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Shared Anchoring of Marine Renewable Energy Devices Utilizing Monopiles

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Introduction

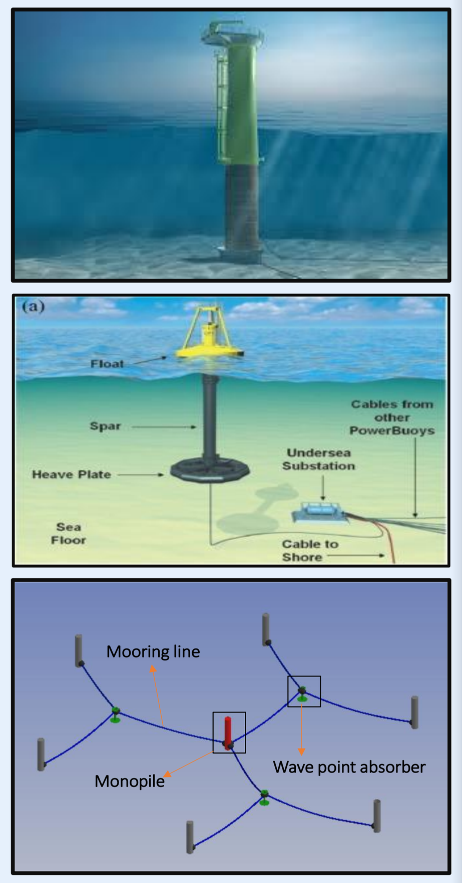

Fig. 1 OWT monopile (Saipem SA), floating point absorber (Xie et al., 2013), and a schematic co-located system.

Kitty Hawk and **Wilmington offshore** wind lease areas have a combined potential power generating capacity of nearly 4 GW. There is an opportunity to deploy Marine Hydrokinetic **(MHK)** devices integrated with Offshore Wind Turbines **(OWT)**.

- Optimizing the cost of installation and operation.
- Increasing the energy yield.
- contributing to optimal use of natural resources.

Monopile foundation is the most likely to be used in the relatively shallow waters of **North Carolina offshore** wind lease area. Common standards for analyzing monopiles are for long and slender elements employed in oil and gas industry.

Fig. 2. Monopiles for Taiwan's Formosa 1 offshore wind farmPhoto.

Large monopile wall thickness is required for drivability, hence under design loads excess capacity exists. Therefore, shared anchoring is possible. However:

- **No information** in Standards are related to **Shared Anchoring**.
- **Lack of guidance** to address the impact of pipe **size** and lower flexibility **monopiles** on the foundation system response under loading.

Objective

- A Systematic assessment of **excess capacity** of OWT **monopiles** as a function of the embedded length/diameter, while meeting Ultimate Limit State **(ULS)**, and Serviceability Limit State **(SLS)**.
- Investigating the effect of monopile wall thickness/diameter on the **natural frequencies** and **damping** of the system with and without **shared anchoring** approach.

Modeling and Methods

The **reference model RM3** device, which is a two-body floating point absorber **(FPA)** is considered as the **MHK** device. To keep the floating device in position, the point absorber is connected to a **mooring system**, per **Fig. 3**. The **RM3** device is designed for water depths of **40-100 m**. For the case of **North Carolina offshore** wind, the water depth is less than 40m, the device was scaled at **1/3 scale**.

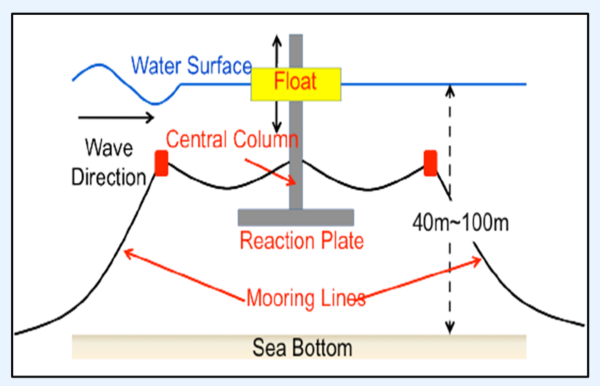

Fig 3. The schematic side view of RM3 (Neary et al., 2014).

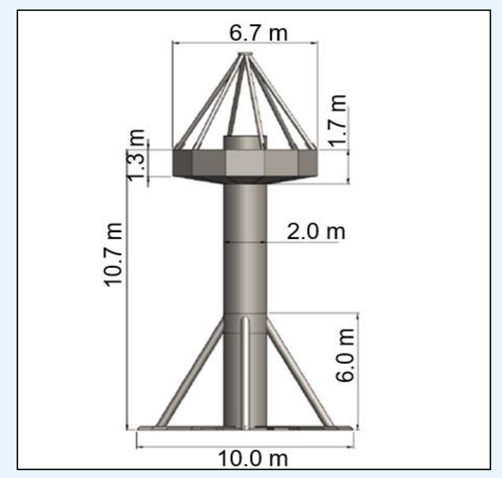

Fig.4. RM3 scaled down device.

Table 1. Model and full-scale parameters.

Parameter	unit	Scaling Coeff	Model scale	Full scale
Mass	ton	α^3	25	680
Rated power	kW	$\alpha^{3.5}$	6	286

ANSYS-AQWA software is used to simulate the effect of waves and wind on the tension in the **mooring system** under different **dynamic** loading scenarios per **Table 2**.

Table 2. Summary of wind and wave characteristics for loading scenarios considered in the project.

	Symbol	Unit	Normal and operational condition	Extreme wind load scenario
Wind speed	U	m/s	12.94	20.1
Wave height	H	m	5.30	10.0
Wave period	T	s	8.10	11.2

In **Fig. 5**, a **600 seconds simulation** using a time step of 0.01 seconds under the action of **extreme load scenario** is presented. The maximum force in cable one occurs at t = 149 sec and is equal to 958 kN. The corresponding forces in cables 2 and 3 are 494 kN. These forces are applied on the **monopile** as a support for the **co-located** system.

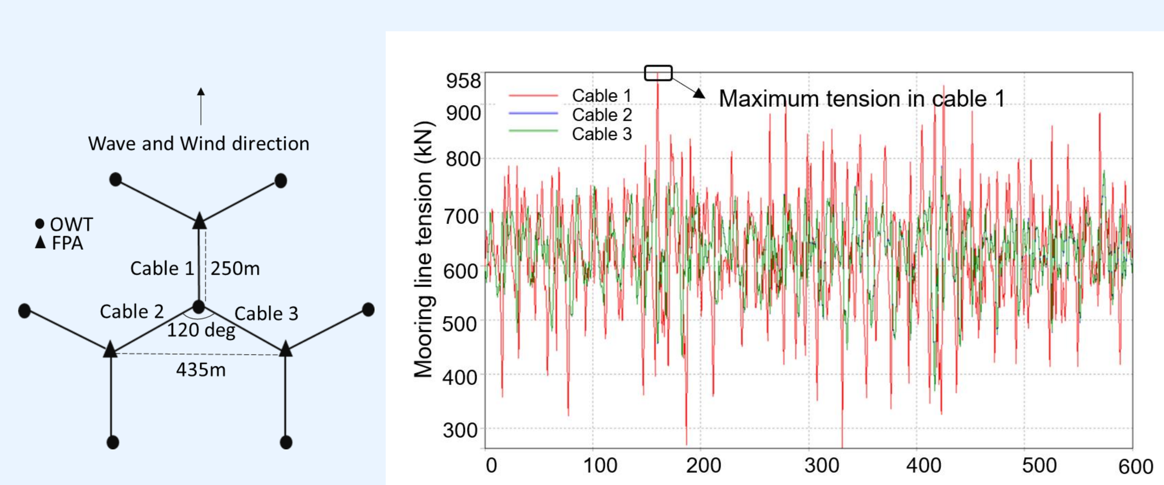

Fig.5. Schematic plan view of co-located system and mooring lines tension.

Modeling and Methods (contd.)

PLAXIS 3D is employed to perform numerical **static** and **dynamic** simulation of OWT **monopile**. A parametric study is performed for the **Gunfleet Sands** OWT (Table 3) With the Siemens SWT-3.6-107 **3.6 MW** as the **wind turbine**.

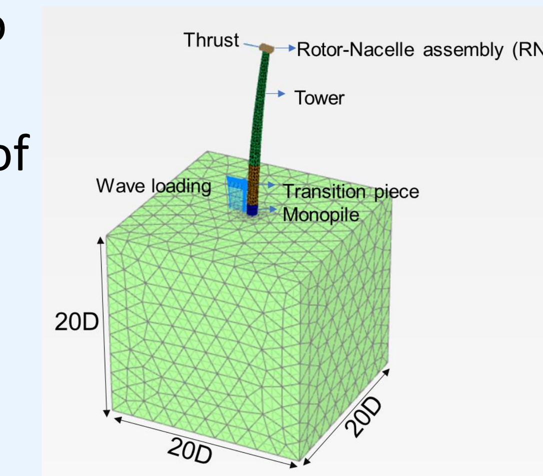

Fig. 6. Numerical 3D model in PLAXIS.

Table 3. Wind turbine data (after Arany et al., 2016)

Parameter	Symbol	Value	Unit
Hub height from MSL	Z_{hub}	73	m
Depth of water	d_w	18	m
Mass of the rotor	m_{RT}	243	Tons
Pile diameter	D	5	m
Pile wall thickness	tp	50	mm
Embedded length	Le	38	m
Pile Young's modulus	E_p	200	GPa
Pile material yield stress	f_{yp}	355	MPa
Rotor operational frequency	f_{1p}	0.077 to 0.2	Hz
Blades turning frequency	f_{3p}	0.231 to 0.6	Hz
Soil relative density	D_R	75	%

Results

Monopiles with **L_e of 28-48m** and **t_p> 40mm** meet **ULS** and **SLS** design criteria and have extra capacity to carry additional loads from WEC.

Increasing t_p from **35 to 55mm increases f_n** from **0.3Hz to 0.325Hz**. Wind turbine operates within blade turning frequency (f3P) outside the **soft-stiff** zone.

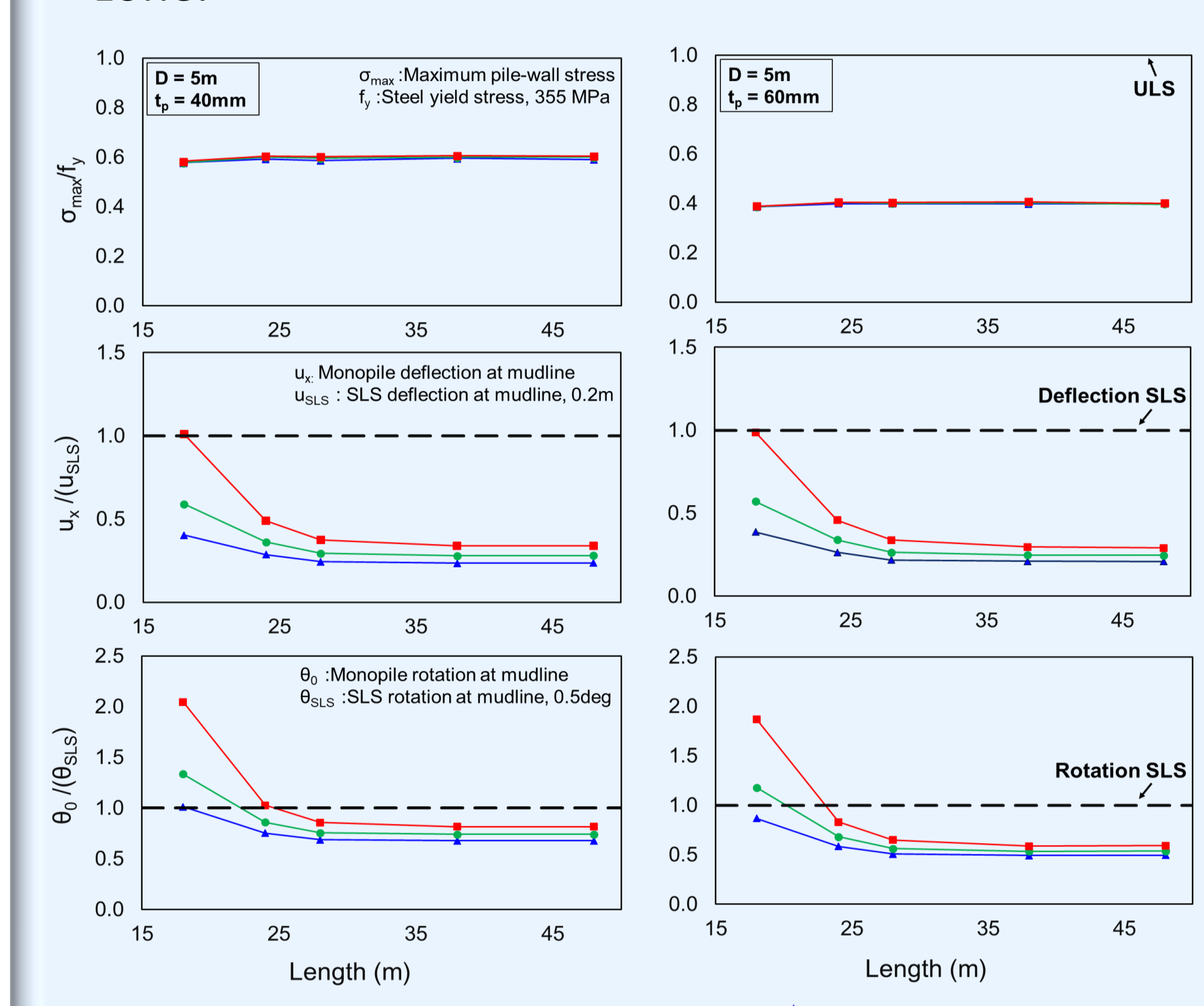

Figure 7. Effect of L_e and t_p on monopile response.

Results (contd.)

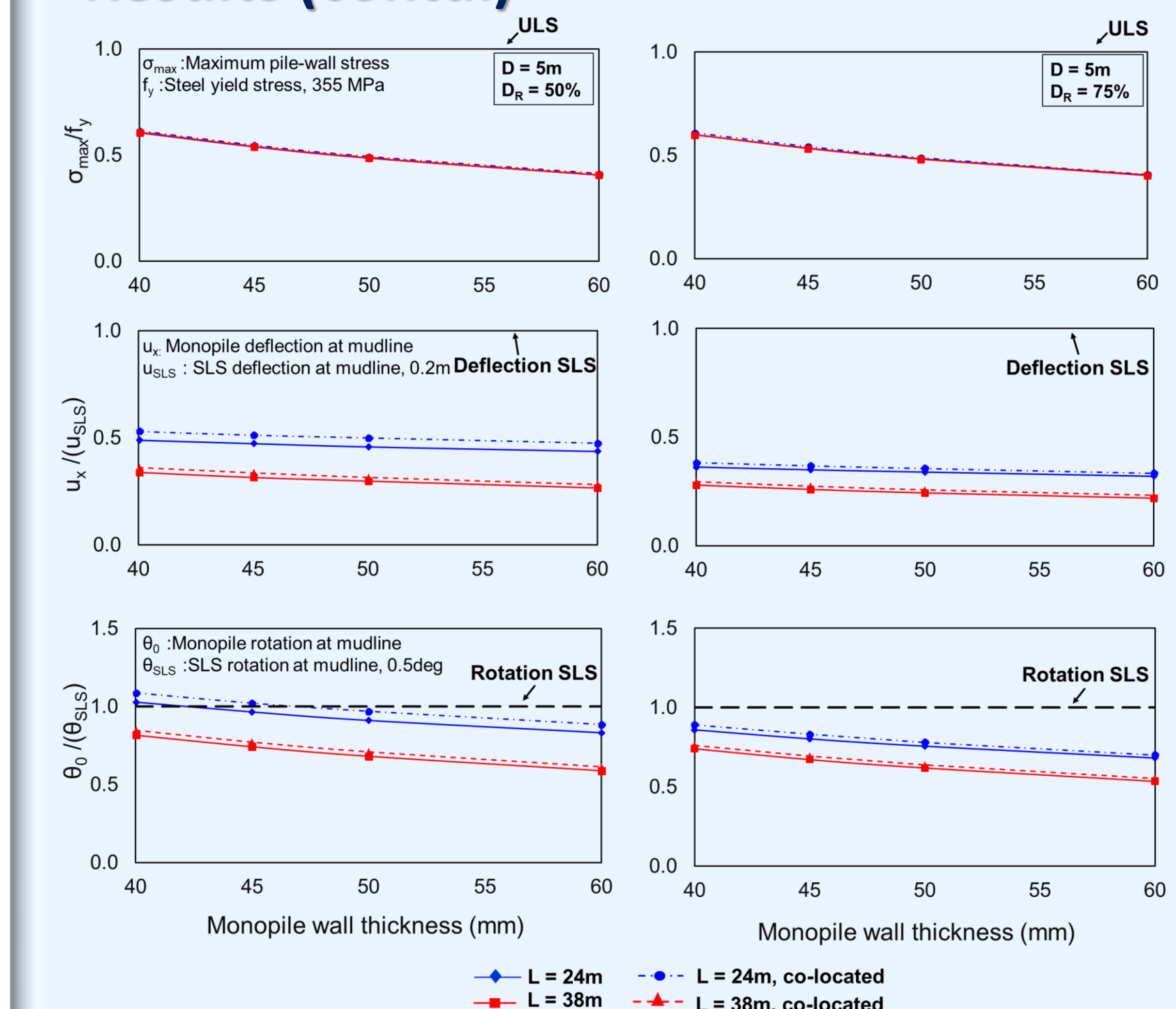

Fig. 8. Effect of t_p on the response of the co-located system.

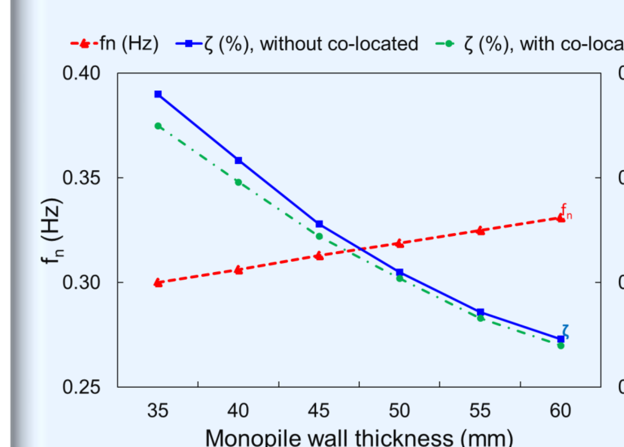

Fig. 9. Effect of t_p on f_n and damping.

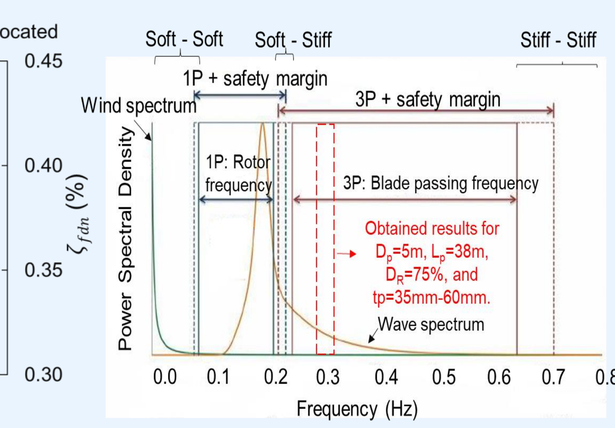

Fig. 10. Frequency diagram for the Siemens OWT (after Arany et al., 2015b).

Conclusion

- OWT **monopiles** with **L_e = 28-48m** and **t_p> 40mm** meet **ULS** and **SLS** specifications with and without **shared anchoring approach.**
- The **co-located** configuration system does not significantly change the f_n and foundation **damping**.
- The **Gunfleet Sands** turbine operates within blade turning frequency. These analyses suggest changes in tower dimensions would be required to bring the f_n into the **soft superstructure-stiff substructure** region.

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