SJOR - PUBLIC REPORT

TSE HE 2016

Eindverslag over de uitvoering van de activiteiten en de resultaten ervan

Title: Slip Joint Offshore Research
Abbreviation: SJOR
Project number: TEHE116334
Project period: 09-12-2016 / 31-12-2019

Consortium partners:

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Ministerie van Economische Zaken

TOPSECTOR ENERGIE
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1. EXECUTIVE SUMMARY

Background & Objectives

To lower the cost price of offshore wind energy, this project focussed on the connection between the foundation monopile and the wind turbine. The current state of the art has two solutions: grouting or bolting (see Figure 1). When the grouted option created an industry-wide problem due to incorrect design standards, the bolted connection came into fashion. It however requires regular inspection and maintenance during its operational lifetime and is therefore also not considered as the ultimate offshore proof solution.

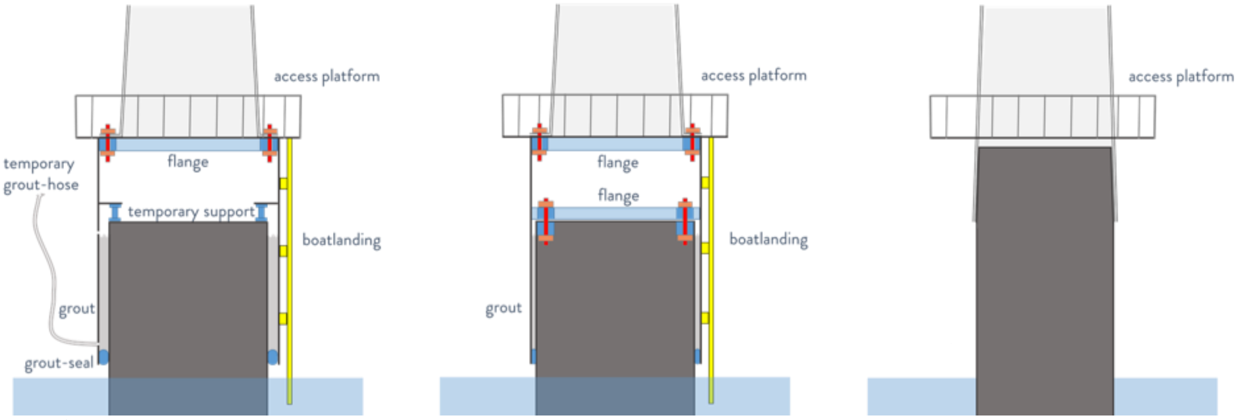

FIGURE 1 | SCHEMATIC REPRESENTATION OF A GROUTED (LEFT), BOLTED (MIDDLE) AND SLIP JOINT (RIGHT) CONNECTION

The slip joint connection is an alternative form of connecting the wind turbine tower to its foundation in which two conical steel tubulars are placed over each other. The slip joint principle uses the friction between two conical shapes to create the required structural connection; compare two paper coffee cups, upside down, sliding into each other. The connection requires no bolting, grouting or welding which decreases material costs and valuable installation time offshore. The objectives of this research were to demonstrate the slip joint technology offshore at real life scale and investigate its long-term performance in a series of laboratory tests in parallel, with the goal of developing a generic slip joint design procedure.

Project plan

The first batch of laboratory tests was dedicated to research on the determination of the contact area in the slip joint. Small scale experiments were performed in order to develop a method to localise the contact area between two steel layers. To this end, the acoustic response on the impulse impact on a steel to steel surface was measured and mapped: Hammer tests. Next, contact area experiments were performed on an actual existing decommissioned slip joint: the Duinvogel. The second batch of laboratory tests comprised of dedicated friction tests for the derivation of the coefficients of friction for a variety of steel surface and loading conditions. The test program contained 25 test specimen variants (in total 75 tests), varying contact pressures and (combination of) various surface conditions. The final batch of laboratory tests comprised of fretting fatigue tests. The goal of these tests was to quantify the effect of a fretting-fatigue force on the slip joint life time. Tests with a variety of steel surface and loading conditions were performed, in air and in an artificial sea water environment. For reference, fatigue tests were also executed without fretting.

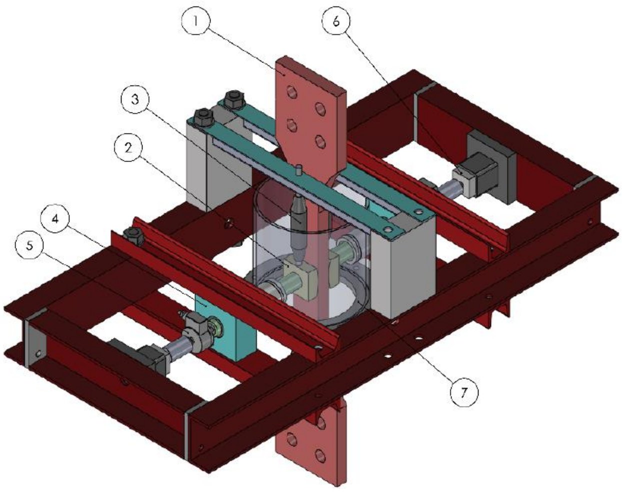

FIGURE 2 | EXPERIMENTAL TEST SET-UP FRETTING FATIGUE TESTS: 1 SPECIMEN; 2 FRETTING PAD; 3 LOAD CELL; 4 BEARING SUPPORT; 5 LOAD CELL 6 AIR CYLINDER; 7 WATER TANK

An offshore track record needs to be realised to convince the market of the applicability of the slip joint concept. Therefore, in parallel to the indoor laboratory tests, a full-scale offshore test was prepared; main items that are required to deliver loads on the slip joint: A monopile foundation and a fully operational hydraulic DOT wind turbine. The offshore installation was planned in two separate offshore campaigns: 1) The floating installation on dynamic positioning of a monopile using a Vibro Lifting Tool (VLT). As this was a world first, a dedicated test campaign was set up to test the effect of vessel hook load and VLT vibrating frequency on pile driving time, pile driving depth and noise emissions during installation. 2) The offshore installation of the hydraulic DOT wind turbine including slip joint. Test data was acquired regarding slip joint settlement, stress distribution and accelerations both during installation and the subsequent wind turbine operation.

FIGURE 3 | MONOPILE FOUNDATION (LEFT) + OPERATIONAL HYDRAULIC DOT WIND TURBINE (MIDDLE) = (SIGNIFICANT) TEST LOADS (RIGHT 2X) ON THE SLIP JOINT CONNECTION

Project results

The laboratory experiments proved that the contact area of a slip joint can be detected to a certain resolution using acoustic measurements. During the friction tests, both the static coefficient at first onset of sliding and after the first reversal were determined. In addition, the dynamic coefficients of friction during sliding in compression and during sliding in tension were determined. The static coefficients of friction were found to be generally speaking independent of the nominal contact pressure. The results of the frettting fatique tests (see Figure 4) were compared to existing S-N curves for rusted steel (D) in sea water, rusted steel (B) in air and coated steel in sea water. The results were incorporated in the slip joint design procedure which proves that this phenomenon can be controlled and accounted for in the design.

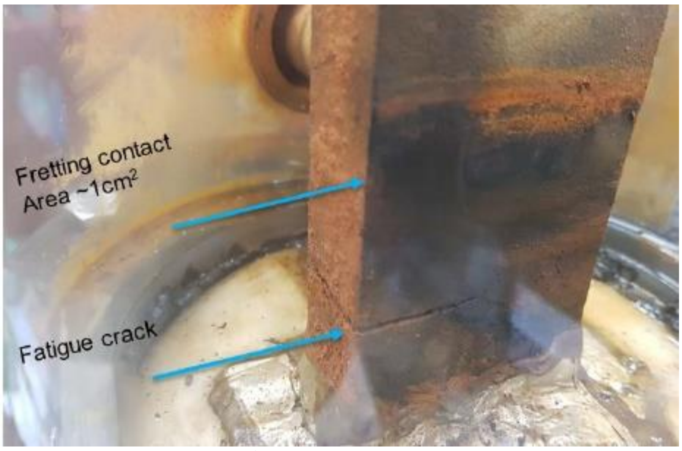

FIGURE 4 | EXAMPLE OF SPECIMEN FRACTURE

The floating installation on dynamic positioning of a monopile using a Vibro Lifting Tool (VLT) was feasible within set installation targets. The inclination of the monopile during vibro installation was successfully influenced, adjusted and corrected. The wind turbine was successfully installed using a world first slip joint connection in the offshore environment. The installation was performed within the required tolerances, within 1 hour, which is a significant reduction in the installation time of a typical wind turbine using a bolted or grouted connection (see Figure 5). The first part of the offshore tests consisted of measurements of hoop stress, axial stress, accelerations and settlement during slip joint installation. Directly after installation, the slip joint had almost entirely settled to the desired design overlap of 5.2 [m]. The results showed that the slip joint settles in a predictable, controlled and smooth manner. During the second part of the offshore tests, insight was acquired in the same measurement parameters during operation, continuously over a series of days. The results showed that settlement reaches a new equilibrium after each subsequent (higher) load case; the slip joint is prestressed in an increasing manner over its lifetime. All operational measured slip joint stresses were compared to the relevant design criteria via a unity check: Both the long term quasi-static settlement induced stresses as well as the instantaneous dynamic stresses (and a combination of the two) were well below the allowable limit.

Concluding, all project objectives and deliverables have been fulfilled; a full-scale offshore test and various onshore laboratory tests were performed in parallel and successfully completed. The results and insights that were obtained were combined in the development of a complete, fully reviewed, slip joint design procedure. The project was performed in close collaboration between all project partners, in a constructive manner and in good spirits. The consortium is proud to look back on delivering a very successful project.

FIGURE 5 | INSTALLATION OF SLIP JOINT IN PROGRESS

Knowledge dissemination

During the course of the project, multiple knowledge dissemination events were undertaken. In total, one seminar was organized, six presentations were given at five different events and five conference posters and papers were produced (see Figure 6). The project got the attention of the media as well, as more than thirteen individual press releases related to the project results generated publicity for the slip joint technology.

FIGURE 6 | SELECTION OF DISSEMINATION EVENTS

Next steps

The first direct spin-off was already initiated during the SJOR project: The SJOQ project. It was a direct follow up, or rather an extension of the first project, aiming to increase the TRL and certification level of the slip joint technology even further at minimal additional cost. Several other initiatives were initiated already during or after the SJOR and SJOQ projects that concerned the commercial application of the slip joint technology. Sif developed an innovative secondary steel concept using a slip joint, omitting the need for a transition piece. Van Oord designed and installed an underwater slip joint, connecting a 9.5 MW turbine to its monopile foundation, installed in the Borssele V project by the Two Towers consortium. Furthermore, several new research and development projects have been initiated. Two concrete examples being the DOT6000 FOX (TEHE119004) project, in which a 3MW+ slip joint is installed by means of a floating vessel, and the C-FLO (TEHE118023) project, set up to reduce the uncertainties in the evaluation of the combined degradation mechanisms corrosion and fatigue to derive improved calculation tools for design and maintenance of monopiles.