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DP CHALLENGES IN ANA PLATFORM JACKET INSTALLATION

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Summary

Installation of jacket platforms requires simultaneous and combined operations of multiple assets. When the whole process has to be planned, it is necessary to predict in a fast and reliable way the possible weather limitations that may occur during the operations. The paper will present the major challenges of this unusual and innovative Dynamic Positioning analysis which has been carried out for Ana Jacket installation. The obtained results show that the Dynamic Positioning system of the core vessel in intact configuration is capable to hold the position for the investigated vessels' arrangements and design operative weather conditions. Lifting, upending and installation of Ana Jacket were carried out successfully in 2021.

Key words: *Offshore installation; Dynamic Positioning; Multibody dynamics*

1. Introduction

The western part of Romanian Black Sea offshore area is under development within the XV Midia block, which is located approximately one hundred kilometres to the east of the city/port of Constanta. The most recent activities have been carried out at Ana discovery where an unmanned platform has recently been installed and put into operation. The platform houses the wellheads and the production control facilities, including the support to the nearby Doina field. The gas collected from both sites will be routed to shore and then to the new gas treatment plant at Vadu, where it will be treated and delivered to the final users both in Romania and EU countries. The installation of the Ana Jacket required the joint operation of several offshore units. The core vessel during operations was the DP-2 Vessel Bigfoot-1 (BF-1), which is fitted with 6 azimuthing thrusters with a maximum power of 2200 kW each. Since the other vessels of the installation asset have no propulsion systems, BF-1 has been used to assure their station keeping. In this scenario, the Dynamic Positioning (DP) investigation of BF-1 was intended to obtain the maximum sustainable wind speed associated with the allowable significant wave height for keeping position of different vessels' arrangements during installation. In the open literature, there are no comparable examples of DP calculation processes involving the combinations of more than two units, and small cases for lifting from barges are mainly analysed in time-domain [1, 2, 3] without providing a methodology for the interaction between different bodies. Therefore, a new process has been implemented to evaluate the DP performances in terms of DP capability [4]. The obtained capability results, oriented to minimising power consumption [5, 6], allowed the proper determination of power margins assuring safe operations. This paper presents the principal challenges of the unusual and innovative DP analysis of multi-vessel configurations that were planned for installation. The obtained results showed that the DP system in intact conditions is capable to hold the position for all the vessel's arrangements and design weather conditions. The preliminary study findings ensured the successful lifting, upending and laying of the Ana Jacket.

Table 1 Main vessel characteristics and cluster configurations

Main Particulars				
Item/Vessel	**BF-1**	**NEP**	**BF-2**	**Spacer**
Length, L_{OA} [m]	135.00	83.00	122.45	30.30
Beam, B [m]	42.00	79.68	30.50	14.30
Depth, D [m]	8.00	44.00	7.60	3.20
Draft, T_M [m]	4.60	4.60	3.85	1.60
Configurations				
Tandem mode (1)	YES	YES	NO	NO
Cluster mode (2)	YES	YES	YES	YES
Jacket mode (3)	YES	YES	NO	NO

2. Vessels description

Hereafter a description of the vessels and barges involved in the operation is given, namely:

- **BF-1**: Bigfoot 1, pipe-layer barge equipped with 6 Rolls Royce USL 255 P30 FP Retractable Azimuth thrusters (2200kW each) for DP operations. DP system is capable to hold position within DP 2 failures according to ABS. Fixed stinger type with three sections (45 + 36 + 10 m).
- **NEP**: Neptun, Lifting Crane Barge with lifting capability of 1800 tons.
- **BF-2**: Bigfoot 2, heavy lift and semi-submersible ocean going deck cargo barge.
- **Spacer**: small spacer barge for auxiliary duties.

The main characteristics of the vessels corresponding to the examined loading conditions are summarised in Table 1. In particular, the schematic representation of thruster's locations on barge BF-1 and corresponding identification numbers are shown in Figure 1, together with the reference system adopted for the CFD predictions.

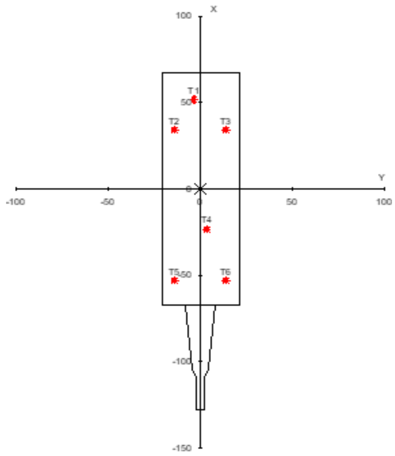

Fig. 1 BF-1 schematics reference system, thrusters' location and identification.

3. Installation overview

The installation operations of the Ana Jacket were successfully completed on the first of April 2021. The jacket was transported to the location onboard BF-2. The jacket installation was performed with the help of Neptun crane, moored to BF-1, the Spacer and BF-2 (Figure 2). After removing the welded sea fastening, the jacket was lifted from BF-2 and Neptun lowered the steel structure in place (Figure 3). A similar strategy has been adopted for the successive installation of the top-side. No particular problems were encountered during both operations.

Fig. 2 Vessels in Cluster mode configuration.

Fig. 3 Vessels during Jacket installation

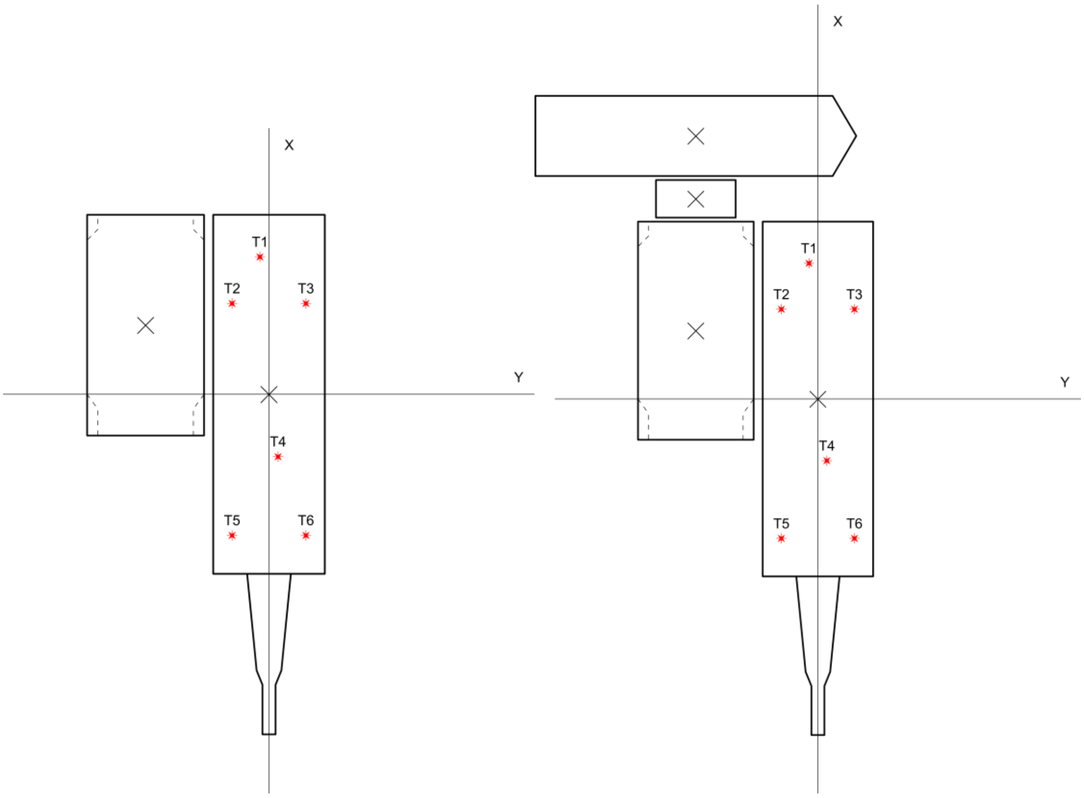

Fig. 4 BF-1 Tandem mode (*left*) and Cluster mode (*right*) vessels' configurations.

This study reports the preliminary CFD analyses aimed to understand the DP capabilities of DP-2 Vessel BF-1 to safely keep position during the installation of Ana Jacket and to evaluate the maximum allowable weather conditions assuring the stand-by position. Three different vessels' arrangements have been examined:

- **Case 1**: Initially, the BF-1 vessel has the heavy-lift floating crane barge Neptun secured to the Port side with soft mooring lines (Vessels in Tandem Mode).

- **Case 2**: After that, when the two co-joint vessels are in Tandem Mode and ready to perform the installation, the submersible ocean-going deck cargo barge BF-2 transporting the Ana Jacket, is moored at the bow of GSP-Neptun (Vessels in Cluster Mode). The Spacer barge is used in the between.
- **Case 3**: In the last phase the two vessels BF-1 and Neptun are again in Tandem Mode and perform the Ana Jacket laying to the sea bottom (Vessels in Jacket Mode). In this arrangement, the Ana Jacket is close to the touch down condition.

For the Ana Jacket installation, the conditions of lift-off, upending and laying were studied to investigate the DP requirements for BF-1 vessel to hold the Tandem and Cluster systems in position. All the analyses have been carried out assuming limiting weather conditions during installation and stand-off operations. Here we present the results for the maximum weather conditions corresponding to V_w= 20 kn, V_c=0.85 kn, Hs=1.2 m and Tp= 4-7~s. Figure 4 shows the schematic description of the analysed configurations.

The DP analysis of barge BF-1 and vessels' arrangements as per *Case 1*, *Case 2* and *Case 3* needs a breakdown of the global problem into several sub-problems and, therefore, the following strategy has been adopted:

- No open-source data exist for vessels in tandem/cluster modes. Therefore, the environmental loads have been estimated according to statistical data/procedures on mono-hull vessels/barges that are provided by Institutions [4, 7] or Classification Societies [8,9], by explicitly considering the shielding effects when they occur.
- Intact conditions, i.e., a quasi-static DP analysis for *Case 1*, *Case 2* and *Case 3* has been performed by assuming the vessels rigidly connected in their initial position and considering all thrusters running.
- Single and multiple thruster failures, i.e., a quasi-static DP analysis has been carried out for *Case 1*, *Case 2* and *Case 3* by assuming the units in their initial position and rigidly connected. Environmental loads from appended semi-submersed jacket have been accounted for. Multi-thruster failures are related to the loss of one of the two installed gensets. In particular, the loss of forward genset implies the failure of T1, T2 and T5, while the loss of aft genset implies the failure of T3, T4 and T6.

To perform the station-keeping CFD predictions a quasi-static approach has been used to determine the DP capability curves [10]. The quasi-static calculation requires the equilibrium resolution of forces and moment acting on the vessel in the horizontal plane, considering both thruster actions and external loads [11, 12]. To this end, a thrust allocation algorithm [13,14,15] has been used to solve the following 3DOF equilibrium system:

$$\begin{cases} \sum_{i=1}^{N_T} Fx_{Ti} = Fx_{ext} \\ \sum_{i=1}^{N_T} Fy_{Ti} = Fy_{ext} \\ \sum_{i=1}^{N_T} \left(Fy_{Ti} x_{Ti} - Fx_{Ti} y_{Ti} \right) = Mz_{ext} \end{cases} \tag{1}$$

where the subscript T indicates the actuators installed on the vessel and N_T is their number. For the investigated cases, system (1) presents more unknowns than equations, thus, its solution requires the application of a dedicated algorithm. Among the multiple solutions developed by the authors [16, 17, 18], here, the thrust allocation solver, used for DP calculations, is based on a genetic algorithm capable to determine automatically the thruster-thruster interaction areas [19].

4. Environmental loads

The preliminary activity has been devoted to evaluate the environmental loads due to wind, current and waves (drift), which are acting on the vessels in both tandem (Case 1) and cluster modes (Case 2). The loads on the jacket have been considered separately and suitably added to the system in tandem arrangement during the final laying operations (Case 3).

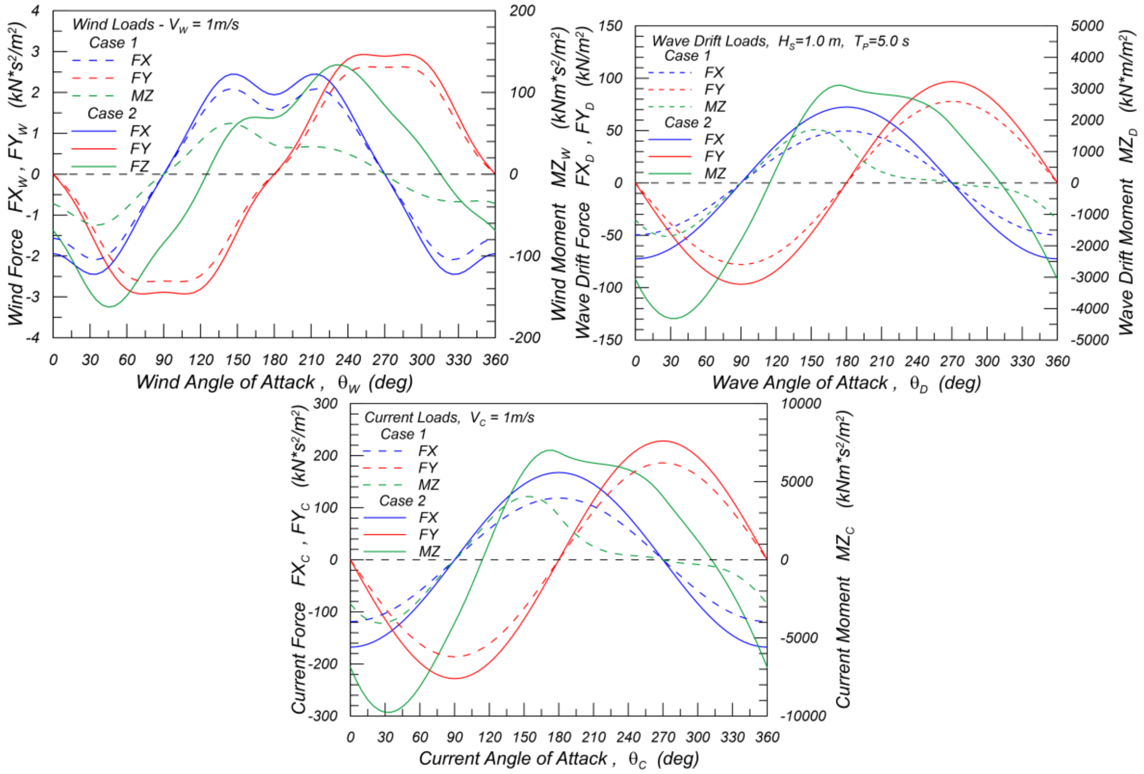

Fig. 5 Breakdown of wind, wave and current specific loads for *Case 1* and *Case 2*.

4.1 Wind (Case 1\Case 2)

The wind loads have been separately computed for all the vessels according to API/ABS/IMCA recommendations [4, 7, 10]. The shielding effects due to the hull and upper-deck structures have been considered, while no shielding has been assumed for cranes due to their relatively large distance and permeability [20]. The effects due to BF-1 stinger in air have been added to the total wind load. Since a 3D model has not been implemented, reference is made to the exposed areas for head, stern and beam (port/STBD) directions. For the intermediate directions of the vertical momentum, DNV-GL recommendations [9] have been used by separately considering the asymmetric effects of wind on longitudinal and transversal force. The geometric asymmetry of the exposed areas with respect to the pivot point at BF-1 mid-ships implies that the wind moment has higher values for STBD coming-from weather directions. For the two examined cases Figure 5 (top-left) shows the unitary wind force (V_w=1 m/s) on the exposed surface of unit area.

4.2 Current (Case 1/Case 2)

Current loads are affected by viscosity, which cannot be accounted for without the implementation of a CFD model or proper experiments. The gap between barges is a source of vorticity and leads to additional loads due to vortex shedding. However, with respect to the total current load, it can be reasonably assumed that the effects due to the gap between barges can be considered negligible. The reciprocal distance of the nearby bodies is too small to justify the onset of a significant contribution.

In first approximation, the current loads have been computed for a vessels' arrangement which can reasonably be assumed as a single rigid body geometry. The shielding of the vessels for head, stern and beam (port/STBD) directions has been considered. To be on the safe side, the OCIMF current load coefficients have been assumed [7].

For intermediate headings the DNV-GL recommendations [9] have been applied. Also in this case, the geometric asymmetry of the underwater exposed areas with respect to the pivot point at BF-1 mid-ships implies a higher current moment for STBD coming-from current directions. The unitary current force (V_c=1 m/s) on the surface of unit area is shown in Figure 5 (bottom) for the two cases.

4.3 Wave Drift (Case 1/Case 2)

The drift loads due to incoming waves have been computed for the initial rigid configuration of the vessels. Since the drift is due to the short-wave effect, the distance of nearby bodies is too small to expect a significant interaction effect between the hulls. More exact loads can be obtained by CFD or experiment.

The drift loads have been computed in short-wave approximation [21] for head, stern and beam (port/STBD) directions, considering standard long-crested JONSWAP spectrum for irregular waves. In the frame of this approximation, the incident high-frequency waves are reflected by the hull so allowing the evaluation of mean drift forces by pressure integration on the vessel's overall exposed surface. The procedure, if properly managed with actual geometry constraints, is capable to handle multi-body systems and to include the shielding effects as well. This semi-empirical method certainly overestimates the actual QTF's but can be enhanced and conveniently applied to multi-body configurations by a suitable cutting of different frequency contributions through a frequency-draft reduction [22]. The reliability of the procedure has been established for ship added resistance predictions [23, 24] and independent benchmarks on tandem offshore vessels [25]. Therefore, according to the experience, it is expected that the evaluation of wave drift forces is on the safe side. For intermediate wave headings the most appropriate DNV-GL recommendations [9] have been applied. The geometric asymmetry of the underwater exposed areas with respect to the pivot point at BF-1 mid-ships implies a higher wave drift moment for STBD coming-from weather directions. Figure 5 (top-right) shows the unitary mean wave drift forces (Hs=1 m) for unit surface at Tp=5 s.

4.4 Additional loads on the jacket (Case 3)

A new model has been implemented for the DP analysis of the vessel system BF-1 and Neptun co-joined (Vessels in Tandem Mode) with jacket vertically appended on hook and its bottom above seabed before touch-down (Vessels in Jacket Mode, *Case 3*).

The implementation has been carried out according to the following steps:

- Vessels BF-1 and Neptun have been assumed in their initial position and the jacket vertically appended with its bottom 3 m above seabed.
- Interaction of appended/immersed jacket with Neptun has been modelled in terms of load reactions at crane boom tip.
- The loads on jacket (additional loads) have been added to the environmental loads on BF-1 and Neptun co-joined in tandem mode (basic loads).
- No interaction and/or shielding effects due to jacket’s relative position with respect to the incoming weather have been considered.

- Static and concurrent additional loads due to wind, current and waves have been amplified by the dynamic allowance coefficient.

Additional loads on jacket have been supplied in terms of 3D force components for the operative weather conditions. The boom tip reactions on Neptun's crane, computed by hydrodynamic analysis software, include wind, current and wave loads for the maximum operative weather conditions. Since the recommended DP analysis is based on varying wind speed, the breakdown of the additional loads on jacket has been done to separate loads due to wind (V_w = 20 kn) and those simultaneously due to current (V_c = 0.85 kn) and waves (Hs = 1.2 m; and Tp= 4-7 s). The following scheme has been adopted:

- *Wind*: the wind loads on the appended semi-submersed jacket have been computed off-line for the effective wind-exposed area above the sea water surface according to API/ABS/IMCA recommendations [4,7,10]. Then, the wind loads for speed V_w = 20 kn have predicted and subtracted from the total additional load to identify the current/wave load component in operative conditions. In carrying out the DP analysis, the wind load with varying wind-speed (as requested by standard predictions) has been computed step by step and added to the current/wave component. In this way the effective additional load on the boom tip has been obtained for any wind speed.
- *Current/Wave*: The current and wave loads on the jacket have been obtained from the total environmental load after subtracting the operative wind load component at 20 kn wind speed as explained beforehand.

Figure 6 shows the total environmental forces on the system obtained for the three investigated cases at the design weather conditions with Tp= 5 s.

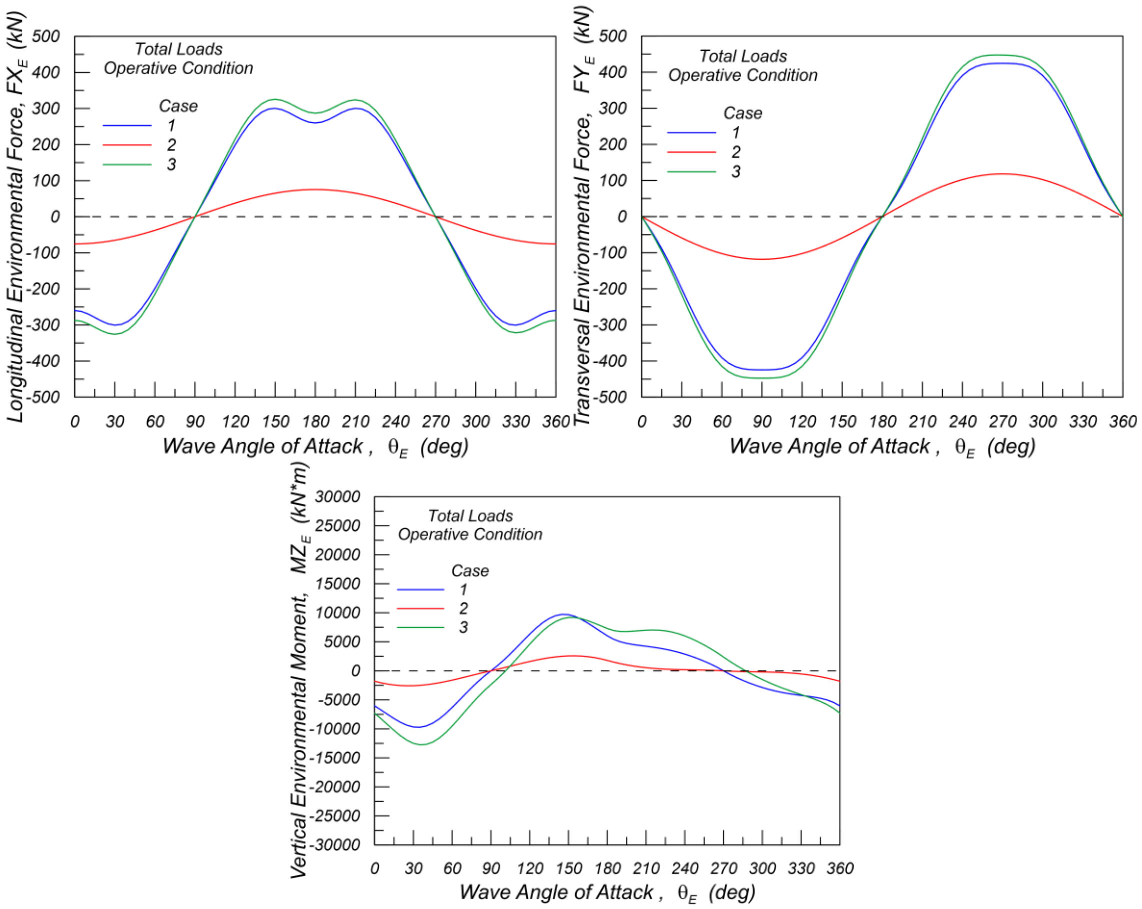

Fig. 6 Comparison of total environmental loads for the three investigated cases.

5. DP capability results

The present quasi-static DP calculations make reference to the predicted external loads, considering the thrusters' layout given in Figure 1. A thrust deduction of 10% (thrust efficiency=0.90) has been applied to approximately take into account the deductions due to inflow velocity [9], oblique inflow cross-coupling effects, propeller/hull interaction, etc. Moreover, a dynamic allowance factor 1.2 [9] has been used to be on the safe side of a quasi-static analysis. Calculations have been performed considering the environmental loads as described in the previous sections, with a constant current speed V_c=0.85 kn and a single sea state (combination of Hs=1.2 m and Tp=4-7 s), incrementally changing the wind speed V_w in such a way to find the maximum sustainable wind speed the DP system can counteract. The environmental loads were supposed to be collinear [9,10]. The results are reported in the form of conventional DP Capability Plots [10] in Figure 7.

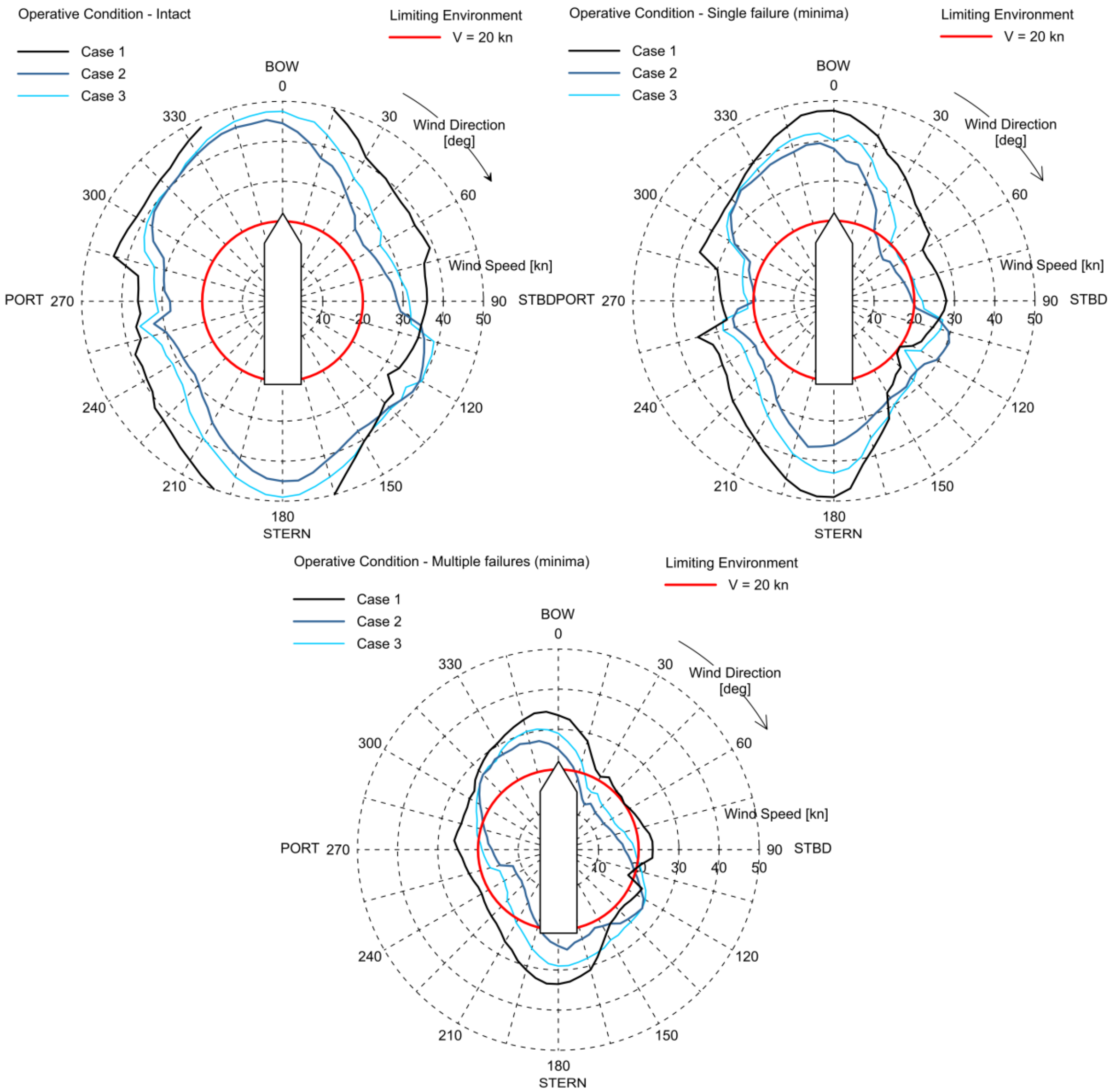

Fig. 7 DP capability plots for intact (*top-left*), minimum envelopes of single failures (*top-right*) and multiple failures (*bottom*).

When examining the results for *Case 1* and *Case 2*, the following indications can be derived:

- Due to the asymmetry of the vessels' arrangements, the leading factor for determining the DP capability of BF-1 barge is the environmental moment load component.
- Intact configuration for both *Case 1* and *Case 2* does not present station keeping problems when the vessels are at operative weather conditions. In stand-off weather conditions the requested design wind speed limit of 20 kn is not satisfied in the heading interval of 45-90 deg for wave peak periods above 5 seconds.
- For intact conditions the headings having a higher safety margin with respect to the 20 kn design wind speed limit are the ones corresponding to the range between 330-350 deg.
- The loss of thruster T1 is the most restrictive in terms of capability between the single failure cases. For *Case 1*, this single failure is not limited by 20 kn wind speed limit. In operative conditions for *Case 2* the position cannot be kept in the range of headings 30-90 deg.
- For single thruster loss, the most favourable heading remains approximately in the range 330-350 deg, where additional thrust capability remains available for safely keep position.
- When one of the gensets is failed, it results that the loss of the forward genset is seriously limiting the incoming angles in operative weather conditions. Also in this case additional thrust margin is available in the heading range between 330-350 deg.
- The loss of the aft genset is less restrictive and position can be maintained for operative weather conditions at almost all headings. The system cannot keep position for *Case 2* approximately around 240 deg of heading.

For *Case 3* the following considerations can be added:

- Since the environmental loads are located between *Case 1* and *Case 2*, the corresponding DP capability will be intermediate and, therefore, between the limits of the two previously examined cases (see Figure 6).
- Intact configuration for *Case 3* does not present particular problems at operative weather conditions.
- The DP capability for *Case 3* in case of loss of thruster T1, which is the most restrictive in terms of position keeping between the single failure cases, is on the wind limit of 19.0-19.5 kn for the range of headings 45-90 deg.
- Single loss of other thrusters (T2 to T6) does not present any particular problem.
- The loss of forward genset is seriously limiting the incoming weather angles in operative conditions for STBD head and port quarter directions.
- The loss of aft genset does not limit the DP capability. The system is on the limit of 20 kn wind speed around 240 deg of heading

Further benefits for operators may derive from the evaluation of DP operativity [26, 27], recently developed by the authors, and that can be the next frontier for the preliminary prediction of unconventional DP operations.

6. Conclusions

The present paper describes the application of preliminary non-standard DP calculations for a complex geometrical layout of several offshore vessels, which are kept in position by a unique DP-equipped unit, the core vessel. Problems related to shielding effects have been considered and suitably solved. The operability margins have been established by ensuring that the weather conditions in the installation area can be counteracted by the allowable thrust of the DP system, in DP-2 mode, for both intact and failure conditions. The operators benefited of the provided preliminary predictions to successfully carry out jack-up lying and top-side installation of Ana platform.

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