Material Composition of Bucket Foundation Transition Pieces for Offshore Wind Turbines

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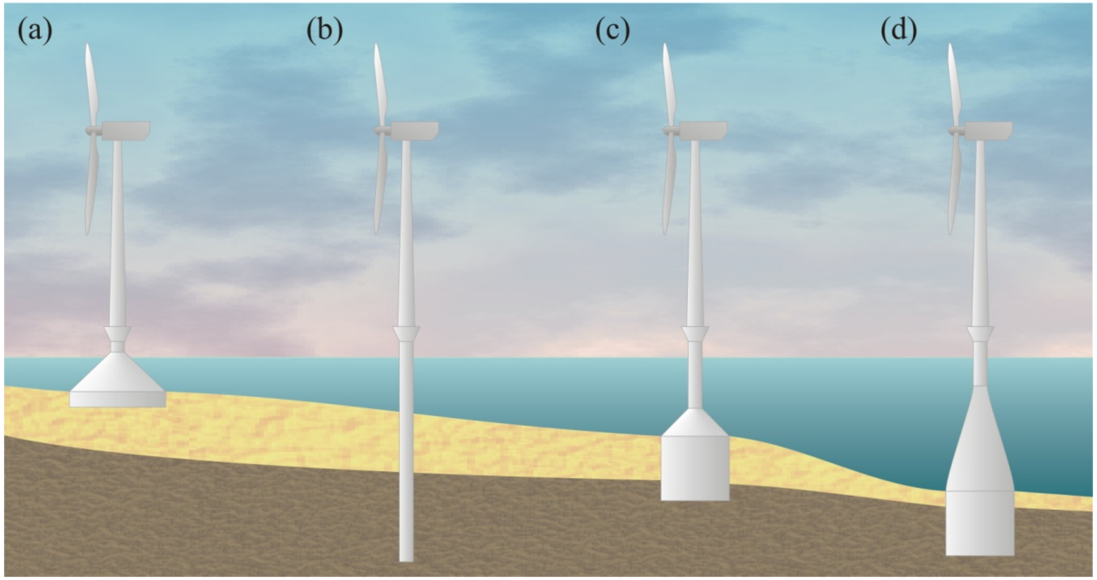
Outline of presentation

- ❑ Motivation for the work
- ❑ Structure and loads
- ❑ Computational model
- ❑ Analysis and results
- ❑ Conclusions

Motivation for the work

Types of foundations for offshore wind turbines:



a) Gravitational footing;
b) Monopile;
c) Suction bucket with traditional transition piece;
d) Suction bucket with shell transition piece

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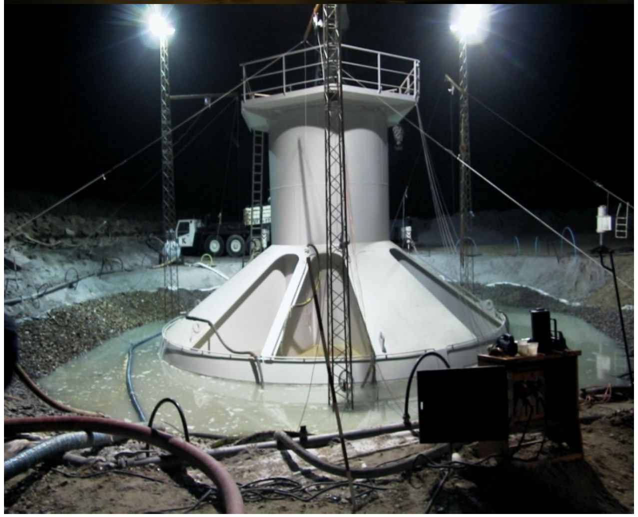
Motivation for the work

❑ *Strengths of suction bucket vs. monopile:*

- ✓ Fair simplicity of installation
- ✓ Possibility of decommissioning
- ✓ Stiffer structures (required for deeper water depths)
- ✓ No need of scour protection

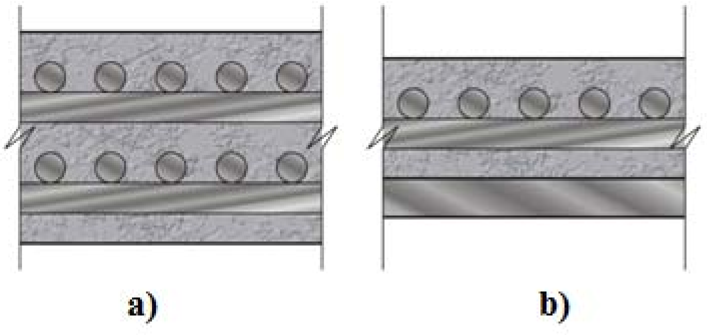
❑ *Weaknesses:*

- ✓ Complicated structure to manufacture
- ✓ Requires extensive welding work
- ✓ Fatigue at the welded joints due to cycling wind / wave loads
- ✓ Can only be installed in residual soil

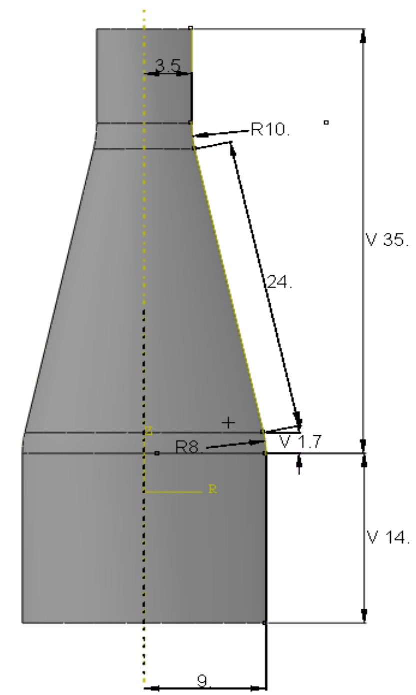


Structure and loads

Suggested cross-sectional profiles for the transition piece shell:



a) CRC (Compact Reinforced Composite) with traditional reinforcement;
b) CRC–steel composite.



- ✓ One layer of reinforcement is replaced with a thin steel sheet (~5–10 mm) glued to CRC
  → good material properties in tension, compression and bending.

- ✓ Moulding concrete on a steel plate sprinkled with bauxite on a damp two-component epoxy adhesive provides good attachment.

- ✓ Limited application of CRC until now:
  - reconstruction of steel bridges,
  - joining the tower and foundation of offshore wind-turbine structures.

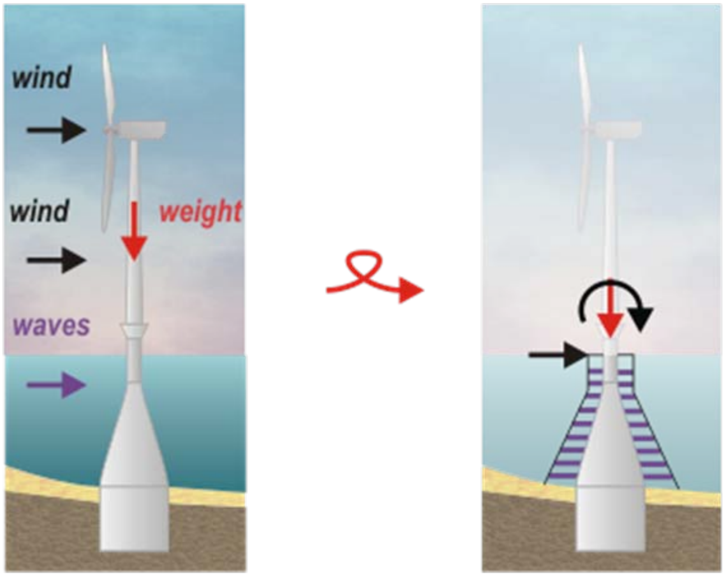
Structure and Loads

	Conventional concrete	High Quality Concrete			High-quality steel
		CRC matrix		CRC with rebar	
		0–2 vol. % fibres	4–12 vol. % fibres		
Compressive strength [MPa]	80	120-170	160–400	160–400	500~600
Tensile strength [MPa]	5	6-15	10–30	100–300	
Density [kg/m^3]	2500	2500–2800	2600–3200	3000–4000	7800
Modulus of elasticity [GPa]	50	60–100	60–100	60–110	210
Failure energy [N/m]	150	150–1500	5000–40000	$2\cdot10^5$–$4\cdot10^6$	$2\cdot10^5$
Frost Resistance	Moderate	Frost-proof outside air mixing			
Corrosion Resistance	Moderate	Safe, even with thin cover layer			Poor

Source: Bache H.H. "Concrete Engineering - New Concrete New Technologies", Aalborg Portland, 1992.

- CRC vs. conventional concrete
  - ✓ **2-5 times higher** compressive strength and durability
  - ✓ **20-60 times higher** tensile strength and increased tensile ductility (fibre dependent)
  - ✓ Strong CRC matrix allows to utilize of 5–10 times more reinforcement → much stronger structures
  - ✓ **3-10 times thinner cover layer (5–15 mm** against **50 mm** for conventional concrete)
  - ✓ Low chloride permeability due to high density with "clogging" effect over time
  - ✓ High price of the material
  - ✓ No internationally accepted design recommendations exist

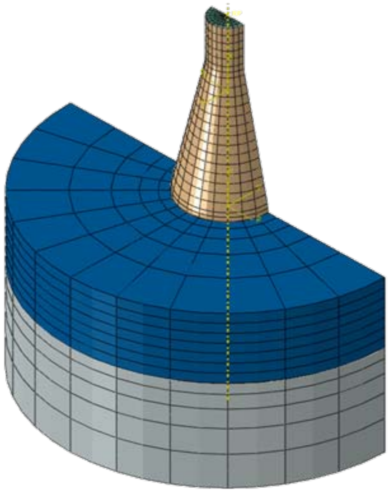
Structure and Loads

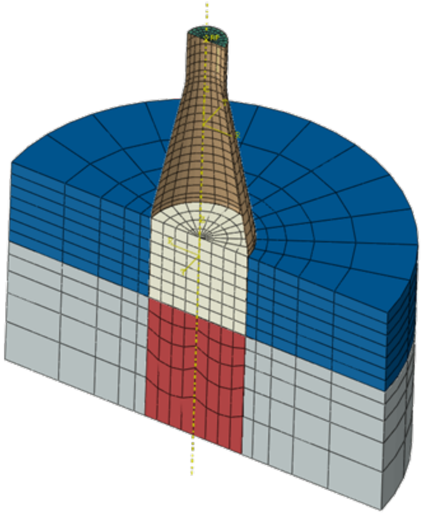


- ✓ 5 MW wind turbine installed at 35 m water depth
- ✓ Total mass of the structure is applied as a vertical concentrated force *V* = 7.5 MN
- ✓ Extreme wind load *H* = 2 MN is applied as an equivalent quasi-static force to the top of the transition piece with a corresponding moment M=182 MN·m
- ✓ Gravity (self weight) is induced on structures below the water surface
- ✓ Wave load is simplified based on potential theory as inertia (added mass) and drag (fluid resistance) parts.

Computational model

- ✓ Half of the structure and soil is modelled
- ✓ Simple model for the soil (elastic)
- ✓ Material models:
  - Steel rebar - von Mises yield criterion with linear hardening;
  - CRC – Damaged Plasticity Model;
- ✓ Radius of the discretized area is 35 m , i.e. ~ 4 times the radius of a bucket
- ✓ Bottom boundary is 21 m below the suction bucket foundation base
- ✓ Element types:
  - Soil - solids with quadratic interpolation and reduced integration
  - Structure - 8-noded shell elements with reduced integration
- ✓ Tie constraints at the interfaces between bucket and soil → sliding along the interfaces is disregarded
- ✓ The loads from the wind turbine are applied on a rigid lid placed on top of the transition piece

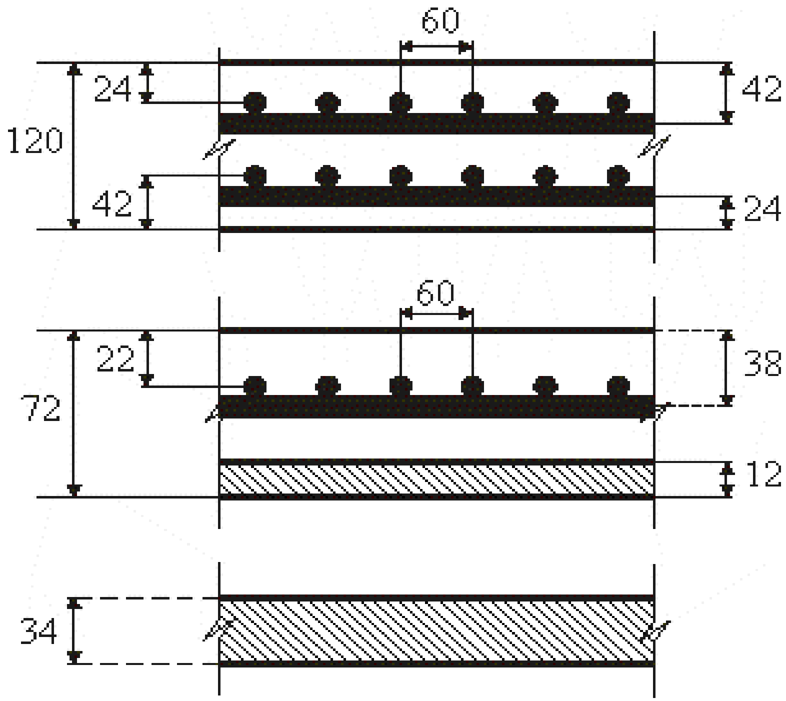




Analysis and results

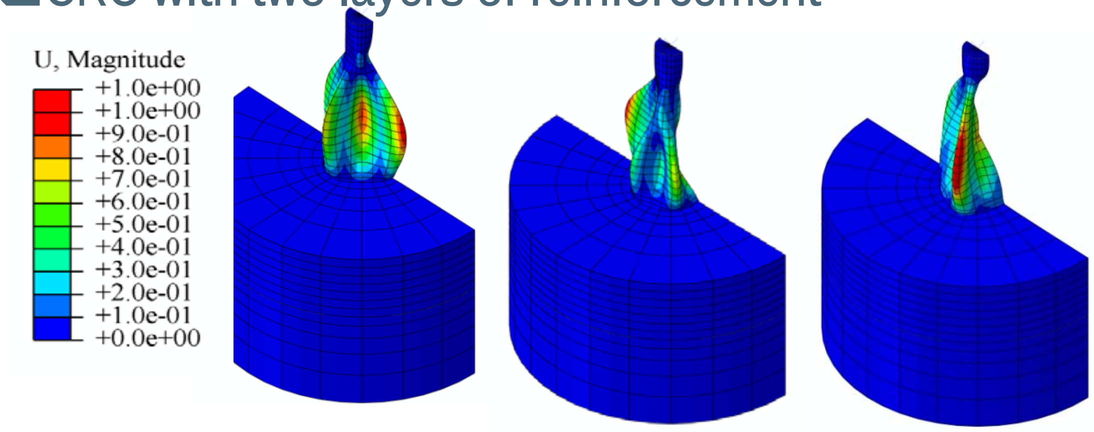
- Analysis
  - ✓Ultimate limit state (material failure)
  - ✓Prebuckling (linear perturbation)

- Results
  - a) CRC with two layers of reinforcement;
  - b) CRC–steel composite with a single layer of reinforcement;
  - c) Reference case (steel sheet).

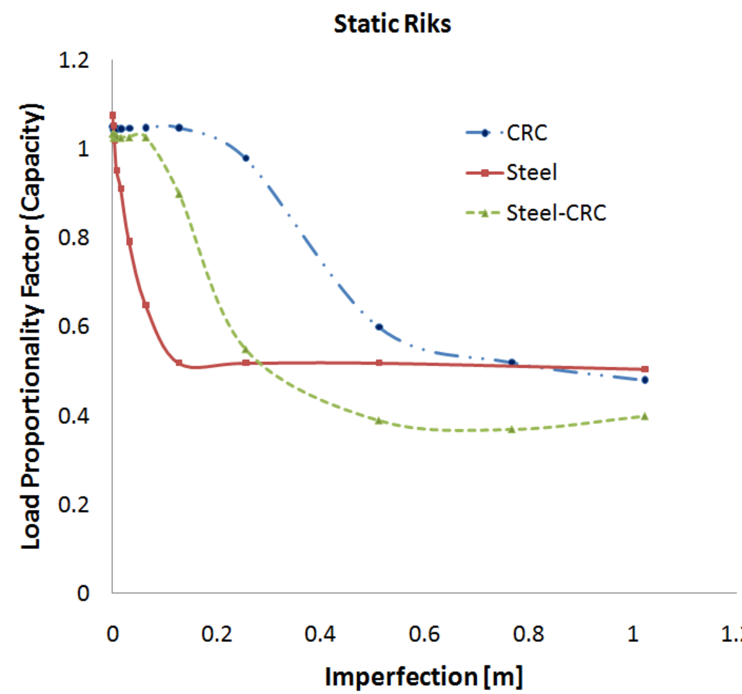


Analysis and results

- CRC with two layers of reinforcement



First three pre-buckling modes



Prebuckling mode / Construction material	First eigenvalue	Second eigenvalue	Third eigenvalue	Weight, tons
a) CRC	6.33	7.41	7.98	456
b) CRC–steel sheet	2.83	3.05	3.67	343
c) Steel sheet	1.11	1.23	1.45	327

❑Conclusions

- ✓ Reference case (steel) showed excessive use of steel in low tensile stress regions.
- ✓ Welding two sheets with various thicknesses, can minimize use of steel → complicated and costly.
- ✓ CRC structure of 120 mm thick increased the weight of the substructure by 40 %.
- ✓ CRC-steel composite material increased the weight of the structure by 5 %.
- ✓ Amount of ductile steel in the form of reinforcement and steel sheets, carrying majority of the tensile stresses, is likely to dictate a transition-piece design.
- ✓ Steel substructure is the most sensitive to geometrical and loading imperfections, while the transition piece made of CRC was the least imperfection sensitive.

❑Future work:

- ✓ Further investigation and experimental testing of structure made of prefabricated composite CRC–steel shell elements.;
- ✓ Optimization of the shape to reduce amount of the materials used.
- ✓ Performing cyclic tests to check fatigue behaviour by experimental testing as well as simulation.

Thank you for your attention

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