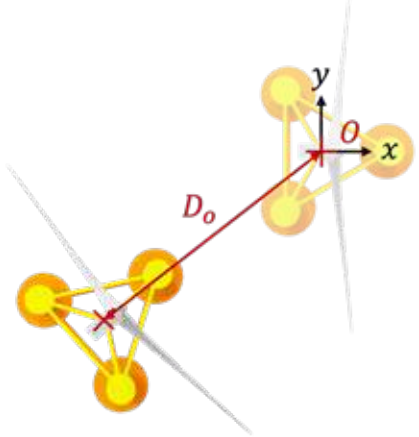


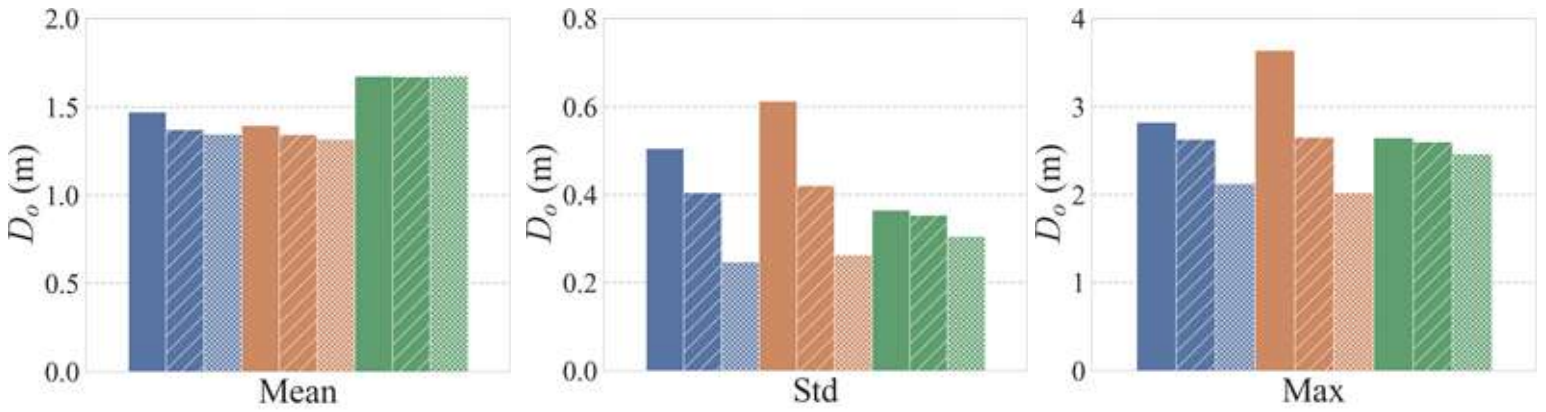
Tension Time History

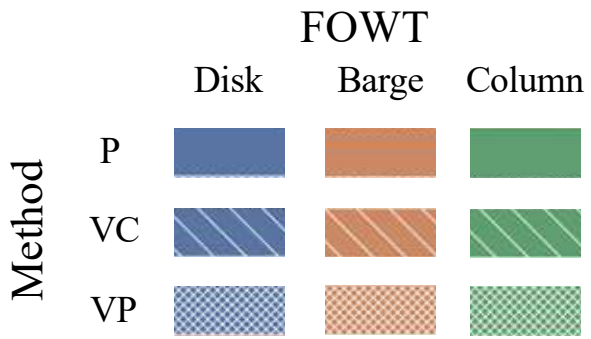


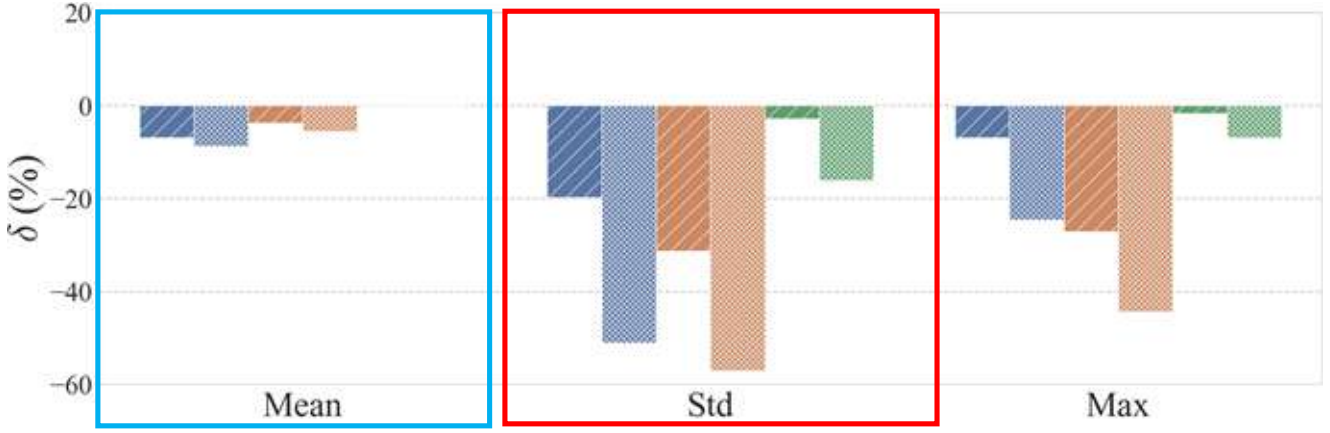
Rated Wind Speed Condition

Offset



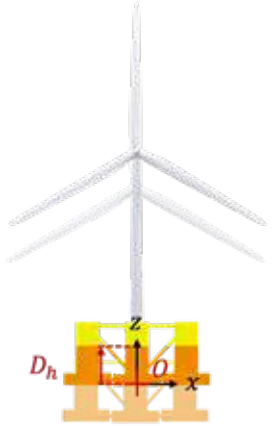


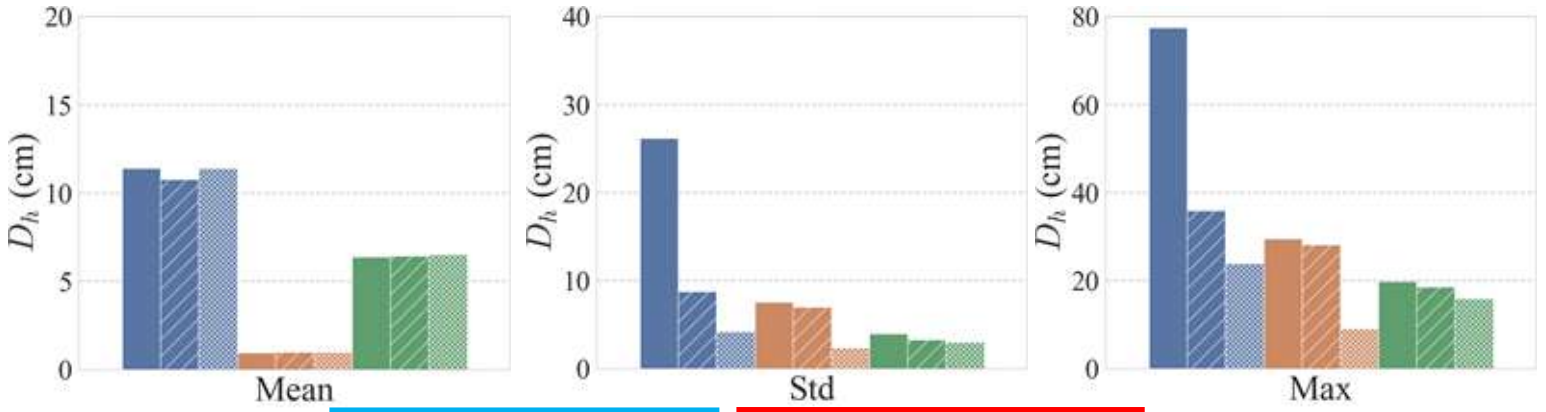


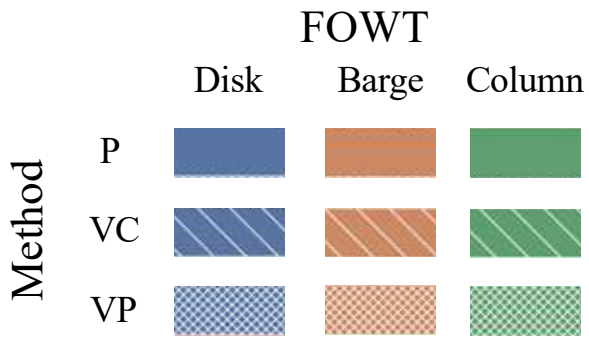


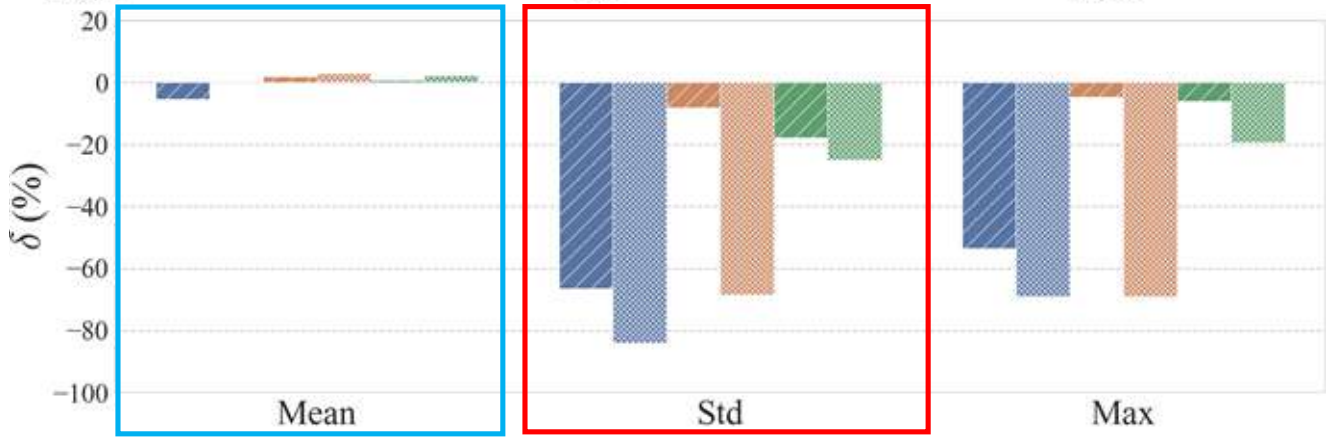
Rated Wind Speed Condition

Heave



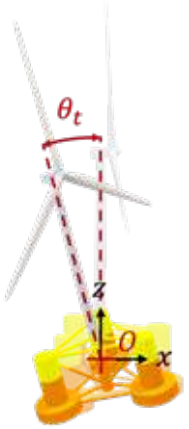


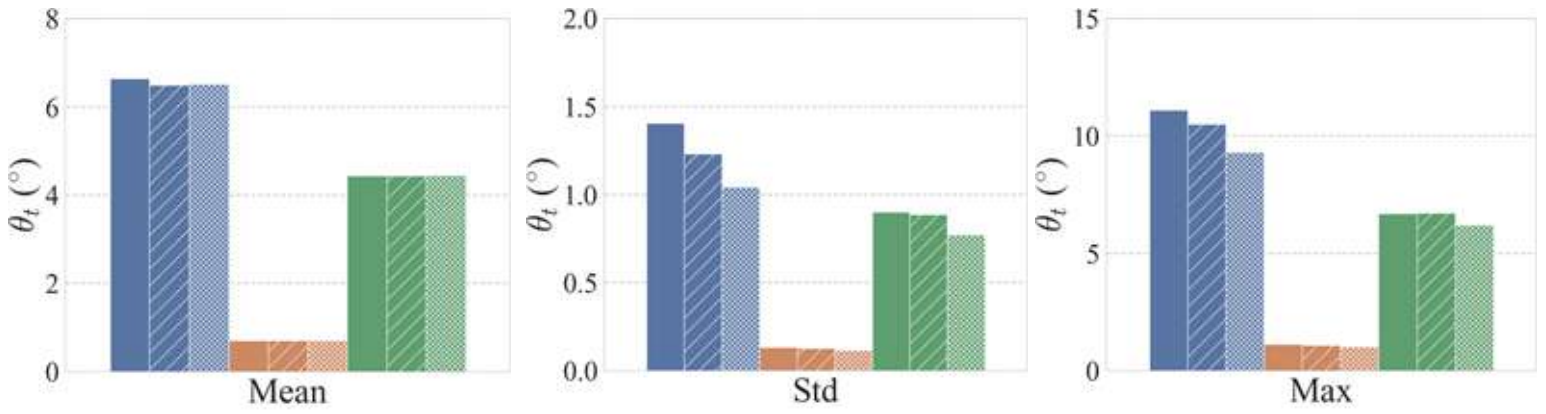


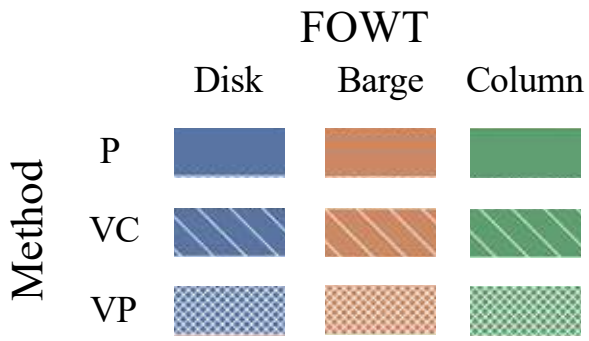


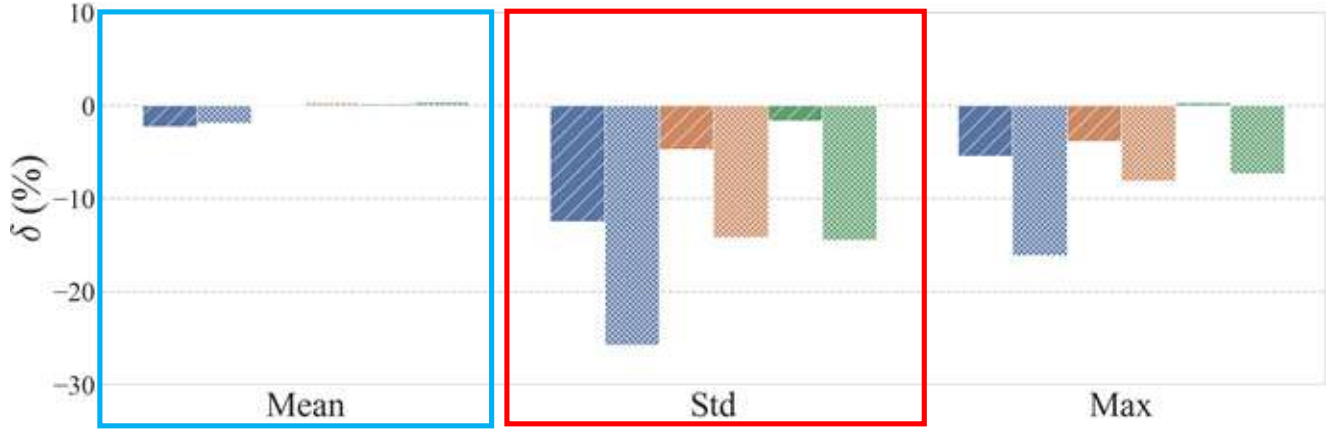
Rated Wind Speed Condition

Tilt Angle



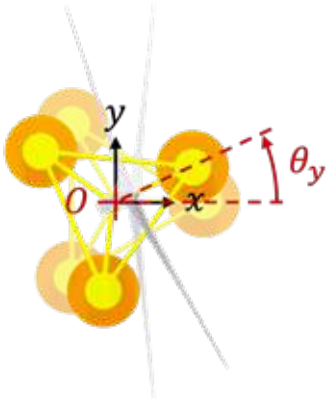


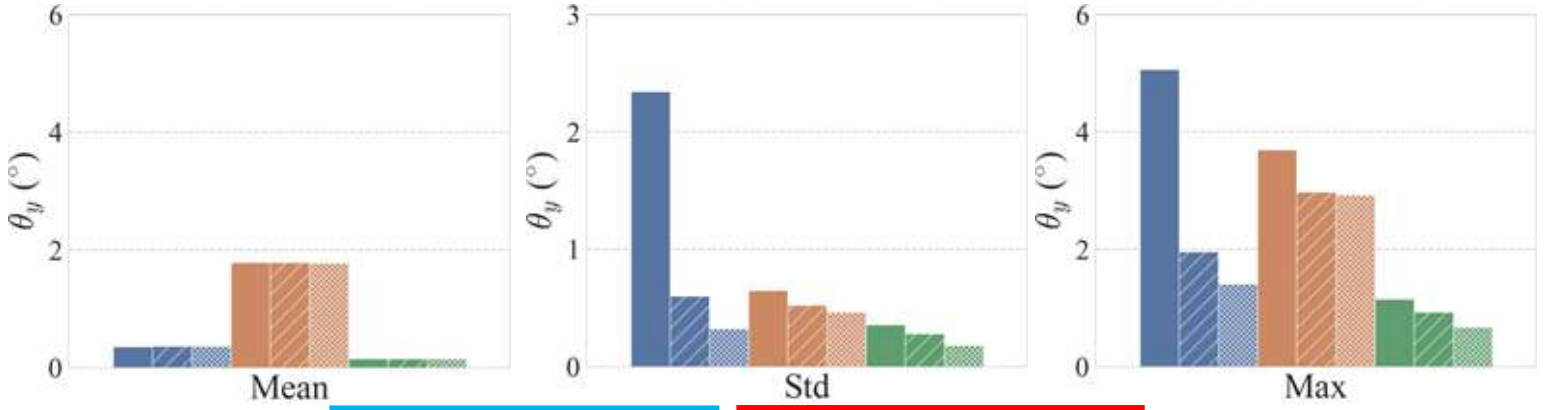


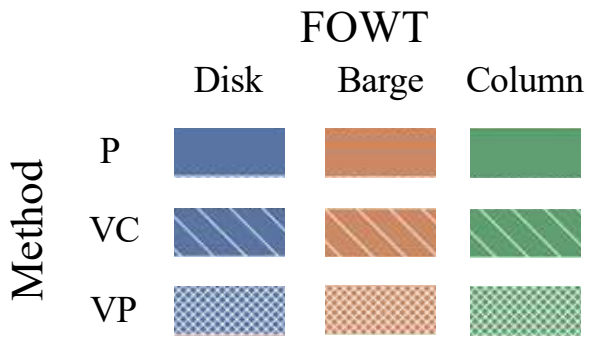


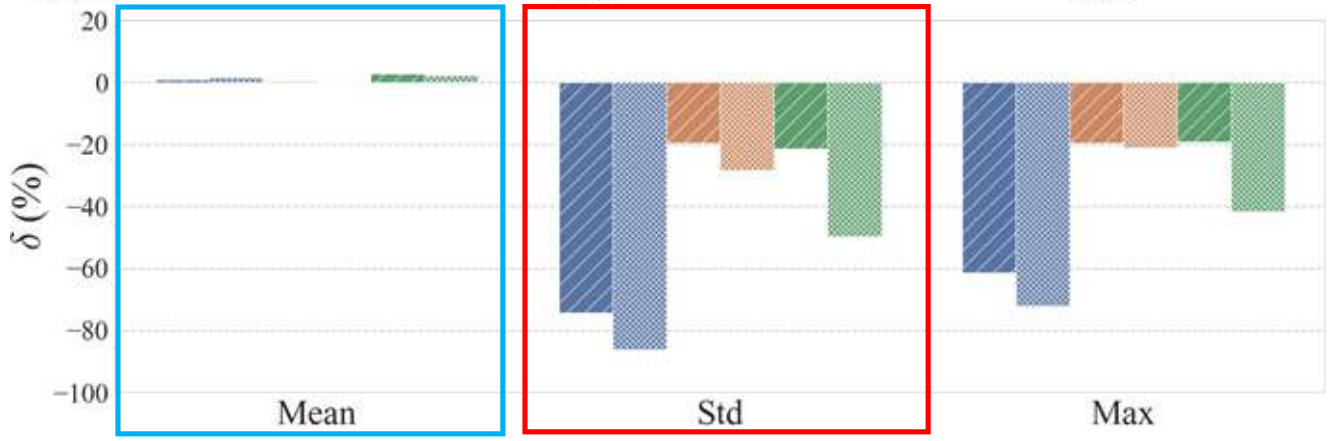
Rated Wind Speed Condition

Yaw



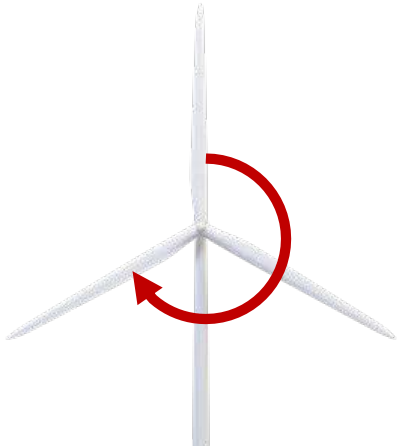


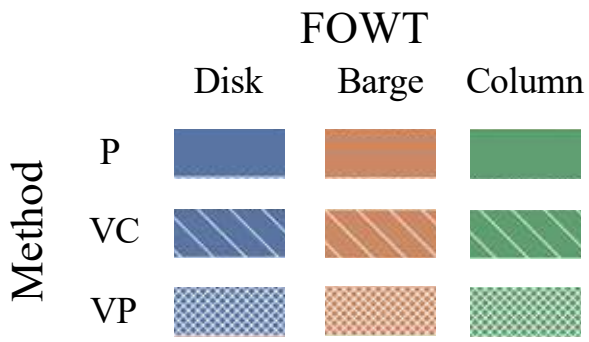


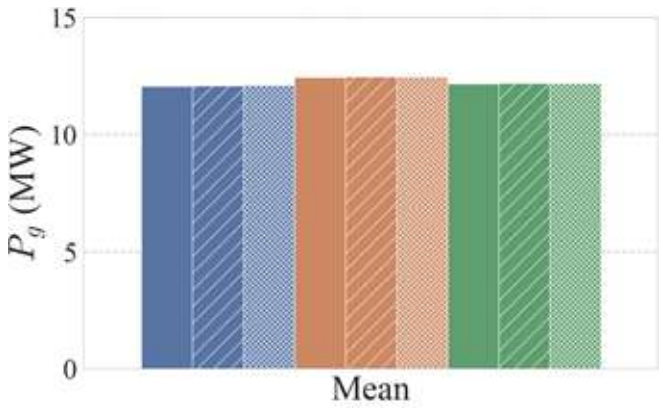


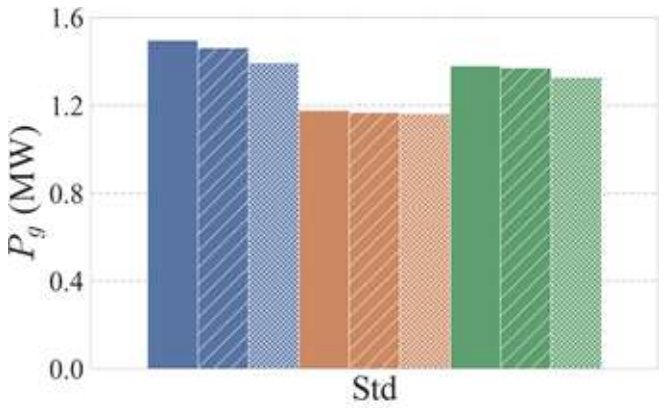
Rated Wind Speed Condition

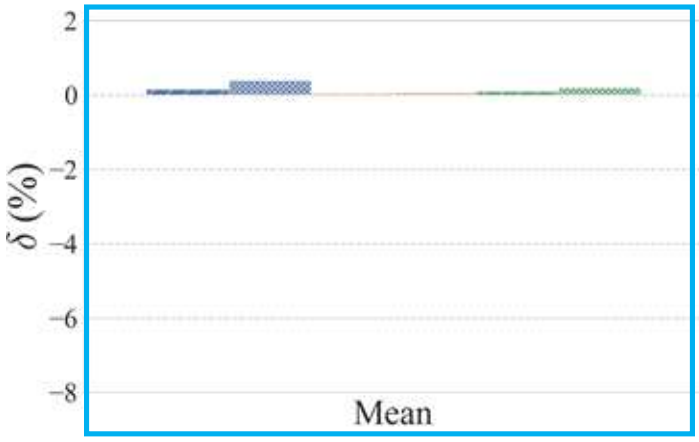
Generator Power

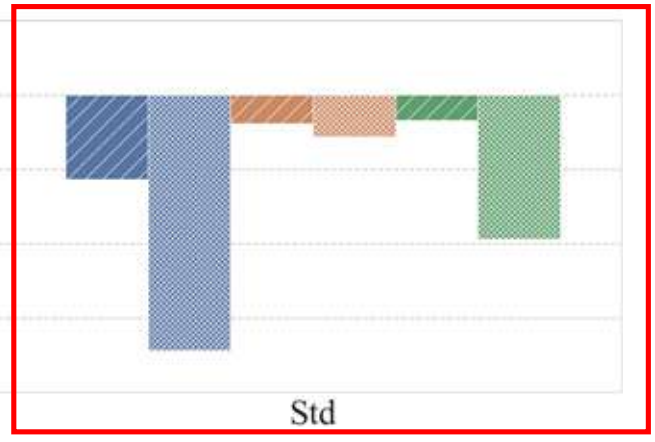






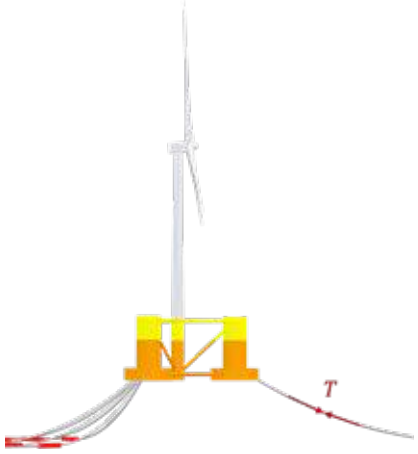


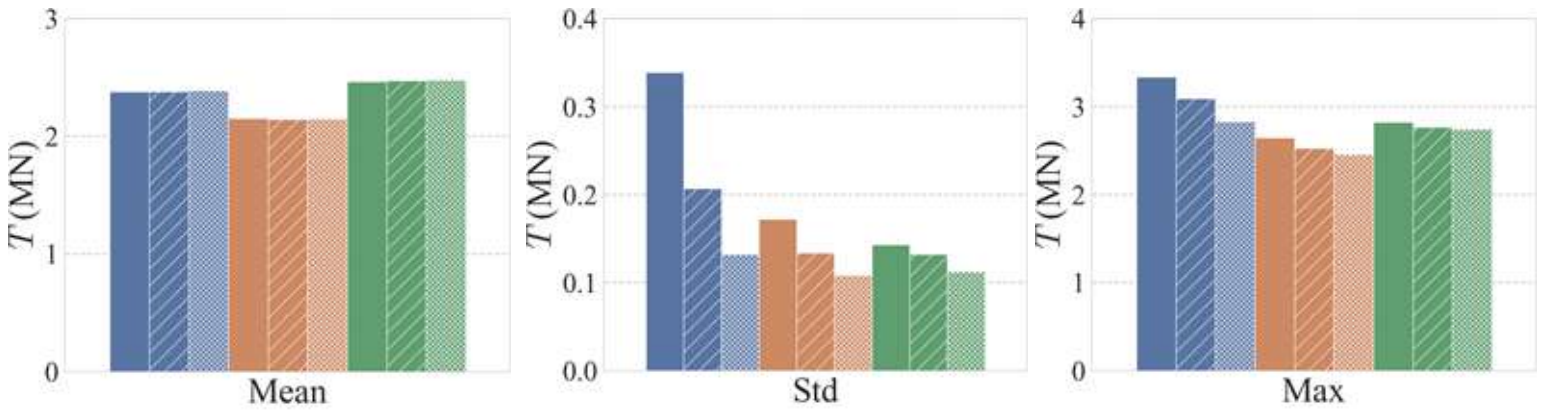


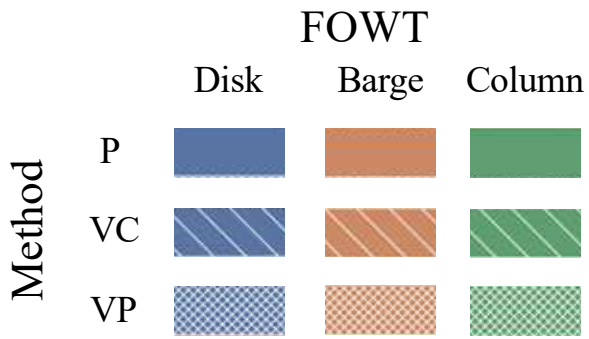


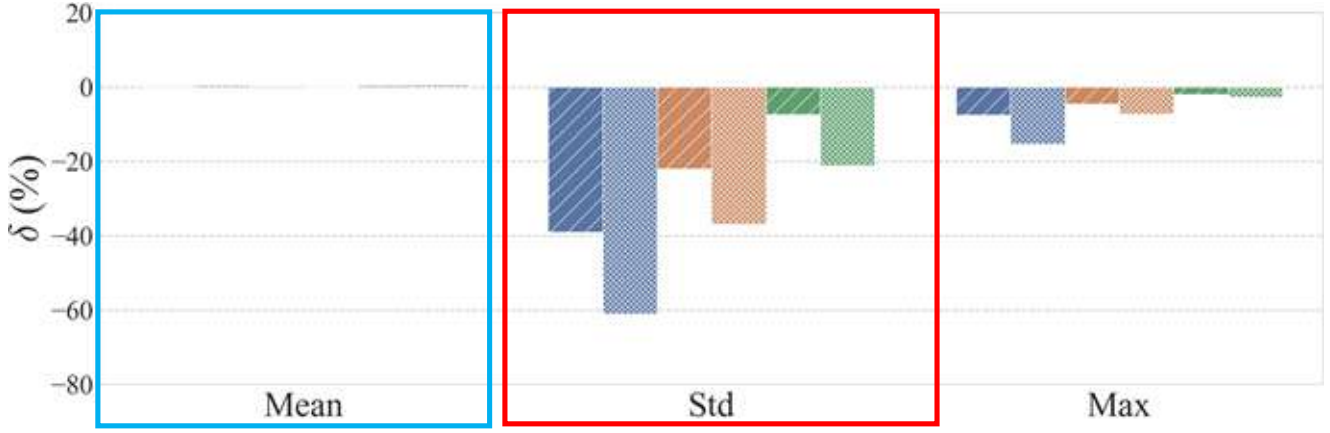
Rated Wind Speed Condition

Mooring Line Tension



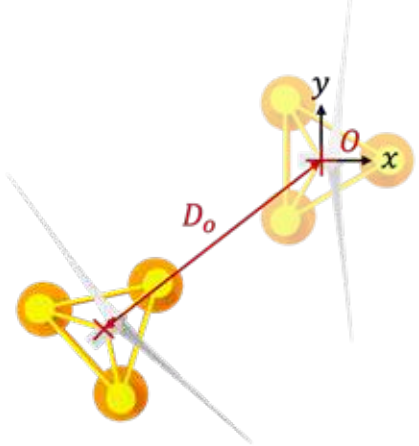


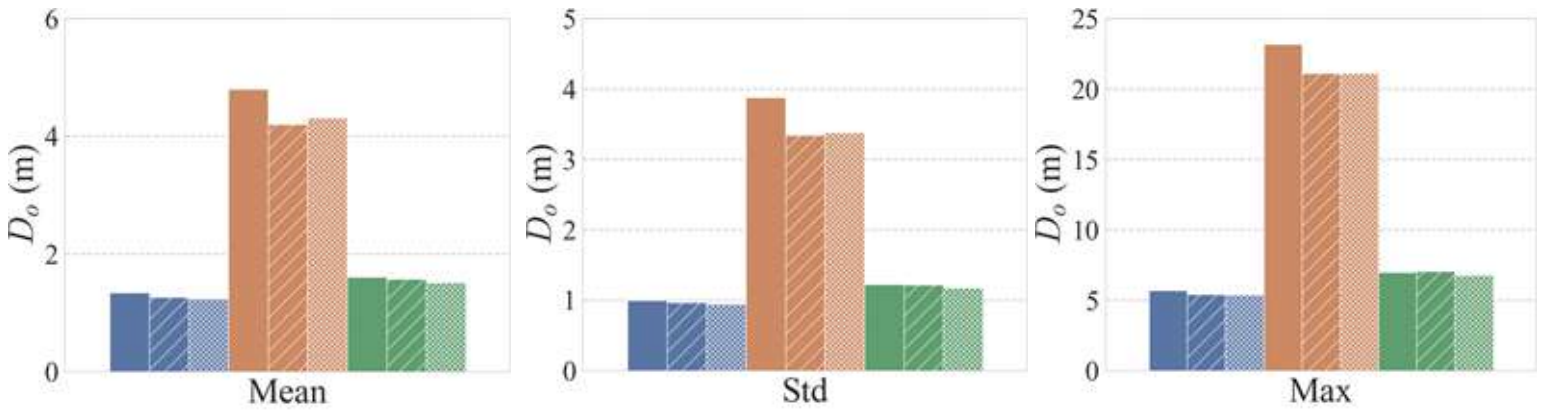


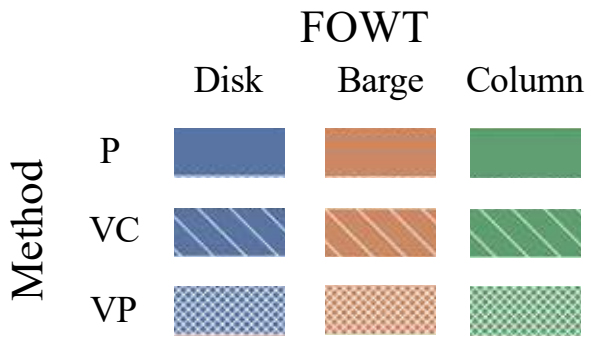


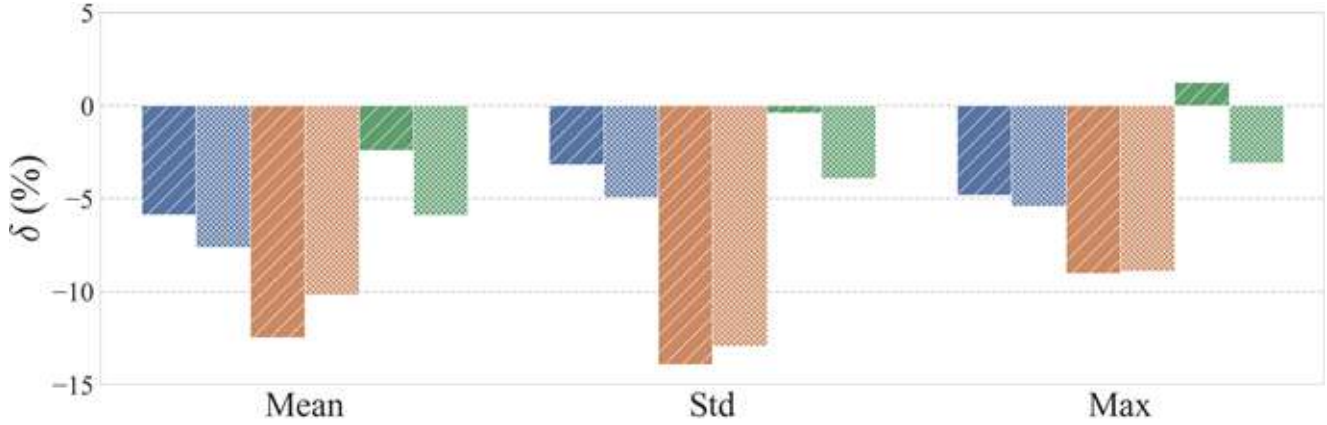
50-Year Return Period Wind Speed Condition

Offset



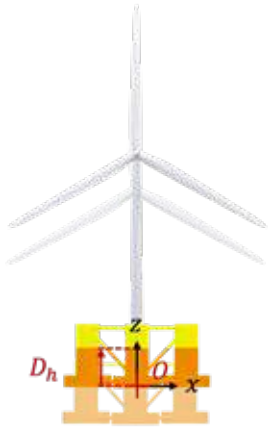


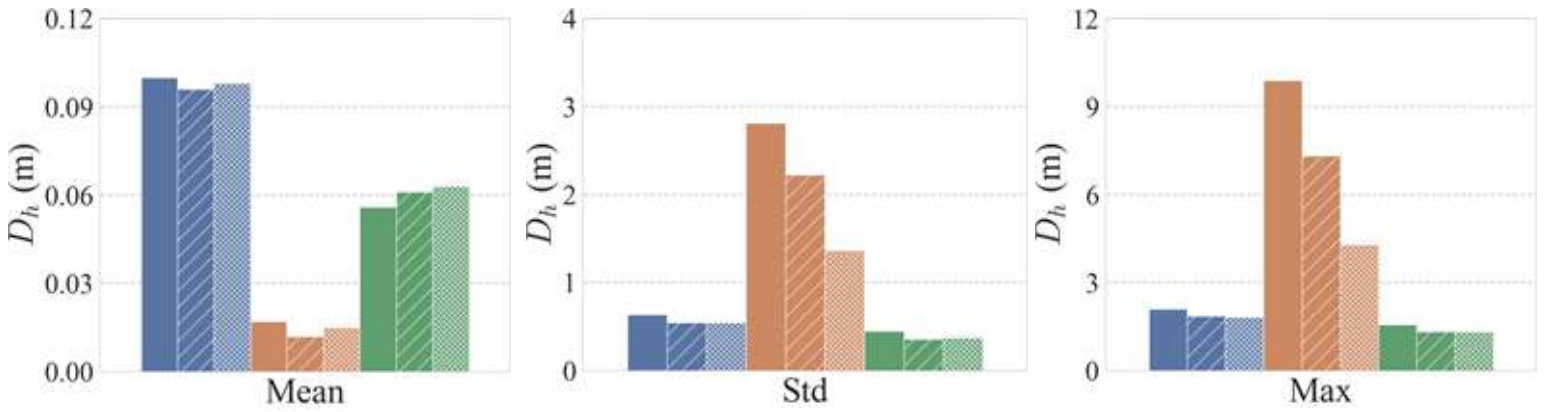


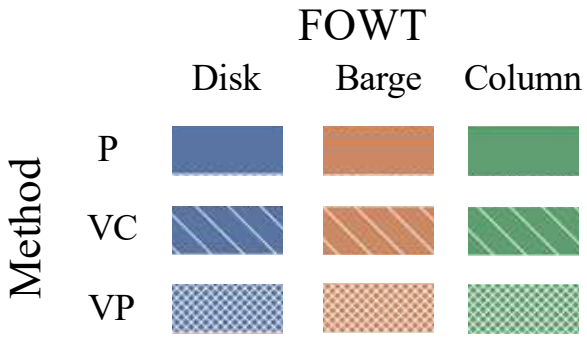


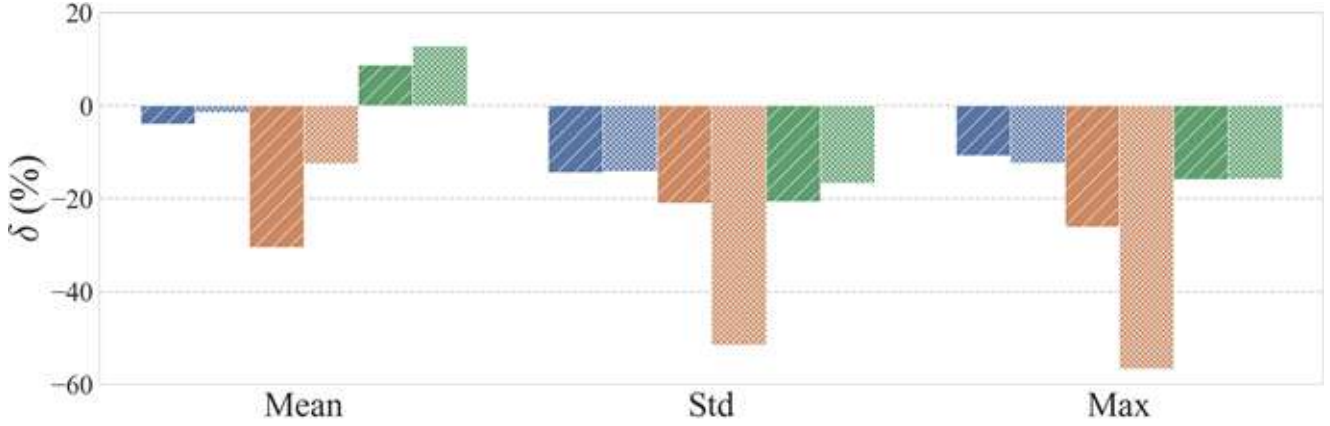
50-Year Return Period Wind Speed Condition

Heave



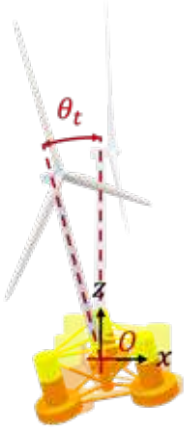


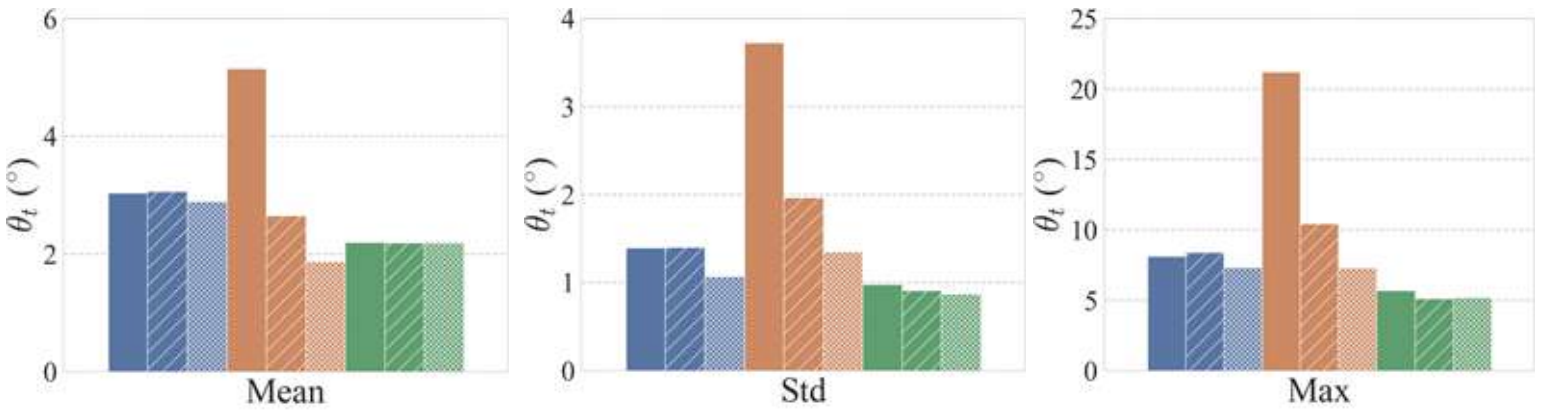


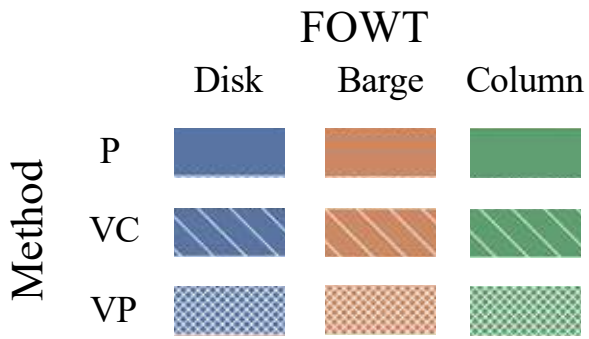


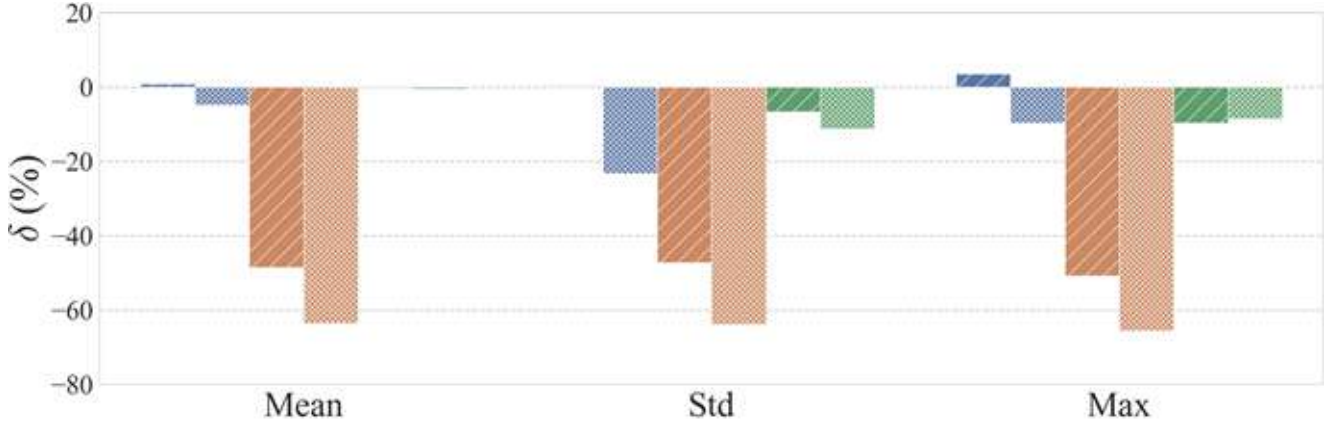
50-Year Return Period Wind Speed Condition

Tilt Angle



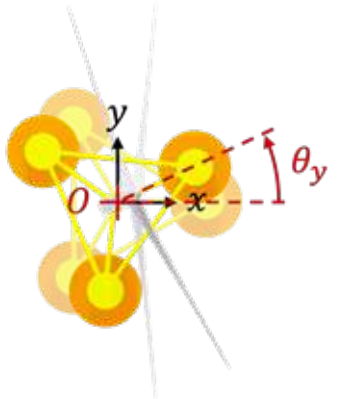


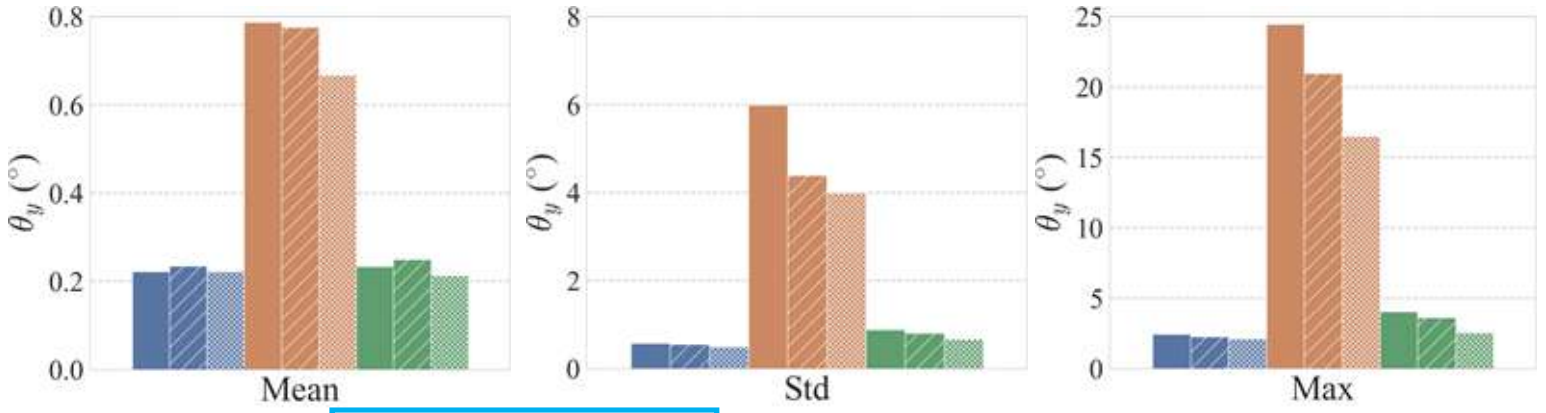


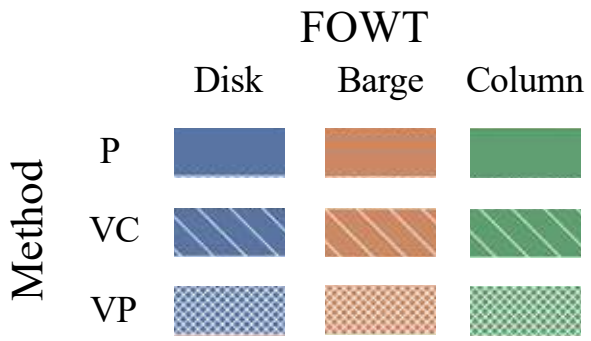


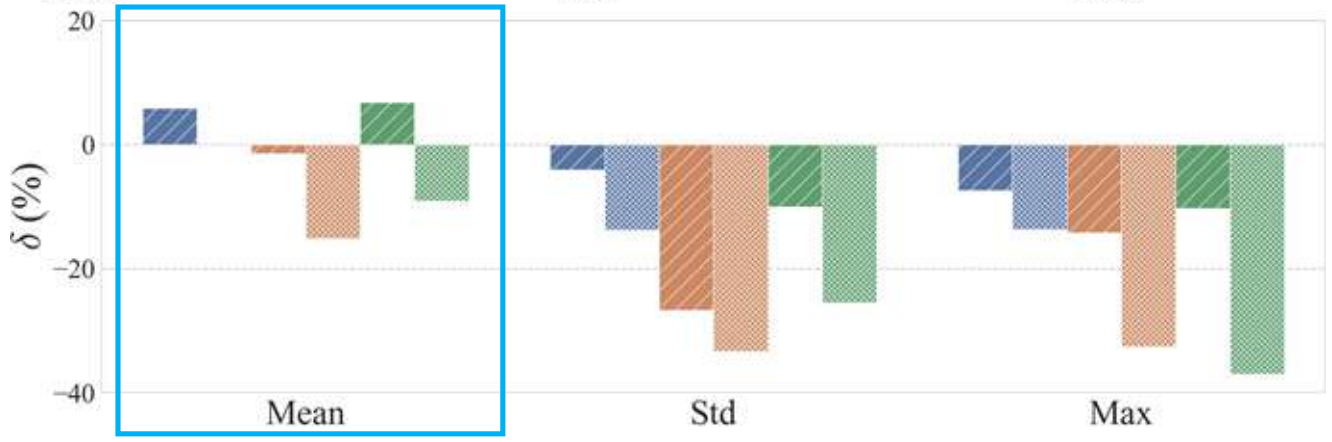
50-Year Return Period Wind Speed Condition

Yaw



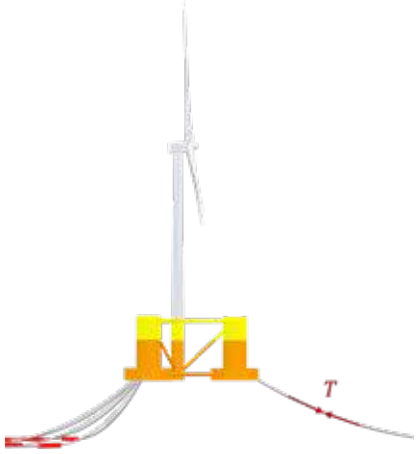


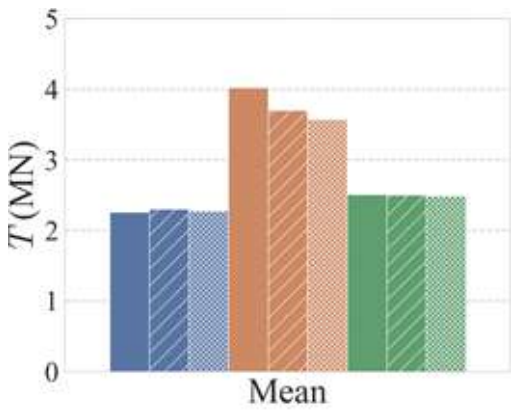


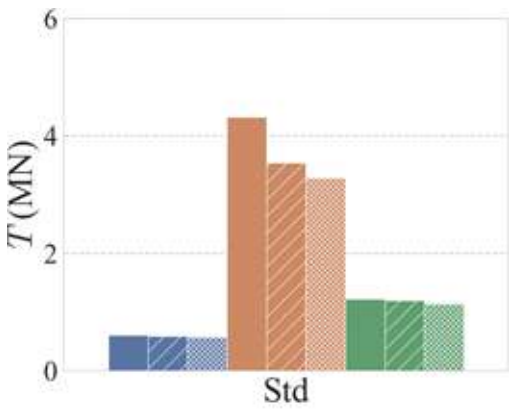


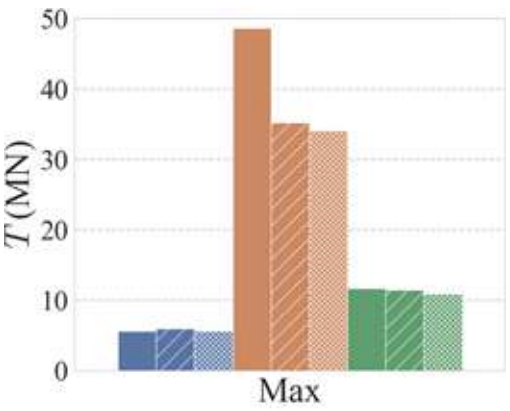
50-Year Return Period Wind Speed Condition

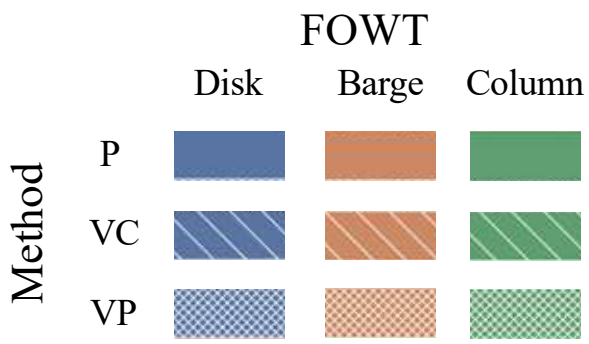
Mooring Line Tension

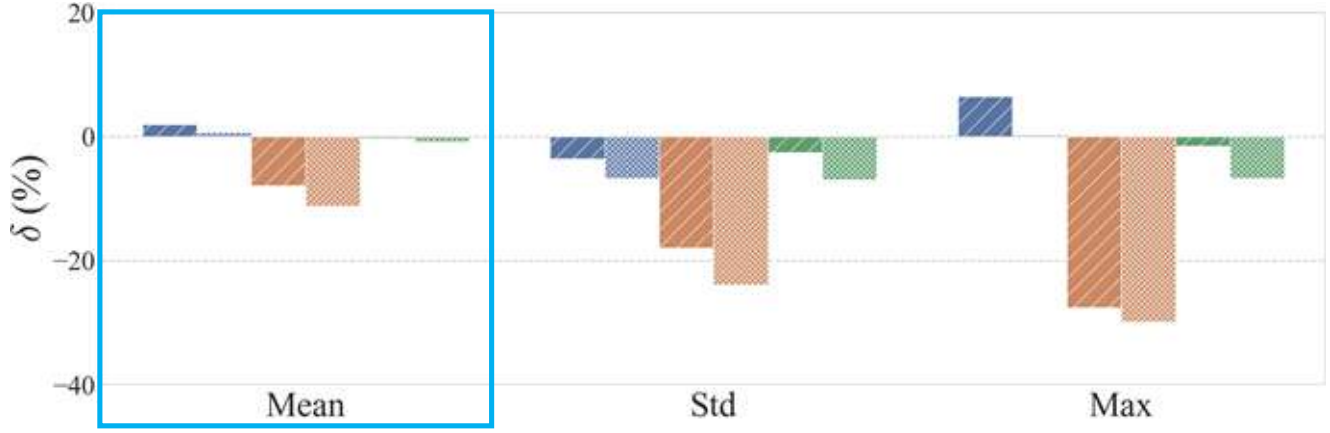






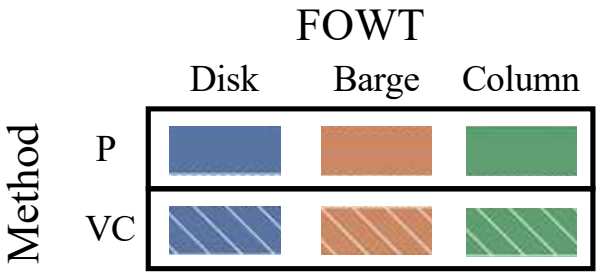






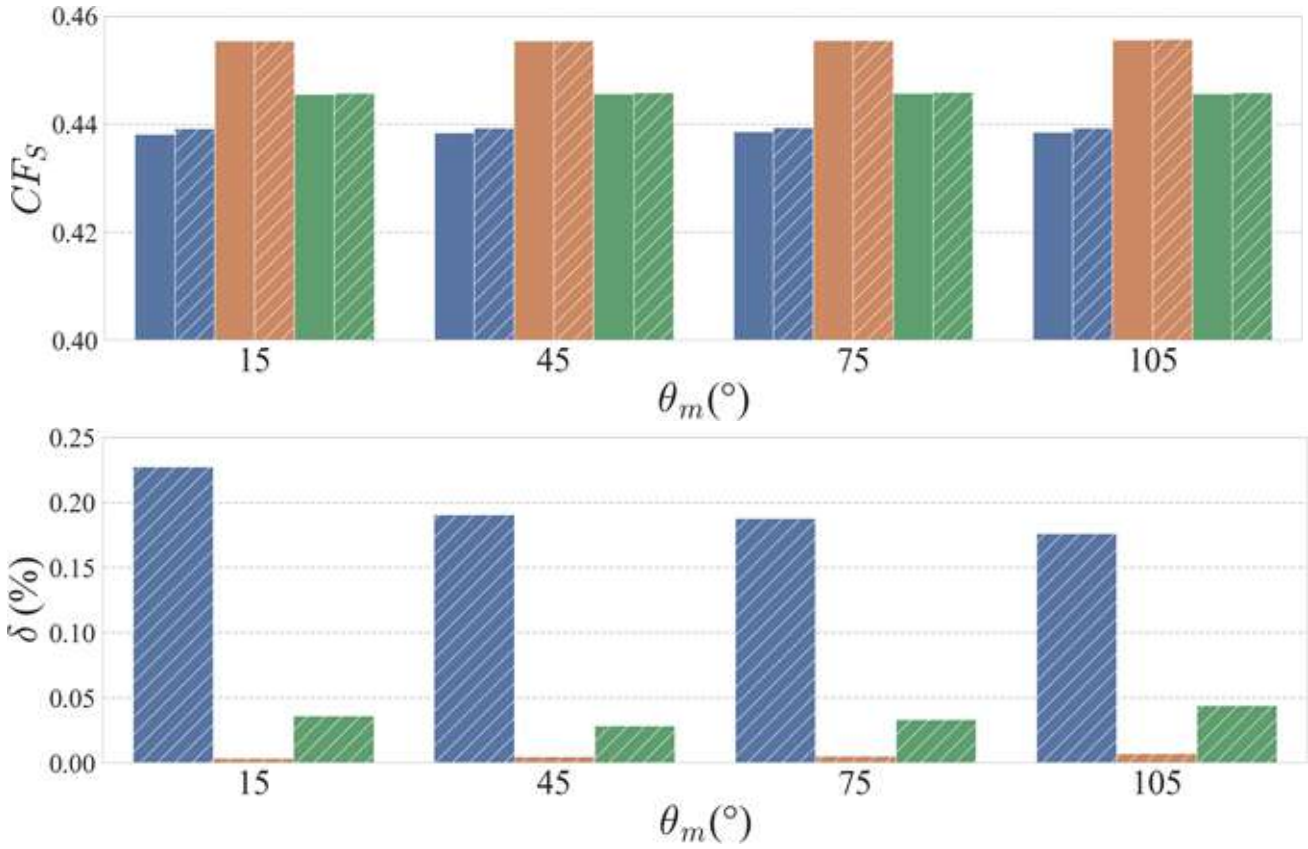
Long-Term Condition

Capacity Factor

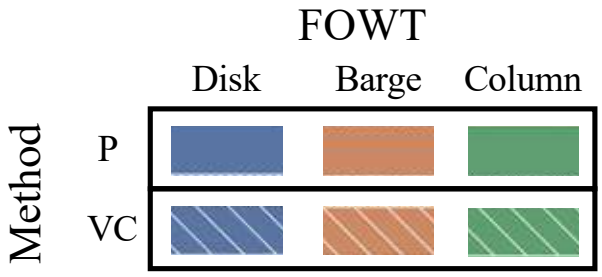


$CF_T = 0.4646$ $\eta_{CF} = CF_S/CF_T$

FOWT		P	VC
Disk	CF_S	0.438	0.439
	η_{CF}	94.4%	94.6%
Barge	CF_S	0.456	0.456
	η_{CF}	98.0%	98.0%
Column	CF_S	0.446	0.446
	η_{CF}	95.9%	96.0%



Long-Term Condition

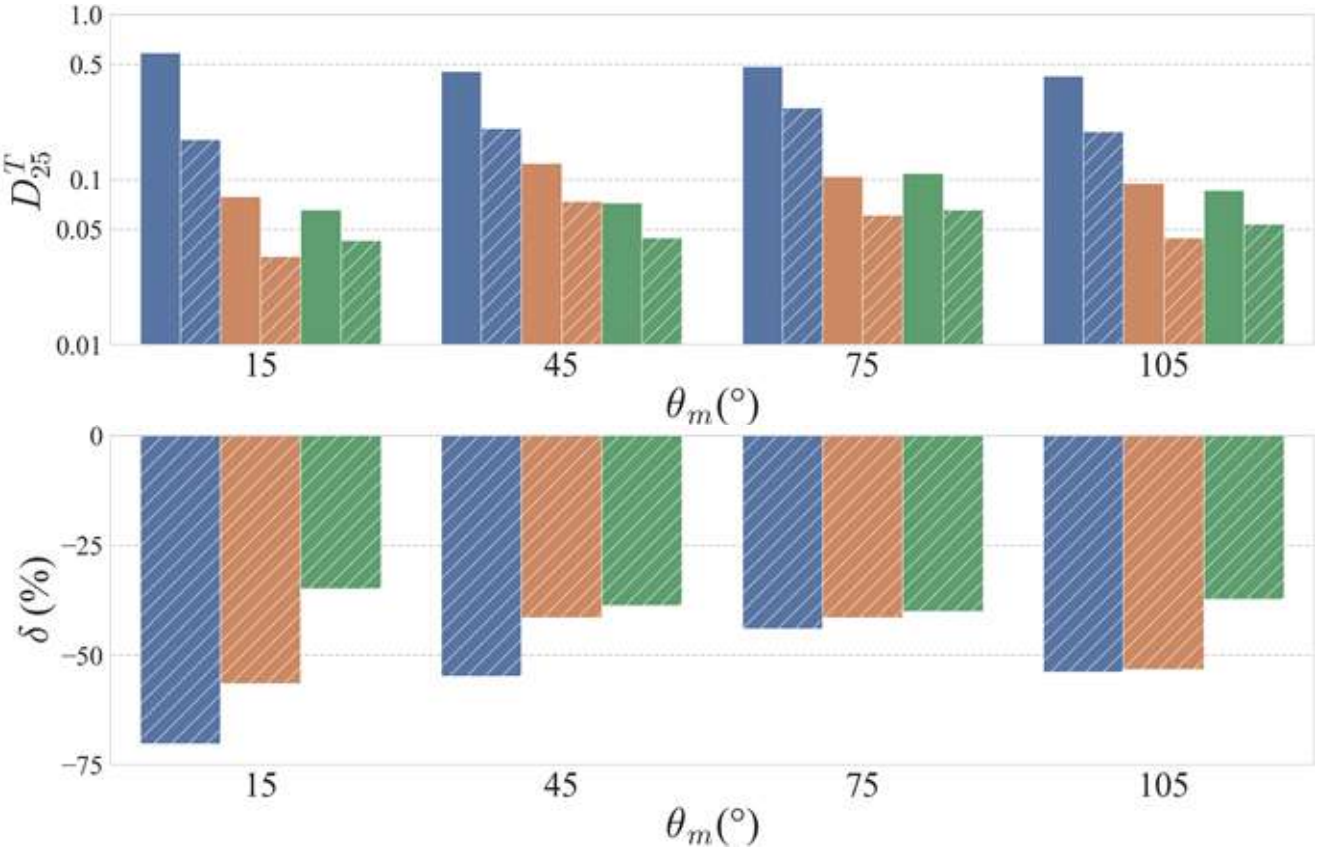


$$D_{25}^{L} = \begin{cases} 0.2 & D_r \le 0.8 \\ \dfrac{1}{5 + 15(D_r - 0.8)} & D_r > 0.8 \end{cases}$$

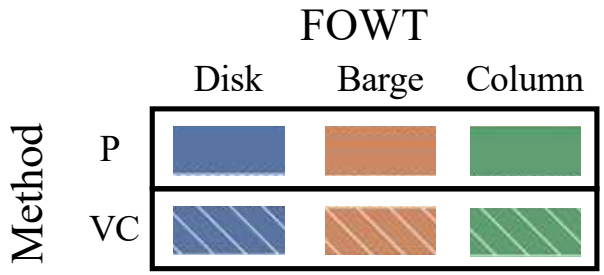
$$\eta_D = D_{25}^{T} / D_{25}^{L}$$

FOWT	P	VC
Disk	0.423-0.587	0.175-0.272
Barge	0.079-0.126	0.034-0.074
Column	0.066-0.109	0.043-0.066

Mooring Line Fatigue Damage



Long-Term Condition

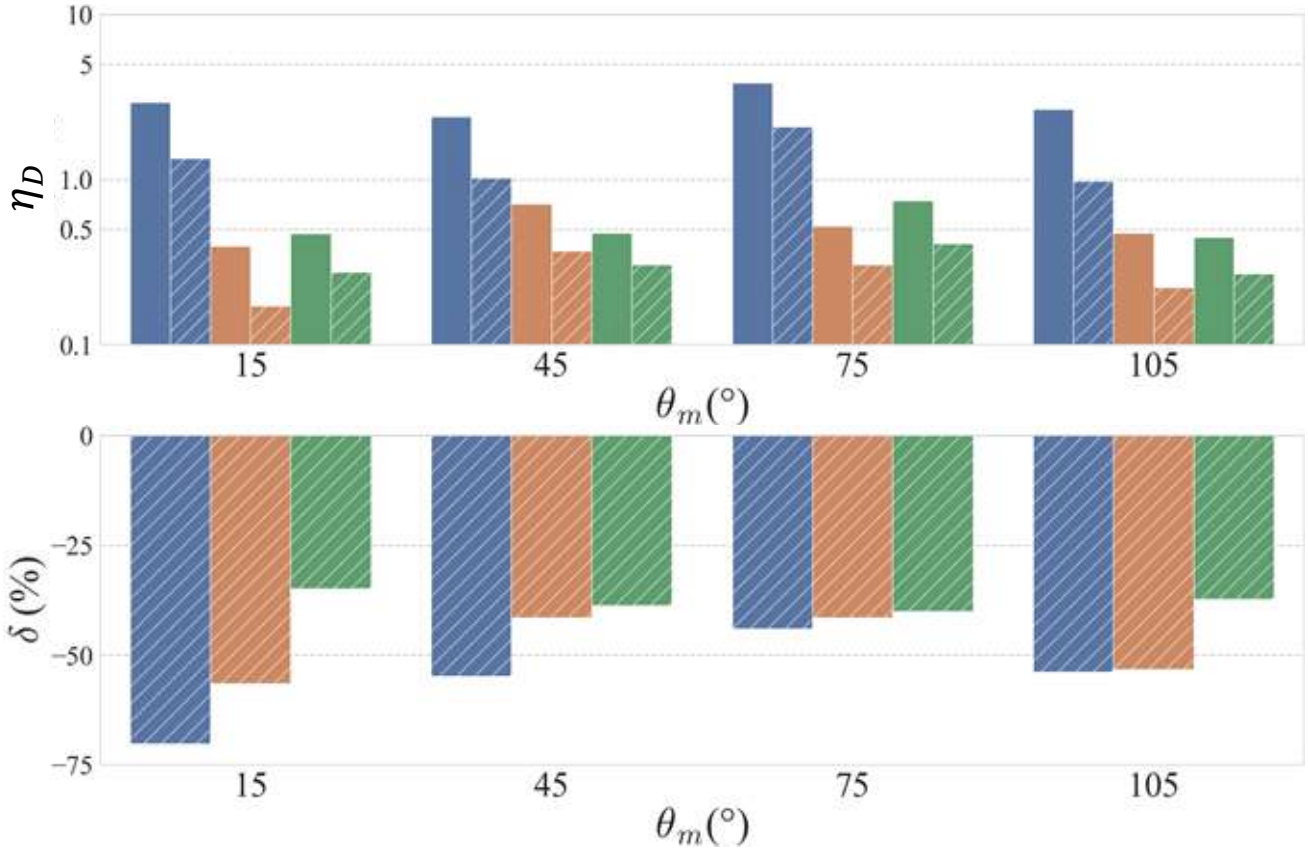


$$D_{25}^{L} = \begin{cases} 0.2 & D_r \le 0.8 \\ \dfrac{1}{5 + 15(D_r - 0.8)} & D_r > 0.8 \end{cases}$$

$$\eta_D = D_{25}^{T} / D_{25}^{L}$$

FOWT	P	VC
Disk	2.401-3.858	0.974-2.089
Barge	0.394-0.709	0.171-0.368
Column	0.446-0.746	0.270-0.411

Mooring Line Fatigue Damage



Conclusion

Least Impact → Greatest Impact

1. The Impact of Fluid Viscosity on Floating Wind Turbine

Rated Wind Speed Condition

FOWT-type	Column-type	Barge-type	Disk-type
Statistics	Mean Value	Maximum Value	Standard Deviation

50-Year Return Period Wind Speed Condition

FOWT-type	Disk-type	Column-type	Barge-type
Statistics	Mean Value	Maximum Value	Standard Deviation

Long-Term Condition

Generator Capacity Factor	Barge-type	Column-type	Disk-type
	0.004% ~ 0.007%	0.028% ~ 0.044%	0.176% ~ 0.227%
Mooring Line Fatigue Damage	Column-type	Barge-type	Disk-type
	-34.91% ~ -39.99%	-41.41% ~ -56.43%	-44.04% ~ -70.16%

Conclusion

Least → Greatest

2. The Motion Response on Floating Wind Turbine

Rated Wind Speed Condition

Platform Type		Disk	Barge	Column
< 21 m D_o^M (m)	P	2.822	3.640	2.646
	VC	2.628	2.654	2.061
	VP	2.128	2.026	2.462
$> 10°$ θ_t^M (°)	P	11.095	1.117	6.696
	VC	10.494	1.074	6.716
$< 10°$	VP	9.311	1.027	6.208
$> 5°$ θ_t^m (°)	P	6.646	0.700	4.434
	VC	6.497	0.700	4.442
	VP	6.520	0.701	4.452

50-Year Return Period Wind Speed Condition

Platform Type		Disk	Barge	Column
> 21 m D_o^M (m)	P	5.697	23.193	6.980
	VC	5.423	21.102	7.068
	VP	5.389	21.126	6.765
$> 15°$ θ_t^M (°)	P	8.136	21.218	5.681
	VC	8.149	10.453	5.128
$< 15°$	VP	7.344	7.307	5.199

Conclusion

3. The Generator Performance on Floating Wind Turbine

Rated Wind Speed Condition

Platform Type		Disk	Barge	Column
P_g^m (MW)	P	12.062	12.458	12.174
	VC	12.080	12.463	12.184
	VP	12.110	12.466	12.199

Long-Term Condition

Platform Type		Disk	Barge	Column
η_{CF} (%)	P	94.31-94.41	98.02-98.08	95.90-95.95
	VC	94.53-94.58	98.03-98.08	95.93-95.98

Conclusion

Least → Greatest

4. The Mooring Performance on Floating Wind Turbine

Rated Wind Speed Condition

Platform Type		Disk	Barge	Column
< 15.29 MN	P	3.340	2.649	2.822
T^M (MN)	VC	3.091	2.527	2.767
	VP	2.828	2.458	2.744

50-Year Return Period Wind Speed Condition

Platform Type		Disk	Barge	Column
> 15.29 MN	P	5.596	48.609	11.643
T^M (MN)	VC	5.958	35.226	11.461
	VP	5.612	34.085	10.862

Long-Term Condition

Platform Type		> 1 Disk	Barge	Column
η_D	P	2.401 -3.858	0.394-0.709	0.446-0.746
	VC	0.974-2.089	0.171-0.368	0.270-0.411

< 1

Thank you for listening.

chausw@ntu.edu.tw