Cargo Oil Shifting on FPSOs Stability Analysis – Lessons Learned from P-34 Incident

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ABSTRACT

This paper presents a study based on several different scenarios for accidental cargo oil shifting on FPSOs of different lightweights, VCG positions and tankage. Presentation of the applicable criteria and stability evaluations for different simulations are shown with the associated limit for each situation. Solution possibilities regarding oil distribution on loading / offloading situations are discussed and evaluated together with normal operation procedures. Potential amendments on the applicable criteria are also discussed.

1. INTRODUCTION

P34 is the result of the conversion of the oil tanker "Presidente Prudente de Moraes" in a 46,500 DWT FPSO. In October 2002 the vessel passed through a fail in the automation system that controlled the hydraulic valves of the cargo system. As a consequence, the oil on starboard tanks shifted to center tanks by gravity, generating a more than 30º heel and the abandonment of the unit. Recovery teams worked through 7 days on non stop basis until they have managed to put the vessel on up right position and save the unit.

The P34 incident has brought to attention that the applicable criteria for damage stability, on vessels of this type, does not cover the situation occurred. Damage stability analysis for FPSOs considers three major criterions from IMO: ICLL, MARPOL and MODU Code.

On these rules, different approaches on damage length, run-off considerations and heeling moments cover the hull damage possibilities on normal operation. However, in none of these, any consideration on cargo oil shifting is made. The lack of evaluation on this kind of incident creates a number of possibilities not foreseen in any stage of the design. The combination of oil distribution, tankage, draft and GM may lead to potential accidents which origin is not covered by any applicable rule on the FPSO design or operation procedures.

It shall be noted that the main cause the incident was a failure in the automation system that controlled the hydraulic valves on the tanks. The work presented here intends to evaluate only the consequences of this failure in the stability of the units, and not to discuss the automation system, what is obviously another subject on the same problem.

When the hydraulic valves failure occurred, the cargo oil on starboard tanks shifted fast by gravity to the center cargo tanks, causing a massive heeling moment.

Figures no. 1 and no. 2 show a sketch on the oil distribution before and after the failure.

2. THE P34 INCIDENT

The main characteristics of the FPSO P34 are presented below:

Length Over All:	240.30 m
Length Between Perpendiculars:	231.10 m
Moulded Breadth:	26.00 m
Moulded Depth:	16.87 m
Minimum Draft:	5,00 m
Maximum Draft (summer):	12.76 m
Deadweight:	48,072 t

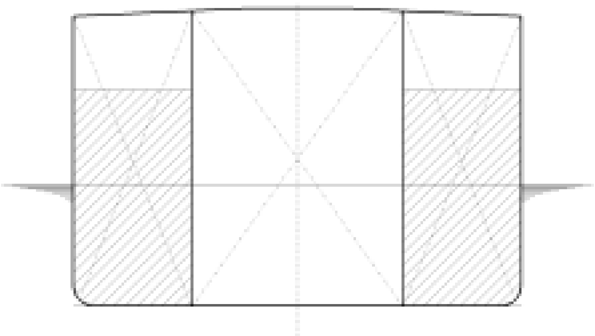

Figure 1 oil distribution before the shifting

The oil transfer generated a heel angle of more than 33^{o} and the abandonment of the unit. One interesting detail to note is that, after the oil started to shift, the consequent heeling took the remaining oil to the drainage system and all oil in each of the tanks was transferred to the adjacent one.

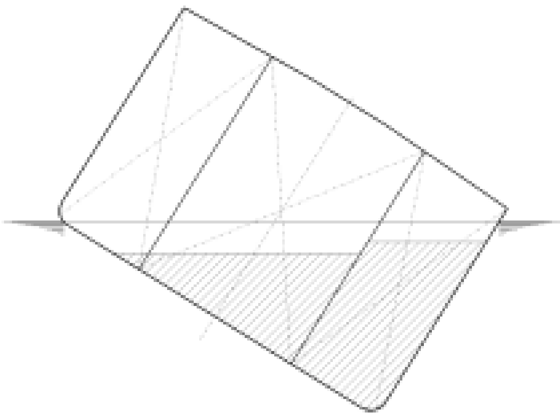

Figure 2 oil distribution after the shifting

Figure 3 P34 after the incident, in October 2002

The vessel was recovered after 7 days of work by ballasting the starboard tanks and redistributing the remaining cargo oil.

The accident has brought to attention that this kind of situation has never been studied for an FPSO in design stage. Nevertheless, the possibility of occurrence indeed exists.

3. APPLICABLE DAMAGE STABILITY CRITERIA

Although there is no change in the vessel displacement, a liquid cargo shifting is similar to an external damage in terms of heeling moment generation and the vessel capacity to respond. Therefore, the stability verification criteria were assumed to be the same as an external damage for the cargo shifting analysis.

The applicable damage stability criteria to a FPSO can be briefly described as follows:

3.1 ICLL

The International Convention on Load Line presents one of the most severe damage stability criteria applicable to a FPSO design.

The vessel in considered to be in the summer load line draft, even keel. The VCG position is calculated from a hypothetical loading condition where all cargo tanks are 98% filled with a liquid of a specific gravity that, combined with the vessel lightweight, leads the unit to the above described condition, with consumables (fresh water and diesel oil) at 50%. In this situation, every significant compartment shall be damaged and no run-off (when the existing liquid in the tank is considered to have been substituted by the flooding water) can be considered.

A brief summary of the criteria is presented below:

- Heel angle at equilibrium smaller than 15^o
- Heel angle range from equilibrium to righting arm 0 or flooding angle larger than 20^o
- Area under the righting arm curve from equilibrium to righting arm 0 or flooding angle larger than 0.0175 rad x m
- Maximum righting arm larger than 0.100m

3.2 MARPOL

The MARPOL regulation presents a damage longitudinal extention criterion that normally gets two or more compartments to be damaged, what turns this criterion to be very severe, especially for FPSOs with large tanks on deep drafts. The verification criterion is defined as follows:

- Heel angle at equilibrium smaller than 25^o
- Heel angle range from equilibrium to righting arm 0 or flooding angle larger than 20^o
- Area under the righting arm curve from equilibrium to righting arm 0 or flooding angle larger than 0.0175 rad. x m
- Maximum righting arm larger than 0.100m

3.3 MODU

This is certainly the less severe damage stability criteria to be applied to a FPSO. Only one compartment is to be considered damaged at a time and the run off can be applied. Even the 50 knot wind heeling moment added is not enough to take the analysis close to the criteria limit.

The verification criterion itself is the same as MARPOL:

- Heel angle at equilibrium smaller than 25^o
- Heel angle range from equilibrium to righting arm 0 or flooding angle larger than 20^o
- Area under the righting arm curve from equilibrium to righting arm 0 or flooding angle larger than 0.0175 rad x m
- Maximum righting arm larger than 0.100m

3.4 Stability Criteria

The ICLL criterion is not directly applicable to this study, since it depends on a hypothetical loading condition that would not reflect the loading conditions where an accidental cargo shifting can occur.

Since MODU and MARPOL present the same stability curve analysis criterion, but different considerations in damage lengths and external conditions, the stability curve verification from these codes will be applied in the following case studies.

4. CASE STUDIES

Cargo oil shifting have been studied for five FPSOs, divided in three different tankages and process plant capacities (and therefore larger vertical moment), that would reflect in the vessels response. It shall be noted that these analysis were independently performed, apart from the design process and are not presented in any documentation from the projects.

4.1 Case Study no.1: P47

The FPSO P47 is a production unit with a small dewatering process plant. Main characteristics are as follows:

Length Over All:	344.424m
Length Between Perpendiculars:	329.184m
Moulded Breadth:	51.816m
Moulded Depth:	26.518m
Minimum Draft	6.000m
Maximum Draft	20.735m
Deadweight (approx.)	260,000t
Lightweight (approx.)	45,500t

The oil shifting study considers the heeling moment generated from one tank shifting occurring after the other. The results for the stability criteria are shown in the following table:

Limit \ Oil Transfer	5SB to 5C	1SB to 1C	3SB to 3C
Heel angle at equilibrium smaller than 25o	7.02	11.64	14.48
Heel angle range from equilibrium to righting arm 0 or flooding angle larger than 20o	79.62	74.81	71.52
Area under the righting arm curve from equilibrium to righting arm 0 or flooding angle larger than 0.0175 rad x m	large	large	1.493
Maximum righting arm larger than 0.100m	2.567	2.148	1.821

As we can see, P47 comply with all criterions, even when 3 cargo tanks shift the oil to the adjacent tank. Not only is the lightweight/VCG couple favourable to the vessel response to a heeling moment, but the tankage itself too, since small tanks represent the majority of the side tanks. The P47 tanks arrangement is shown in figure no.4.

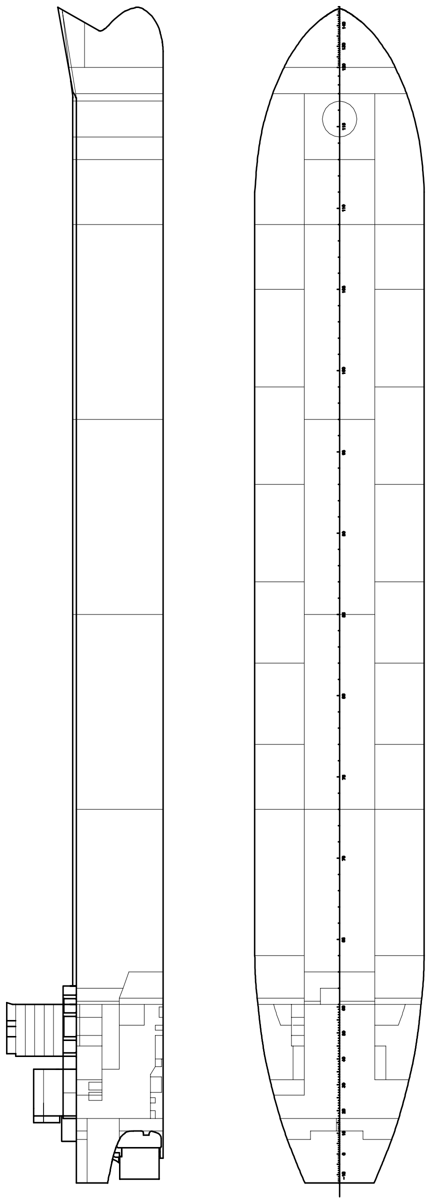

Figure 4 P47 tanks arrangement

4.2 Case Study no.2: P43 & P48

The FPSOs P43 and P48 are the result of the conversion of the sister ships “Stena Continent” and “Stena Concordia” respectively. The FPSOs have the following main characteristics:

Length Over All:	337.06 m
Length Between Perpendiculars:	320.00 m
Moulded Breadth:	54.50 m
Moulded Depth:	27.00 m
Minimum Draft	8.00 m
Maximum Draft	21.00 m
Process Plant Capacity	150,000 bbl
Deadweight (approx.)	248,000 t
Lightweight (approx.)	70,000 t

Figure no.5 shows the tank arrangement of these FPSOs.

As the arrangement shows, these vessels have very large tanks, resulting in large heel angles when calculating damage stability.

These FPSOs wouldn’t comply with ICLL damage stability criteria and wouldn’t comply with MARPOL criteria when in deep drafts and low fillings on lateral tanks. Therefore, they have a limitation on their operation: lateral tanks no. 2P/S, 3P/S and 4 P/S can’t be with less than 35% filling when operating in a draft deeper than 19.333m. This draft corresponds to “type B” freeboard on ICLL rules and therefore there is no need to comply with this criterion. This limitation also avoids a large volume of water to flow in the tank, since the run-off consideration will change the oil in the tank for the flooding water when applying the MARPOL criterion. As a consequence, the damage heeling moment will also depend on the amount of cargo in the tank.

However, there is no limitation on side by side tanks filling, what may result in severe responses if a cargo oil shifting accidentally occurs.

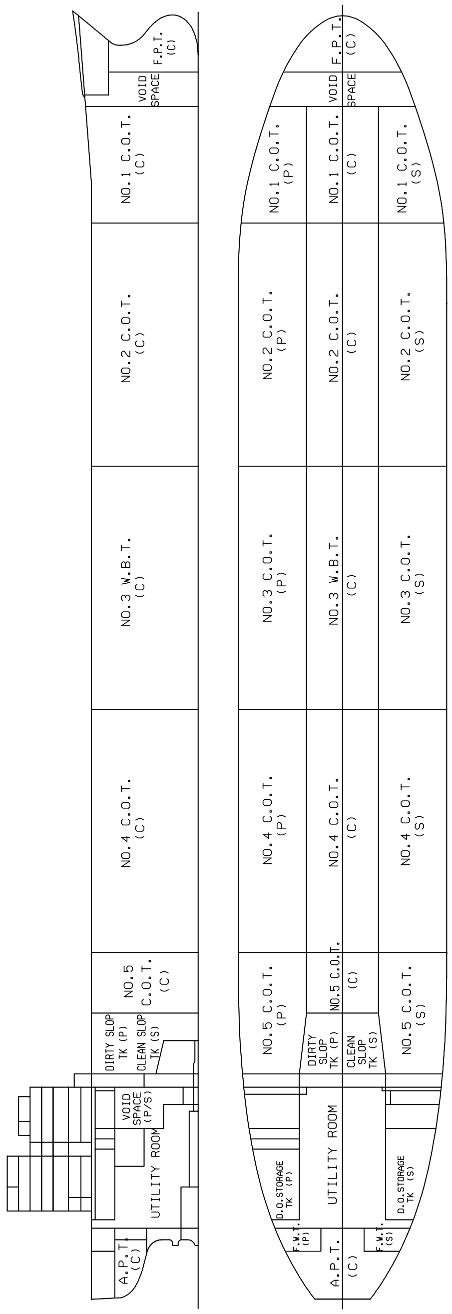

Figure 5 P43 / P48 Tanks Arrangement

The following table shows the heeling results for different potential cargo oil shifting:

Limit \ Oil Transfer	2SB to 2C	4SB to 4C
Heel angle at equilibrium smaller than 25o	14.00	Capsize
Heel angle range from equilibrium to righting arm 0 or flooding angle larger than 20o	24.61	-
Area under the righting arm curve from equilibrium to righting arm 0 or flooding angle larger than 0.0175 rad x m	0.348	-
Maximum righting arm larger than 0.100m	1.124	-

The simulations results show that the accidental cargo oil shifting on these vessels can be as dangerous as an external damage. Capsize can occur for only two tanks oil shifting.

4.3 Case Study no.3: P50 & P54

The FPSOs P50 and P54 are the results of the conversions of the sister ships “Felipe Camarão” and “Barão de Mauá” respectively. Figure no.6 shows the tank arrangement of these FPSOs.

The vessels have the following main characteristics:

Length Over all:	337.00 m
Length Between Perpendiculars:	320.00 m
Moulded Breadth:	54.50 m
Moulded Depth:	27.80 m
Minimum Draft	7.00 m
Maximum Draft	21.00 m
Process Plant Capacity	180,000 bbl
Deadweight (approx.)	245,000t
Lightweight (approx.)	73,000t

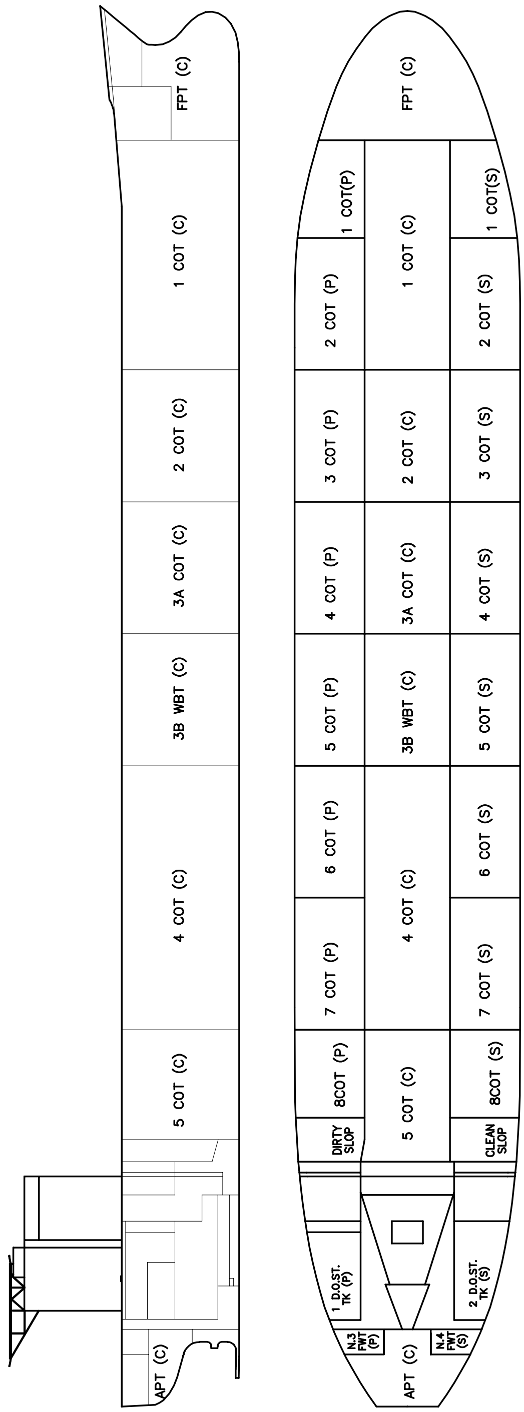

Figure 6 P50 / P54 Tanks Arrangement

It can be noted that the tankage of the vessels are similar to P43 and P48 ones, but the lateral tanks have half the size, what gives these units a much less severe response, when comparing to P43 and P48 figures.

The initial loading condition is similar to the one assumed for P47, P43 and P48 analysis, with center tanks empty and side tanks full. Again, the simulation considers the shifting from starboard tanks to center tanks, one after another. The table below shows the vessels results for cargo oil shifting, similar to the ones simulated for P43 and P48.

Limit \ Oil Transfer	2SB to 2C	4SB to 3AC	5SB to 3BC
Heel angle at equilibrium smaller than 25o	8.95	16.28	Capsize
Heel angle range from equilibrium to righting arm 0 or flooding angle larger than 20o	25.96	18.63	-
Area under the righting arm curve from equilibrium to righting arm 0 or flooding angle larger than 0.0175 rad x m	0.411	0.135	-
Maximum righting arm larger than 0.100m	1.223	0.558	-

As expected, the heeling moment generated from the oil shifting is proportional to the volume of the tank. A smaller tank can be the solution for oil shifting from one tank to another shifting or even two at a time, but will not present any advantage if valves from 3 or more tanks in a line fail simultaneously. However, it shall be noted that P50 and P54 cargo lines are located above the main deck and therefore, are not subjected to cargo oil shifting by gravity. Nevertheless, we would have the same problem if an error on operation, followed by a problem on the cargo system occurs.

5. CARGO OIL DISTRIBUTION

The most simple and effective way to minimize the risk on large heel angles due to cargo oil shifting on FPSOs already operating, is to control the oil distribution on board. In general, large differences in filing of tanks positioned side by side shall be avoided. However, this will lead to loading conditions with a large amount of tanks partially filled and therefore lots of free surface, what is not desirable.

The normal loading operation starts the tanks filling by the side tanks and then center tanks. This is done this way for some reasons. One of them is to guarantee that, in case of an external damage, the heeling moment generated is minimized, since the flooding water will find a space already occupied by the oil.

6. CARGO PIPE LINES POSITIONED ABOVE THE MAIN DECK

Another way to eliminate the risk of oil shifting from the valves system fault is to position the cargo line above the main deck, since in this configuration, no transfer by gravity between tanks would be possible. However, this solution is only feasible in the design phase.

7. CONVERTED FPSO STABILITY LIMITS

The results show that these vessels have a critical behaviour regarding damage stability and potential oil shifting. The main reason for these results is the large weight increase of the process plant built over the main deck. If we consider an average lightweight of 40,000t for the VLCCs that originated the vessels and a mean dismantling weight of 5,000t, the weight built on board represents about 50% or more of the final lightweight. As the major part of this built in weight is positioned significantly above the main deck, the resultant vertical moment is much higher than the ones in the original VLCCs design. This, strongly impacts not only the damage stability results, but the intact stability as well. The graphic presented in Fig. 7 shows a typical intact stability curve for P50 on maximum draft, with the criteria verification according to IMO 749 General Intact Stability Criteria for All Ships.

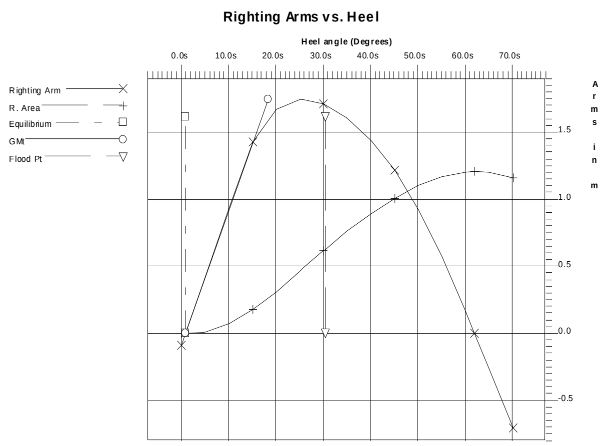

Figure 7 P50 intact stability righting arms curve

As we can see, the FPSO is in the limit for the angle in which the maximum righting arm angle occurs (25^{o}). This kind of result can be seen in P43, P48 and P54 as well. It is important to note that this limiting criterion does not depend on any flooding point position, being it only function of the physical properties of the floating body.

8. CONCLUSIONS

The process plant capacity and the consequent weight increase have leaded the origin VLCCs to their stability limit, bringing problems that the original design vessels didn’t have.

The results presented here show that the accidental cargo oil shifting can be as critical as an external damage, although, no reference to the problem is made in any of the applicable criteria in a FPSO design.

Applicable rules to FPSOs stability analysis should consider the possibility of cargo oil shifting occurrence, since they represent a real risk to the vessel operation. Stability criteria could be the same applied to external damage cases.

Finally, it is important to note that this paper is far from ending the subject discussion. Detailed studies on cargo lines systems and the associated risk analysis shall be carried out to establish the real possibilities on failure occurring. Furthermore, prevention solutions on design and operation, besides possible counter measures shall be analysed to guarantee that the risk on this kind of problem is minimized and a safer operation to all involved is obtained.

9. REFERENCES

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