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Master Thesis

8 MW Offshore Wind Turbine Installation With a Self-propelled Jack-up Vessel

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Content

- Recent developments in offshore wind industry
  - Jack-up installation vessels
  - Wind turbines
- Load conditions in North-Atlantic region
- Research problem – Jack-up vessel crane lifting response in the operational mode
  - General considerations
  - Case study – Dynamic lifting loads
  - Case study – Monopile lowering
- Main tendencies in jack-up vessel design since 2010

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Recent developments – Offshore wind turbines

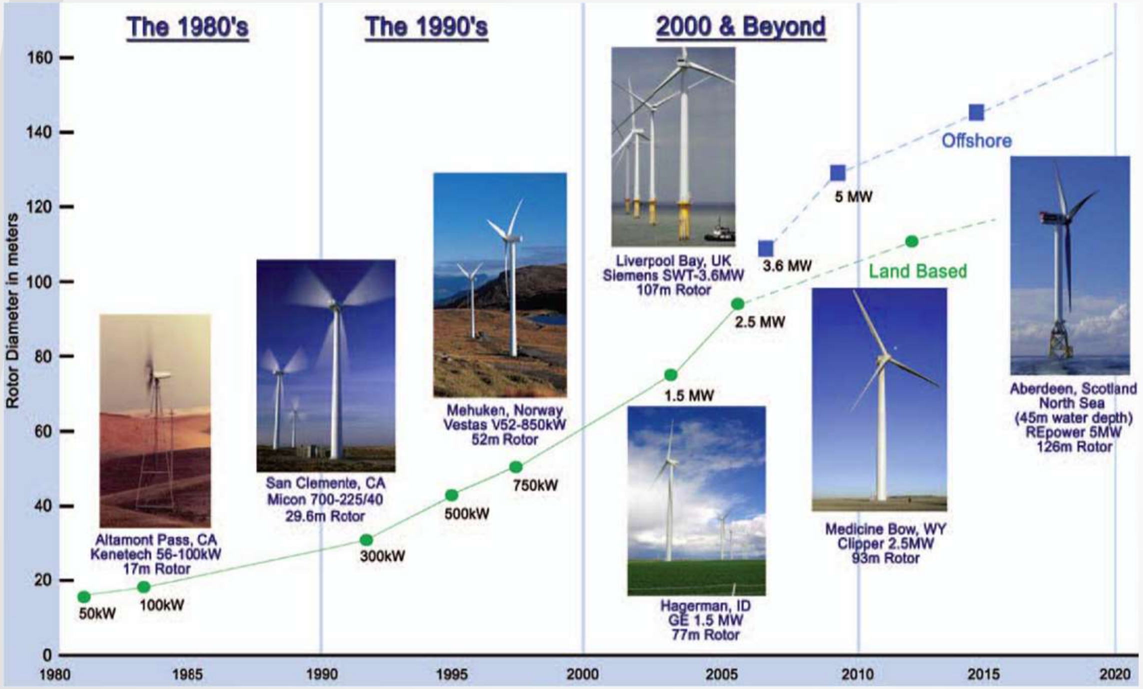


Figure 2. Evolution of the wind turbine technology

Figure 3. Vestas V164-8.0MW prototype

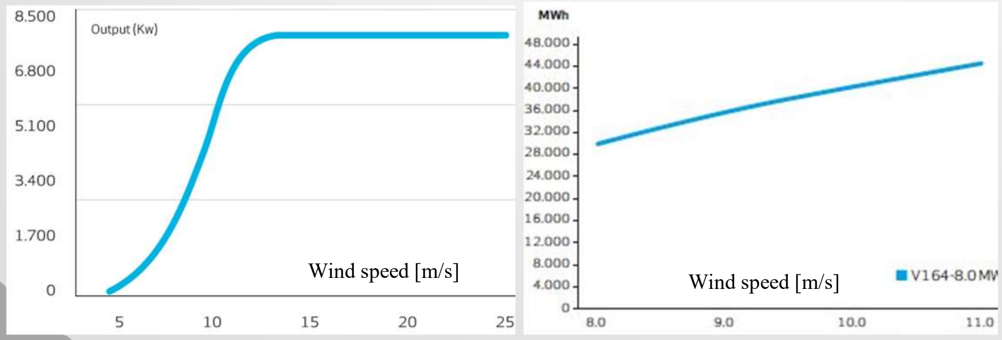


Figure 4. Vestas V164-8.0MW characteristics

Load conditions – Waves

Wave conditions may be described either by deterministic design wave methods or by stochastic methods.

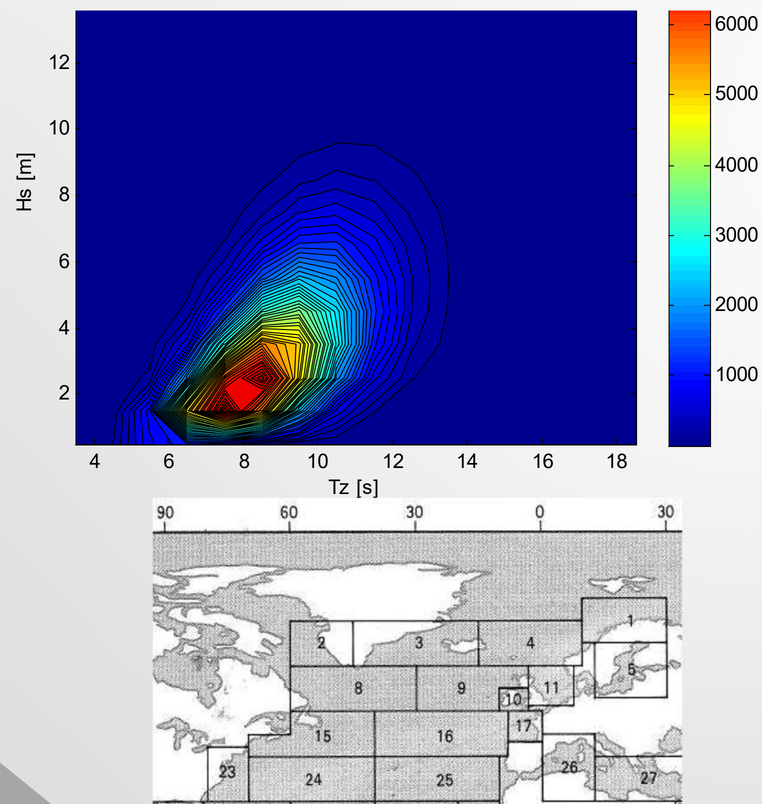


Figure 5. Wave scatter diagram (above) of the North Atlantic regions 8, 9, 15 and 16 (below)

$$S(f) = \alpha \frac{5}{16f^5}\frac{H_s^2}{T_p^4} exp\left(-\frac{5}{4T_p^4 f^4}\right)\gamma^{exp\left(\frac{-\left(f-\frac{1}{T_p}\right)^2 T_p^2}{2\sigma^2}\right)}$$

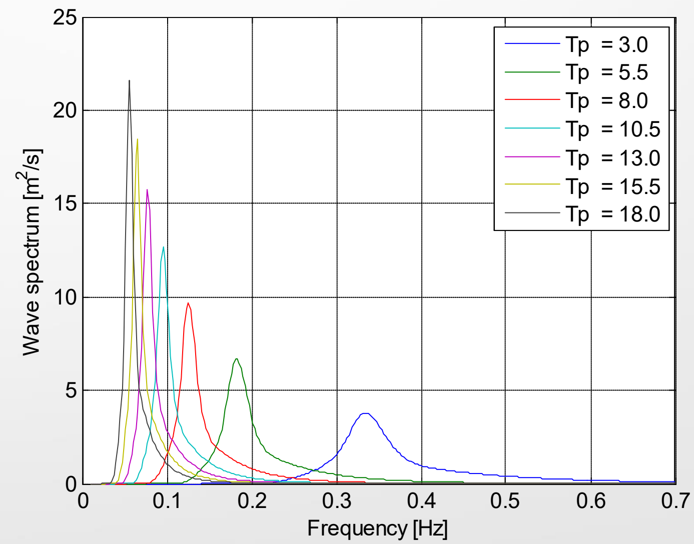


Figure 6. JONSWAP Spectra sea state

Load conditions – Current and wind

Although current impact is usually not remarkable compared to other environmental loads, their effect to vortex induced motions and vibrations has to be carefully considered.

$$v_C = v_T \left(\frac{d-z}{d}\right)^{1/7} + v_w \left(\frac{d_0 - z}{d_0}\right)$$

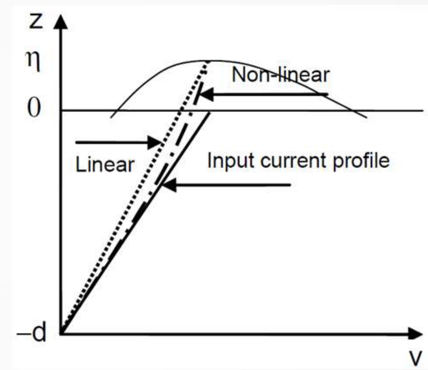


Figure 7. Current profiles

Wind speed varies with time and also with the height above the sea surface.

$$U_{10,T_R} = F_{U_{10,max},1\,year}^{\ \ -1}\left(1 - \frac{1}{T_R}\right);\ T_R > 1\ year$$

$$v(z) = v_R \left(\frac{z}{z_0}\right)^{\frac{1}{n}}$$

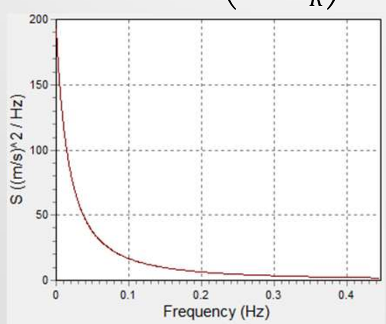


Figure 8. Wind API spectrum

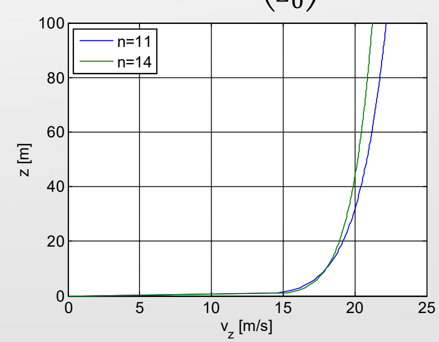


Figure 9. Wind profile at v_R =18 m/s and z_0 = 10 m

Crane lifting response – Considerations

Due to the uniqueness of different lifting procedures, extra attention should be paid to its interaction with other factors.

Crane lifting operations cannot be neglected from the global response analysis.

Main considerations, between which the appropriate approach is selected:

- Stochastic versus deterministic analysis
- Non-linear versus linear analysis
- Dynamic versus static analysis

General form of the dynamic equations:

$$m\ddot{r} + C\dot{r} + kr = F$$

$$F = C_D(v - \dot{r})|v - \dot{r}| + C_f\dot{v} + C_M(\dot{v} - \dot{r})$$

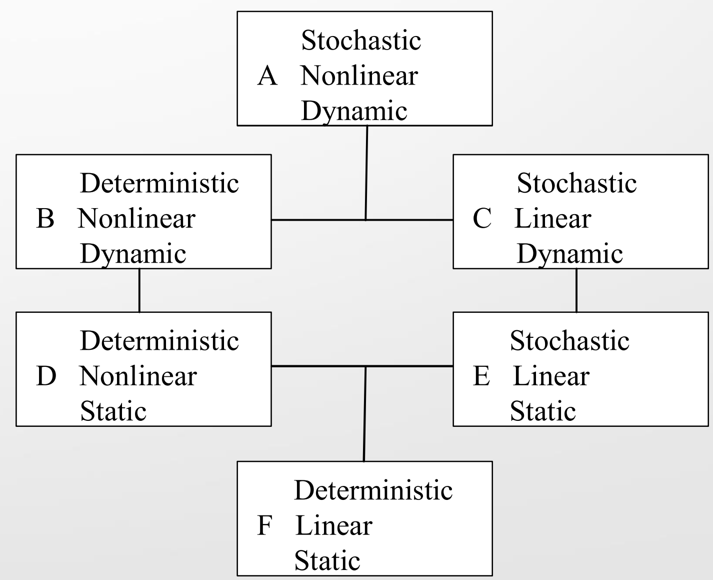


Figure 10. Options for simlification of response analysis

Case study I – Dynamic Hook Load

Lifting operations cannot be represented by a single well defined loadcase, but rather a sequence of different / critical ones.

For most conventional lifts however, the entire sequence is adequately covered by the basic loadcases. The Dynamic Hook Load for single hook lifts:

$$DHL = DAF\left(W + W_{rig}\right) + F(SPL)$$

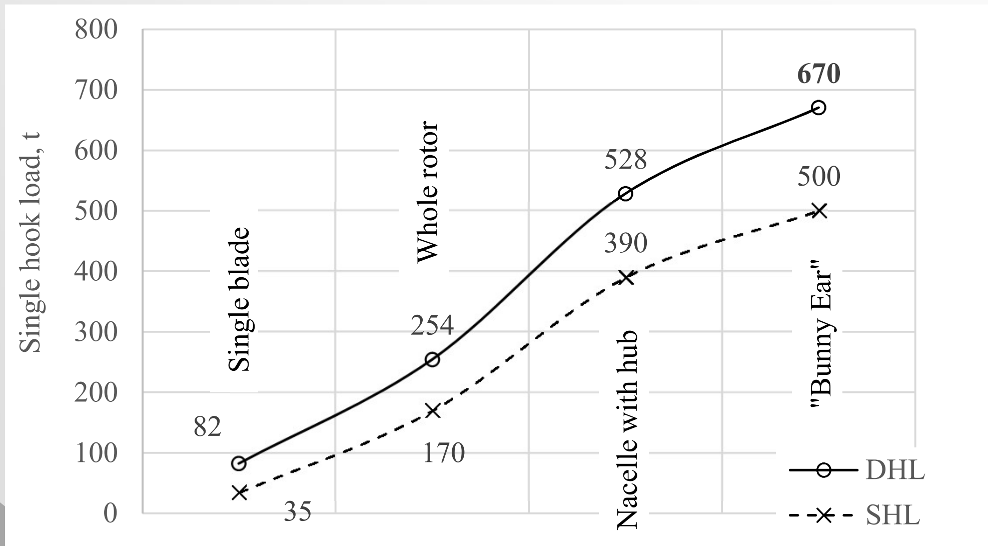


Figure 11. Hook loads

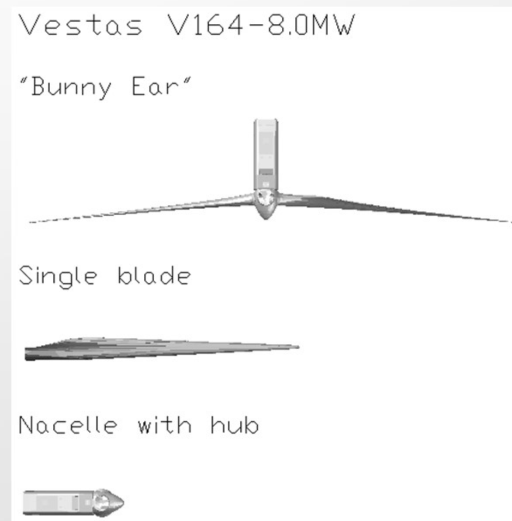


Figure 12. Turbine components

Case study II – Monopile lowering

Case study focuses on large offshore wind turbine monopile foundation lowering through wave zone till seabed with a jack-up vessel crane.

Monopiles are the most commonly used foundations in water depths up to 40 m, and it is estimated that more than 75% of all installations are founded on monopiles.

The design of larger monopiles is often driven by stiffness, in order to keep the natural frequency of the complete wind turbine structure above wave loading frequencies.

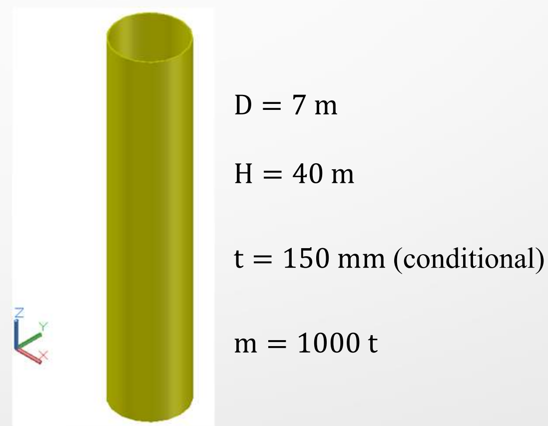


Figure 13. Monopile foundation

Main environmental conditions:

- Waterdepth: 35 m
- Significant wave height: 2.5 m
- Wave peak period: 3 ÷ 25 s

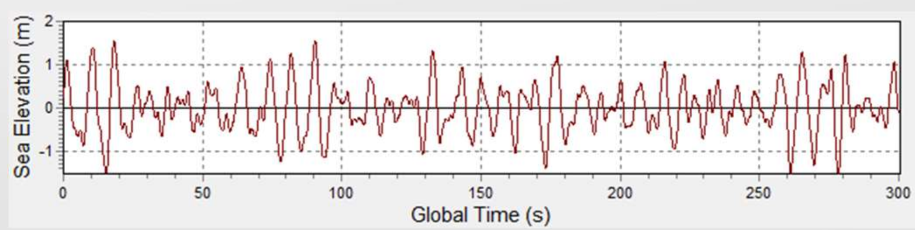


Figure 14. Sea elevation (Tp = 8.50 s)

Case study II – Monopile lowering

OrcaFlex is a fully 3D non-linear time domain finite element program developed by Orcina for static and dynamic analysis of a wide range of offshore systems, including all types of marine risers (rigid and flexible), global analysis, moorings, towed systems and installations.

The model consists of the marine environment to which the system is subjected, plus a variable number of objects chosen by the user:

- Vessel
- Winch
- Links
- 6D Buoy

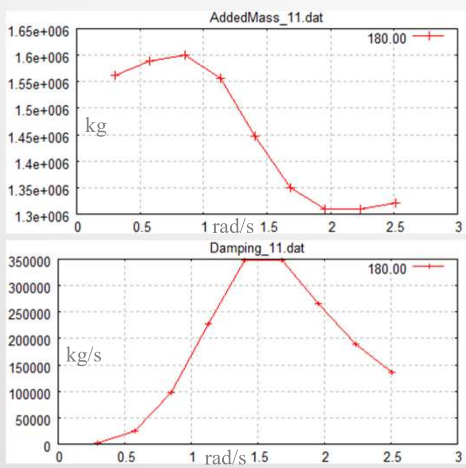


Figure 15. Monopile hydrodynamic properties

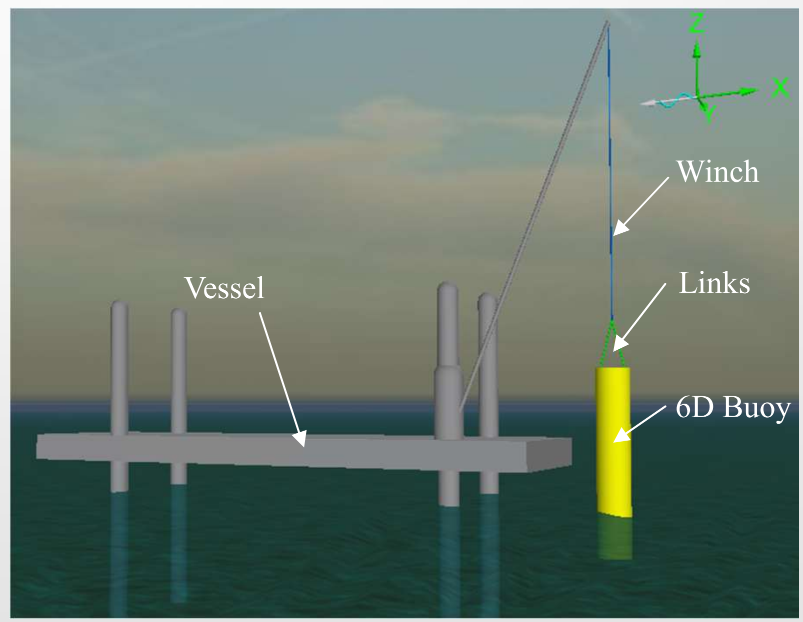


Figure 16. OrcaFlex model

Recent tendencies in jack-up vessels design

During the recent 6-year period (since 2010) in total 25 self-propelled jack-up installation vessels were built. 14 of them could be conditionally considered as suitable for next generation (6-8 MW) offshore wind turbine installation (lifting capacity > 700 t, available deck area > 2000 m^2).

When investigating the available deck area and payload of those 14 jack-up vessels under comparison, one may distinguish tendency to build vessels with larger capacities.

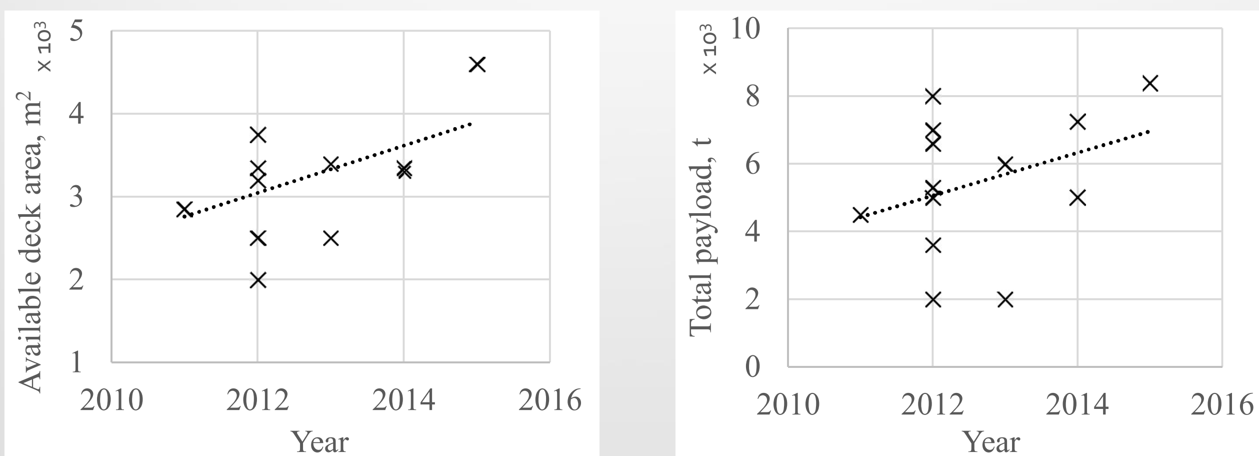
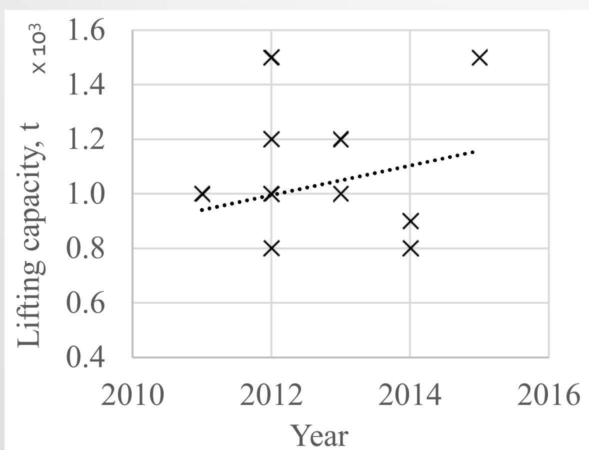


Figure 20. Available deck areas (left) and total payloads (right) of large jack-ups, built since 2010

Recent tendencies in jack-up vessels design

One can say, that the (foundation) components of OWT-s that are located in deeper water have normally bigger mass.

It founds some confirmation that the crane lifting capacities of self-propelled jack-up vessels show tendency to increase and in addition it may be concluded, that a modern jack-up vessel should have the operation depth at least 50 m in order to be fully competitive in the market.



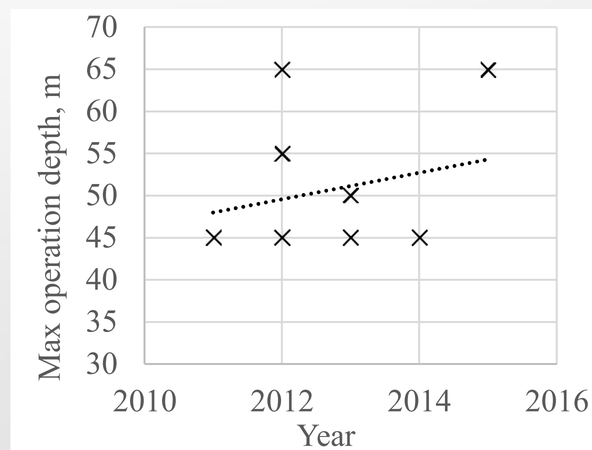


Figure 21. Lifting capacities (left) and operation depths (right) of large jack-ups, built since 2010

Main conclusions

- Dynamic load effects have remarkable proportion of total hook load
- Large lateral forces to monopile and corresponding motions, though reaction in winch wire tension is not remarkable
- Tendencies in jack-up vessels design ensure technical feasibility

Main references

1. Hirdaris, S. E., et.al., 2014. Loads for use in the design of ships and offshore structures. *Ocean Engineering*, 78, 131-174.

2. Li, L., et.al., 2014. Analysis of lifting operation of a monopile for an offshore wind turbine considering vessel shielding effects. *Marine Structures*, 39, 287-314.

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Thank you for the attention!

Questions?