Experience and Risk assessment of FPSOs in use on the Norwegian Continental Shelf
Descriptions of Events

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ABSTRACT

With this paper we will summarize the operational experience of FPSOs in Norwegian waters as seen from the regulatory point of view. Reported incidents, challenges and lessons learnt in the years after the first production vessel came on stream will be described, and utilized in an assessment of risk. At the end of 2000, five production vessels are in operation on the Norwegian Continental Shelf. Norne FPSO has been on location in the Haltenbanken region since 1997. Petrojarl Varg has been on location in the North Sea since 1998. Åsgard A has been on location in the Haltenbanken region since 1998. Balder FPU and Jotun A has been on location in the North Sea since 1999. In addition, there are three floating storage units; Polysaga, Njord B and Åsgard C. Totally these vessels represent more than nineteen years of offshore experience.

KEY WORDS

Floating production, operational experience, green sea incidents, inspection findings, collisions, heading control, corrosion, turret

INTRODUCTION

A production vessel was first introduced on the Norwegian Continental Shelf (NCS) in 1986. Petrojarl 1 was applied to do production testing in the period September 1986 to June 1988 at the Oseberg field, and December 1989 to October 1991 at the Troll and Balder fields. However, a permanently installed FPSO was first introduced in 1997.

The FPSOs on the NCS are all turret moored. Accordingly, are all weather-vaning, which means that the turret is located in the forward half of the vessel, and waves and wind will normally keep the FPSO with its bow towards the weather. Aiding the vessel to maintain a steady controlled course, the FPSOs are equipped with thruster assistance systems. Three of the FPSOs are located in the North Sea in water depths from 85 to125 metres, the other two are located in the Norwegian Sea in water depths of 300 metres and 380 metres.

According to the regulations for petroleum activity incidents related to permanently installed installations shall be reported to the Norwegian Petroleum Directorate (NPD). The operators are also required to submit an annual condition report concerning loadbearing structures summarizing operational experience and inspection findings. We compile the information for use in statistics and analysing trends. For this purpose the CODAM database is applied. The database contains information such as incidents, inspection findings, specific installation- and pipeline data etc and has recorded data from the mid 1970s. Initially the database was designed for jacket structures and pipelines. Later adjustments have made it suitable for all types of installations. Incidents and inspection findings are classified into one of three severity levels; Insignificant, Minor or Major.
CODAM is an in-house database maintained by NPD, but the recorded information is available for public use upon request. Sharing information and experience is in our view regarded as essential in the learning process and hopefully this paper will contribute to that.

Although FPSOs have a relatively limited record on the NCS, compared to jackets, jack-ups, gravity based structures or semi submersibles, NPD has received information regarding collisions, green water incidents, mooring line failures, pitting corrosion in cargo tanks, cracking of rails in turret area and loss of heading control.

COLLISIONS

Since the introduction of permanently installed production vessels, three impacts are reported. Two impacts occurred while the vessels were in operation and caused damage to the FPSOs. The third impact occurred during mooring line hook-up, but made no significant damage.

While off-loading fluid from supply vessel to Petrojarl Varg (former Varg B), in weather conditions with strong wind and current, the supply vessel made contact just aft of the turret area on the port side. A contributor to the incident was insufficient length of the loading hose, resulting in a short distance between supply vessel and FPSO for performing loading operation under the existing weather conditions. The hull was dented at two locations, elevation 12.2 and 14.6 m above keel, causing a total dent area of 4 m^2. Welds and base material were non-destructively examined, but no cracks were detected (Saga Petroleum, 1998).

Jotun A during mooring line hook-up. The anchor-handling vessel was operating close to the FPSO when the thruster lost power and the vessel drifted towards the FPSO. Damage were limited to minor scratch marks only.

When switching the Dynamic Position (DP) system from weather vane to auto position mode, in order to reposition the shuttle tanker Knock Sallie after a loading operation, the thrusters gave maximum thrust, and consequently the tanker touched Norne FPSO. The impact zone was aft on the port side. Members and bracings of the flare structure were damaged, a 1.8 m long crack between aft stern and tank deck was created and the cargo vent boom was hit at the connection between foundation and boom (Statoil, 2000a). The weather condition was moderate, significant wave height 2.9 m and wind velocity 15 m/s, at the time of the incident. The following investigation concluded that the likely cause to the signal of maximum thrust was a combination of mal function in the DP system, mal operation of it and slow response (Statoil, 2000b). The damage to the aft, flare and cargo vent boom have been repaired.

It's worth noting that we have not received reports of collisions between FSUs and vessels. However, the operational lifetime of these is accounted for, as the loading operation is similar to that of a FPSO.

Collision statistics on the Norwegian Continental Shelf

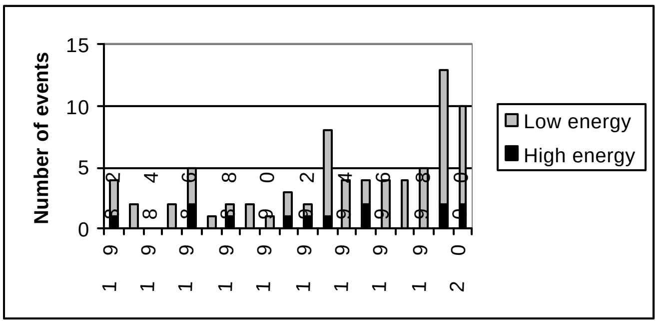
Collisions on the NCS in the period 1982 – 2000 are shown in figure 1.

A collision is classified as "high energy" when involving the following:

a) Vessels above 5.000 tonnes
b) Vessels having a "high" speed when colliding with a small vessel (one event recorded)
c) Collisions with unauthorized vessels (two events recorded)

The "high energy" collisions seem to be fairly evenly distributed over time, but the number of collisions peak in 1993 and 1999 - 2000. The reason for this might be that NPD in these years made special efforts to collect data and thus highlighted the collision risk to the operators. There seems also to be an increase of events over time, but this might be caused by the improved reporting routines. An average number of ten collisions each year is not unrealistic for the 1990s. Most of them have a small potential to cause significant damage.

Figure 1: The number of collisions on the NCS 1982 - 2000 as reported to NPD. The collisions are classified as low- or high energy as described in the text.

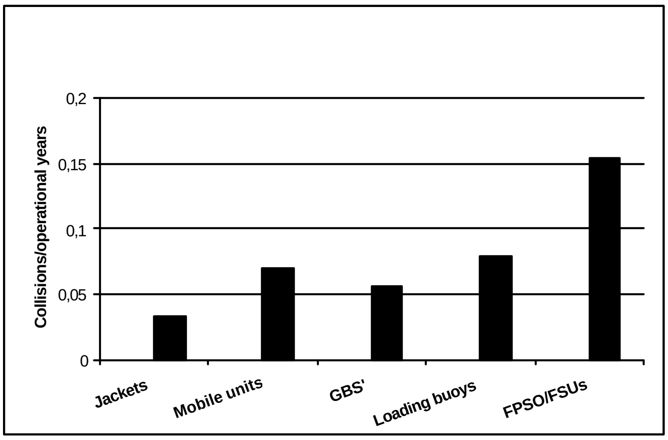


The number of reported collisions on the NCS is lower than for the UK sector. The NCS is not among the waters with most ship traffic in the world. Calculations of collision frequencies from unauthorized vessels calculations and experience (Tilly, 1998).

In figure 1, most events are connected to vessels operating close to an installation. All but one of the "high energy" collisions with authorized vessels is connected to errors and mal operation of the DP system. One "high energy" collision occurred when the vessel lost power to thrusters.

Historically NPD have recorded five incidents which directly can be linked to cargo offloading operations. Four of the incidents were between loading platforms and tankers. Figure 2 shows the estimated collision frequencies based on the reported number of collisions and operational years for the specific installation type.

Figure 2: Collision frequencies on the NCS 1982 – 2000.



The average collision frequency for jackets, mobile units, GBS' and loading buoys are in the order of 0.059, while the overall collision frequency for FPSO/FSUs are more than 2 $^{1}/_{2}$ times higher. If we compare collision frequencies involving offloading cargo from either a loading buoy or FPSO/FSU, our data seems to come out almost equal with 0.078 and 0.051, respectively. The collision frequencies for mobile units and loading buoys are 0.149, combined, and in line with the overall frequency estimated for FPSO/FSUs of 0.154. From this it may be concluded that the collision probability for FPSO/FSUs, loading buoys and mobile units are almost equal. When performing cargo offloading from FPSO/FSUs, the consequences of a possible impact is regarded as higher than for other installations due to the size of the visiting vessels. Our data also show that DP system errors (mal function/operation) account for the major part of all impacts for all kinds of visiting vessels. We have also received one report of drift off and one of drive off while positioning tankers for a loading operation. An increasing use of shuttle tankers operating close to the installations will therefore contribute to a higher risk.

GREEN WATER INCIDENTS

Green water events have caused local damage on Norwegian production vessels. The damage has occurred in the bow area, amidships and aft. Significant modifications have been made, such as raised forecastle and installation of wave-breaking walls. Operational restrictions have also been introduced, including restriction to personnel access and storage limitations. The incidents and mitigations are described in detail in (Ersdal et al, 2000a), (Ersdal, 2000b) and (Ersdal et al, 2000c). A brief overview is given here.

Green water incidents
The vessel has experienced a couple of green water events. Minor damage to fire equipment storage and a crane were registered.

Green water mitigation
The operator concluded that a storage limitation (maximum 71% storage) and a static trim were necessary during the winter season. The FPSO has an all year restriction for personnel both on tank deck and in the process area when the significant wave height exceeds 6 m. Wave-breaking walls between tank- and process deck have been installed on starboard and port side.

The limitation in storage capacity and static trim were effective from the winter 1998 – 99. During this period no green water events were observed. The restrictions to storage lead to loss of production and additional costs, as the off-loading could not be performed in an optimum manner.

Åsgard A

Åsgard A and Norne FPSO is in general similar, but the bow of Åsgard A was raised by 4.7 m late in the project to account for green water.

Green water incidents
13 and 14 February 1999 wave damage was observed. The events occurred in a situation when the vessel was high in the sea.

Damage to the following equipment were registered; glass fibre boxes for fire equipment storage, steel cabinets, piping to fire hydrant, rails and cable trays. The incident occurred amidships at tank deck.

Åsgard A also experienced green water 30 November 1999. This incident led to stop of production. No damage was reported.

Green water mitigation
Wave-breaking walls have been installed, both on starboard and port side at tank deck in order to reduce risk of damage to equipment.

Petrojarl Varg

Green water incidents
Former Saga Petroleum reported wave damage to Petrojarl Varg during a period of harsh weather 5 and 6 February 1999. The wave caused the loss of a life buoy, a fire equipment storage locker torn from its fastening and minor damage to cable trays. All these items were located amidships. Due to the weather forecast, all personnel were removed from lower deck. “Sea spray” was observed in this situation.

30 November 1999 Petrojarl Varg also experienced green water. Damage to gas sensors, fire hose cabinets, and doors on deluge stations for the chemical injection module was reported.

26 December 1999 Petrojarl Varg again experienced green water. At this event damage to cable trays, fire stations, lifebuoys and deluge cabinets were also reported.

So far, the most critical green water event in the Norwegian sector occurred at the Varg field 29 January 2000. A wave caused damage to the forward part, amidships and aft ship of Petrojarl Varg. The incident occurred when the ship was almost fully loaded with a static trim of little less than 1 degree. The damage was severe all over the vessel, but most critical was water ingress into the living quarter. Several types of

deformed.

Green water mitigation
During the spring of 1999 local protection was fitted for critical equipment. The living quarter and helicopter deck support was strengthened. In addition, some operational measures have been taken related to draft, trim and personnel access to green water zones in the future.

Jotun A

Green water incidents
No green water incidents have occurred on the Jotun A vessel.

Green water mitigation
According to model test results and calculations, waves can reach above the bow and enter onto the tank deck amidships. Structures and equipment have been evaluated for potential damage from green water. This includes fire deluge skids, hydrants, emergency generator container, cable trays, pipe support and HVAC. Preventive actions have been taken by fabricating protection screens in front of critical equipment such as fire deluge skids, hydrants and emergency generator container. Cable trays around the turret have been strengthened. Equipment regarded as standard tanker equipment is not protected as it is “proven by history to be ok”.

Balder FPU

Green water incidents
Balder FPU experienced water on deck 25 December 1999. Minor damage to insulation on the port side of the main deck was reported. In addition, the vessel experienced water on forecastle deck and water through freeing ports in green water protection screen on main deck 29 January 2000. The water on forecastle deck caused damage to an escape ladder from the forward part of the helicopter deck. The grating on the intermediate platform was torn off and a holding bracket on the light fixtures was broken. Furthermore, a windshield wiper on a control room window was bent.

Green water mitigation
According to model testing and calculations, waves can reach above the bow and onto the tank deck amidships. Structures and equipment have been evaluated for potential damage from green water. Preventive actions have been taken by strengthening of eight helicopter deck support columns, adding a 4.25 m high protection wall along side edge of the vessel to prevent green water impacting the facilities. The wall extends along the full length of the exposed main deck. Restriction for personnel access to some areas will also be made.

Classification of green water incidents

A classification of the green water incidents with regards to consequence is summarized in table 2. The incidents mentioned earlier in this paper is classed according to NPDs knowledge of the individual incidents.

Table 2: Green water incidents with Norwegian FPSOs. The number of incidents in the respective consequence class is indicated.

	High consequences	Moderate consequences	Low consequences
Balder FPU			2
Jotun A			
Petrojarl Varg	1	2	1
Norne FPSO			1
Åsgard A		2	

personnel were directly exposed to the green water, but not injured. Two incidents on Petrojarl Varg and Åsgard A respectively, have lead to production shut down or damage to safety equipment, hence they are classified as moderate consequence. There are also reports of low consequence green water incidents, but the numbers shown here are regarded as underestimated due to the lack of reporting and registering. With 10.3 operational years (FPSOs only), the frequency of green water events is relatively high. Without taking proper precautions green water will give a notable contribution to the total risk.
The risk of green water incidents is relevant and an important input in risk analysis for FPSOs.

MOORING LINES

During production testing at the Troll field in a water depth of 330 metres, Petrojarl 1 experienced failure of three mooring lines over a short period of time (Norsk Hydro, 1990). The FPSO had 8 lines of the type "K4-rig". Production started 10 January 1990, and the lines failed 13 and 16 February and 6 March that year. The mooring lines failed close to the fairleads in significant wave heights ranging from 3 to 8 m.

The conclusion stated that the first two failures were due to incorrect heat treatment sequence. However, no direct link was found between the inadequacies of the heat treatment and the line failures. The mooring lines were not moved at the time of the failures, and an obvious cause could not be established.

A fatigue crack was found on a link in the third failing line. The crack had started at a wear mark initiated by the fairlead, and had developed due to bending stresses. New calculations pointed at the relationship between the natural frequency of the mooring lines and the ship movements. Large variation in dynamic load in the mooring lines may have been the result. The initial mark on the link was probably caused by a steep angle between the chain and the vertical due to the deep water. This left little contact area between chain and fairlead for moving the fairlead in the correct direction according to the movements of the FPSO.

The following actions were taken:

a) A part of the chain segment was replaced by wire.
b) The vertical angle was improved by adjusting the line tension.
c) The chain was frequently moved in the fairlead area, avoiding the same links to be engaged continuously.

No further failures occurred at Troll. However, Petrojarl 1 later experienced line failures in other waters.

Mooring line failure statistics on the Norwegian Continental Shelf

Presented in table 1 is the number of mooring line failures reported in the period 1999 – 2000.

Table 1: Reported failures to anchor systems on the NCS 1990 – 2000.

Incident \ Activity	Exploration	Production
Loss of one line	5	3
Loss of two or three lines	2	-

In the period the number of semi submersibles units e.g. drilling and accommodation, have been approximately 20 at any time. With each unit having typical eight anchor lines, the anchor line years summarize on each production semi submersible and -vessel, the anchor line years summarize to approximately 1000 years.

For drilling and accommodation units the frequency for loss of at least one anchor line is nearly $4.4*10^{-3}$ (7/1600) and loss of two or more lines nearly $1.3*10^{-3}$ (2/1600). From our data the frequency of one anchor line failure for production units is $3*10^{-3}$ (3/1000). The figure is uncertain and based on events with one FPSO during a limited period of time only. To date, a situation resulting in failure of all anchor lines have not occurred on the NCS, but based on the data above a conservative estimate for such an event will be approximately $1*10^{-3}$. The failure frequency of anchor lines during production activities is lower than for exploration, but not so unlikely than it can be disregarded.

CARGO- AND BALLAST TANKS

Cracking of welds between cargo- and ballast tanks have been experienced on Norne FPSO, and was first detected in March 1999. 6 of 10 cracks are through thickness and have caused oil seepage from the cargo tanks into ballast tanks (Statoil, 1999). Figure 3 (in the appendix) is an example of where a crack has occurred. The figure shows the transverse frame; see the intersection between the transverse frame and the knuckle line and longitudinal stiffener. The cause of these cracks is not properly settled yet. It is worth mentioning that all the cracks have been repaired continuously.

Pitting corrosion in 8 of 12 inspected cargo tanks, with a maximum depth of 60% of the plate thickness is measured. The pitting was first observed summer 1999. Small quantities of mud and produced water, containing sulphur-ions, have penetrated into crevices or underneath sludge deposits. In this environment sulphur reduction bacterias have the necessary conditions enabling sulphide and H_2S to cause pitting corrosion (Statoil, 1999). To avoid further corrosion the coating in all, but three, cargo tanks were blasted, and detected corrosion was ground and sealed.

With the compartmentation of FPSOs, a limited number of cracks and corrosion will only give a minor contribution to the possibility of a significant accident. The operator has established a condition monitoring program in order to detect and repair findings at an early stage.

TURRET

On Petrojarl Varg and Balder FPU, inspections have detected surface breaking cracks on rails in the turret area. The vessels have a similar rails system. For Petrojarl Varg a condition monitoring program has been initiated and replacement of rail segments considered (DnV, 1999 and Norsk Hydro, 2000). Since the operator was advised of cracking rails on Petrojarl Varg mitigation measures could be initiated e.g. replacing some cracking rails prior to mooring Balder FPU. (Esso, 1999a)

As mentioned previously, FPSOs on the NCS are all weather-vaning. The turret acts as a fixed point which the vessel rotates around. Incidents which may obstruct the rotation are considered as serious due to the risk of encounter unfavourable weather condition if the FPSO should be locked in one direction.

There have been two situations, both with Balder FPU, where problems with heading control occurred. The first situation was when the wind direction suddenly changed 180°, and the FPSO was not able to turn accordingly (Esso, 1999b). This resulted in the aft heading towards the wind. At the time of the incident the wind velocity was approximately 25 m/s and significant wave height 6 – 7 m. Turning the FPSO was not straightforward. Several factors had to be taken into consideration, e.g. would it be possible to keep the speed of rotation low enough to enable the turret to follow the rotation to avoid twisting of mooring lines, would the thruster power be sufficient to turn the FPSO 180° under the existing weather conditions, and would the maximum tension in the mooring lines exceed the allowed tension when the vessel turned its broadside towards the wind. An option, which was considered for a while, was to turn the FPSO with assistance of a standby vessel. Because of the weather conditions it was rejected. After a few hours the weather had calmed somewhat, and the FPSO was turned with normal operation of thrusters and turret.

The other situation occurred when one of the two gyros failed resulting in signals to starboard thruster to give maximum effect. The FPSO changed heading, but due to swift reaction, a situation that may have lead to uncontrolled turning of the FPSO and consequently twisting or tension exceeding allowed tension of mooring lines, was avoided. Twisting of mooring lines was limited to less than 10 degrees, but in less favourable weather conditions they could have been damaged. Immediately after the incident the failing gyro was replaced and installation of a third gyro is being evaluated (ExxonMobil, 2000).

Employment of maritime personnel has for some FPSOs been regarded as not necessary and has been compensated for by giving control room operators and maritime advisors additional maritime competence in accordance with the requirements in the Norwegian Maritime Directorate's regulations of 1996 concerning certificates of competency and qualification requirements for the manning of mobile offshore units. In our opinion personnel handling ballasting, stability etc. should have maritime competence in accordance to requirements for corresponding personnel onboard mobile offshore units. The draft of the new NPD operational regulation has more precise requirements to such functions.

ASSESSMENT OF RISK

A production vessel being at a fixed location will have a higher risk for environmental damage from wave loading than merchant tankers. The loading pattern is more or less constant over time as the ship heads towards the weather. Also failures in station keeping, heading control and frequent use of the ballast system is adding to a higher expected failure frequency for production vessels compared to merchant tankers (Kvitrud et al, 2001).

CONCLUSIONS

1. Based on the limited number of incidents and operational years, the estimated collision frequency for cargo offloading operations from FPSO/FSUs is in line with the estimated collision frequency of loading buoys. The overall FPSO/FSU collision frequency is comparable with mobile units and loading buoys. The coming years will show if the trend continues or changes.

damage to safety equipment are classified as "high consequence" events. The frequency of green water events is relatively high. Without taking proper precautions green water will give a notable contribution to the total risk.

3. The failure frequency of mooring lines is lower than for explorations activities, but is not so unlikely that it can be disregarded.

4. Cracking of welds between cargo- and ballast tanks and on rails in turret area have caused operational challenges and resulted in replacement of rails, additional maintenance etc. early in the FPSOs lifetime.

5. Loss of heading control is regarded as an area of concern due to the possibility of undesired twisting and tension of mooring lines exceeding allowable limits.

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APPENDIXES

Table 3: Collision frequencies on the NCS 1982 – 2000. Note: Mobile units include jack-ups.

	# of collisions	Operational years	Collision frequency
Jackets	30	929	.032
Mobile units	25	354	.071
GBS'	10	181	.055
Loading bouys	4	51	.078
FPSO/FSUs	3	19,5	.154

Figure 3: Example of cargo- and ballast tank where crack has occurred.