Proceedings of OMAE 2013
32th International Conference on Ocean, Offshore and Arctic Engineering
June 9-14, 2013, Nantes, France

OMAE2013-49897

MODIFICATIONS OF THE PSA REGULATIONS BASED ON CASE STUDIES OF STABILITY ACCIDENTS

Arne Kvitrud
Petroleum Safety Authority Norway (PSA)
Professor Olav Hanssens vei 10
NO-4003 Stavanger, Norway

ABSTRACT

The paper describes available information about eight accidents worldwide related to the stability of petroleum units since 2000. A further seven stability incidents in Norway during the same period are also described. These accidents and incidents are used as cases for an evaluation of the existing Norwegian regulations on the stability of floating offshore petroleum units.

The accidents and incidents are grouped in categories based on the causes, and examples are given for each group.

The paper describes which Norwegian requirements could have prevented the accidents if they are complied with. Most of the accidents have involved deviations from the Norwegian regulations. Compliance with Norwegian regulations and (high-level) standards would cover most of the accident scenarios. However, some changes in the regulations have been found necessary. The paper describes these amendments, and the reasoning behind them.

INTRODUCTION

After the Deepwater Horizon accident in 2011, the PSA conducted a multidiscipline review of its regulations and guidance on offshore petroleum units. An evaluation was also carried out on stability and ballasting. We looked more broadly than Deepwater Horizon alone, and also collected available information about other accidents worldwide. Access to information about accidents abroad, and especially to investigation reports, was not easy. The information is frequently treated by companies, flag states and continental shelf authorities as proprietary. However, several US government organisations and Petrobras have provided details about their accidents. All credit to them. My descriptions are from numerous sources, including newspapers, and the accuracy is not readily verifiable. This paper is based on chapter 8 in our evaluation of the Deepwater Horizon accident (Askedal et al, 2011).

ACCIDENTS WORLDWIDE, 2000-2012

Where damaged condition is concerned, the Norwegian regulations largely require a demonstration that the unit is safe at a list of up to 17 degrees. We have therefore reviewed accidents where the unit concerned either sank or listed beyond 17 degrees.

Semi-submersible are more vulnerable to stability errors than monohull units. This is because they have a substantially lower water-line area. According to Tinmannsvik et al (2011, page 98), an increase in mass of two per cent typically gives a one-metre increase in draft. The corresponding increase in draft for an FPSO is 20-30cm – ie, lower by a factor of three-five. This requires continuous precise control of load distribution and centre of gravity, and ballast adjustments. A significant need also exists for a high level of expertise and good skills, particularly in accidents.

The sinking of Deepwater Horizon is one of a number of stability-related accidents with semi-submersible. The most serious accidents since Norway's Alexander L Kielland disaster in 1980 (for details see Næsheim et al, 1981) with which I am familiar are Henrik Ibsen in Norway (20-degree list in 1980 – for details see Woad), Ocean Ranger in Canada (sank 1982 – for details see US Coast Guard, 1983 and the Royal Commission, 1984), Sedco J (sank 1989 – for details see Woad), Ocean Developer (sank 1995 – for details see Cowi, 2003 and Woad), Petrobras 36 (sank 2001), Thunder Horse (21-degree list in 2005), Aban Pearl (sank 2010), Deepwater Horizon (sank 2010) and Jupiter 1 (sank 2011). The most recent of these accidents are described in more detail below. In addition, a large number of incidents related to stability have occurred. Where the Norwegian continental shelf (NCS) is concerned, we refer briefly to minor incidents in the PSA's annual reports on the level of risk in the Norwegian petroleum industry (as in PSA, 2011).

Jackups are vulnerable during towing operations because of their large hull, which provides a considerable exposed area thanks to a shape which is not well fitted for sea transport, and their long legs. Norway's biggest accident was the sinking of West Gamma in 1990 (Kvitrud, 2011a). Since 2000, several accidents related to stability have been reported by Jack et al (2007, page 17). They included six cases with structural damage and a jackup which sprang a leak while being towed. None of the reported cases seem to have had a list above 17 degrees (based on additional information in Woad). However, a capsize occurred in Belize in 2007, killing one person. The jackup was being transported on a barge (7Newsbelize, 2007). It is possible that one of the jackup legs hit the seabed, causing the barge to tip over (News5, 2007). Since this was primarily a barge accident, it is not covered further here.

Other units suffering floating stability accidents are an FPSO (Petrobras P-34) and a TLP (Typhoon). The number of FPSO and TLP units worldwide is small, and it is not fair to base an accident frequency on such limited figures. But the frequencies experienced are high.

As the denominator in the probability calculation, we used the number of unit years in 2000-2011 for each type of facility. We do not have access to exact data, and must therefore estimate the level of activity.

For the number of accidents per active unit year, an average figure for active units in use was accordingly required. Based on the overview by Triepke (2009) for June 2005-December 2009, we estimated the average to be 350 active jackups per year. If they spend roughly 10 weeks on average at each location, and three days being transported, about 15 jackups are in a floating phase at any given time.

Where semis are concerned, we have not found exact figures for active units covering the whole 2000-2011 period. Ocean Shipping Consultants (2008) stated that the global semi fleet at the beginning of 2008 consisted of more than 170 units. This figure also included units not under contract. Rigzone (2011) put the number of semis in July 2011 at 174, and fleet utilisation during May 2008-May 2011 at 80-90 per cent. On that basis, we estimate the average number of active semis in the 2000s to be 170*0.85 = 145 per year. With an addition for production semis, the final figure might be about 200 units per year.

So an average of 250 offshore floating units since 2000 should be the correct order of magnitude.

With eight accidents in 13 years causing the unit to sink or list more than 17 degrees, the accident frequency is unpleasantly high ($8/(250*12) = 27*10^{-4}$).

An average in the order of 150 semis in the world during 1980-2011 means the observed accident frequency has been about $19*10^{-4}$ per unit-year. The damage frequency has not improved over the past decade, with five serious accidents ($5/ (150*12) = 28*10^{-4}$). These frequencies are high.

Petrobras 36 (P-36) semi – sank in 2001

Petrobras P-36 was fabricated in 1995 by Fincantieri at Genoa in Italy as a drilling unit. It was converted in Canada to a production unit in 2000 and owned by Petrobras.

Gas in one of its columns was ignited and 11 members of a fire team were killed on 15 March 2001. The explosion also destroyed a fire water pipe in the column below the water line. The pipe was connected to a sea chest valve under the unit. The fail-safe condition of the valve in such situations was to be open. Large volumes of water flooded the room. Some watertight openings to other rooms had recently been opened for ventilation prior to repairing cracks. This meant that water could flood large parts of the column, inclucuseding the thruster, pump and water injection equipment rooms, ballast tanks and an adjacent stability box (at about 1 500 m^3). In addition, the bilge pumps were out of service for repair. Later, the list also caused chain lockers to fill. The unit soon developed a 20-degree list, and later 25 degrees. Rescue operations included the use of divers and pumping gas into the hull, but were insufficient. The unit sank on 20 March 2001.

This summary is based on the Petrobras report (2002).

Petrobras P-34 FPSO – 34-degree list in 2002

The hull of Petrobras P-34 was built in 1959 as a tanker. It was converted to an FPSO in 1995 by Marítima in Brazil and owned by Petrobras.

This FPSO developed a list of about 34 degrees. The investigation concluded that this resulted from inadequate design factors relating to the supply of power to electrical panels controlling valves located at the bottom of ballast and cargo tanks, plus inadequate programming of the valve control system. These failures triggered a command which caused the valves to open and allowed liquids to flow to the port side. A maintenance error caused the main generator to crash, taking down the FPSO – including the high-level control system. The lower-level PLC (programmable logic controller) controls remained partly alive since the uninterruptible power supply (UPC) was partly up and partly down. In this situation, the lower-level PLC was confused and ordered all the valves to open. The residual energy in the hydraulic system executed this command when emergency power was established (less than 60 seconds later). Unfortunately, the order could not be reversed since the hydraulic system was not connected to the emergency generator. The incident began on 13 October 2002 and the unit was normalised on 17 October.

This summary is based primarily on the Petrobras report (2005).

Thunder Horse semi – 20-degree list in 2005

The hull was built by Daewoo in South Korea and completed at Kiewit in the USA. It was operated in the Gulf of Mexico by BP.

On 8 July 2005, personnel were evacuated because of the forthcoming Hurricane Dennis. According to the monitoring system on board, water began to flow shortly after all personnel had been evacuated. After about six hours, the unit had a list of about 16 degrees to port. On 11 July, the list reached about 20 degrees. Since the unit already had a 16-degree list before the passage of Hurricane Dennis, the waves caused by the storm may have contributed to the inflow of seawater.

The four hydraulic power units (HPUs) controlling the ballast control valves were isolated as part of the evacuation process. Shortly after the HPUs were isolated (immediately before evacuation), they received a significant number of alarms indicating a large number of unintended valve movements. Recorded data indicate that more than 80 ballast and bilge pump valves moved.

Tests were conducted on two of the four HPUs to recreate the condition they were left in before evacuation. These showed that the isolation was not efficient and that the HPUs were still able to provide sufficient hydraulic power to cause 80 bilge and ballast valves to open gradually from their original closed position.

The movement of water occurred from a number of ballast tanks into other tanks and areas in different parts of the hull. Two ballast tanks full of water immediately before evacuation were found to be empty. Each tank was about 40 feet above the keel. That gave sufficient hydrostatic pressure for the water to pass through partially opened valves. Three check valves in the pipe system were installed in the wrong position, and one check valve was found to be unusable. A number of errors also existed in cable passages through the bulkheads. Openings were made in watertight bulkheads for electric and instrument-signal cables. In essence, moulded plastic blocks sealed each cable. The leaks occurred in areas filled with empty blocks. Cabling was improperly installed.

The MMS (2010) stated that inspection of the hull both above and below the water line had not revealed any cracks or holes. In addition, inspection and testing of all penetrations in the hull below the normal water line (instrument ports, sea chests, etc) revealed no evidence of a leak.

This summary is based on the MMS report (2010).

Typhoon TLP – capsized in 2005

The Typhoon TLP in the Gulf of Mexico was operated by Chevron in 640 metres of water. It had a Seastar design.

In preparation for Hurricane Rita, the TLP was evacuated on 20 September 2005. It was found floating upside down following the passage of the hurricane. On 23 September, the emergency position indicators inside the lifeboats began to broadcast. These broadcasts indicated the approximate time of the capsize (MMS, 2007).

The MMS investigation in 2007 revealed that the most likely cause was the loss of integrity of the tension leg systems on pontoon 1 in the bottom connector system with two piles. Further metallurgical analysis of recovered material from inside the shrouds revealed evidence of ductile shear overload, plastic deformation and deformed surfaces. After losing the tendons in one corner, the unit was unstable. The failure of the mooring system on pontoon 1 caused a capsizing rotation around a central axis located between the centre-line tips of pontoons 2 and 3. This conclusion was supported by extensive damage to the flare boom and the lifeboats. These were located on the side of the unit that would impact the water first. It was also supported by major damage to the tendon porches for several tendons.

Aban Pearl semi – sank in 2010

The Aban Pearl sank on 13 May 2010 while drilling on the Dragon 6 field in Venezuela. This unit had an Aker H-3 design and was fabricated in Singapore. It was owned by Aban and operated for PDVSA.

I do not know the details of why it sank. PDVSA (insidecostarica.com, 2010) stated in an early phase that the accident could have been caused by problems related to valves and pumps or by a collision. The alarm sounded three hours before the unit sank, which gave sufficient time for evacuation. All 95 people aboard were evacuated safely. Most of the crew boarded the lifeboats and got away when the unit had an list of 10 degrees. The well was disconnected at a 15-degree list. The captain and two assistants threw themselves into the sea and were picked up when the list was about 45 degrees, indicating that the crew could have had a chance to save the unit even in this situation. Why the leak occurred is unknown. The most probable cause seems to be a significant water inflow to a machinery room in a pontoon and on into a column. This flow exceeded the capacity of the ballast pumps. The water level most probably caused blackouts in the electrical systems, listing and eventual sinking. The weather was calm.

No investigation report has been available to us, even after contact with both the flag state (Singapore) and the continental shelf authorities in Venezuela. The outline given above is based on information provided orally and in newspapers.

Aban Pearl developed a list of 15 degrees off Trinidad and Tobago in 2009 (Connelly, 2009). It began to list after its flotation devices took on water in heavy seas but had been stabilised. This incident occurred a week after it had been in dry dock.

Neither the flag state nor the shelf authority wanted to give us further details.

Deepwater Horizon semi – sank in 2010

Deepwater Horizon was delivered in 2001 by Hyundai in South Korea and owned by Transocean. It had a Reading & Bates Falcon RBS-8D design.

After a blowout on 20 April, explosions and hydrocarbon fires occurred both on Deepwater Horizon and on the sea surface. The semi sank 36 hours after the blowout started. Eleven different vessels arrived to fight the fire on Deepwater Horizon using water monitors. Fire fighting efforts were poorly coordinated until 21 April. With the large volumes of water applied to the fire, some portion of the water probably began to accumulate inside the hull and migrated within it. By the morning of 22 April, as more openings became submerged, Deepwater Horizon began taking on increasing amounts of water until it sank (US Coast Guard, 2011).

The US Coast Guard's causal analysis (2011, pages xvi-xvii) points out:

* Although the exact cause of the loss of stability on and sinking of Deepwater Horizon cannot be determined on the basis of the limited information available, possible factors include (1) damage to the mobile offshore drilling unit (Modu) from the explosions and fire, (2) accumulation of water from fire-fighting efforts in the interior of the Modu, known as "down flooding", and (3) migration of water within the Modu through watertight barriers that were damaged, poorly maintained or left open by crew at the time of evacuation.
* Some amount of water from fire-fighting efforts remained on board, increasing the weight of the vessel and reducing its stability. A Coast Guard post-casualty stability analysis revealed that the Modu's water displacement increased by too great an amount to have been caused by the shifting of loads on board prior to the explosion.
* In the absence of the volume of fire-fighting water applied to Deepwater Horizon, the structure would probably have been exposed to more extreme heat; this could have expedited a catastrophic structural failure. It is therefore not possible to conclude that water from the fire-fighting vessels accelerated its sinking.

Prior to the explosions, Deepwater Horizon was not in compliance with established requirements for maintaining the watertight integrity of its internal compartments. Faulty watertight closures could have accelerated progressive flooding.

Oil on the sea surface has been reported in the area in 2012. This might have been caused by the release of oil entrapped in the hull (Lewis, 2012).

Jupiter 1 semi – sank 2011

Jupiter 1 was designed and built as a flotel by Götaverken in Sweden in 1978. The hull consisted of six columns and 11 braces.

This unit began to take in water at 07.39 on 12 April 2011 after the failure of a mechanical valve (Pemex, 2011). Seven hundred and thirteen people were on board. The bilge pumps were insufficient to prevent flooding. Evacuation continued until completed at 13.30. An attempt to halt the water intrusion with divers failed, and the work was stopped to protect diver safety. After several attempts to rescue the unit, Jupiter sank at 14.30 in about 38 metres of water. Everyone was rescued.

No investigation report has been available to us, but Pemex (2011) provided some information. Why the valve failed is unknown. The failure of a mechanical valve alone should not be sufficient to cause the accident. From my perspective, therefore, a likely scenario is that the accident was caused by a combination of errors in the valve and in watertightness.

Kolskaya jackup – sank in 2011

Kolskaya was a jackup built in 1985, and sank during towing on 18 December 2011 in the Sea of Okhotsk off

Russia with the loss of 53 lives. The unit was designed by Gusto Engineering in the Netherlands, built in 1985 by Rauma Repola in Finland, and owned by ArcticMorNefteGazRazvedka.

The information has derived mainly from newspapers, and is highly uncertain. No investigation reports have been available.

The unit was being towed in wind speed of about 19 m/s, a wave height of four metres and an air temperature of -17°C. A representative from the insurance company was on board to ensure that the sea fastening was conducted properly and that it was ready for towing. The tow line broke in the open sea. Survivors said the waves smashed portholes in the dining room and destroyed equipment. They tried to prevent flooding by pumping ballast water, but lacked sufficient capacity. The unit experienced rapid water flooding and sank in more than 1 000 metres of water in less than an hour.

Different attempts to give explanations of the accidents are given in several newspapers as Kommersant (Barentsnova, 2011), Komsomolskaya Pravda (Barentsnova, 2011) and Dagbladet (Moe, 2011), but is highly uncertain.

According to Sharples (2011), high waves destroyed two air tanks on the unit. Water started gushing inside, pumps worked at their highest pitch to remove it. Crew accommodation portholes were smashed. Furthermore, Kolskaya had experienced technical problems even before the accident, and had been forced to pump water out of one of its air tanks owing to a leak. Ships&People (2011) adds that “Air taps of tanks No 35 and 37 were destroyed”.

The investigation by Rostransnadzor (Rostransnadzor, 2012 and Barentsnova, 2012) concluded that the accident occurred because “considerable hydrodynamic forces of wind and waves applied to the rig’s hull and superstructure” caused leak damage. Rostransnadzor did not want to give us further details.

Relevance for Norway

Norwegian companies have been involved through design, supply of equipment and certification in several of the accidents worldwide. Products delivered to the NCS are largely the same as those used in other parts of the world. In addition, some of the units (Aban Pearl, Kolskaya and Jupiter 1) have operated off Norway and in the North Sea area. In my view, most of the accidents are relevant for Norway and could also, under some circumstances, have happened on the NCS.

NORWEGIAN INCIDENTS 2000-2012

A summary of stability incidents reported to the PSA has previously been reported by Vinnem et al (2006). This paper gives some more details, but restricts the reported incidents to the period from 2000. Incidents with leaks above 100 cubic metres or more than three degrees of listing are included. Cases of minor water ingress, such as thickness cracks causing minor leaks, are not included.

West Venture semi in 2000

A fire-water pipe running through a ballast tank ruptured, filling the tank. The composite pipe broke instantly. Two fire pumps with a capacity of 500 cubic metres/hour started up and normalised the situation. The leak rate was about 350 cubic metres in 20 minutes, and the list was two-three degrees (Vinnem et al, 2006).

Åsgard B semi in 2000

A tug collided with the Åsgard B semi at the Rosenberg yard on 13 April 2000 (Aanestad, 2000). It punched a hole in a buoyancy tank, below the water line. The tank was quickly filled with 150 cubic metres of water, and gave the semi a list of 1.5 degrees.

Polar Pioneer semi in 2002

During a ballasting operation, 400 cubic metres of water flowed through a valve which the control panel indicated was closed (Transocean, 2003).

Snorre B semi in 2003

After a fire alarm had been tripped, the deluge system was activated. “No fire” was confirmed after 20 minutes. Indications of weight displacement owing to deluge water were found. Ballasting with about 200 cubic metres of water normalised the situation (Vinnem et al, 2006).

Gjøa production semi in 2010

The Gjøa semi experienced two incidents before it was due to be towed to the field.

Owing to a fault involving short circuiting in the ballast control system in the safety automation system (the SAS I/O cabinet) at the top of a column, the facility listed three degrees. This fault caused all the valves between ballast tanks in one of the quadrants to open, which in turn led to a shift in the ballast water and thereby also in the unit’s centre of gravity. Valves in the ballast water intake from the sea remained shut. The fault in the electrical supply spread to other equipment. Input boards malfunctioned and required manual resetting after the loss of power. The software controlling the input boards had the wrong parameters, and opened all the valves as a consequence of the fault in the input boards. The interlock designed to prevent multiple valves from opening simultaneously failed to once after the valves had already been opened incorrectly. The applicable ballasting procedure did not include the use of an emergency stop during a crisis (Aker Solutions, 2010, and PSA, 23 August 2010).

One week before the tow out, an error was found in the stability calculations. Physical changes had to be made in the hull compartmentation and caused a five-week delay. The intact stability with small angles of floating units is determined by the metacentric height GM – the distance between the centre of gravity (G) and the metacentre (M) – as follows: $GM = KB + I_w / V – KG$. When collision damage occurs at the water line, the water-line area is reduced. The moment of inertia of the water-line area (I_w) is reduced as a result, causing an equivalent reduction in GM. The effect of this is that listing with minimum potential energy will occur around a system of axes which rotates in relation to intact symmetry axes. This condition was not identified (PSA, 23 August 2010).

Åsgard A FPSO – leakage in 2011

Corrosion on an internal 10-inch drainage tube (in a return flow of central fresh cooling water to the main generators) 2.3 metres below the water line caused seawater to flood into a pump room at the stern of the Åsgard A FPSO on 4 October 2011 (Statoil, 2011). The room’s volume was 3 800 cubic metres. Two gauges showed less than 30 per cent water fill. An operator also discovered water in the stairwell. The bilge pumps were started, but had insufficient capacity. A ballast pump was activated, but experienced start-up problems. Starting the ballast pumps had no effect on the water level in the ballast pump room. Three gas-powered fire pumps and repair clamps were flown in from Åsgard B. After some troubleshooting, the leak was identified. The tube was immediately sealed with a wooden plug, and secured with cargo straps. The water intrusion was limited to the thruster room and the adjacent stairwell. The leak was stopped after about two hours.

Scarabeo 8 semi – list in 2012

The Scarabeo 8 semi suffered a seven-degree list on 4 September 2012 (Eni, 2012 and Dybvig et al, 2012). Around 14.40, the control room operator (COOP) noticed a movement in the unit indicating that the rig was listing in the aft direction. The COOP started to operate the ballast control system to counter the effect. A sea chest valve and a ballast valve were opened. This was done 14.49. His actions had no effect, and the list continued to develop. The COOP tried several measures to no effect. He had not understood the situation, and became more and more stressed. The stability section leader and the offshore installation manager arrived shortly afterwards, and started to work the ballast control system together. The "close all valves" function in the ballast control system was activated at 15.12. By that time, the rig had an aft list of seven degrees. The situation was then stabilised. Eni's conclusion was that the COOP in question was not fully qualified to be alone in the control room. Two valves had been opened from the sea to an aft ballast tank with a volume of 1186 cubic metres in a pontoon. If the tank had been completely filled, the unit would have developed a list of 12.3 degrees (Eni, 2012).

Floatel Superior semi – list in 2012

The night between 6 and 7 November 2012 an anchor caused eight holes, flooding of two ballast tanks and a list of approximately 5.8 degrees on Floatel Superior (Andersen et al, 2013). The direct cause of seven of the holes, were penetrating strokes of a loose anchor. The last hole occurred when a damaged part of the anchor bolster, failed due to fatigue. The bolster lost three members to the sea floor. The damage had occurred over time. After the failures, the remaining parts of the bolster did not prevent the anchor to hit directly into the hull. The anchor was hanging freely, and hit repeatedly into and damaged the hull in rough weather. The damage occurred after all eight anchors had moved with repeated blows to structural components of the bolster. Damages in different stages of development have been observed on all four bolsters. The incident was mainly caused by choices made in the design, and linked to the decision that Floatel Superior could keep position both with mooring and dynamic positioning with the anchors placed in weather rough positions in the bolsters. The design resulted in several unfortunate choices:

- The anchors could not be securely attached to bolster,
- The bolster was not designed for the actual loads,
- Doubling plates used as weak links failed due to fatigue.
- The hull was not designed to withstand direct hit of the anchors.

Testing the barriers of mobile units

We have collected test data from 2006 on watertight doors and valves in the ballast system on mobile units from their owners.

No clear correlation exists between the number of errors and the number of tests, but those with the lowest number of tests had the highest error rate (number of errors/number of tests), and also probably the largest system downtime. Some 20 000 tests on closing watertight doors were carried out in 2011, with a failure rate of about 0.75 per cent. Roughly 260 000 tests on ballast valves were carried out in the same year on Norwegian units, with a failure rate of 0.1 per cent. "Error" is defined as failure to comply with the requirements.

The number of errors in ballast valves has steadily increased in recent years (Figure 1). Variability from year to year is greater for watertight doors, but the overall failure rate has risen. We have also compared age and failure rates. Units have been divided into four age groups: 1976-1983, 1984-1990, 1991-2003 and 2004-2011. The number of units in each group is about the same. As Figure 2 shows, the youngest units have the most errors. The increase in the failure rate over the past few years mainly reflects a large number of new units with many errors.

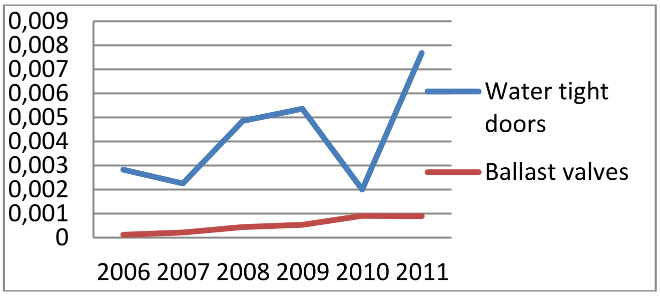

Figure 1: The number of errors on mobile units divided by the number of function tests on watertight doors and valves in ballast systems as a function of fabrication year.

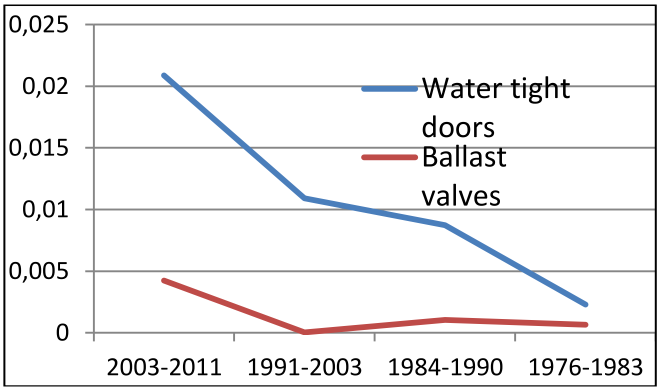

Figure 2: The number of errors divided by the number of function tests of watertight doors and vents in ballast systems as a function of fabrication year.

COMMON CAUSES

I have tried to compile the commonest causes and some possible causes and contributory factors as to why offshore floating units can sink or have stability problems. These causes formed the basis for the evaluation of our regulations on stability and ballasting. It is possible, of course, to classify these cases in accordance with other criteria. Alternatives tested included design, fabrication or equipment errors, and lack of maintenance, inspection or expertise.

1. Explosions may create openings, destroy critical safety equipment and move equipment to cause changes in weight or the centre of gravity. *An example might be Deepwater Horizon. Cases are also well known from the shipping industry.*
2. Apart from creating openings, fire can impair load-bearing structures and destroy critical safety equipment. Fire at sea may puncture the hull and destroy safety-critical equipment. *An example is Deepwater Horizon. Cases are*

also well known from the shipping industry. Norway has an average of two significant fires on offshore units per year (PSA, 2011, page 97).

3. Deluge and fire water pumped from external sources may cause water to flow into the hull through openings above the damage line, open doors or openings created by fires or explosions. The unit's own deluge system can be triggered by fires or by mistake. *An example is Deepwater Horizon. Norwegian incidents include Visund and Snorre B. Many other examples are also known from shipping, such as SS Normandie and MS Al-Salam Boccaccio 98.* Oil from blowouts can flood the hull through openings in the same way as fire water, possibly together with water. *An example might be Deepwater Horizon.*
4. Environmental loads or inadequate structural capacity. *Examples are Alexander L Kielland, West Gamma and Kolskaya.*
5. Programming errors in the ballast system computer software. Errors have been triggered by short circuits or faults in the electrical system with valves opening. An automated start of the ballast pumps can unintentionally pump water into the unit. Valves can be opened or closed unintentionally by software bugs. *An example is Petrobras P-34. Norwegian examples are Gjøa and Transocean Arctic (Vinnem, 2006).*
6. Openings in bulkheads or damaged piping may escalate situations. These could exist in a number of circumstances. They may include, for example, work in the area, venting, somebody forgetting to close an opening, cable routings through a bulkhead not properly sealed, or malfunctioning of watertight doors. Water can then spread unintentionally. *Examples of such events have occurred on Henrik Ibsen, Petrobras P-36 and Thunder Horse. A Norwegian example was Åsgard A.*
7. Valves, either internal or towards sea, can be opened, wrongly installed, malfunctioning or removed for repair or maintenance. *An example is Thunder Horse. A Norwegian example occurred on Polar Pioneer*.
8. A hydraulic power pack (HPU) can cause valves to open and water to flow through. *Examples include Thunder Horse.*
9. Improper ballasting caused by lack of expertise or training may lead to accidents. Filling tanks without venting or with venting sealed can destroy them. *Examples have occurred on Ocean Ranger, Petrobras P-36 and Ocean Developer (in 1995). A Norwegian incident occurred on Scarabeo 8.*
10. Changes in weight and the centre of gravity can occur during storms, as a result of waves hitting the deck or through movements of equipment. Moving equipment can also damage safety-critical hardware. *Examples are West Gamma (equipment on deck destroyed tank sealing) and Mars TLP (drilling derrick toppled), and possibly on Kolskaya.*
11. Collisions can puncture the hull close to or below the water line. *Norwegian examples include collisions with subsequent stability incidents on Ocean Traveler (Kvitrud, 2011) and Åsgard B. The Floatel Superior incident also demonstrated that anchors can cause significant damage.*
12. Grounding while under tow can hole the hull below the water line. *An example is the Deep Sea Driller accident in Norway in 1976 with six fatalities, and the jackup in Belize in 2007.*

DISCUSSION AND CONCLUSIONS

The basis for improvements

In Norway, industry players are responsible for the safety of their units. The regulatory philosophy is based on the legal expectation that those who conduct petroleum activities are responsible for complying with the requirements of the Acts and regulations. Furthermore, the regulations require a management system that systematically checks and ensures such compliance at all times.

Use of flag states and class certificates

The US Coast Guard (2011) stated: "The Republic of the Marshall Islands (RMI) failed to directly ensure that Deepwater Horizon was in compliance with all applicable requirements, including those relating to the electrical equipment in hazardous zones, degradations in watertight integrity, crew training, emergency preparedness, and others. RMI entrusted these duties to ABS and DNV, and did not conduct sufficient monitoring of those classification societies to detect oversight failures. This incident raises serious questions about the regulatory model under which a flag state may rely entirely on classification societies to do its inspection and investigative work".

Norway has a similar system, with most mobile units registered under a flag of convenience. The flag state delegates supervision to classification societies such as the ABS, DNV or Lloyd's Register. A few units fly the Norwegian flag. Acceptance of the flag state and class certificates as proof of compliance with the requirements is stipulated in section 3 of the framework regulations, and is a result of political decisions. We have no opportunity to change the system.

In addition to flag state certification, Norway requires all mobile units to have an acknowledgement of compliance (AoC) from the PSA as the continental shelf authority. The owners must compare the present status of the unit with the requirements of the Norwegian regulations. The PSA makes some spot checks of documentation, technical conditions and organisational factors. Furthermore, the unit's owner must check compliance with the regulations of the Norwegian Maritime Authority (NMA) concerning stability and ballasting, regardless of the flag state and classification society rules. Some NMA requirements are more stringent than those of the classification societies.

PSA regulations on stability and ballasting

Several regulations and sections of the regulations are relevant for stability and ballasting. Those I consider the most relevant are outlined briefly. Guidance has also been issued for each of the sections, with references to external documents.

Section 17 of the management regulations requires the responsible party to "carry out risk analyses that provide a balanced and most comprehensive possible picture of the risk associated with the activities …" However; this regulation does not provide any specific details on stability and ballasting. The guidance refers to the NORSOK Z-013 standard on risk and emergency preparedness analysis, which gives advice on what should also be analysed where stability and ballasting are concerned.

Sections 39 and 62 of the facilities regulations essentially require compliance with the technical requirements of

* Section 2 and sections 7 to 22 of the NMA (1991a) regulations on ballast systems on mobile units.

* Sections 8 to 51 of the NMA (1991b) regulations concerning stability, watertight subdivision and watertight/weathertight closing mechanisms on mobile units.
Section 62 of the facilities regulations requires: "Floating facilities shall be in accordance with the requirements in Sections 8 through 51 of the Norwegian Maritime Authority's Regulations relating to stability, watertight subdivision and watertight/weathertight closing mechanisms on mobile offshore facilities (in Norwegian only). There shall be weight control systems on floating facilities, which ensure that the weight, weight distribution and centre of gravity are within the design specifications. Equipment and structure sections shall be secured against displacement that can influence stability".
In addition, the guidance refers to section 7.10 of the NORSOK N-001 standard.
Section 11 of the facilities regulations states: "The loads that can affect facilities or parts of facilities shall be determined. Accidental loads and environmental loads with an annual probability greater than or equal to $1x10^{-4}$, shall not result in loss of a main safety function". This is an important requirement for structural design, but is not always easy to apply to maritime systems. DNV-OS-A101 has a similar requirement for mobile units.
Furthermore, section 21 of the present activities regulations requires that: "The responsible party shall ensure that the personnel at all times have the competence necessary to carry out the activities in accordance with the health, safety and environment legislation. In addition, the personnel shall be able to handle hazard and accident situations ...". The guidance to section 21 of the activities regulations recommends the use of NMA regulations concerning qualification requirements and certificate rights for personnel on Norwegian ships, fishing vessels and mobile offshore units. Unlike the NMA, however, the PSA regulations do not require certificates. We recommend at present that the person responsible for stability has "stability manager" expertise, which is a lower standard than the NMA requirement ("unit manager"). The important difference between these two positions (unit manger versus stability manger) in the PSA and NMA regulations lies in the requirement for operational simulator training. Furthermore, section 23 of the activities regulations requires "... training, so that staff are able at all times to handle operational interruptions and hazard and accident situations in an effective manner".

Evaluation of Norwegian regulations on intact condition

Nothing in the accidents before December 2011 indicated that the requirements of the NMA regulations on intact conditions should be changed. As far as we know, most of the accidents were not related to external actions or the capacity of the structures. The Typhoon and Kolskaya accidents might have involved this aspect, but too little information is available. Was the failure on Typhoon related to random errors in fabrication, or was it a more fundamental problem? Did waves damage tank sealing on Kolskaya, or was damage to the sealing a secondary effect of waves hitting equipment on deck? Did the main error lie in the sea fastening, was the draft during the tow too low, did icing on the legs influence what happened, or was it something else?
The NMA requirement on metacentric height (GM) is stricter than that imposed by DNV and the ABS, but the practical difference is considered small. The NMA requires GM to be one metre for a semi-submersible. The ABS requires that units have a positive GM, while DNV has no specific requirements for GM.
Wind-load requirements for the intact condition appear almost identical in the NMA, DNV and ABS rules, and specify that the area under the stability curve should be 30-40 per cent larger than the wind area.
From where I stand, the accuracy of methods for calculating the behaviour and response of undamaged floating structures is reasonable – even if model testing is necessary in many cases.

Evaluation of Norwegian regulations in damaged condition

Comparing requirements in damaged condition and how to prevent accidents is far more difficult. The requirements in the NMA regulations are fundamentally the same as those used elsewhere, but with the essential difference that they require reserve buoyancy in the deck for semis. If a large list occurs, the buoyancy of the deck will help to keep the unit afloat.
Would compliance with the current Norwegian regulations have been sufficient to prevent the accidents seen worldwide since 2000? The NMA regulations are primarily aimed at external damage to the hull arising mainly from collisions with defined damage, while most of the accidents mentioned above have other causes. But detailed requirements also cover other damage cases.
We have reviewed Norwegian regulations in the light of the common causes listed above. The comparison with common causes and the references to regulations, guidance and standards are given in Askedal et al (2011, pages 73-74).
Our main conclusion was that, at an overall level, compliance with Norwegian regulations and standards will most likely cover several of the accident scenarios. In particular, demand for reserve buoyancy for semisubmersible units in section 22 of the NMA stability regulations might have saved the day or delayed the accident development in several situations.

Proposed changes to the present rules

Based on our review, we have proposed some changes to the regulations, which will be circulated for public consultation in 2013. Reference is also made to some recent changes in NORSOK N-001. Both the ABS and DNV have their own requirements for stability. Since neither the PSA nor the NMA refers to these, we have not considered the need for changes to these standards. However, we have asked DNV and the ABS to revise their N-notation text in accordance with the proposed changes.

Section 62 of the facilities regulations should incorporate a functional requirement that "Floating units shall be secured against capsizing or sinking, so that personnel are not injured or large emissions/discharges made to the environment". The NMA regulations relate mainly to accidents resulting from collisions and accidents, as on Alexander L Kielland. Faults in maritime systems during operation have consistently been identified as causes of stability accidents, creating the need for a more general requirement. The requirements in the NMA regulations do not specifically address the stability of TLPs and spars. The new requirement will not have any immediate implications, but will give the PSA a legal basis in relation to other types of units than those covered in the NMA regulations.

Section 62 of the facilities regulations should acquire an addition at the end of the first paragraph: "other possible injury cases than specified in the NMA regulation shall also be taken into account". This should be accompanied by the following guidance: "…a complete analysis of potential accidents should be made, and the likelihood and consequences of the accidents reduced". We have proposed additional text to NORSOK for inclusion in NORSOK Z-013 to describe the accident cases that should be investigated in more detail. Inclusion of this text will depend on when the next edition of the standard is issued. In most cases, the "complete analysis" will mean a risk analysis. Most risk analyses at present pay relatively superficial attention to stability. They typically find the systems good, without challenging the design or identifying potential enhancements. Where stability is concerned, risk analyses should end up with design loads, requirements for testing and simulations against simple errors and systematic errors to ensure redundancy and system integrity, recommendations related to the use of simulator technology with the introduction of error conditions and special operational requirements for expertise. They should also propose risk reduction measures, and measure the level of risk against the acceptance criteria.

Section 62 of the facilities regulations, with reference to the NMA's stability regulations, says nothing about how snow and ice loads are to be included in the stability analysis and the calculation of load conditions. The NMA (2010) stated that this will be corrected in the next edition of its rules for mobile units. It is unreasonable for the PSA to include rules on detailed calculation in its regulations, but the new NORSOK N-001 standard (2012, section 7.10) provides detailed provisions on snow and ice measures. These require that such action must be included in checks of intact and damage stability. A reference to the new NORSOK provisions will be incorporated in the PSA guidance. The relevance of snow and ice loads was highlighted by the Kolskaya accident.

Section 62 of the facilities regulations, with reference to the NMA stability regulations, deals with the requirement that a single failure should not cause an accident. Systematic errors in design, fabrication or operation are difficult to handle in the regulations. The new NORSOK N-001 standard (2012, section 4.7) includes some additional requirements on assessing robustness. A robustness check covers an evaluation of the vulnerability of a maritime system, in addition to the ALS check for accidental loads as described in a risk analysis. It includes an evaluation of the vulnerability of the maritime system to local errors in design, fabrication and operation, to damage or to human error in installation and operation. However, this check is not intended to cover fundamental or systematic failures. The latter must be identified through a proper quality system. All maritime systems must be categorised with regard to safety criticality, redundancy and robustness. A reference to the new NORSOK N-001 standard will be included in the PSA guidance.

Section 36 of the facilities regulations requires: "On facilities where firewater is supplied from fire pumps, the pumps shall start up automatically in the event of a pressure drop in the fire main and upon confirmed fire detection ...". For floating structures, fire water can be disastrous and lead to listing and in rare cases to sinking or capsizing. The requirement may also provide excess weight capacity of permanent units. Modification of the requirements will be proposed through the addition of the following statement: "Automatic start of fire water pumps with maximum flow of fire water shall not lead to weight or stability problems".

Guidance to section 40 of the facilities regulations should acquire the following addition: "The unit should have the capacity to drain away fire water from both unit deluge and fire water delivered from ships in order to avoid unwanted weight and stability changes". Where floating structures are concerned, the Deepwater Horizon accident showed that fire water can be disastrous and lead to sinking or capsizing. Compliance with the text might be difficult, since it can be hard to evaluate the volume of water from fire-fighting vessels. That is why we have proposed the inclusion of this text in the guidance rather than the regulation.

Guidance to section 11 of the facilities regulations will be given an addition: "Units should withstand a collision energy of at least 35MJ. FPSOs and FSUs used in tandem loading should resist a collision energy of at least 60MJ against shuttle tankers". This is based on our evaluation of visiting ship collisions presented in Kvitrud (2011) and of shuttle tankers in Kvitrud et al (2012). Two collisions with shuttle tankers have occurred since 2000, and four near-collision events with such vessels have been reported. Several supply vessel collisions have also occurred, with 70MJ as the highest collision energy.

Guidance to section 21, letter g, sub-letter a, of the activities regulations should be changed to: "*The person responsible for the operation of maritime systems on fixed or mobile units should meet the qualification requirements for comparable positions in the regulations referred to in this guidance letter g Control Operators maritime operating systems, in the same manner as mobile units should meet the requirements for certification of control operators in the same regulations. The person responsible for stability on board should have a maritime competence equivalent to the unit manager in the same regulations"*. The underlined change is from "stability manager" to "unit manager". The recommendation is the same as the NMA requirement for the crew of Norwegian-registered units. It will require additional training of personnel on production units, particularly for handling unintended situations. We have intentionally specified a lower requirement than the NMA regulation on the assumption that handling of a unit in a fixed location would require less expertise than on a mobile unit. Experience has identified a substantial need for a high level of expertise in responding to unintended situations during petroleum operations.

ACKNOWLEDGEMENT

Peter Sandvik at Marintek has been a valuable source in discussing chapter 8 in our PSA report (Askedal et al, 2011) in the wake of the Deepwater Horizon. ***Bjørn Arstad*** at the Norwegian Maritime Authority has commented on our draft PSA report. Our thanks to them both.

ACRONYMS

ABS: American Bureau of shipping.
ALS: Accidental limit state.
COOP: Control room operator.
DNV: Det Norske Veritas.
FPSO: Floating production, storage and offloading platform.
FSU: Floating storage unit.
GM: Metacentric height.
HPU: Hydraulic power units.
Iw: The moment of inertia of the water-line area.
KB: Distance from keel to point of buoyancy.
KG: Distance from keel to point of gravity.

MMS: United States department of the interior, minerals management service.
NCS: Norwegian continental shelf.
NMA: Norwegian Maritime Authority.
PLC: Programmable logic controller.
PDVSA: Petróleos de Venezuela, S.A.
PSA: Petroleum Safety Authority Norway.
TLP: Tension leg platform.
UPC: Uninterruptible power supply

REFERENCES

Aanestad Ola M.: Krenget etter taubåtkollisjon, Stavanger Aftenblad, 14.4.2000. *In Norwegian only. On the Åsgard B collision.*

ABS: Rules for building and classing, mobile offshore drilling units, 2006.

Aker Solution: Gransking av Gjøa Semi krengingshendelse 03.03.2010, Synergi nr. 209957, 15.03.2010. *In Norwegian only.*

Andersen Terje, Jan Erik Jenssen and Arne Kvitrud: Rapport etter gransking av krengning av Floatel Superior 7. november 2012, Petroleum Safety Authority, 2013. *In Norwegian only. The report is available on http://www.psa.no.*

ANP / DPC commission: Analysis of the accident with the platform P-36, Report of the ANP / DPC commision of investigation, July 2001.

Askedal Sven Arve, Ola Heia, Bjørn Andreas Hanson, Ove Hundseid, Kristen Kjeldstad, Vidar Kristensen, Arne Kvitrud, Øyvind Lauridsen, Rune Solheim, Jorunn Elise Tharaldsen, Hilde-Karin Østnes and Ingrid Årstad: Deepwater Horizon-ulykken – Vurderinger og anbefalinger, Petroleumstilsynet, 2011, chapter 8.2 – http://www.ptil.no/getfile.php/PDF/Hovedrapport%2013.6.2011.pdf. In Norwegian only.

Barentsnova: Kolskaya platform: under hatches of icy waters, 19.11.2011.

Barentsnova: A guilty seven for Kolskaya case, 2.5.2012.

Cowi: Ageing semi-submersibles, Review of major accidents, Causes and barriers, Report no. P-055481-B-32, 20.11.2003.

Connelly Corey: Rough seas flood oil rig, Trinidad and Tobago Newsday, 15.10.2009.

DNV: Woad - Worldwide Offshore Accident Databank, *Available from* http://www.dnv.com. *Password is required.*

DNV: Stability and Watertight Integrity, DNV-OS-C301.

Dybvig Gunnar, Jorunn Tharaldsen and Leif J. Dalsgaard: Investigation Saipem – ballast incident Scarabeo 8, 4 September 2012. *Available on www.psa.no.*

Eni: Event Investigation Report, Eni Norge Synergy no. 2822, Saipem Synergy no. 23360, Ballast incident Scarabeo 8, 4.9.2012, Investigation Report Completion date: 17.9.2012.

Fotland Kjell, Espen Funnemark and Stine Utgaard Musæus: Woad statistical report 1998, statistics on accidents to offshore units engaged in oil and gas activities worldwide in the period 1970-97, DNV, Høvik, 1998.

insidecostarica.com: Group Investigates Sinking of Venezuelan Rig, 15.5.2010 - http://www.insidecostarica.com/dailynews/2010/may/15/latinamerica10051502.htm.

Jack R L, M J R Hoyle and N P Smith: The facts behind jack-up accident statistics, The eight international conference – The jack-up platform, design, construction & operation, London, 2001.

Jack R L, M J R Hoyle, R J Hunt and N P Smith: Jack-Up Accident Statistics: Lots to Learn!, The eleventh international conference - The jack-up platform, design, construction & operation, London, 2007.

Kvitrud Arne (2011). Collisions between platforms and ships in Norway in the period 2001-2010, Proceedings International Conference on Ocean, Offshore and Arctic Engineering (OMAE), Rotterdam, 2011a.

Kvitrud Arne: Requirements to and in service experiences of jack-ups in Norway, The Thirteenth International Conference, The Jack-Up Platform, Design, Construction & Operation, London, September 13th – 14th, 2011b.

Kvitrud Arne, Harald Kleppestø and Odd Rune Skilbrei: Position incidents during offshore loading with shuttle tankers on the Norwegian Continental shelf 2000-2011, Proceedings International Conference on ISOPE, Rhodes, 2012.

Lewis Hilde Øvrebekk: Nytt oljeflak stammer fra Deepwater Horizon, Stavanger Aftenblad, 12.10.2012. *In Norwegian only.*

Lotsberg Inge, Odd Olufsen, Gunnar Solland, Jan Inge Dalane and Sverre Haver: Risk assessment of loss of structural integrity of a floating production platform due to gross errors, Marine Structures, volume 17, number 7, November 2004, page 551-573.

Moe Sigrid: Den skulle aldri ha blitt tauet i slikt vær. Oljerigg med 67 om bord sank i Okhotskhavet i natt. Dagbladet, 18.12.2011. *In Norwegian only.*

News5: Seagoing oil rig topples, worker killed, July 17, 2007.

NORSOK standard N-001: Integrity of offshore structures, revision 8, September 2012.

NORSOK standard N-003: Actions and action effects, revision 2, September 2007.

NORSOK standard Z-013: Risk and emergency preparedness analysis, revision 2, September 2001.

Norwegian Maritime Directorate: Regulations of 20 December 1991 nr. 878 concerning stability, watertight subdivision and watertight/weathertight closing means on mobile offshore units, 1991a.

Norwegian Maritime Directorate: Regulation 20 December 1991 No. 879 concerning ballast systems on mobile offshore units, 1991b.

Norwegian Maritime Directorate: Regulation 22 December 1993 No. 1239 concerning risk analyses for mobile offshore units, 1993.

Norwegian Maritime Directorate: Spørsmål om snø- og islaster i forbindelse med stabilitet, letter to PSA 15.12.2010. *In Norwegian only.*

Næsheim Thor, Torgeir Moan, Aksel Kloster, Per Bekkvik and Sivert Øveraas: The Alexander L. Kielland accident, Report of a Norwegian public commission appointed by royal decree of March 28, 1980, presented to the Ministry of Justice and Police March 1981.

Ocean Shipping Consultants Ltd: Offshore Rigs: Global Prospects to 2020, 2008.

Pemex: Hundimiento parcial de la plataforma, 12.4.2011. *In Spanish only. On the Jupiter 1 accident.*

Petrobras: Inquiry commission, P-34 Listing, final report, Rio de Janeiro, 25.11.2002.

Petroleum Safety Authority and others: The activity regulations + the framework regulation + the facility regulation. They are all published in 2010. *Available on* http://www.psa.no.

Petroleum Safety Authority: Stability and ballasting of semi-submersible facilities. Press release 23.8.2010. *Available on* www.psa.no.

Petroleum Safety Authority: Risk of collisions with visiting vessels. Press release 5.1.2011. *Available on* www.psa.no.

Petroleum Safety Authority: Risikonivå i petroleumsvirksomheten. Hovedrapport, utviklingstrekk 2010, norsk sokkel, Stavanger, 2011. *In Norwegian only. The report is available on* http://www.psa.no

Pitt Anthea, Gareth Chetwynd and Noah Brenner: Aban Pearl reported trouble last year, Upstream, 13.5.2010.

Rigzone: Offshore Rig Utilization by Rig Type, http://www.rigzone.com/data/utilization_rigtype.asp, visited 26. July 2011.

Rostransnadzor: Результаты расследования комиссии Федеральной службы по надзору в сфере транспорта очень серьезной аварии самоподъемной буровой установки «Кольская», затонувшей в Охотском море 18 декабря 2011 года, 2.5.2012. *Available from* http://www.rostransnadzor.ru. *In Russian only.*

Royal Commission: The Report of the Royal Commission (Canada) on the Ocean Ranger Marine Disaster, Ottawa: Canadian Government Publishing Centre. 1984. *Available on* http://www.worldcat.org.

Sharples Malcolm: Kolskaya – Jack-Up – Towing in Bad Weather – Late in the Season, PowerPoint-presentation, 2011.

Ships&People: Russian maritime accidents daily reports, 18.11.2011 - http://www.ships.ru. *On the Kolskaya accident.*

Statoil: Dybdestudie av vannlekkasje i akterskipet Åsgard A, 13.12.2011. *In Norwegian only.*

Tinmannsvik R.K., Albrechtsen E., Bråtveit M., Carlsen I.M., Fylling I., Hauge S., Haugen S., Hynne H., Lundteigen M.A., Moen B.E., Okstad E., Onshus T., Sandvik P.C. and Øien K. 2011. Deepwater Horizon-ulykken: Årsaker, lærepunkter og forbedringstiltak for norsk sokkel. SINTEF rapport A19148. *In Norwegian only.*

Transocean: Risikoutviklingen på norsk sokkel… Stavanger, 3.1.2003. *In Norwegian only.*

Triepke Joseph: 2009 Jackup Review, 2009 - http://www.rigzone.com/news/article.asp?a_id=83956&hmp=1.

United States Coast Guard: Report on Ocean Ranger. Report of U.S. Coast Guard Marine Board of Investigation including Commandant's Action Report. Washington, D.C.: U.S. Coast Guard, 1983. *Available on* http://www.uscg.mil.

United States Coast Guard: Report of Investigation into the Circumstances Surrounding the Explosion, Fire, Sinking and Loss of Eleven Crew Members Aboard the Mobile Offshore Drilling Unit Deepwater Horizon in the Gulf of Mexico April 20 – 22, 2010, Volume I, MISLE, Activity Number: 3721503, 27.4.2011.

United States department of the interior, minerals management service Gulf of Mexico region accident investigation report, 1.1.2007. *On the Typhoon TLP accident.*

United States department of the interior, minerals management service Gulf of Mexico region accident investigation report, 28.7.2010. *On the Thunder Horse accident.*

Vinnem Jan Erik, Arne Kvitrud and Liv Rannveig Nilsen (2006). Stabilitetssvikt av innretninger på norsk sokkel – Metodikk for risikoanalyse, Petroleumstilsynet, 21.2.2006. *In Norwegian only.*

7Newsbelize.com: Oil Rig Capsizes Near Big Creek; 1 Man Dead, July 17, 2007.