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Testing of a new transport and installation method for offshore wind turbines

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Abstract. Transport and installation of offshore wind turbines require considerable efforts and can be time consuming, in particular when jackups are used for lifting operations. This is mainly due to the specific weather window requirements for towing and locating the jackups. A goal is ultimately to finalize all turbine assembly work onshore and at quayside and to transport the completed turbine to the site for easy installation. We suggest that this can be achieved by a transport and installation method we denote "the MINT method" whereby the wind turbine foundation is located on a barge while the tower is resting on a support system, a "MINT" system that is located at the stern of a mid-size standard offshore support vessel. The MINT is specifically designed for the transport and installation operations allowing relative motions and rotations between the tower and the transport vessel. In order to qualify the "MINT installation method", a numerical study of the feasibility of the transport and installation was carried out by Sintef Ocean using their SIMO software package [1]. The method was found feasible in favourable weather conditions. To further document feasibility, it was decided to carry out a *proof of concept test in a wave tank* to identify concerns with respect to the suggested method for transport and installation. This paper reports the findings of this test. The test is to be considered to represent an initial activity in the concept qualification process, see [2], and is not a full wave tank test carried out to measure stresses and strains for member sizing. The *objective of the paper* is therefore, to show how an initial wave tank test can be useful for concept qualification.

1. Introduction

For bottom fixed offshore wind turbine concepts in shallow water, state of the art is to use jack-up type vessels for offshore operations. The jack-up technology is, however, vulnerable to waves and the spud cans could leave large footprints in softer soils. The effects of these limitations may be high downtime during installation and heavy maintenance operations. It should, in particular, be noted that the need to change location of the service vessel very often during wind farm installation and maintenance work highlights the requirement for suitable weather windows.

For bottom fixed offshore wind turbine concepts in deeper waters, state of the art is to use crane vessels for offshore installation and maintenance operations; however, the use of these vessels might not be attractive in view of the costs of employing sufficiently sized vessels that can operate under a variety of weather conditions. It should be noted that smaller barge type crane vessels might have movement characteristics (resonance between waves and the heave, pitch and roll periods of these vessels) that will make such operations difficult or impossible during long periods of the year, in particular in North Sea wave climate conditions. It would be greatly advantageous if offshore service vessels developed for the offshore oil and gas industry could be used for offshore operations. A recent study of the details of 87 wind farms installed between 2000 and 2017 is presented in [3]. For discussions of the State of Art technology, see [4 -8]. More details of actual installation of offshore wind turbines is disused in [9] and [10]. Reference is furthermore given to [11].

The associated costs of using cranes are large. Considerable savings can be achieved in case completed structures/ facilities can be manufactured in a dry dock or near to a quayside and transported to the offshore site with use of transport vessels/ barges. Thereafter, installation should be achieved by ballasting only, for the vertical transfer onto the bottom.

Green Entrans AS has developed a method (herein called "MINT") for transport and installation (Figure 1) of one-mono-tower offshore structures, termed MC-7, see also Figure 2. The offshore support structure MC-7 is consisting of a mono-tower which penetrates the surface being supported by a tripod foundation. Figure 1 (upper part) shows the structure in the transport mode. This geometry is suggested to represent a minimum support structure for the topside functions.

The transport and installation method is considered to be particularly interesting for water depths in the range from 50 to 120m (Figure 3); outside the range of using mono-pile offshore structures and outside the range of the smaller installation jackups used in the wind industry for monopile foundations.

The main objective of the wave tank testing conduced at MaREI Centre, Lir - National Ocean Test Facility in Cork, was to document that the newly developed transport and installation method for the MC-7 offshore structures is practically feasible under specified wave conditions. The test was, therefore, part of concept qualification process as required by [2].

The following two complete MC-7 structural solutions were tested in scale model 1:50:

- "MC-7 Wind" complete for 70 meters water depth with an 8 MW / 380-ton wind turbine corresponding to a total full-scale weight of 3 425 t.
- "MC-7 Petro" complete offshore oil and gas wellhead platform for 120 meters water depth with a top-side corresponding to a full-scale weight of 600 tons and a total weight of 4750 t.

This paper reports on the test of the solution intended for wind energy generation, "MC-7 Wind" see Figure 4. The wind turbine substructure is higher than a support structure for oil and gas facilities as a wind turbine mono-tower must be extended to the height of the nacelle. The challenges to transport and install a concept for wind energy generation are, therefore, larger than the challenges to transport and install an oil and gas wellhead platform. Of largest concern is the stability associated with the high centre of gravity of the nacelle and the rotor during the installation phase, see Figure 5. For reference to the test report, see [12].

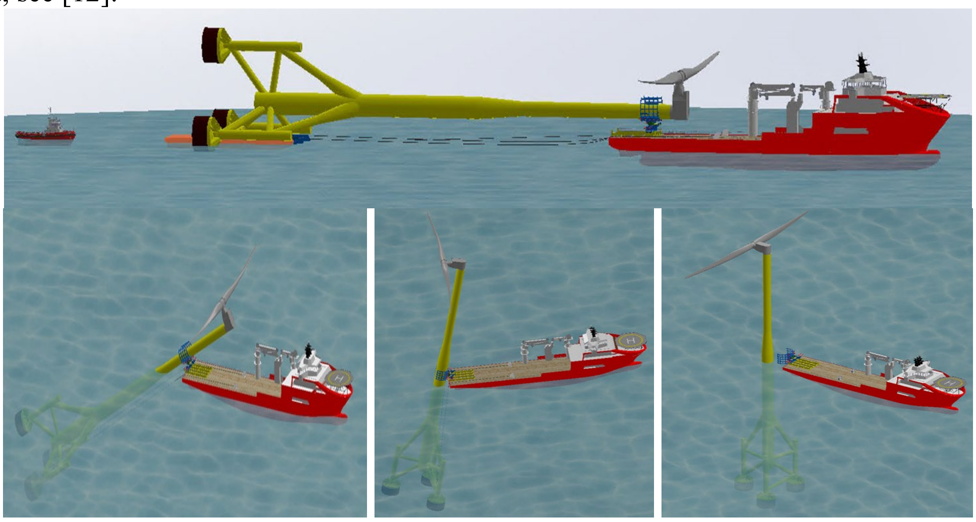

Figure 1. The MC-7 structure for water depths 50 -120 meters transported and installed as a complete unit by the MINT method.

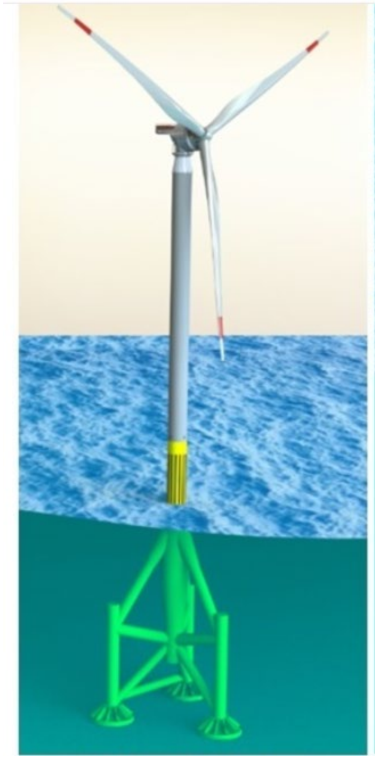

Figure 2. MC-7 Wind turbine for 50 to 120 m water depth.

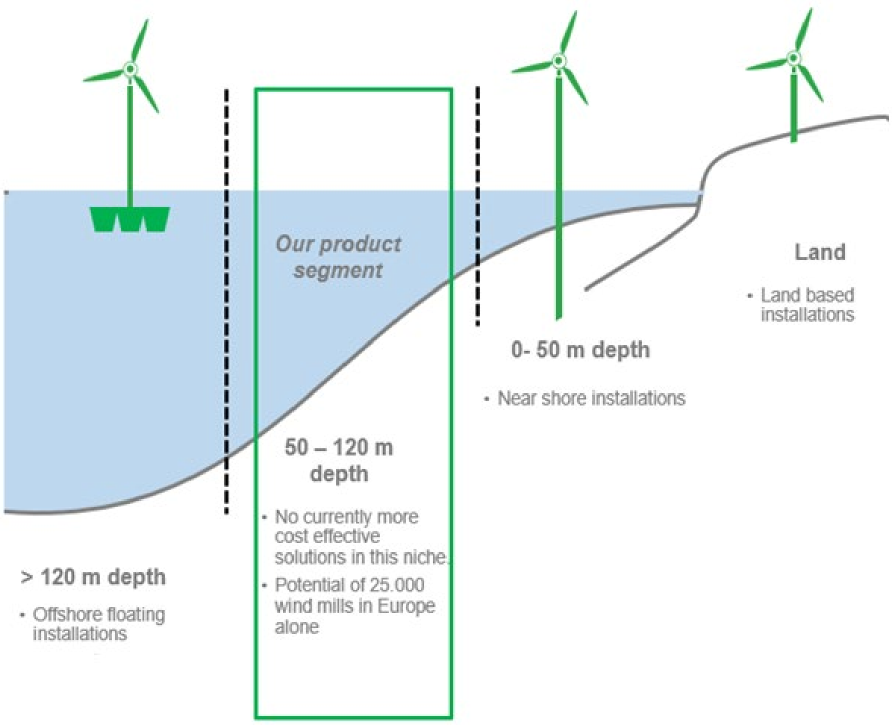

Figure 3. MC-7 Product segment.

Figure 4. Arrangement of test facilities for the testing of the MINT transport and installation method for wind turbines.

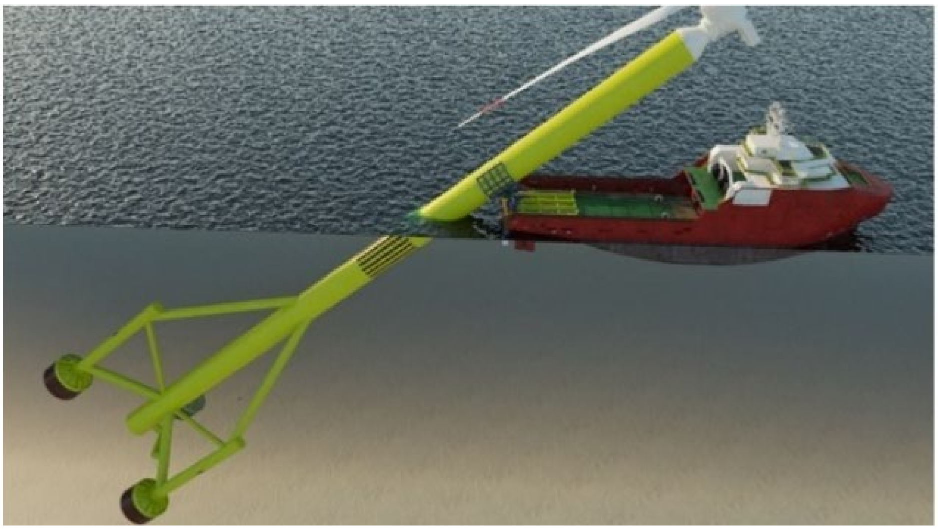

Figure 5. MC-7 Installation when the structure is being upended.

2. The MC-7 Wind unit and the MINT transport and installation concept

The basic idea behind the MINT concept for transport and installation of one-column offshore units is shown in Figure 2. The basic idea to simplify the transportation and installation is to use a mid-size support vessel and a barge for the transport. The two units have different Response Amplitude Operators (RAO's) and will move differently in wave conditions at resonance where the vessel has a larger resonance period than the barge in most degrees of freedom. Of particular concern would be large pitch response, creating a considerable bending moment in the tower.

Sintef Ocean prepared a verification report [1] of the feasibility of transporting and installing the concept using the SIMO software. A limited sea-state for transport of a complete MC-7 structure in an Hs of 2.5m was recommended. Sintef Ocean's verification report, however, concluded that an

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installation by direct transfer of the structures from the barge was not rotationally stable and therefore not feasible, as the wind turbine blades could come in contact with the sea. The launching procedure from the barge was modified according to Sintef's recommendations, and the MC-7 center of buoyancy and center of gravity as well as the separation procedure were adjusted. The new solution was implemented in the testing at Cork.

The objective to carry out the test was to further qualify the concept in accordance with the requirements of DNVGL [2]. It was, considered very important to document the feasibility of transport and installation by wave tank testing as a test would provide the required knowledge about the following two maritime operational aspects:

- How does a marine tow behave when a structural load is supported on 2 hulls located at different distances?
- How is the movement pattern when the unit is floating, but held over the water at one end of a floating hull?
- The test should also, by turning the structure from horizontal to vertical position, reveal a safe handling procedure to ensure the stability of the installation operation.

3. The tank test set up and test execution

The model tested was fabricated by Green Entrans AS at a 1:50 scale using Froude similitude scaling factors. The main parts are listed below:

- An installation vessel
- An installation barge
- A wind turbine named "MC-7 Wind" with a mass of 27.4 kg
- An installation system named MINT (Mono column Installation Technology) was located at the stern of the installation vessel to hold and control the MC-7 Wind column during transport and installation.

The test structure represented a full-scale wind turbine for the following conditions:

- Turbine size: 8 MW
- Turbine weights: 380 tons
- Hub height: 109 meter over sea
- Water depth: 70 meters
- Substructure weight including Tower: 2300 tons

The model assembly was composed of the installation vessel supporting the MINT system, the installation barge and the MC-7 Wind. It was placed in the basin with the installation vessel moored to the basin instrument bridge using 5 horizontal bungee cords located close to the water surface, 1 on the bow and 2 on each side. The barge was moored to the stern with a horizontal line attached to the end beach of the basin at water level. The vessel and the barge were only linked by the MC-7 structure being tested (as shown in Figure 6). The MC-7 Wind was equipped with water ballast chambers which could be fully filled or emptied depending on the towing or installation sequence.

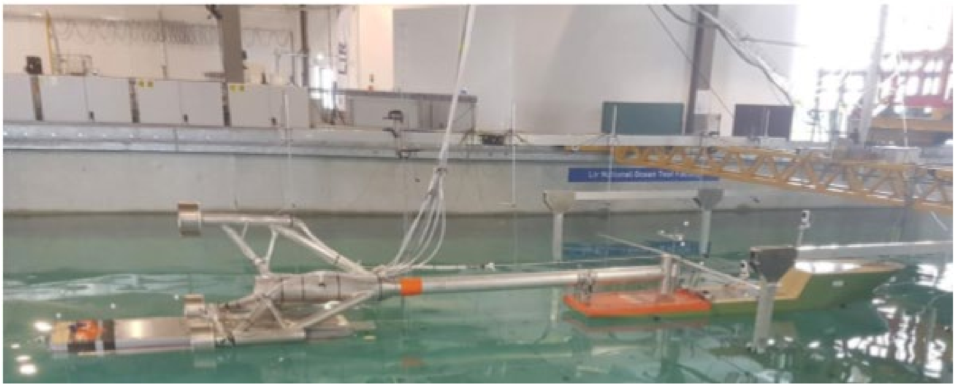

Figure 6. The test set up in the wave tank. (Note the heel of the barge, indicating roll motion).

A total of 245 wave tank tests as required by the authors of this paper were carried out in regular scaled waves (1:50) with heights from 2.5 to 7.4 m and with wave periods from 6 to 12 seconds. Wave directions were 0 to 30 degrees relative to the test object. The tests in regular waves corresponded to swell wave conditions. Additional tests in irregular waves, which correspond to real sea states, were thereafter conducted to simulate swell wave conditions.

Note that transport and installation of the "MC-7 Petro" solution for use as wellhead platform in the oil and gas industry was also tested during the testing period. The results are not included in this paper, however, the stability during installation is easier obtainable for the oil and gas solution due to the lower centre of gravity for the topsides facilities of an offshore oil and gas platform compared with the high centre of gravity for the nacelle and the rotor of wind turbine facilities. The following "MC-7 Wind" model configurations were tested:

- Transport test: in regular and irregular waves, the vessel was moored to an instrument bridge spanning the wave tank, the barge was moored to the beach at water level and the "MC-7 Wind" was placed on both vessel and barge with its transport ballast characteristics. There was no bridge movement.
- Separation test: the test was started as for the transport test. Additional ballast was placed in the bottom of the foundation of the MC-7 model and once the required ballast was reached, the instrument bridge was moved at a constant speed of 0.2m/s to implement separation between the MC-7 and the barge. After separation, the MC-7 was actively controlled to bring it to vertical position and landing it onto the tank floor. The active control included ballasting by adding water in the model whilst controlling the MINT and winch systems on the installation vessel.

4. The test results

4.1 Transportation phase

Vessel and barge motion displacement data and load data (measured by load cells) were collected during all tests. The pitch RAOs were found to be the most critical for both regular and irregular waves. Results for 0-degree orientation are shown in Figure 7 representing the installation vessel pitch motion, in Figure 8 representing the "MC-7 Wind" pitch motion and in Figure 9 representing pitch motion of the "MC-7 Wind" in relation with the installation vessel. The relative motion is the most critical to avoid contact between the"MC-7 Wind" column and the stern of the vessel or the "MC-7" Wind nacelle and the vessel deck. For further presentation of the results of the testing, see [12].

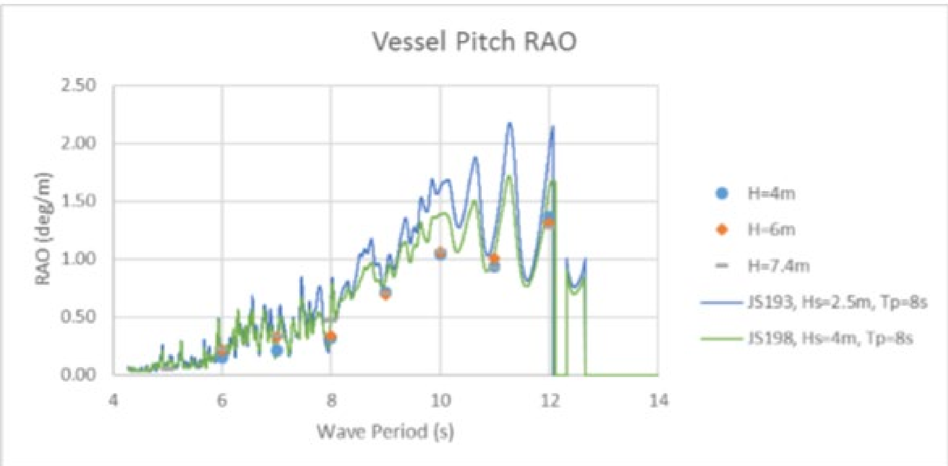

Figure 7. Pitch RAO of the installation vessel with the MC-7 Wind structure (JS = Jonswap spectrum)

Continuous measurement.

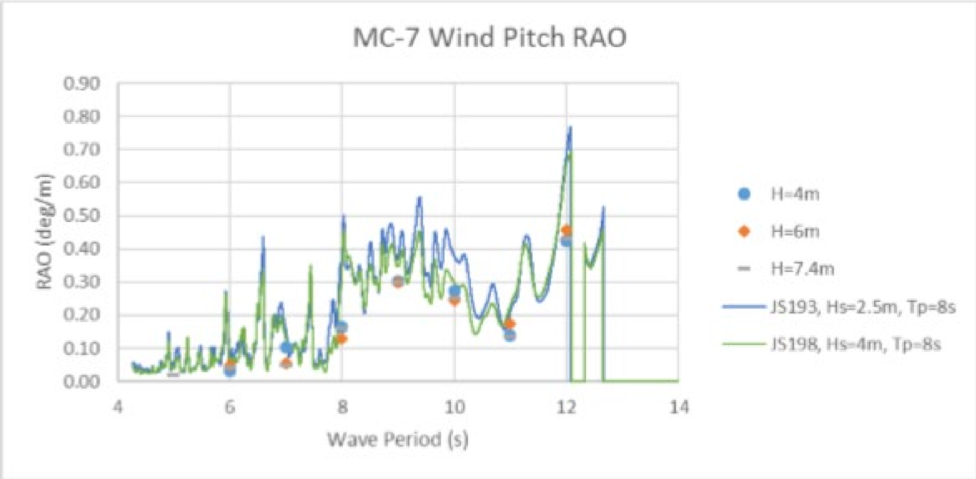

Figure 8. Pitch RAO of MC-7 Wind (JS = Jonswap spectrum). Continuous measurements.

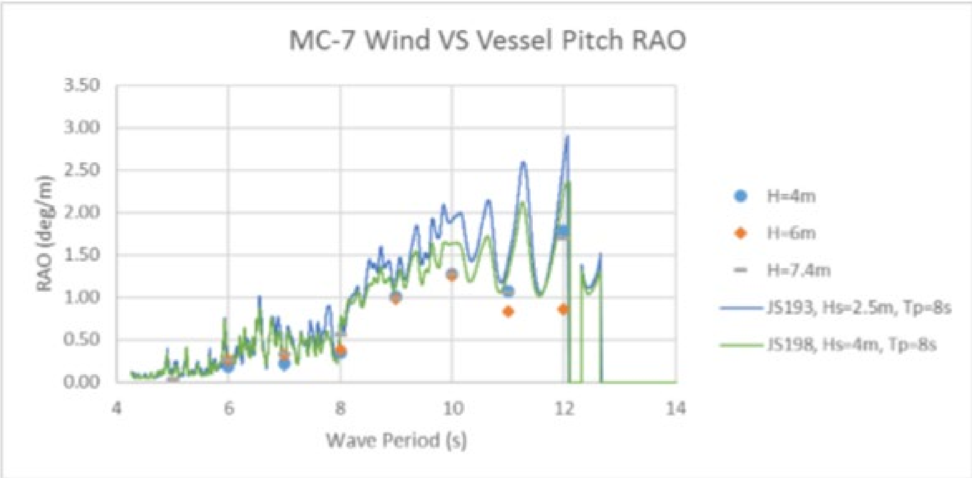

Figure 9. Pitch RAO of MC-7 Wind relative to the installation vessel with the Wind structure (JS = Jonswap spectrum). Continuous measurements.

4.1.1 Regular wave test results, see also [12]: Transportation phase, waves from front (0 degrees):

Barge

- The barge showed resonance in pitch for 6 second waves, RAO – 0,5
- The barge has large RAO values in pitch and heave for waves with 9 -10 s periods, RAO – 1.0

Vessel

- The vessel starts to pitch in 7 – 8 s waves, RAO – 0,3
- The vessel has large RAO values (RAO – 1.0) in pitch and heave for waves with 10 – 11 s periods.
  Comment: A vessel with an X-bow vessels should in principle do better with respect to pitch as the X-bow is designed to minimize vessel pitch. This will be investigated during later analysis.

Combined

- The combined unit's motion at the MINT location has large RAO values (RAO – 1.0) in pitch in regular waves above 8 seconds

- The amplitude of the motions at MINT location are reasonable for regular waves of up to 6 m height
- The behavior of the platform at the MINT location is sensitive to swell waves of 8 seconds and more, this is becoming critical for waves of height 6 m and more

Waves coming in at 15- and 30-degrees angle: The unit is starting to roll at the same periods as above. In case of heavy swells, waves from an angle should be avoided.

4.1.2 Irregular waves test results: Transportation phase, waves from front (0 degrees)

- The motion in irregular waves are smaller than in regular waves with similar wave heights, as is expected.
- The wave conditions for transport should through the test be demonstrated for Hs of 3 m with safe survival at Hs of 4m, provided the waves are not too long.
- The limiting wave conditions are based on spectra with peak periods of 7 to 8 seconds. For wave conditions with longer periods the accepted significant wave heights are reduced

The tests showed that the transport restrictions can be increased from the level recommended by SINTEF Ocean [1] to 6 meters (Hs 3 m), however, the wave periods must be assessed against vessel / barge sizes for the MC-7 structural solution in order to avoid resonance.

4.2 Test of installation phase

The MC-7 model stability during separation was thereafter tested when the side mooring bungee links were removed so the installation vessel was only moored on its bow. General comments on the separation motion stability are as follows:

- The pitch angle is -90 degrees when the MC-7 is vertical (up ended). This value may vary by a few degrees because the 0-degree value corresponds to the MC-7 structure in its transport position on both the installation vessel and barge and the column may not be held exactly horizontal.
- For all testing, a large roll, up to 40 degrees, is observed just after separation. This could cause some damage to the structure or the MINT. It is caused by the side bungees used in the mooring system. However, the large roll did not happen when the mooring bungees were removed.

As the large roll motion at separation was removed when testing without the side mooring bungee cords, the stability of the structure is acceptable in the wave conditions tested. However, the MINT system does not control the roll motion of the MC-7 structure and the commercial scale operation should ensure no external element, such as ballast pipes, has the potential to generate roll motions.

The vertical loads on vessel deck are shown in Figure 10. It should be noted that the vertical loads on the vessel deck after the separation from the barge are smaller than the loads during the transport. Following the separation from the barge, the wind turbine is floating and resting on the MINT (Figures 1 and 5) until it is installed on the bottom. The results from this test are now being used to improve on the transport and installation procedures. The large break-out loads in the winch and the barge during lift off from the barge were due to lack of procedures for this activity and the results are very useful for designing safe procedures.

The tests were carried out successfully and after some model modifications including trial and errors to adjust the ballasting procedures, all operation modes gave satisfactory results. Two main parameters should be taken into account for full scale operations:

- The maximum allowed pitch angle between the MC-7 structure and the installation vessel and barge should not be exceeded.
- Special attention should be given to reduce any mechanical loading capable of inducing roll motion on the MC-7 structure during the separation ~~installation~~ as the MINT installation system does not control this motion. The structure up-right itself when the upper leg structures are engaged in the water.

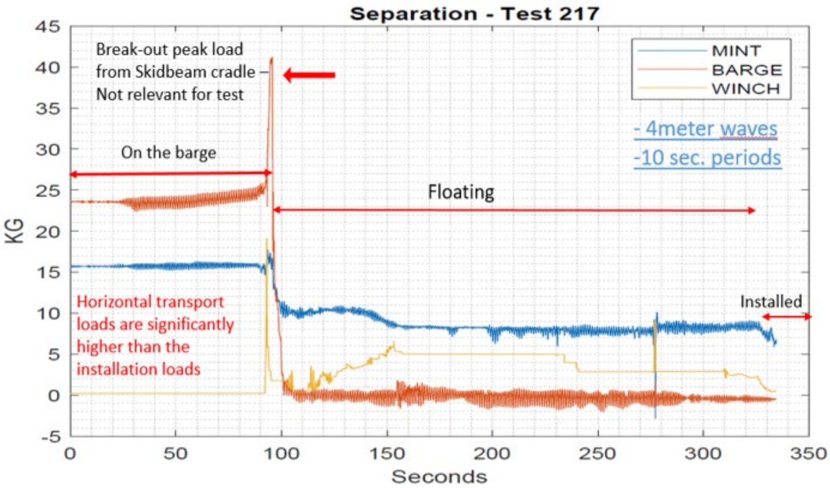

Figure 10. Vertical loads on vessel deck during the installation phase.

5. Conclusions

In general, the wave tank tests confirmed the initial assessments made by Sintef Ocean [1] for transportation in Hs 2,5 to 3 meter: With adjustment of the ballasting procedure during the upending phase, the transport and installation method is feasible.

The transport function was tested with both regular and irregular waves with wave heights from 2,5 to 7,4 meter. Heading variations from 0 to 30 degrees were investigated. 3 hours Jonswap spectra wave tests were also run with following set wave heights and periods: Hs = 2,5 m/ Tp = 8s and Hs = 4,0 m / Tp = 8s. Strain gauges and loadcells installed on the mono-tower and the barge did not reveal any large stresses during the transport and installation conditions except during the lift off situation of the structure from the barge where procedures must be developed to limit the loads.

5.1 Transport; recommended maximum sea-state criteria:

- Hs 3 meter
- Wave periods 8-9 seconds

Note: The transport survives Hs 4meter in 30 deg. heading.
The designed Transport solution is concluded robust and ready for full scale detail engineering.

5.2 Installation; Recommended maximum criteria:

- Hs 2,5 meter
- Wave periods 8-9 seconds

Note: The installation survives Hs 3 meter in 30 deg. heading
Note: The recommended transport and installation criteria are based on specific vessel and barge sizes /designs. The criteria may change when using other vessels / barges.

Data availability

On request to Green Entrans AS, test data will be made available, provided the results of the data analysis be shared with the data owner.

Author contributions

The test was managed by J Haugvaldstad, Green Entrans AS in collaboration with O. T. Gudmestad – University of Stavanger and the University College of Cork-Ireland. The basin tests were executed in the MaREI – LiR test center in Cork – Ireland under the leadership of Senior Marine Engineer F. Thiebaut.

Disclaimer

The results from the wave tank tests are presented in this paper. However, any misunderstandings regarding the presentation of the results reported in this paper are not the responsibility of the authors. Any use of the technology reported herein should be clarified with the technology owner, Green Entrans AS.

Acknowledgements

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References

[1]. SINTEF Ocean AS (Solaas and Sandvik), Report 017 F-025, "SIMO simulations of towing and launch phases. MINT installation tool", June 2017.
[2]. DNVGL RPA203 2017 Technology qualification, Recommended Practice. Høvik, Oslo, Norway
[3]. Lacal-Arántegui, L, Yusta J M and Domínguez-Navarro J A 2018 Offshore wind installation: analysing the evidence behind improvements in installation time, *Renewable Sustain. Energy Rev.* **92**, 133-145.
[4]. SBM, GustoMSC. 2018 Equipment for Offshore Wind Turbine installation
[1] https://www.kivi.nl/uploads/media/5644b984995fc/Offshore%20Windturbine%20Installatie% B%20hoe%20hoog%20kun%20je%20gaan%20-%20ir.%20R.%20Noordermeer.pdf
[5]. Ahlström C, Andersson A and Blomgren N 2014 Optimus Pråm - Semi-submersible wind farm installation vessel for Blekinge Offshore https://publications.lib.chalmers.se/publication/208702.
[6]. Gintautas T, Sørensen D J and Vatne, R S 2016 Towards a risk-based decision support for offshore wind turbine installation and operation & maintenance, *Energy Procedia* **94**, 207 - 217, Presented at 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind' 2016, 20-22 Jan., Trondheim, Norway.
[7]. Seyr H and Muskulus M 2016 Safety indicators for the marine operations in the installation and operating phase of an Offshore wind farm, *Energy Procedia* **94**, 72 – 81. Presented at 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind' 2016, 20-22 Jan., Trondheim, Norway.
[8]. Paterson J, D'Amico F, Thies P R, Kurt R E and Harrison G 2018 Offshore wind installation vessels: A comparative assessment for UK offshore rounds 1 and 2, *Ocean Eng.* **148**, 637-47.
[9]. Gudmestad OT, Grønli J and Straume H 2010 *Marine operations for installation, intervention and decommissioning of Offshore Windmills*, Presented at The Royal Institution of Naval Architects conference Marine & Offshore Renewable Energy, 21 -23 April 2010, London, UK, Proceedings ISBN 978-1-905040-70-4, 175-184.
[10]. Bennett Offshore. Jack up units, a technical primer for the offshore industry professional, 2005. http://www.bennettoffshore.com/primer.html
[11]. Lloyds Register. Guidance Notes for Wind Turbine Installation Vessels, 2014. London. https://www.lr.org/en/guidance-notes-for-wind-turbine-installation-vessels/
[12]. Green Entrans AS, "Test Report, MINT Transport and Installation Tests, Technology Qualification". RFV report 04, Stavanger, December 2018.