Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

MOSWOZ – 3D FEM Investigation of ship impact against wind turbine foundations in the Dutch part of the North Sea

Information session

30 April 2024

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Maritime Safety and offshore windfarms

Package of measures up to 2031

Our preventive and repressive measures keep the North Sea safe for shipping. We monitor their development and effectiveness so that we can advise on adjustments should the situation develop differently than expected. We do this through the MOSWOZ programme.

- Preventive measures
- Repressive measures

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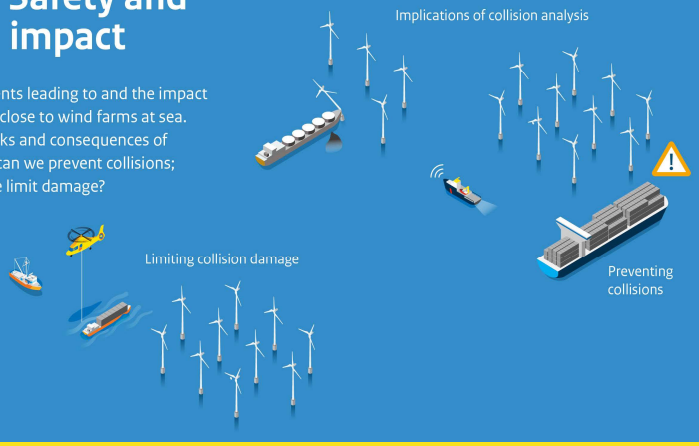
Nautical Safety and collision impact

We analyse the events leading to and the impact of collisions in and close to wind farms at sea.

- What are the risks and consequences of collisions; how can we prevent collisions; and how can we limit damage?



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Phase 2 – 2FE
Ship Impact: Investigated Ships

- Kruiplijn coaster 1.554GT
- Supply vessel 3.200GT
- Chemical & Product tanker 10.000GT
- Passenger vessel 100.000GT
- Containership 192.784GT

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Ship impact: Soil failure results

Drifting ship	Stopping power foundation					
	Wind farm 1	Wind farm 1	Wind farm 2	Wind farm 2	Conceptual designs	
	K07	C01	HIGH	LOW	P001	P002
Kruiplijn coaster	Yes	Yes	Yes	Yes	Yes	Yes
Supply vessel	Yes	Yes	Yes	Yes	Yes	Yes
Chemical tanker	Yes	Yes	Yes	Yes	Yes	Yes
Passenger vessel	Yes	Yes	Yes	Yes	Yes	Yes
Container ship	No	Yes	Yes	Yes	Yes	Yes

Sailing ship	Stopping power foundation					
	Wind farm 1	Wind farm 1	Wind farm 2	Wind farm 2	Conceptual designs	
	K07	C01	HIGH	LOW	P001	P002
Kruiplijn coaster	Yes	Yes	Yes	Yes	Yes	Yes
Supply vessel	No	Yes	Yes	Yes	Yes	Yes
Chemical tanker	No	No	No	No	Yes	Yes
Passenger vessel	No	No	No	No	No	No
Container ship	No	No	No	No	No	No

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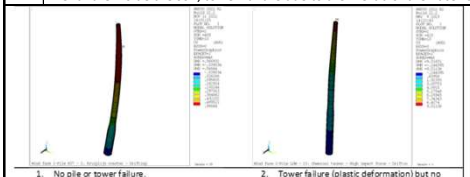
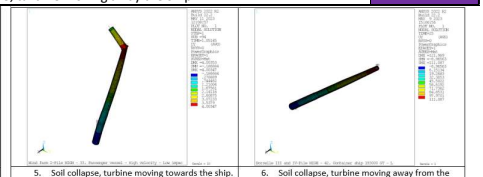
Ship Impact: Observed failure modes

Nr.	Description	Color
1	No pile or tower failure, just elastic foundation deformation, the foundation remains standing and oscillates in its 1st eigenmode	1
2	Tower failure (plastic deformation) but no tower collapse.	2
3	Tower failure (plastic deformation) and collapse, turbine moving towards the ship.	3
4	Tower failure (plastic deformation) and collapse, turbine moving away from the ship.	4
5	Soil collapse, turbine moving towards the ship.	5
6	Soil collapse, turbine moving away from the ship.	6
7	Pile failure inside the soil, tower failure due to the inertia of the nacelle, turbine moving towards the ship.	7
8	Pile failure inside the soil, tower failure due to the inertia of the nacelle, turbine moving away the ship.	8



1. No pile or tower failure.
2. Tower failure (plastic deformation) but no tower collapse.
3. Tower failure/collapse, turbine moving towards the ship.
4. Tower failure/collapse, turbine moving away from the ship.



5. Soil collapse, turbine moving towards the ship.
6. Soil collapse, turbine moving away from the ship.
7. Pile failure inside the soil, tower failure due to the inertia of the nacelle, turbine moving towards the ship.
8. Pile failure inside the soil, tower failure due to the inertia of the nacelle, turbine moving away the ship.

Ship impact: Shell buckling

REFERENCE + WIND/WAVE/CURRENT LOAD ACTING ON FOUNDATION AND TURBINE, SHELL BUCKLING FAILURE

Drifting / Sailing				Reference + Wind load				Shell buckling			
Ship	Simulation run	Ship motion	Impact direction	Failure mode				Failure mode			
				Wind farm 1		Wind farm 2		Wind farm 1		Wind farm 2	
Foundation				K07	C01	HIGH	LOW	K07	C01	HIGH	LOW
Kruiplijn coaster	1	Drifting	90 Deg; Below rotor	1	1	1	1	1	1	1	1
	2	Sailing	90 Deg; Below rotor	6	1	1	4	2	4	4	4
	3	Sailing	270 Deg; Below nacelle	1	1	1	1	1	1	4	3
Supply vessel	1	Drifting	90 Deg; Below rotor	2	1	1	1	2	2	3	4
	2	Sailing	90 Deg; Below rotor	5	3	3	3	5	3	3	3
	3	Sailing	270 Deg; Below nacelle	5	3	3	3	5	3	3	3
Chemical & Product tankers	1	Drifting	90 Deg; Below rotor	6	1	4	4	5	2	3	4
	2	Sailing	90 Deg; Below rotor	5	5	5	5	5	5	5	5
	3	Sailing	270 Deg; Below nacelle	5	5	5	5	5	5	5	5
Passenger vessels	1	Drifting	90 Deg; Below rotor	3	2	4	4	3	3	3	3
	2	Sailing	90 Deg; Below rotor	5	5	5	5	5	7	5	5
	3	Sailing	270 Deg; Below nacelle	5	5	5	5	5	5	5	5
Container ship	1	Drifting	90 Deg; Below rotor	6	6	6	6	5	8	6	6
	2	Sailing	90 Deg; Below rotor	5	5	5	5	5	5	5	5
	3	Sailing	270 Deg; Below nacelle	5	5	5	5	5	5	5	5

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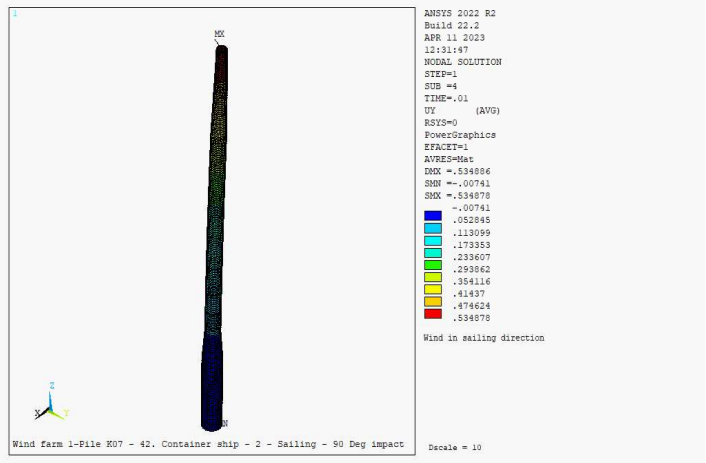
Ship Impact; Failure mode 5



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Ship impact: Main conclusions windturbines

Drifting impact:

1. For ships between 10.000 tonnes and 20.000 (10.000 GT) tonnes it will depend on the impact velocity whether failure will occur.
2. For ships above 20.000 tonnes (10.000 GT), the foundation will in general collapse above the impact point. Whether the turbine will move towards the ship or away from the ship will depend on the circumstances.
3. For very large ships, e.g. Container ships of 223.000 tonnes (19.3000 GT) the foundation will be overrun due to collapse of the soil. The ship will drift over the foundation.

Sailing impact:

1. For ships between 3.000 tonnes (1.600 GT) and 7.000 tonnes (3.200 GT) the foundation in general will fail above the impact point under sailing impact. For foundations with small penetration depths even soil collapse can occur. The simulations indicate that it is more likely that the turbine is moving towards the ship when collapse occurs.
2. For ships between 10.000 tonnes and 20.000 (10.000 GT) tonnes foundation collapse above the impact point will occur and depending on the impact velocity also soil failure might occur.
3. For ships above 20.000 tonnes (10.000 GT) collapse of the soil will occur, combined with failure of the foundation at or above the impact point. The turbine can either move towards the ship or away from the ship at the moment of collapse.

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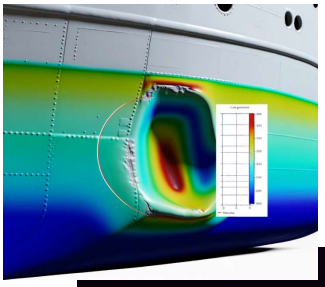
Resulting damage to the vessel after turbine collision

Phase 3 - 3D FEM

- The 3D FEM simulations should be based on realistic windturbines and more or less identical ships of phase 2.
- The runs of the 3D FEM simulations should provide insight into the damage to the ship's hull in order to determine any risks of cargo outflow, sinking and/or personal injury.
- The 3D FEM simulations should be based on ship types: Tanker, Passenger Ship and Container Ship



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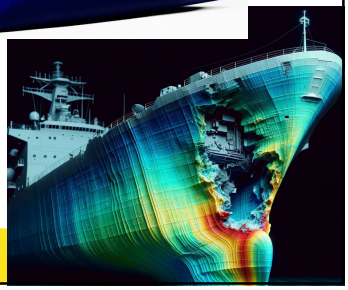

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