Ship collision analysis on Offshore Wind Turbines with monopile foundations

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Introduction

Every year the offshore wind industry is expanding and new offshore wind farms are built in deeper waters and closer to the traffic lanes for commercial and passenger ships leading to possible collision events. The consequences of such events can range from minor structural damage to collapse of the Offshore Wind Turbine (OWT), with probability of ship sinking, pollution and at worst, to loss of human lives. Therefore, a collision risk analysis becomes a necessity in the pre-design stage of an offshore wind farm in order to identify the collision scenarios having the greatest probabilities of occurrence but also the most dangerous ones.

The objective of this research is to investigate numerically the influence of the impact velocity and wind loads on the OWT's behaviour when subjected to ship impact. A 5 MW wind turbine was considered for this research and the striking ship was conservatively assumed to be rigid. The description of the Finite Element model is presented as well as the main results obtained.

Description of the Finite Element model

Nonlinear numerical simulations of ship – OWT head-on collisions have been performed using the explicit time integration solver LS-DYNA. The particularities of the considered OWT are presented in Table 1. The structure is composed of three main parts: the monopile, the transition piece and the tower. In order to simplify the F.E. model, the nacelle and rotor blades haven't been modelled, but replaced by a lumped mass located at the top of the tower.

The striking ship is a 5000 t Offshore Supply Vessel (OSV) which was modelled as a rigid body. The main characteristics are presented in Table 2.

Table 1 – Particularities of the OWT [1]

Monopile	Diameter (base)	5 m
	Diameter (top)	4,3 m
	Thickness	0,07 m
Transition piece	Diameter	4,3 m
	Thickness	0,06 m
Tower	Diameter (base)	4,3 m
	Diameter (top)	3 m
	Thickness	0,045 m
Height		115 m
Nacelle mass		350 t
Water depth		25 m

Table 2 – Particularities of the OSV [1]

Type	bulbous bow
Length	102,4 m
Breadth	23,23 m
Depth	25,89 m
Draft	4,12 m
Displacements	5000 t
Water (added mass)	250 t

Impact velocity

The influence of the impact velocity was investigated for five collision scenarios in which the velocity of the striking ship varied from 1 m/s to 5 m/s. For this case, only gravity load was considered for the simulation, while the wind loads were neglected in order to capture only the influence of the impact velocity on the structural behaviour of the OWT.

The deformed shape of the structure corresponding to the maximum top displacement is presented in Figure 1.

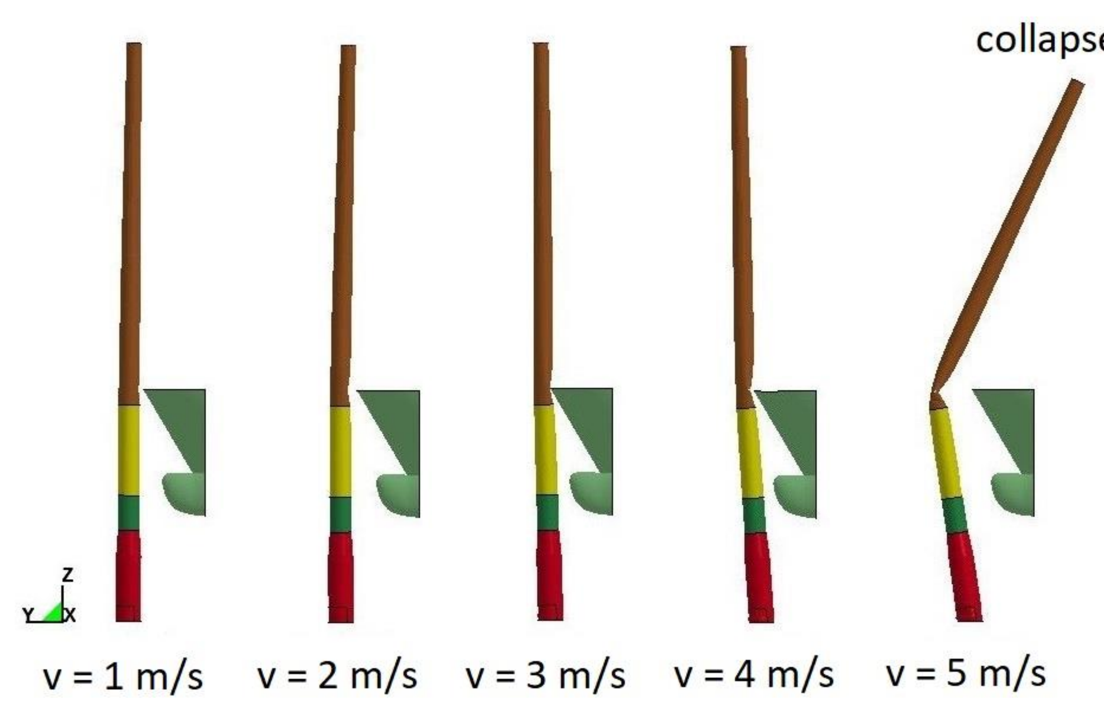

Figure 1 – Deformed shape of the OWT [1]

The cross section of the OWT suffers deformations in the contact area where the impact occurs with the prow of the ship as shown in Figure 2. For an impact velocity of 5 m/s, the cross section is reduced by 56%, leading to the development of a plastic hinge followed by the collapse of the OWT.

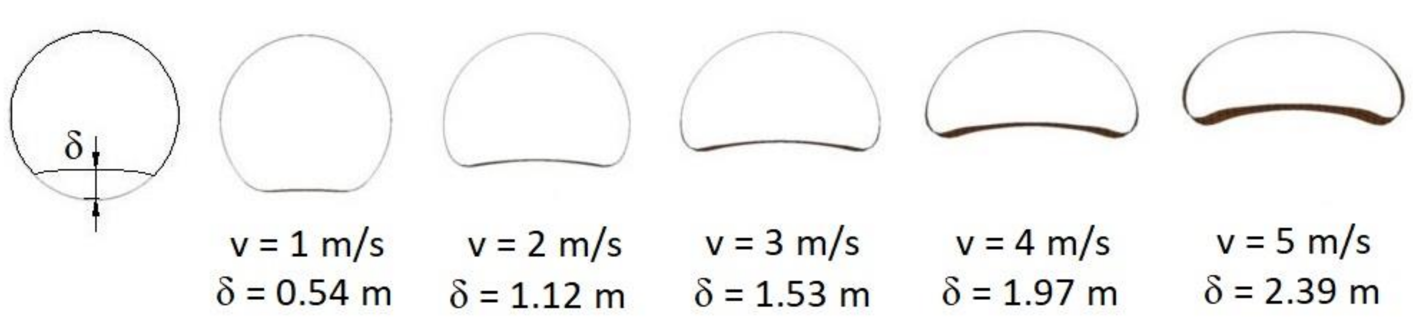

Figure 2 - Cross section of the deformed shape of the OWT in the contact area [1]

The impact velocity has a great influence of the OWT's behaviour during collision. From the damage analysis, three types of deformations are highlighted:

- Small deformations (v = 1-2 m/s): no repairs of the OWT are required;
- Critical deformations (v = 3-4 m/s): heavy repairs or tower replacement are required;
- Collapse (v = 5 m/s): the entire structure should be replaced.

Wind loads

The main loads acting on the structure during the normal operation of the OWT are induced by the wind. Three cases were analysed for different wind directions with respect to the collision direction as shown in Figure 3. The wind loads and moments exerted by the rotating turbine are applied to the central node of the tower, as depicted in Figure 4 and the values used are presented in Table 3.

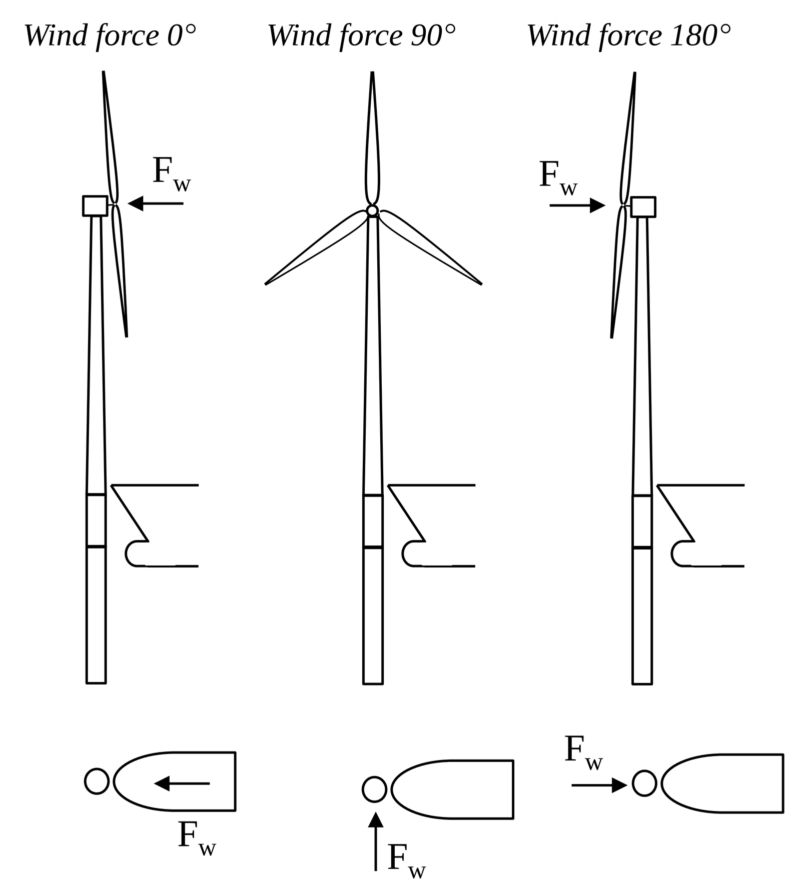

Figure 3 – Disposition of wind loads [1]

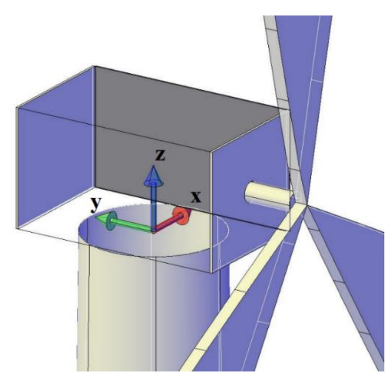

Figure 4 – Coordinate system of the wind loads [1]

Table 3 – Wind loads [1]

F_x	-38,9 kN
F_y	586 kN
F_z	-78.5 kN
M_x	3922 kN·m
M_y	2967 kN·m
M_z	-3144 kN·m

The behaviour of the OWT during collision is highly sensitive to wind loads : in some cases the OWT can collapse for an impact velocity of only 3 m/s and the structure can fall directly on the ship (Figure 5). The wind direction influences also the overall collapse behaviour of the OWT. When it blows in the same direction as the ship (*case 0°*) , the tower falls in the same direction, while when wind and ship are in opposite directions (*case 180°*), the tower falls on the ship as shown in Figure 6. When the wind force acts perpendicularly to the ship direction, the tower collapses at an angle of 30° with the x axis.

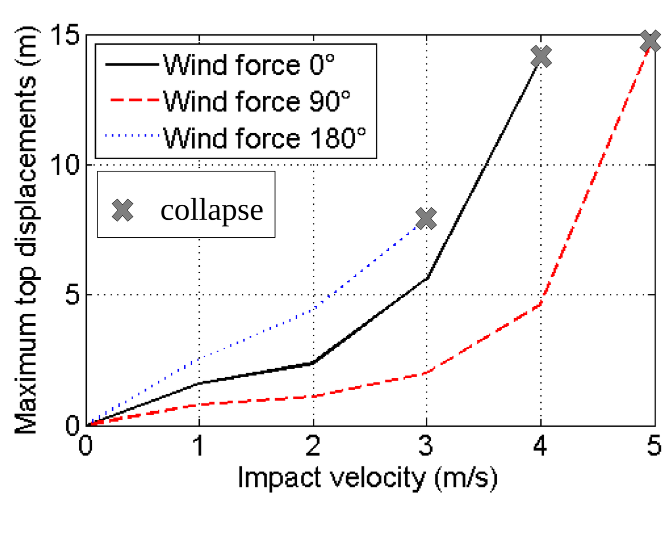

Figure 5 – Impact velocity vs maximum top displacements [1]

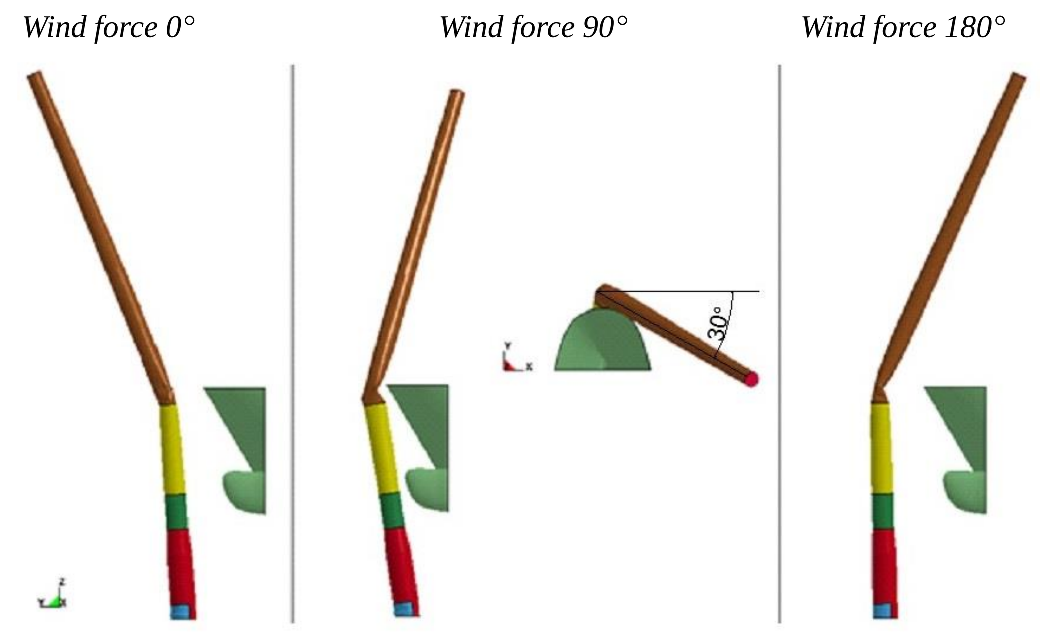

Figure 6 – Collapse behaviour of the OWT [1]

Bibliography:

[1] Bela, A., Le Sourne, H., Buldgen, L., & Rigo, P. (2017). Ship collision analysis on offshore wind turbine monopile foundations. *Marine Structures*, *51*, 220-241.

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