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Defining Expanded Sectors for DP Assisted Offloading Operations in Spread Moored Platforms

By Eduardo A. Tannuri

University of São Paulo, Numerical Offshore Tank, TPN-USP

Ana Luisa de Barros Orsolini, Felipe Santana Castelpoggi, Douglas Gustavo Takashi Yuba, Gilberto Beduhn Machado, Cap. José Luiz P. Malafaia

Petrobras

Abstract

This paper presents a complete methodology applied by Petrobras for the definition of expanded operational sectors of DP shuttle tankers in offloading operations in Spread Moored Platforms, increasing the time availability and still guaranteeing the operations' safety.

The methodology consists at first in a Preliminary Risk Analysis to assess the potential hazards associated with the operation on the new expanded sector and, if necessary, some detailed analyses take place. Then, downtime analyses and a power demand analyses are made to evaluate the advantages of this proposition. The next step is performing real-time simulations commanded by experienced Captains in a full-mission simulator equipped with the actual DP System, in a hardware in the loop simulation architecture. The simulations are performed so that most critical conditions are recreated in the presence of the Captains so they can give their opinion on how safe the operation would be.

The new offloading sectors were then programmed in the DP software and a real operation was executed in order to test and validate the new proposition. Some minor improvements were included in the sectors, and an operational guideline with the new sector, combined with the updated DP console software, will be adopted for all Petrobras' DPST fleet.

Introduction

F(P)SO platforms have received special attention in oil exploration activities in Brazil on the past years, especially because of operations in ultra-deep water and remote fields. In this scenario, the offloading operations are usually accomplished through Dynamically Positioned Shuttle Tankers, or DPSTs.

In order to ensure low risk of collision during the oil transfers, Petrobras has adopted guidelines that limit the operational sector of DPSTs and determine that offloading must be aborted in case the shuttle tanker is incapable of maintaining position inside it.

Even with the increasing propulsive capacity of the most modern vessels, some environmental conditions still interrupt offloading operations, especially in Spread Moored platforms in Santos Basin, because they tend to push the shuttle tanker out of the operating sector. This has a significant impact on the unavailability or downtime of the operation.

One possible solution for reducing this downtime is to expand the operational sector angles which allows the ship to stay longer time connected to the F(P)SO, as long as this is shown to be safe and not to imply very large power demand on the tanker.

Fig. 1 presents the current Petrobras operational sector for offloading operations in Spread Moored Platforms. The area between the green dotted lines represents the sector where the DPST is allowed to be positioned while offloading. The allowable heading range is -45º (45º to portside) – to avoid excessive risks on the riser balcony side –and +60° (60º to starboard). If the shuttle tanker's heading exceeds this maximum angles and ingresses on the yellow sector, the Captain is allowed to stay there just during the necessary time to attempt bringing the DPST back to the green sector. If the tanker reaches the yellow sector border line (-60º or +80º), the DPST Captain has to contact the F(P)SO OIM requesting the cargo transference immediate interruption (OESD 1). The red sector is a forbidden zone. By reaching the -70° or +90° limit, the DPST Captain is required to initiate OESD 2 procedure, by disconnecting the offloading hose line from the BLS and the mooring hawser that connects the DPST to the oil platform as an extra safety measure.

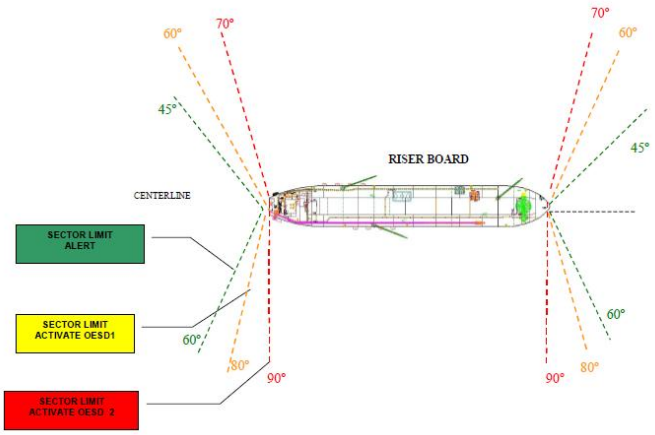

Fig. 1. Petrobras' original operating sector

Previous studies (Corrêa, 2012; Corrêa et al., 2013) have proposed to increase starboard's green sector limit to 90º, showing that uptime increase would be significant both in Campos and Santos Basins and that more flexibility to position the ship can increase the operation's safety by letting it assume a most comfortable position for its thrusters. However, some operational issues (explained in the Risk Analysis and in Orsolini et al., 2016) indicated that the green sector should be limited to 75º at starboard, as illustrated in Fig. 2 that presents the final proposition for the new expanded operational sector. In this sector, there is a "bow rotation" zone in which the DP operation mode is changed from "Auto Position" to "Bow Rotation" when the shuttle tanker attaints green sector limits.

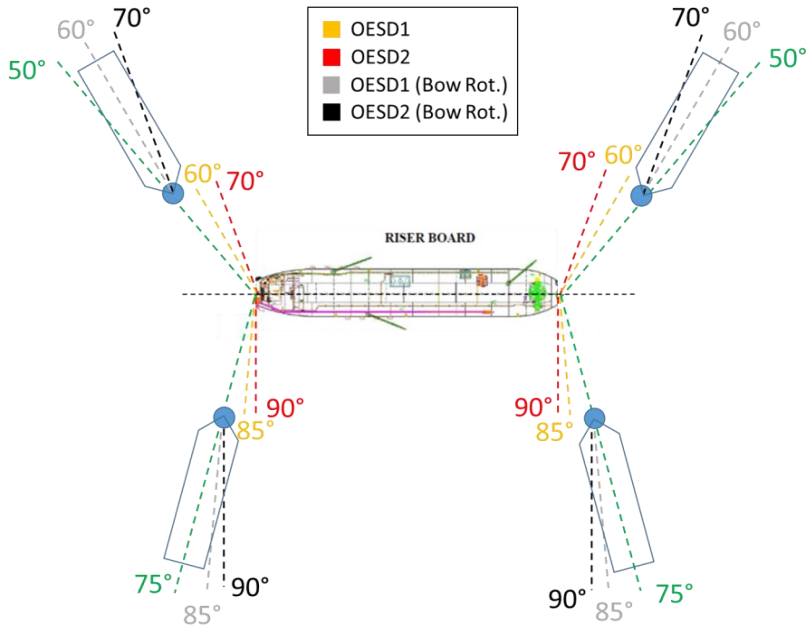

Fig. 2. Operating sector proposition

This work presents a deeper analysis of that proposition, including a more comprehensive calculation of the reduction of the downtime, risk analysis, real time simulations and, finally, field tests of the new control strategy.

Methodology

The methodology proposed by this paper was applied in Petrobras' context, considering one typical DPST of Transpetro's fleet, and one typical FPSO of Petrobras' fleet. Environmental conditions were used both from Campos and Santos Basins.

Initially, a Preliminary Risk Analysis was made to assess the potential hazards associated with the operation on the new expanded sector. The main purpose was to better understand what could go wrong and what the consequences would be. Drive-off and blackout failures followed by collision with the F(P)SO were the main focus of this work.

The PRA session identified the need of changing a few parameters of the initial proposition, that was considered in the next stages of the analysis. The PRA group also identified a few risks that were never experienced by the industry and needed better investigation, so the activity was followed by a detailed risk evaluation. This was accomplished by performing stability simulations in Petrobras' SSTAB software.

The next step was the evaluation of the advantages of this proposition by calculating the downtime reduction and the power demand on the DP System. This was accomplished by performing several static analyses to determine the ship's capability of maintaining position and thrusters demand for every environmental condition expected to happen over six years in Campos and Santos basins.

Finally, a series of real time simulations took place after having mastered all the uncertainties assessed on previous steps. The real time simulations were followed by two experienced DPST masters so they could evaluate in practice the proposed operational sector and manifest their opinion on how safe the offloading operation in the new sector would be in real life.

The new offloading sectors were then programmed in the DP software and a real operation was executed in order to test and validate the new proposition. Some minor improvements were included in the sectors, and an operational guideline with the new sector, combined with the updated DP console software, will be adopted for the actual and new tankers.

Preliminary Risk Analysis

This step consisted in a qualitative risk assessment session whose main goal was to identify all the possible risks associated with the operational sector increase from 60° to 90° in order to analyze if the proposal was feasible.

By analyzing the offloading operation only on the extended sector, it was expected to check if operation in the new zone presents additional or higher risks if compared with the operation in the original sector.

The PRA group was composed by the authors of this paper and other participants (one Naval Architect from Petrobras, two experienced DPST Captains from Transpetro, a former manager of 9 Transpetro shuttle tankers and two risk analysis specialists from DNV). The methodology of this work followed Petrobras norm N-2782 – Applicable Techniques for Industrial Risk Analysis.

One of the first conclusions that the group achieved was that the offloading operation with a 90º heading cannot take place because Petrobras policy requires the DPST to operate with a hawser connected to the FPSO. This requirement exists to increase safety in case the DPST presents a black-out, because hawser will help holding the tanker until there is enough time to safely disconnect offloading hose. Since this tensioned rope is present during all the offloading operation, a 90º heading would surely imply in several

geometric interferences between the hawser and the platform's structures, and this will certainly cause severe damage to these structures.

That being agreed, the group established that the maximum heading to define the green sector must be an angle for which there is sufficient time to disconnect the hose and the hawser in case of sudden weather change or DPST degradation before the tensioned rope reaches any structure on the production unit. The DPST masters' experience defined that maximum heading of the tanker should then be 75º in the green sector. Yellow sector could go through 75º to 85º, and red sector could start from 90º on.

Despite this concern in limiting the green zone to 75º, the shuttle tanker masters agreed that they would feel comfortable in operating between 75º and 80º as long as the environmental conditions were mild and the thrusters' power demand was low.

Hence, the PRA group proposed a new operational sector that they considered acceptable which is shown in Fig. 3. From -45º to 75º the shuttle tanker is free to operate. In the sector hatched in green from 75º to 80º, it can operate as long as power demand is low. OESD 1 should take place at 85º and OESD 2 at 90º.

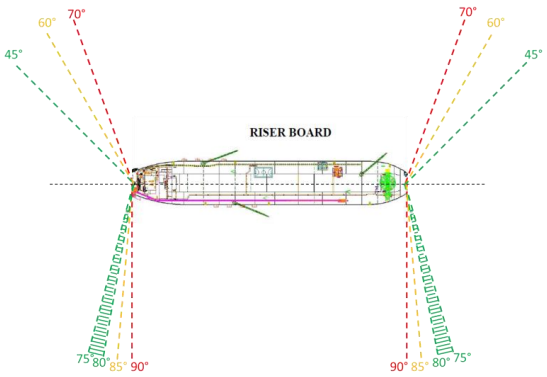

Fig. 3. PRA group proposed sector

This sector, however, was not technically possible to be programmed into Kongsberg's software, because of the hatched green sector – the system is not able to trigger alarms over the thrusters' power demand. Hence, this proposition was later replaced by the one showed in Fig 2, which has the same effects – because the bow rotation mode automatically reduces power demand over the thrusters.

After proposing the change in the operational sector, the PRA group identified all the hazards for the offloading operation. The majority of the risks were considered moderate if the recommendations are implemented. Most of those hazards are also identified when operating in the original sector, except the following:

- By operating in the extended sector, the DPST will position itself in such a way that if a drive-off takes place the Captain's scape manoeuver will be more difficult to execute and the risk of collision would be higher.
- By operating in the extended sector at the stern station, if a drive-off takes place the tanker could hit the platform's stern and damage the hull causing flooding in the engine room. In case that happens, the FPSO hull girder could be endangered.

Because these two hazards were never experienced in Petrobras history, and the participants didn't have any record of that happening in the offshore industry, it was agreed that they needed to be better evaluated in further steps, as described on the next section.

Detailed Risk Evaluation

As the PRA session identified two risks that were never experienced in Petrobras history and probably neither in the industry, a detailed analysis was done in order to better evaluate the probability or the consequences of these hazards.

First hazard to analyze was the fact that in case a drive-off takes place when the DPST is positioned inside the extended sector, the Captain's scape manoeuver will be more difficult to execute and the risk of collision would be higher. As this analysis required advanced computational resources, this risk was only evaluated at the end of the project with the aid of Real Time Simulations, and are better explained in the corresponding section in this paper.

The second risk to be analyzed was the fact that if a drive-off takes place the tanker could hit the platform's stern and damage the hull causing flooding in the engine/utility room and further damage on the FPSO hull girder.

To confirm the extents of that risk, Petrobras Stability Software SSTAB was used to simulate damage on the engine room in several units of the fleet (see Fig. 4).

The analysis showed that this risk is actually very low. Most part of the simulations showed no need of concern. In some specific loading conditions and in some specific platforms, though, the maximum bending moments or shear forces may come close or slightly exceed the envelope of admissible values. It is important to notice, though, that these envelopes are generally defined for the hull's intact conditions. For this reason, these situations still need better investigation.

Even though, it is possible to conclude that if the FPSO has a contingency plan that takes into account this possibility of engine room flooding and if it provides procedures of cargo or ballast transfer to avoid endangering the hull girder strength, this risk can be considered moderate. This conclusion was then listed as a recommendation in complement to all the other recommendation assessed in the PRA session.

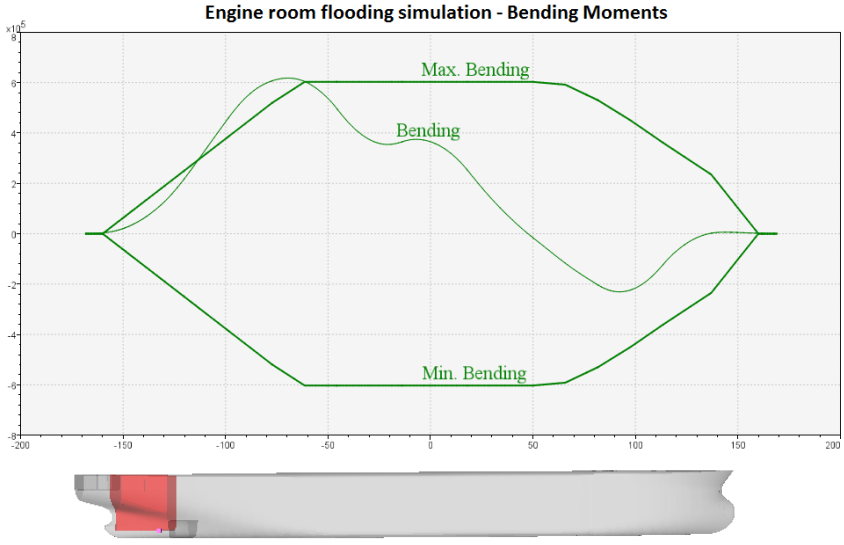

Fig. 4. Engine room flooding simulation for a specific FPSO – hull girder bending moments and envelopes

Downtime Analysis

Downtime calculation uses a MatLab routine which, based on static analysis, computes for various environmental conditions, for several different headings and for two ship loading conditions (ballast and loaded) if the DPST has enough power to maintain position in each combination of conditions.

The input to the routine is the simultaneous combinations of wave, swell, wind and current from Petrobras hindcast database. Here, 6 years of measured and modelled conditions were used, from Jan 1st 2004 to Jan 1st 2010 with 3-hour intervals, totalizing 17537 cases for each Basin.

For each of these conditions, environmental mean forces over the tanker are evaluated, and the mean forces on each thruster are then obtained by a thrust allocation algorithm.

Multi-body interactions are not taken into account to calculate environmental loads. Although they play an important role in the total force acting on the Shuttle Tanker, in most cases, the shielding effect reduces the forces acting on the DPST, since it is on the downstream position. There are some few cases where the force is amplified due to the change on current/wind flow direction by the FPSO (Illuminati et al., 2009). However, the authors see that the shielding effect increases the calculated uptime in comparison with the hypothesis of no-shielding effect, so this last assumption is considered conservative.

As for the allocation algorithm, at this stage, the maximum thrust for each propeller is assumed to be 80% of the nominal value (dynamic factor, as suggested by IMCA, 2000).The numerical models adopted for the estimation of the environmental and thrust forces are adapted from the time-domain simulation code TPN/Dynasim (Nishimoto et al., 2002), (Nishimoto et al., 2003).

Fig. 5 illustrates how this routine works, testing for all possible headings inside the admissible operational sector at the bow and stern offloading stations, if there is at least one solution for a given environmental condition. A more complete description of this routine is presented in Corrêa et al., 2013).

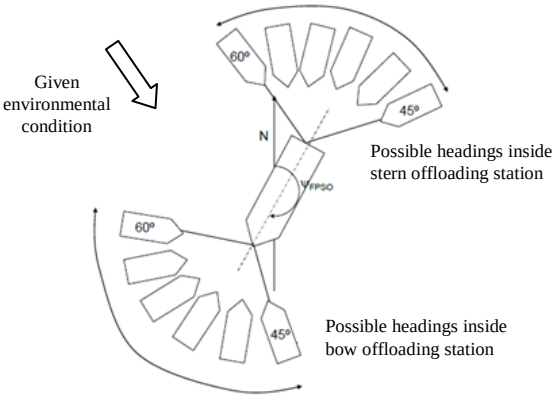

Fig. 5. Downtime calculation routine tries to find at least one solution for a given environmental condition

The average time for the offloading operation is 36h (6h for connection, 24h of oil transfer and 6h for disconnection). So, the acceptance criteria for the 36h time period to be counted as uptime for a particular offloading station are:

1. Hs is less than 3.5m (contractual criterion)
2. Wind speed is less than 40 knots (contractual criterion)

3. Total thruster forces perfectly counteract the environmental force acting on vessel
4. If the environmental force tends to push the ship towards unity, this force must be smaller than 22 kN (which is equivalent to a wind of 10 knots and waves of 1m Hs, according to DPSTs masters experience)
5. The thrust on the most demanded propeller must be less than 80% (dynamic margin of 20% as suggested by IMCA, 2000)
6. Shuttle's roll amplitude is less than 6° (to guarantee comfort on board of the ST, according to Capitains' experience)
7. The criteria 1 to 6 must be valid for the environmental conditions during the 36h operation time

The F(P)SO's heading and the limiting angles of the green sector are also input to this routine. Thus, it is possible to calculate the downtime for the original sector (-45° / +60°) and then for expanded sector (-50° / +75°), in order to evaluate the uptime gain due to the increase of the operating sector.

The shuttle tanker chosen to this analysis is a Suezmax type tanker having a Class 2 Dynamic Positioning System, whose characteristics are listed in Table 1 and Table 2. For this study the platform's hull geometry is not important, because static analysis do not account hydrodynamic interactions between the two hulls.

Table 1: Shuttle tanker main characteristics

Characteristics	Loaded	Ballasted
LOA (m)	278,0	
LPP (m)	262,0	
Breadth (m)	46,0	
Draft (m)	15,85	8,0
Displacement (ton)	170.000	80.000
Wind Lateral Area (m^2)	2668	4842
Wind Frontal Area (m^2)	929	1290

Table 2: Shuttle Tanker DP characteristics

Actuator	Position (related to the midship)	Max. Thrust	Power
Bow Tunnel Thruster	x = 127m y = 0m	+/- 31tonf	2200kW
Bow Azim.Thruster	x = 122m y = 0m	+38tonf; -24 tonf	2200kW
Stern Tunnel Thruster	x = -111m y = 0m	+/- 29tonf	1935kW
Stern Azim. Thruster	x = -91m y = 0m	+38tonf; -24 tonf	2200kW
Main Propeller	x = -125m y = 0m	+211tonf; -135 tonf	18.881kW
Rudder	Not used in the analysis		

According to the results, the increase from 60° to 75° of the green sector is advantageous and represents a gain of 10.6% uptime on the bow station and 13.2 % in the stern station for the offloading operations in Santos Basin. In Campos Basin, these gains are lower, but still significant, being 9.1% at bow station and 8.6% at the stern station. The global uptime, which accounts for bow and stern stations together, presents an increase of 4.0% for Santos Basin and 3.0% for Campos Basin.

The following graphics show the uptime increase for the new sector compared to the original one, on a monthly basis:

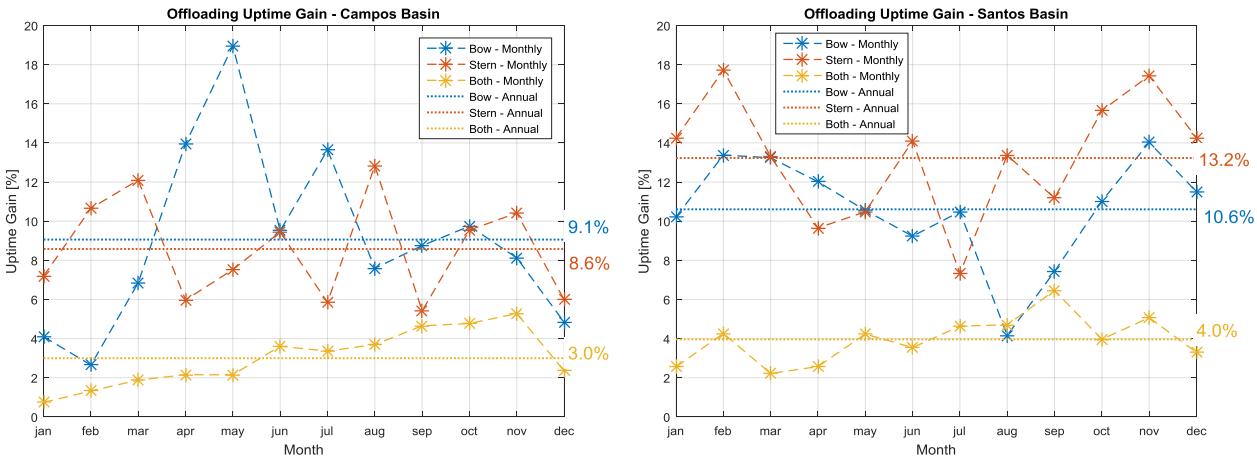

Fig. 6. Uptime gains for the new sector: (left) Campos Basin; (right) Santos Basin

Table 1 shows the calculated annual uptime of the original and extended offloading sectors considering the bow station, stern station and both stations (global uptime). Santos Basin's uptime increased to 65.5% at the bow, to 66.6% at the stern and to 86.7% globally when the extended sector is available. Campos Basin's uptime increased to 82.5% at the bow, to 44.2% at the stern and to 92.3% globally.

Table 3: Final Results of the Static Analysis

Basin	Uptime - Offloading Station					
	Bow [%]		Stern [%]		Both [%]	
	Original	Extended	Original	Extended	Original	Extended
Santos	54.9	65.5	53.4	66.6	82.7	86.7
Campos	73.4	82.5	35.6	44.2	89.3	92.3

Besides increasing the operation uptime, another advantage of extending the offloading operating sector is that, by operating in the extended sector, the shuttle tanker can better align with environmental conditions which would decrease the power demand on the thrusters and hence the risk of blackout. The comparison between the optimized power demand on the DP system when the vessel operates in original and extended sectors is shown below. In order to compare the power demand on both sectors, the results from downtime analysis routine were used.

As explained before, the MatLab routine determines for all environmental conditions and all shuttle headings if it is able to keep position or not by calculating environmental loads over its hull and allocating thrust on the propellers.

With this information, it is possible to find for each environmental 36-hour windows the optimized DP power demand to the DPST. This can be done both for normal and extended sectors. By comparing the optimized power demand, it is possible to conclude if the extended sector helped the shuttle to find a more comfortable heading, with less power demand.

After calculating the optimized DP system utilization for all environmental windows for both sectors, several histograms were generated showing how many cases (environmental windows) request the following ranges of power on the DP System:

- 0 to 10%
- 10 to 20%
- 20 to 30%
- 30 to 50%
- 50 to 80% (maximum utilization, dynamic margin of 20%)

It is clear from the histograms shown in Fig. 7 and Fig. 8 that for the extended sector there is a power demand reduction at both bow and stern stations in both basins. For example, in Campos Basin, for the stern station in January, if the shuttle operates in the original sector the chances that the power demand is lower than 50% are less than 60%. However, if the shuttle operates in the extended sector, this chances increase to almost 80%. This indicates that the sector's extension could make the operation safer in terms of stress on the DP system and risk of blackout due to equipments overheating.

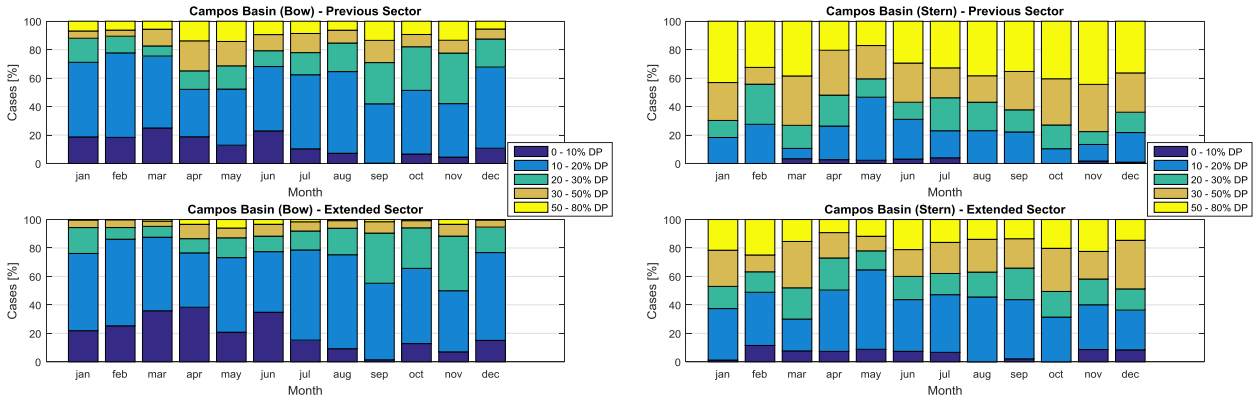

Fig. 7. Average DP power utilization for Campos Basin: (left) bow; (right) stern

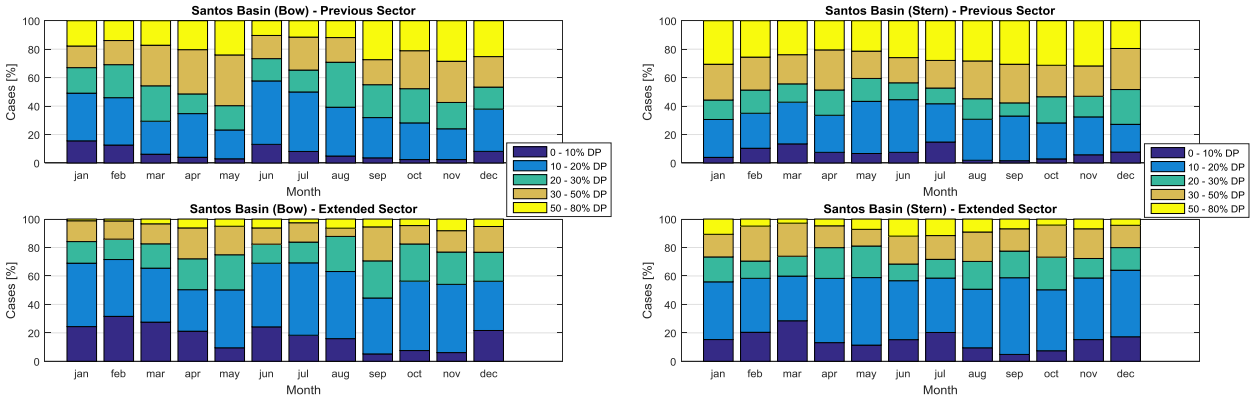

Fig. 8. Average DP power utilization for Santo Basin: (left) bow; (right) stern

Real Time Simulations

Real Time simulations were performed at TPN's Real Time Offshore Simulator (Tannuri et al, 2014) and were followed by two experienced DPST masters so they could evaluate in practice the proposed operational sector and manifest their opinion on how safe the offloading operation in the new sector would be in real life. The Fig. 9 shows a picture of the full-mission simulator, emphasizing the DPST in the extended new sector during the offloading operation.

Fig. 9. Real Time Simulation – DPST in the extended new sector

From the results of downtime analysis, some environmental conditions were chosen to be used in the real time simulations in order to analyze the DPST's performance both in the original and expanded sectors. These conditions were mostly the cases were the static analysis showed that the shuttle tanker could not operate in original sector but could easily operate in the extended one.

A comprehensive set of conditions were tested, and the results have shown that the expanded sector does make a difference and helps increasing operational safety specially for environmental conditions that come from the East.

Fig. 10 shows one of the Santos Basin environmental conditions tested in the simulation campaign. Fig. 11 shows the power demand for each thruster. Red, orange, green, light blue and dark blue colors represent, respectively, the time percentage in which the thruster demand is between 50% and 100%, 25% and 50%, 12.5% and 25%, 0% and 12.5%, and 0% (not in use). It can be seen that when the DPST was positioned in the expanded green sector the DP power demand was remarkably reduced, which represents the increase in operational safety.

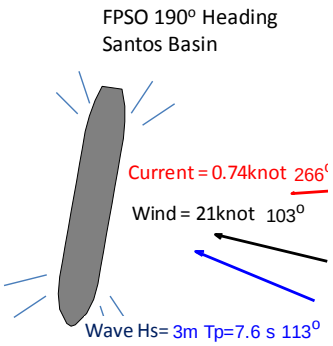

Fig. 10. Environmental condition tested in the Real-Time Simulation

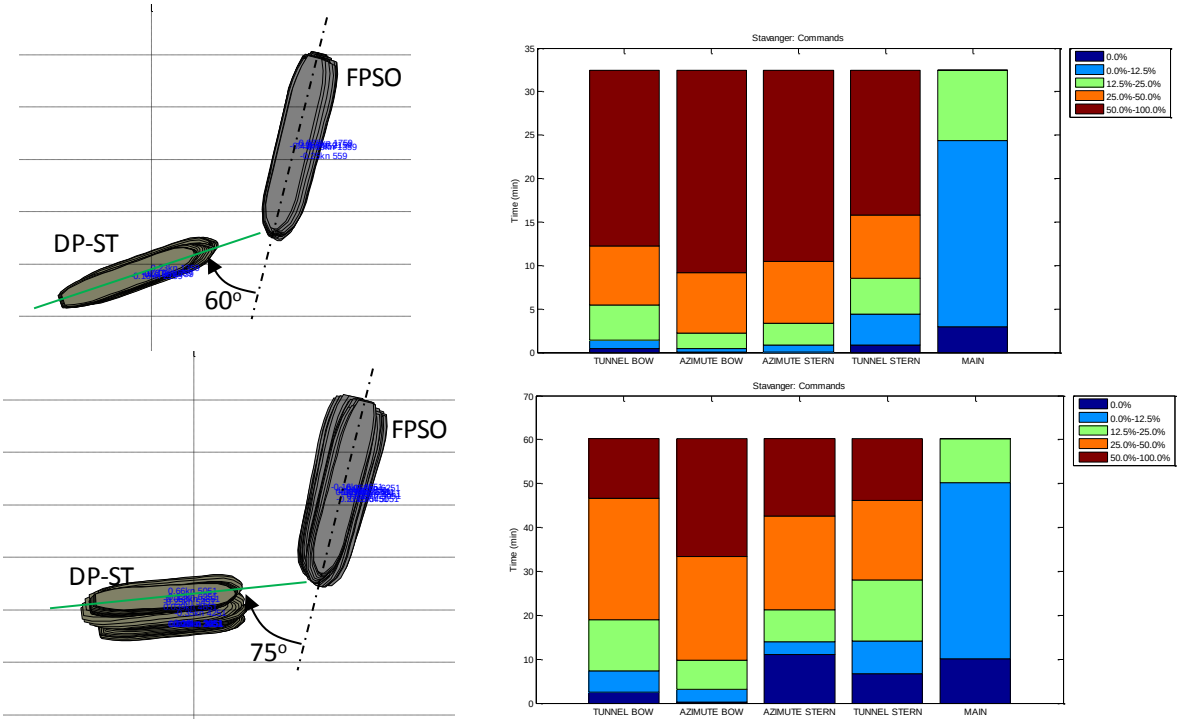

Fig. 11. Simulation results: (Up) – DPST in the today´s green sector; (down) DPST in the expanded green sector

Fig. 12 shows one of the Campos Basin environmental conditions tested in the simulation campaign. The Fig. 13 shows the power demand for each thruster in 3 different position. It can be seen that the average power consumption is reduced as the DPST enters the expanded green zone, as well as the roll motion. This simulation shows a clear advantage of keeping the position inside the expanded green zone.

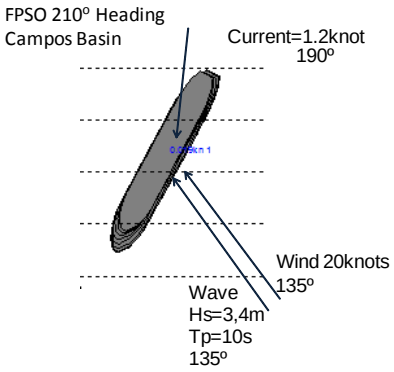

Fig. 12. Campos Basin Environmental condition tested in the Real-Time Simulation

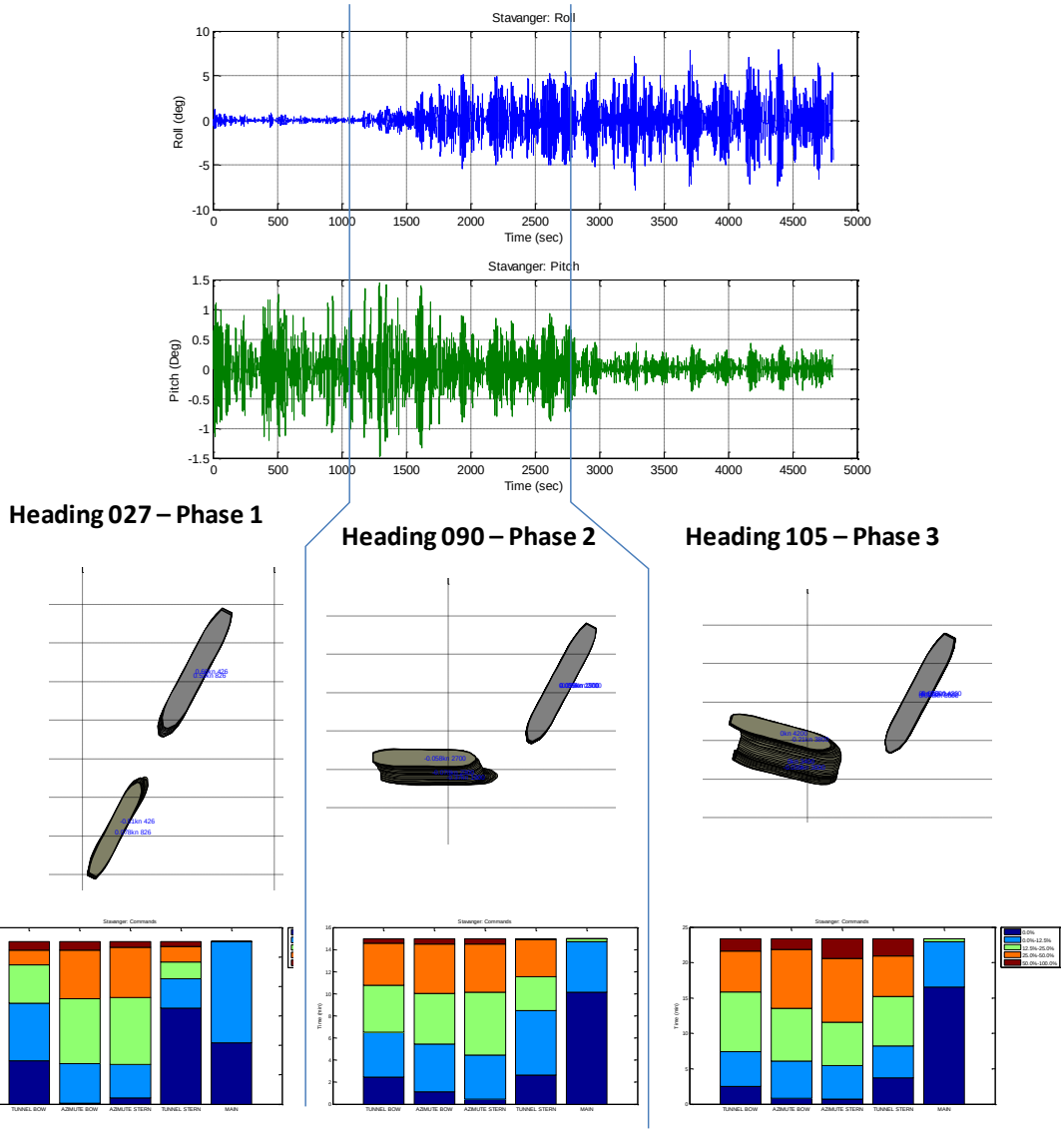

Fig. 13. Simulation results: (Phase 1) DPST aligned with the FPSO; (Phase 2) DPST in the limit of today´s green sector; (Phase 3) DPST in the expanded green sector

Several drive off failure simulations have also been carried out, in order to evaluate if the captain could avoid the collision when the DPST is kept inside the expanded green zone (two cases are presented in the Fig. 14). It could be verified that when using only the propeller and rudder, the distance between the vessels during the escape maneuver was considered unsafe by the captains (less than 40m). With the aid of the tunnel and azimuth thrusters, the distance between the vessels was increased, as shown in the figure.

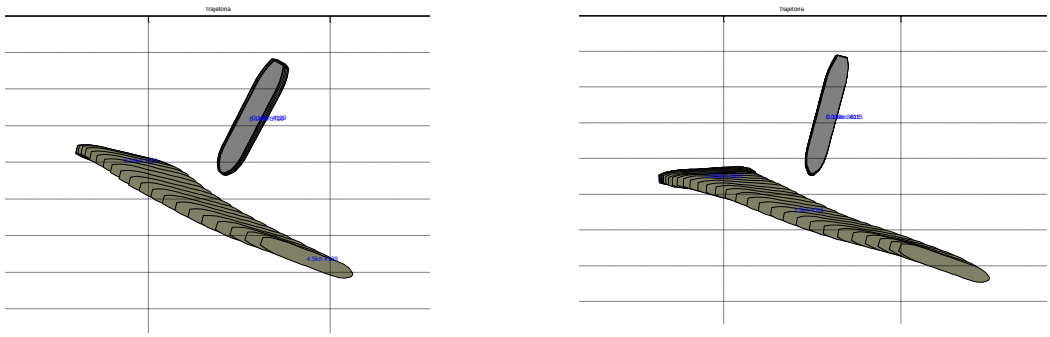

Fig. 14. Drive off simulations: escape maneuver using the thrusters, propeller and rudder

Field Tests

After accomplishing all the methodology steps and verifying that the risks of expanding the green sector were tolerable or moderate, the new offloading sector was programmed in the DP software of a real shuttle tanker and a real operation was executed in order to test and validate the new proposition.

On the day of the test, weather conditions were mild and not pushing the DPST towards the expanded sector. Hence, it was necessary to position the shuttle tanker purposely on the green sector limit only to test the software transition from AUTOPOS do Bow Rotation mode. The tests occurred just fine and, when changing to Bow Rotation mode, it was possible to notice that thrusters' demand decreased, as expected.

Some minor improvements were included in the sectors after the test and operational guidelines with the new sector, combined with the updated DP console software, will be adopted for the actual and new tankers.

Recent feedback from Kongsberg and DPST Captains show that the new sectors and operation modes are being well accepted.

Fig. 15. Field tests

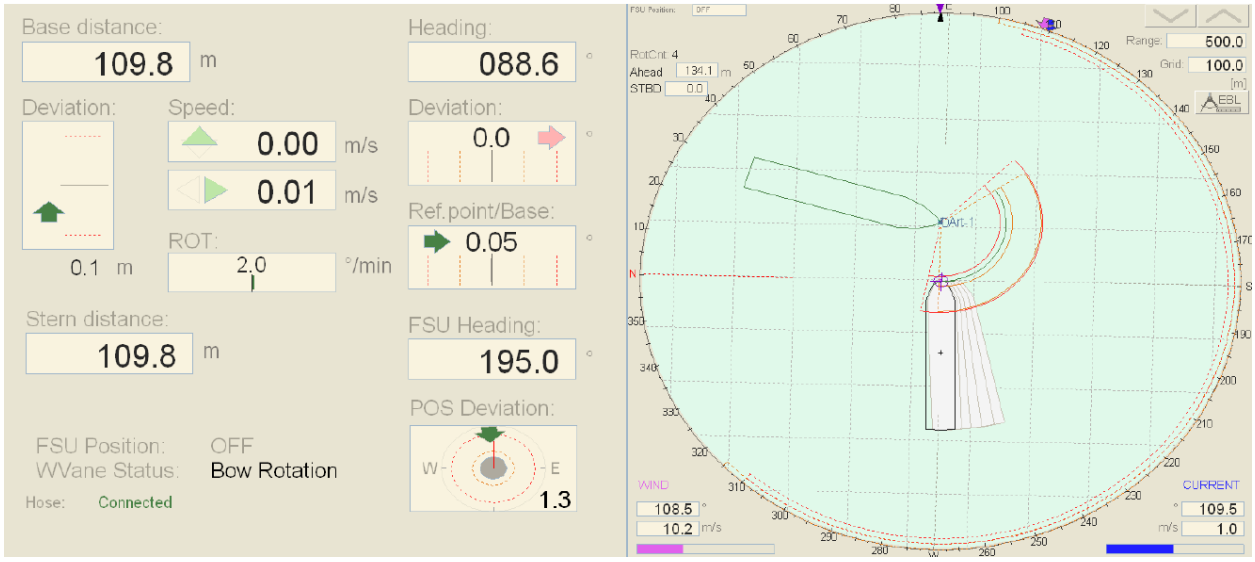

Fig. 16. Field tests – positioning the DPST at the green sector limit

Conclusion

The results from this methodology shows that the offloading operating sector can be extended up to 75° at starboard, without increasing any risks to the offloading operations, since Preliminary Risk Assessment and further detailed investigation showed that all the risks are ranked “tolerable” or “moderate”.

The Downtime Analysis showed that for Campos Basin an annual average uptime gain of 9.1% is found for bow station and 8.6% for stern station. The global system presents an annual availability gain of 3.0%. By analyzing each month of the year individually, it is noticed that some months may present uptime gains of up to 19% or as low as 4%. As for Santos Basin, the uptime gain is even more significant – around 10.6% for bow station, 13.2% for stern station and 4% for the global system (annual average) –

and by analyzing each month individually, some of them present uptime gains of up to 18% or as low as 2.5%.

The Power Demand study confirmed another advantage of extending the operating sector. It showed that, when operating with the extended sector, there is a power demand reduction at bow and stern stations for both Campos and Santos Basin. This indicates that the sector's extension could make the operation safer in terms of stress on the DP system and decrease the risk of blackout by equipment overheating.

The Real Time Simulations complemented all the other analysis showing that the risks of operation are under control; that drive-off escape manoeuvers are feasible; that power reduction on DPS is significant for specific environmental conditions; and that the experienced Captains felt comfortable and concluded that operating in this sector would be safely accomplished in real life.

Finally, field tests confirmed the Real Time simulations conclusions and the new sector is being installed in all Petrobras' DPST fleet. Twelve DPSTs are already operating with the new sector.

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Nomenclature

BLS – Bow Loading System
DP – Dynamic Positioning
DPST – Dynamically Positioned Shuttle Tanker.
F(P)SO – Floating (Production) Storage and Offloading.
Hs – Significant wave height
LOA – Length Overall
LPP – Length Between Perpendiculars
OESD 1 – Offloading Emergency Shut Down Level 1
OESD 2 – Offloading Emergency Shut Down Level 2
OIM – Offshore Installation Manager
PRA – Preliminary Risk Analysis
QRA – Quantitative Risk Assessment
SSTAB – Petrobras Stability Analysis Software
TPN – Tanque de Provas Numérico (Numerical Offshore Tank), University of São Paulo.

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