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OBSERVED WAVE ACTIONS ON NORWEGIAN SEMI-SUBMERSIBLE AND TLP DECKS

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ABSTRACT

Waves have impacted decks on Norwegian semi-submersibles (semis) and TLPs several times. However, it did not get necessary attention before two accidents in 2015.

In 2015, a wave impact caused a fatality and four injured on the semi-submersible drilling rig COSLInnovator. The same year, a wave washed away gratings on Scarabeo 8, causing a man to fall 13.5m to the sea. When examining our records, we found 29 reported incidents related to waves in deck on 17 platforms from 2000-2017. 27 of the wave actions were mainly directed upward and the remaining two were mainly horizontal wave hits.

We describe each incident and the circumstances. We discuss common causes related to weather conditions and the physical appearance of the platforms. Further, we summarise design and operational precautions taken by the industry.

INTRODUCTION

The terminology used in the industry varies. Normally, "green sea" is used for waves entering decks on FPSOs. DNVGL-OTG-13 uses "upwell", "freeboard exceedance" and "air gap" for semis. In addition, our paper uses the word "run-up" to describe water jets near columns. Further, the word "foam" is used to describe sea with less density than green sea. Airgap is used as the distance from the sea level to the lower deck level in absence of waves.

The PSA investigation (2015) of the Scarabeo 8 incident concluded:

- *After periods of bad weather, inspections did not cover all affected areas in order to prevent faults and hazard/accident conditions.*
- *Inadequate identification of conditions that could lead to failures, hazards and accident conditions.*
- *Insufficiently systematic approach dealing with outstanding maintenance on jobs with low criticality.*
- *Inadequate training of safety delegate.*

After the COSLInnovator accident, we made our own investigation (PSA, 6.7.2016). We also discussed further actions with the industry, the Norwegian Maritime Authority (NMA), DNV GL, ABS and Lloyds Register. New detailed model tests and analysis are done. Almost all mobile platforms are modified.

DNV GL issued in 2016 their first edition of their guidelines (OTG-13 and OTG-14) – one concerning the calculation of air gap for semi-submersible facilities, and one on associated pressures. In addition, they issued a letter (DNV GL, 21.9.2016) requesting the rig owners to comply. The NMA (28.9.2016) sent a letter to all owners of Norwegian-flagged semi-submersible facilities, calling on them to implement the DNV GL's guidelines and some additional requirements related to operational draft. Our letter (30.9.2016) urges the industry to implement the same DNV GL guidelines, and the DNV GL and NMA letters. Our letter applies to all the responsible for facilities on the Norwegian Continental Shelf, regardless of flag state and classification society. Later DNV GL made new editions of the guidelines, and ABS have made their own guidelines. From 2017 the DNVGL-OTG-13 documents are referred to from NORSOK N-003, for air gap analysis of production platforms.

Detailed references with respect to the technical information on individual platforms are not given. For some of the cases our files regarding displacement, draft and airgap during the actual incidents are incomplete. Some weather information is taken from eKlima, the weather and climate data base at the Norwegian Meteorological Institute.

ACCIDENTS AND INCIDENTS BACKGROUND

In addition to the fatal accident on COSLInnovator in 2015, a similar incident occurred on Transocean Prospect in 2001. Most of the other incidents gave local damage, but they also represented a potential to harm personnel. We limited our review to the period 2000-2016. No events were reported in 2017. Kvitrud and Leonhardsen (2001) reported Norwegian incidents before 2000. We present the incidents in a chronological order. There are also some insignificant cases, which we have not presented in this paper. Largely, the hazards on semis are to a large extent the same as on FPSOs, described in Ersdal and Kvitrud (2000).

The worst case ever, worldwide, connected to waves on semis occurred in 1982. On Ocean Ranger at the Hibernia field in Canada, a wave destroyed a porthole window in the column, and water accessed the ballast control room. Several circumstances caused the platform to sink, with 84 fatalities. The COSLInnovator accident is not comparable with the Ocean Ranger accident, but both cases caused fatality, structural damage and ingress of water.

Transocean Prospect in 2001

Transocean Prospect was a six-column semi, built in 1983. She was of Bingo 3000M design, with a survival displacement of 27.010 tons. She had Bahamas flag and DNV classification. She was in Norway in 1992-2002. The portholes to the kitchen area were about 1.5-2m above lower deck level. The size of the kitchen area was about 100-130m^2 (Terje Hatlen, personal information, 6.1.2017). The survival draft was 20.77m and the survival airgap is 16.1m. It is uncertain which draft the platform had. The wave conditions indicate that it should have been, in survival draft. The report from 2001 also state that the platform was taken in survival draft the day before, but personnel in Transocean meant 15 years after that it might have been at operating draft or a draft somewhere between the survival and the operating drafts.

11 November 2001 the platform worked at the Heidrun field in the Norwegian Sea for Statoil. Waves and wind came from WSW – slightly on the platform port side front. Haver and Vestbøstad (2001, page 20 and 30) examine the wave measurement on the Heidrun field. A Miros radar and a set of lasers measured the airgap of the platform. The deviation between the two tools varied with about 20%, which illustrate the uncertainty on estimating of the wave conditions. If the Miros radar provided accurate values, the 3-hour mean significant wave height was 15.5m. However, the 3-hour mean significant wave height calculated by the lasers equals 12m. The report concludes that the maximum significant wave height for a shorter period (20-min) could be around 14m. However, for a longer average (3-hours) a maximum significant wave height of 13m was regarded as more reasonable. The zero upcrossing period at Heidrun was 12.5 sec. The NORA10 hindcast database give about 14m of significant wave height (Algerøy, 2017).

At 04:30, a wave hit the living quarter causing severe damage in the mess room. There were two portholes to the mess room in front of the platform, both without storm protection. The porthole closest to the port side was destroyed. The wave entered the room, hit the roof and bent the fixation for roof plates. The light fixtures and about half the roof plates fell down. The wave riddled the room with glass from the destroyed porthole, and glass fragments of about one cm^2 penetrated the wall on the opposite side of the room. The whole floor had about 15cm of water, or 15-20 tons of water. The water caused short circuit of electrical equipment in the mess, kitchen and bakery. The wave tore loose one of the dining tables from the floor and smashed it; bent the floor in the mess upwards. No persons were present (Statoil, 27.11.2001).

The external part of the platform also sustained damage. On both port side walkways, virtually all gratings were turned up, and some were completely removed. All lighting fixtures and emergency lights were destroyed, and other equipment torn loose. All windows in the port anchor winch cabin were destroyed (Statoil, 27.11.2001).

Transocean Arctic in 2001 and 2008

Transocean Arctic was built in 1987 of Marosso 56 design, with four columns. She has an operating displacement of 36.200 tons. She has Marshall Islands flag and DNV GL class notation, and went through a significant upgrade in 2004. The operational airgap is 11.8m.

11 November 2001 she operated at Visund in the Northern North Sea. At approximately 15:10 a person walked on the aft walkway. He noticed a large wave building up, hitting the platform from the starboard side. He managed to cling to the railing when compact sea washed over and around him, taking his helmet and glasses. The walkway is located at 17m above MSL. In addition, the wave teared off grating on the aft starboard escape ladder and bent two exhaust pipes. The wind speed was 21m/s, significant wave height 6.9m and wave period 11.9s (Transocean, 13.11.2001).

21 November 2008 she operated at the Tyrihans field in the Norwegian Sea. At 03:15, a wave runup the port side column hit the double bottom beneath the port side of the living quarter. The significant wave height was 9.2m and 21m/s wind. The wave caused dents of the structure in the double bottom beneath three of the cabins. Some vertical stiffeners were bent. The wave also caused a temporary loss of the satellite communication on the platform (Transocean, 21.11.2008 and 25.11.2008, and StatoilHydro, 21.11.2008).

Scarabeo 6 in 2002

Scarabeo 6 is a six-column semi, built in 1984. She was of Fried & Goldman design, type L-907 Enhanced Pacesetter. The platform was modified in 1998. She had Bahamas flag and DNV classification, and was in Norway from 1998 until 2003. She worked for Norsk Hydro on the Troll field in the northern North Sea at a water depth of 340m. The operational airgap is 14.5m.

11 November 2002 a Super Puma AS332 L1 helicopter landed on Scarabeo 6. At approximately 09:35 the helicopter had embarked the passengers, and the pilots were about to begin the safety briefing when a wave hit the platform causing seawater to wash over the helideck and the helicopter. The water caused the two helicopter motors, which were on idle at the time, to stop (Norsk Hydro, 2002). The waves were 4m and the wind velocity 9m/s (eKlima for Troll A)

Eirik Raude in 2006

Erik Raude is a six-column semi of Trosvik Bingo 9000 design, built in 2002. She had Bahamas flag and DNV classification. She operated in 2006 at Edvarda field in the Norwegian Sea (well 6403/6-1) for Statoil. The survival airgap is 13.5m.

24 April 2006 at 19:48, while running the BOP, a large wave hit Eirik Raude from underneath resulting in water washing through the moon pool area. The wave caused the support brace for the service lines to swing against the diverter housing resulting in one of the guides breaking off. The 10kg guide fell to the floor below almost hitting a crew member, and dropped into the sea. The wind was 15m/s and the significant wave heights 5m (Statoil, 24.4.2006 and Ocean rig, 1.6.2006).

Scarabeo 5 in 2006 and 2007

Scarabeo 5 is a six-column semi, built in 1990 of Moss ME 45000DP design. She has Bahamas flag and ABS classification. The operational airgap is 13m. She worked in 2006 at the Kristin field in the Norwegian Sea for Statoil.

11 January 2006 the significant wave height was 16.5m according to Saipem. The maximum significant wave height at Heidrun further north, was 13,4m and wind 25m/s (eKlima). Water penetrated the ventilation ducts on the starboard aft side (Saipem, 28.1.2008).

In December 2006, waves washed away one section of the forward starboard emergency ladder, from the main deck to the starboard column (Saipem, 6.2.2007).

Transocean Searcher in 2007 and 2013

Transocean Searcher is a Trosvik Bingo 3000 design with six columns, with a survival airgap of 20m. She was built in 1983, has a Marshall Islands flag and a DNV GL classification.

14 December 2007 a wave caught and bent the burner boom at the Åsgard field in the Norwegian Sea, working for Statoil. The significant wave height was 7m, wind 20m/s and heave 4.6m (Transocean, 14.12.2007).

Working at the Knarr field for BG in the northern part of the North Sea the wind speed was up to 25.7m/s and wave heights of 10m significant (Transocean, 24.1.2014). Transocean report damages during the period 24.12.2013 to 26.12.2013 as:

- Wave run-up tore loose gratings around the crane pedestal on the port side centre column.
- A signboard on the aft side was lost.
- Gratings on the port side were tore loose and blown to sea.

Leiv Eiriksson in 2008 - 2016

Leiv Eiriksson is a six-column semi built in 2001 of Bingo 9000 design, with a Bahamas flag and a DNV GL classification. The operational airgap is 13.5m.

28 November 2008, a piece of grating had disappeared from a walkway with limited access near the moon pool area. The grating had a size and weight of 1x2m and 40kg respectively. It was uncertain when the grating fell off. It operated at the Ormen Lange field in the Norwegian Sea (Norske Shell, 28.11.2008). The maximum wave height at the field this day was 5.2m (eKlima).

8 February 2015, she operated in the field 6406/6 in the Norwegian Sea for Maersk Oil Norge. At approximately 14:00, an oil leak was found on a fitting hose, knocked of the BOP carrier port side brake line. Heavy seas and waves the last 24 hours had lifted a grating of platforms/gangways and possibly sheared the fitting. 700 litres of hydraulic oil were reported missing in the hydraulic tank feeding the BOP carriers hydraulic lines (Maersk Oil Norway, 8.2.2015). The waves at Draugen were about 5.5m and the wind velocity 15m/s (eKlima).

12 February 2015, she operated in the field 6406/6 in the Norwegian Sea for Maersk Oil Norge. During an inspection underneath the deck, a person stepped on a section of walkway where sections of the grating had disappeared (1.0*0.8m). He managed to prevent further fall. Several days before the incident Leiv Eiriksson had encountered severe weather conditions, when numerous sections of the under-hull walkway grating had been dislodged or disappeared (Ocean Rig, 12.2.2015). The waves at Draugen were 5m and the wind velocity 8m/s (eKlima).

29 January 2016 she was on DP on Totals Uptonia field (34/6-4) in the northern North Sea. The water depth is 398m. The platform heading was 225 degrees. She was connected to the well with a survival draft. The significant waves were 9-10m and wind from 245 degrees with 35m/s. At 17:31, a wave runup on the starboard aft column hit the underside of an engine room. A "pre lube pump motor" fell on the floor. The motor foundation had three broken stiffeners and dented two girders. The area affected was 2.5*7m (Ocean Rig, 29.1.2016 and DNV GL, 26.5.2016).

Heidrun TLP in 2008

Heidrun is a four-column production concrete TLP installed in 1995 at the Heidrun field. She has a fixed distance from MSL to the weather deck of 32.6m.

20 November 2008 the significant wave height was 10.8m and wind 25m/s. At approximately 15:00, two large waves hit the forward port side of the platform causing damage on the external structure (Statoil 7.9.2010). Damage on walkway and nearby scaffolding as well as jamming a door at 35m above MSL. Damage occurred on handrails with adjacent cables at 28m-29m above MSL.

Åsgard B "prior to 2009"

Åsgard B is an anchored, six column production semi of type GVA 70. She was installed in the Norwegian Sea in 2000 and has a still water airgap of 20m.

"Sometimes" before 2009, a wave lifted up gratings. They relocated the gratings afterwards (PSA, 2016).

Snorre A TLP in 2011 and 2014

Snorre A is a four-column steel TLP operated by Statoil. She has an airgap of 26.2m. She was installed in 1992 at the Snorre field in the northern North Sea.

26 December 2011 a storm hit Snorre A. Statoil reported loose and dislodged grating after the storm (Statoil, 2012). The highest wave height at Gullfaks C this day was 11m and the wind velocity 15m/s (eKlima).

25 January 2014 at approximately 08:00 a person walked into the grating area of the cellar deck (Statoil, 2014). A few meters inside the grating area a large flow or wave, struck up along one of the columns. The person experienced a splashing up through the grating and stopped. When the water subsided, he returned to the stairs he came from, and noticed that the grating next to where he had stopped was gone with an open hole to sea of approximately $2m^2$. The wave height at Gullfaks C was 10,2m and the wind velocity 25m/s (eKlima).

Scarabeo 8 in 2012-2015

Scarabeo 8 is a six-column semi of type Moss CS50 MkII. She drilled from 2012 at the Goliat field in the northern Norwegian Sea, working for Eni Norge. She has Bahamas flag and DNV GL classification. The operational and survival air gap is 12.65m and 14.65m respectively. She operated on dynamic positioning (DP).

3 January 2013 gratings were found on the seabed. Their first storm on the field removed grating on the starboard and port escape stairs to sea level (Saipem, 5.1.2015). No weather information is given.

26 February 2013 a wave hit the forward starboard column, and went upwards. The wave resulted in damage to sections of gratings on stairs and a cantilever walkway (Saipem, 26.2.2015). No weather information is given.

7 February 2015 waves hit the aft external stairways leading from upper deck to ROV area on the port and starboard side. The staircase on the starboard side was almost entirely destroyed. At approximately 21:00 the wind speed was 20m/s. The significant wave height was 6,5m (Saipem, 8.2.2015 and 12.2.2015).

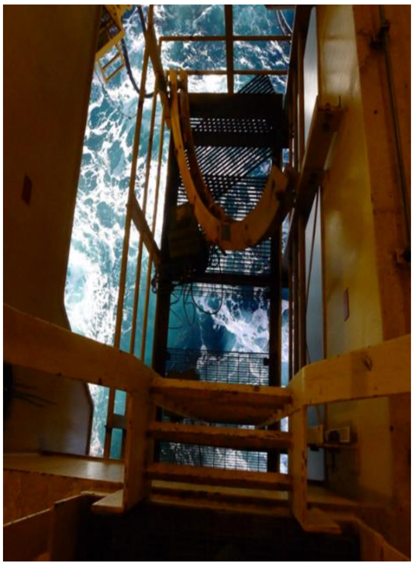

FIGURE 1: THE GAP IN THE GRATING ON THE BOP CARRIER PLATFORM WHICH THE PERSON FELL THROUGH ON SCARABEO 8 (PSA, 2015).

20 February 2015 a man fell overboard from Scarabeo 8. At the time of the incident, two engineers were working in the moonpool area. One of the engineers descended the ladder to a small access platform. As he stepped off the ladder onto the grating below, he fell through a gap directly into the sea 13.5m below. The man was rescued, without serious physical injuries. The exact moment when the grating disappeared is uncertain. The site of this incident is unlikely to have been in use since 6 February 2015. Scarabeo 8 was exposed to rough weather in the two weeks leading up to the incident (Eni, 16.3.2015 and PSA, 14.4.2015).

12 March 2015 a wave damaged and through away gratings at port forward upper deck staircases (Saipem, 28.3.2015). No weather information is given.

15 March 2015 at 22:00, a wave hit the port column. Water entered the upper deck walkways. The wave damaged the port and starboard external escape ways leading to the forward lifeboat station and the Marine Evacuation System (MES). The starboard staircase to the MES was also damaged (Saipem, 28.3.2015). No weather information is given.

Floatel Superior in 2013

Floatel Superior is a four-column semi with a MSC/Keppel FELS DSS20/NS – DP3 design, and built in 2010. She has Bermuda flag and DNV GL classification. The survival and operational air gap is 14,5m and 9,5m respectively.

1 December 2013 at approximately 10:15 a wave hit from aft and ripped off four GRP gratings on the aft main deck walkway (Floatel International, 21.4.2014). She operated on the Kvitebjørn field in the North Sea for Statoil. At Gullfaks C the waves were 6m and the wind velocity 13m/s (eKlima)

COSLInnovator in 2013 and 2015

COSLInnovator is a four-column semi of Global Maritime GM4000-D w/S&B design with extra buoyancy elements. She was built in 2011, has Singapore flag and DNV GL classification. She has a survival draft of 15.75m. The air gap in operational and survival condition is 11.5m and 13.5m respectively.

14 February 2013 at approximately 09:30 a wave hit the bow of the platform when she was at the Troll field in the North Sea working for Statoil. Grating on the main deck and lower deck were torn loose, and some of them fell to sea. The grating was fastened with clamps. There were also damage on light fixtures on lower deck. COSL Drilling reported a maximum significant wave height of 13m (COSL, 21.1.2014).

A wave hit COSLInnovator at 16:38 on 30 December 2015 at the Troll field in the North Sea working for Statoil. The impact occurred forward on the port side, and the platform suffered extensive damage. One person died and four were injured. The damage was confined to parts of the living quarters (COSL, 1.3.2016).

COSLInnovator was in survival draft with a weight margin of about 120 tonnes. The platform positioned with the wind slightly from port side (about 10 degrees), waves slightly from starboard (about 10-15 degrees) and a forward trim of about 1.5 degrees. The platform had a heading of about 160 degrees.

Statoil (12.1.2016) reported a significant wave height 8.5-9.5m, peak period 12-14 sec., wind velocity 24-26 m/s (10m level and ten-minute mean). Magnusson et al (18.2.2016) provided a higher estimate for the sea state (significant wave height of 11.1m and zero upcrossing period 9.3 sec), based on NORA10 hindcast data. At the time of the incident the measured heave and surge motions of the platforms, were at 12-13 sec. (PSA, 6.7.2016).

The wave smashed windows and window frames to the cabins. Several doors from the cabin to the corridor smashed into the wall on the opposite side of the corridor. Personnel reported afterwards that the water was knee-deep, and an odour of electrical short-circuits could be smelled. The estimates of the amount of water inside the living quarter deviates significantly. Two watertight doors on the outside of the living quarter were forced open, by the force of the wave striking the pushbuttons for air-assisted opening. The wave impact also damaged the air supply for local operation of doors, accordingly they remained open.

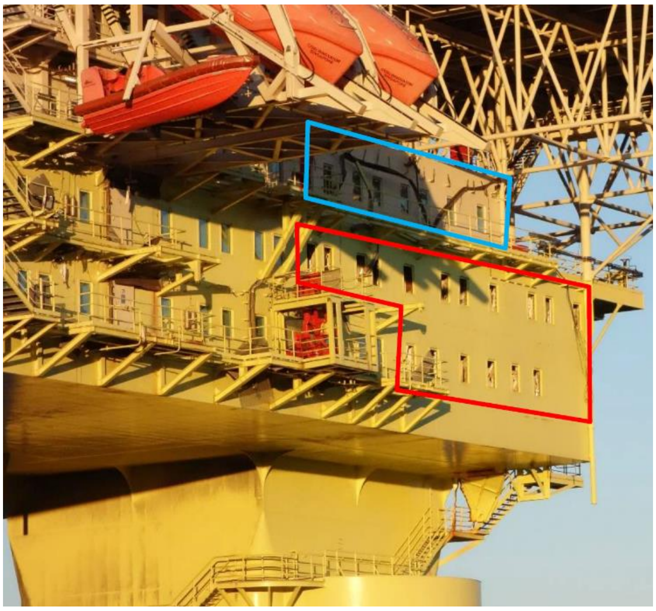

FIGURE 2: FORWARD BULKHEAD OF THE COSLINNOVATOR AT CCB AFTER THE INCIDENT (PSA, 2016). THE RED AREA HAD DAMAGES FROM THE WAVE MOVING HORIZONTALLY. THE BLUE AREA HAD DAMAGES FROM THE WAVE MOVING UPWARDS.

COSLInnovator suffered extensive damage to 17 cabins as well as corridors spread over two decks forward on the port side. Six windows on the lower deck and eleven on the mezzanine deck were forced inwards. The injured had been in their cabins. Above the main deck level, damages to grating panels, cable trays and secondary structures were directed upwards, indicating a run-up effect.

Towards the centre of the box girder's forward face and above deck A-level, damage to glass, grating panels, weathertight doors, cable trays, equipment cabinets and so forth was on a smaller scale and oriented in various directions – both inwards at the midships doors and upwards in the area by the helideck.

Estimates for horizontal pressure from the slamming wave on the windows were from different parties estimated by Stansberg (2016) as 200 – 300kPa, Wood Group (2016) 250 – 300kPa (based on deformed bulkhead plates and stiffeners) and DNV GL 350kPa (PSA, 2016). The failed window frame bolts could take up to 180kPa.

Island Innovator in 2015

Island Innovator is a four-column semi, of GM4000-WI design. She was built in 2012. She has Norwegian flag and DNV GL class. The air gap in operational and survival condition is 11.5m and 13.5m respectively.

13 November 2015 at 17:55 was in operational draft at the well 6407/10-4 in the Norwegian Sea. A wave hit 15 meters of composite gratings on the lower deck in front of the living quarter. Some grating fell to sea, and other parts were relocated. The sea state was 6m, and the access way had been closed for general

access before the incident (Odfjell, 2015). The waves at Draugen were 7m and the wind velocity 14m/s (eKlima).

Bideford Dolphin in 2016

Bideford Dolphin is an eight-column modified enhanced Aker H-3 platform with an operational displacement of 26.867 tons. She was built in 1975 and has Singapore flag and DNV GL classification. The height from MSL to the main deck in survival condition is 18.3m.

29 January 2016 the Tor storm hit the platform anchored on Statoil's Tordis field in the northern North Sea at survival draft. The mean wind speed at 10m height was 33m/s. The waves at the Gullfaks C platform (Miros radar) gave a significant wave height of 12.3m. The measured mean period was 13.6 sec. She was on even keel (Dolphin Drilling, 9.5.2016).

The first wave hit was at 18:30 on the port side. At 19:15, a new wave hit the platform, causing water ingress in watertight doors on the port side. Significant volumes of seawater entered the main deck. The crew reported that the noise was more severe during the second wave hit, indicating that this wave was the most severe.

The main damages were at the aft port side as:

- Damage to aluminium helideck structure.
- Missing gratings around the anchor winch
- Missing door in the helifuel skid.
- Damaged gangway from main deck to upper deck.
- Dent in bulkhead of a cabin.
- Damage to the Selantic container.
- Large amounts of seawater on the main deck area.

Additional reported damage were broken light fixtures at the forward port side and loose cables at the forward starboard side. The platform went to shore for repairs after the incident.

The helideck aluminium floor is located approximately 8m above the upper deck, which is 30m above MSL at survival draft. The damages were probably from wave run-up along the aft port column. The water on the deck was according to Dolphin Drilling caused by sea spray and heavy wind.

Dolphin (9.5.2016) also reviewed historical events related to wave run-up. Most incidents involve minor damages, such as displaced grating and cable trays. None had close to the same damages as the incident 29 January 2016. No details of the previous events are given.

Visund in 2016

Visund is a four-column drilling, production and quarter semi of GVA 8000 design, and she was installed in 1998. She is anchored at 335m water depth and was operated by Statoil in 2016. The survival airgap is 18.5m.

During an inspection in March 2016 Statoil (18.11.2016) reported

- Buckling of upper deck.
- Deformations of deck panels and stiffeners (up to 4 cm).
- Nine cracks in upper deck.
- Deformations causing paint to fall off.
- Buckling and cracks in the double bottom.

The damaged area extends approximately 3m beyond the forward port side column. Statoil concluded that it happened during the Tor storm 29 January 2016. The environmental conditions during the evening 29 January was wind up to 29m/s, significant waves of 13.2m (Miros radar) and peak periods between 14.8s-15.4s. Non-linear finite element analyses performed after the incident indicated a pressure of 150kPa over 0.3 sec., as a vertical load 27m above sea level, was necessary to simulate the damages. Statoil interpreted the incident as a run-up event (Statoil 2016).

Snorre B in 2016

Snorre B is a drilling and production (SSPV) semi operated by Statoil. She was designed by Kværner Oil & Gas and Aker Maritime. She is anchored at a water depth of 350m and was installed in 2001. The airgap is 21m. The hull consists of four "square rounded" columns. The columns are connected in the corners with rectangular ring pontoon.

During the same Tor storm 29 January 2016, Snorre B experienced a wave in deck incident. Statoil found the damages during an inspection in the summer of 2016. Accordingly, the exact timing of the impact is unknown. It is uncertain if the damages were due to direct wave hit, or wave run-up. The maximum measured waves at the Tor storm were 12.0m with 16.1sec peak period. The maximum wind was 29.8m/s. The maximum wave and wind conditions occurred at 18:30. The waves resulted in damage on three of the aluminium profiles as well as deformation of a cable tray under the deck, on inside of the impacted column. The most severe damage occurred about 5m away from the column (Statoil, 18.11.2016).

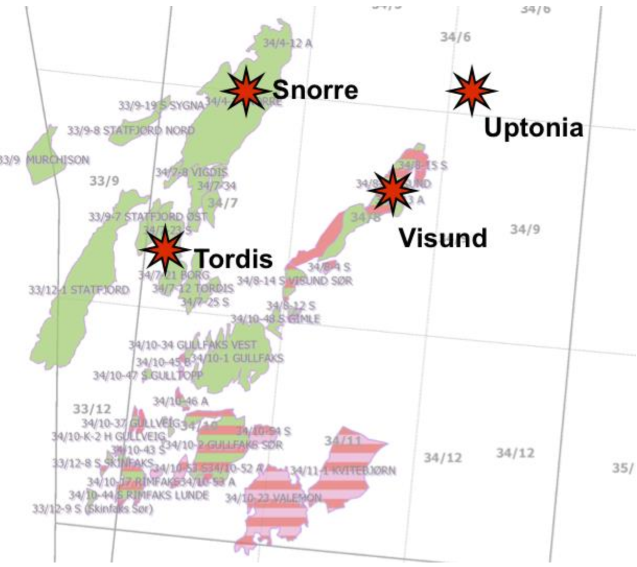

FIGURE 3: THE INCIDENTS DURING THE TOR STORM 29 JANUARY 2016 OCCURRED AT TORDIS (BIDEFORD DOLPHIN), VISUND, UPTONIA (LEIV EIRIKSSON) AND SNORRE B. THE LOCATIONS ARE MARKED ON THE MAP. THE BASIC MAP IS FROM WWW.NPD.NO.

The characteristics of the storm events

Haver and Vestbøstad (2001) reported the maximum weather conditions at the Transocean Prospect incident 11.11.2001 as significant wave height of 14m, zero up-crossing period as 12.5 sec. and wind velocity of 24 m/s. Several measurements and hindcast values are available, and the numbers are their best estimate values.

For the COSLInnovator incident 30.12.2015, Statoil (12.1.2016) estimated the maximum significant wave height to be 8.5-9.5m, peak periods of 12-14 sec. and wind velocity of 24-26 m/s. Magnusson et al (18.2.2016) provided a higher estimate for the sea state with significant wave height of 11m and zero up-crossing period of 9.3 sec. based on the NORA10 hindcast data.

Four events occurred in the Tor storm 29 January 2016 in a limited region of the northern North Sea. The reported maximum sea state varies with location and measuring instrument. Statoil (8.2.2017) reported the significant wave height at Visund as 13,2m, peak periods of 14,8-15,4 sec., Tz as 11,0-11,3 sec. and wind velocity of 29 m/s. Again, the measurements in this part of the North Sea have a significant scatter.

TABLE 1 - WAVE MEASUREMENTS AND WAVE ESTIMATES FOR THE THREE STORM EVENTS WITH THE MOST SIGNIFICANT DAMAGES.

Incident (field)	H_S (m)	T_Z (s)	Source
Transocean Prospect (Heidrun field)	16.5	13	Measurements from Heidrun www.eklima.met.no
-	14	12	Conclusions (Haver and Vestbøstad, 2001)
-	14.3	13.2	NORA10 (Haver and Vestbøstad, 2001)
-	13	12.5	Lasers (Haver and Vestbøstad, 2001)
COSL Innovator (Troll field)	8	9	Measurements from Troll A www.eklima.met.no
-	8.5	9.33	Statoil (12.1.2016), lower range
-	9.5	10.9	Statoil (12.1.2016), higher range
-	10	9.3	Stansberg (2016)
	11	9.3	NORA10 (Magnusson et al, 2016)
Tor storm (Troll A)	10.8 11.9	10 11	www.eklima.met.no www.eklima.met.no measurements at two moments in time
Tor storm (Troll A)	12.1	11.4	Statoil (10.2.2017) measurements
Tor storm (Gullfaks C)	12.9	11.5	Statoil (10.2.2017) measurements
Tor storm (Snorre B)	12	12.5	Statoil (10.2.2017) measurements
Tor storm (Visund)	13.2	11.3	Statoil (8.2.2017) measurements
Tor storm (Tordis)	13	11.1	Dolphin Drilling (29.1.2016) “observations»

Table 1 present wave data for the three worst damage events collected from multiple sources including reports and information from the companies involved and from eKlima. When the wave period is given as peak wave period (T_p) or mean wave period (T_I), the following relations, from DNV-RP-H103 (DNV, April 2011), is used to obtain the zero up-crossing wave period (T_Z), assuming JONSWAP spectre with γ=3.3: $T_p = 1.2859T_Z$ and $T_I = 1,0734T_Z$.

In Figure 4, we have plotted the wave data from Table 1 together with a North Sea contour diagram. The colored dotted lines indicate the range of the reported environmental data, and show how the wave conditions in the storms vary with the different measuring equipment and technique. Each sea state has a large uncertainty.

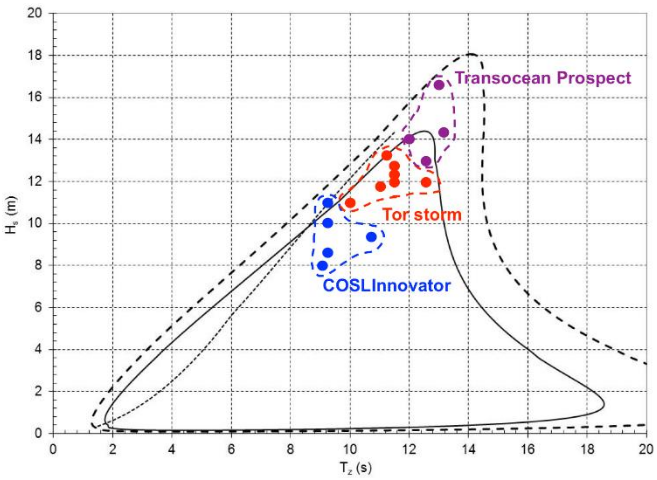

FIGURE 4: THE ESTTIMATES OF THE WAVES (HS AND TZ) AT THE COSLINNOVATOR ACCIDENT 30.12.2015 ARE PLOTTED BLUE, THE TOR STORM 29.1.2016 ARE RED AND THE WAVES IN THE TRANSOCEAN PROSPECT INCIDENT 11.11.2001 ARE PURPLE. THEY ARE PLOTTED TOGETHER WITH AN EXAMPLE OF A NORTH SEA CONTOUR DIAGRAM OF HS AND TZ WITH ANNUAL PROBABILITIES OF 10^{-2} AND 10^{-4} FROM DNVGL-OTG-13. DNV GL HAVE INCLUDED THEIR STEEPNESS CRITERIA (DOTTED LINE). THE DNV GL LINES ARE IN BLACK.

The most severe damages are associated with steep storm events. As shown in Figure 4, the cases with the most significant damage from vertical wave hits (Tor storm) had sea states in between the two horizontal wave hits.

DISCUSSIONS

Similarities and statistics

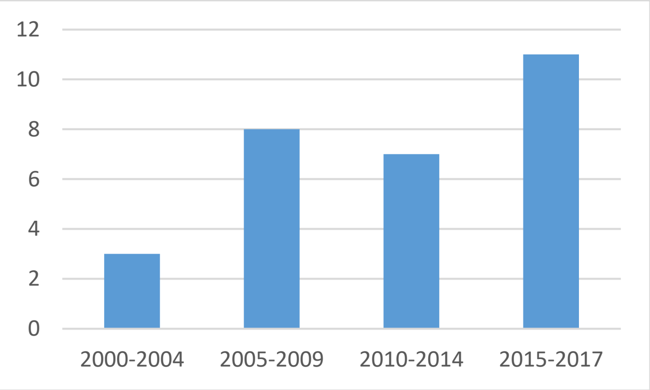

FIGURE 5: THE NUMBER OF REPORTED WAVE IN DECK INCIDENTS FOR FIVE-YEAR PERIODS.

The increased number of reported events can be explained by a significant increased number of platforms. The increased usage of lightweight gratings in aluminium and GRP may have had an impact on the actual damages. Some lightweight grating designs reduce the possibility for water to flow through the grating compared with traditional steel gratings, increasing the loads on the gratings and its fixations.

Most of the incidents occurred in the northern North Sea and in the southern half of the Norwegian Sea. The water depths were about 180m and upwards. It is obviously not a shallow water problem. Some platforms were on DP, others were anchored in different combinations of steel wire ropes, fibre ropes and chains. Two of them were TLPs. The incidents occurred on almost all the design types used on our continental shelf, both on mobile platforms and production platforms

We have had about 310 semi-submersible operation years on the NCS with mobile platforms in 2000-2016. In addition, 186 platform-years on production platforms. Among them, there are two TLPs having 34 years of production in this period. Twenty-four of the incidents occurred on mobile platforms indicating a damage rate of 24/310 or an annual probability of $7.7*10^{-2}$. Five of the incident occurred on production platforms indicating a damage rate of 5/186 or an annual probability of $3*10^{-2}$. Our two direct horizontal wave hits on deck give a frequency of $4*10^{-3}$ per operational year, calculated as 2 / (310+186). The basic numbers are small especially on production platforms, and the probabilities should be used with caution. However, they may indicate an order of magnitude. Three incidents occurred on our two TLPs, indicating a damage rate of 3/34 or an annual probability of $1*10^{-1}$. Here both numbers are small, and the estimated probability very uncertain.

As described above, the damages are governed by the actual weather conditions and the orientation of the platforms related to the wave directions. In addition, we have compared some main characteristics of the platforms involved. We have compared COSLInnovator and Transocean Prospect with the 15 platforms with wave in deck incidents. We collected technical information for this paper on each platform from several sources including classification societies lists of vessels, applications of statement of compliance, drilling consents and more.

COSLInnovator and Transocean Prospect had both lower than the median operational displacement, distances from the top of the pontoon to the water level in survival draft, and the ratio between the columns water line area and the total enclosed area of the columns. But are the two platforms significantly different form the others? First, we asked our self, when is a value significantly different from others? Numbers typically used in statistical analysis is five to ten present probability. If both of our two platforms have a lower value than the third lowest of the 15, the probability is 4%. In addition, we have tested more than one property. The more tests the higher the probability of getting a property that fit with the criteria will occur. Using the third lowest property, the probability to flag a non-existing correlation is judged by us to be acceptable. We could also have assumed a statistical distribution, fitted a set of parameters and calculated the 90 or 95 percentiles directly. The problem then would be to select and test reasonable distributions that fit the data. The conclusion of this exercise was however, that our two platforms had no single parameter that is statistical significant from the other platforms. The same result occurred when we tested the combinations of two parameters. The uncomfortable result is, we cannot disregard horizontal wave actions in decks on the other platforms.

Design precautions

We do not fully understand the physics behind the incidents. However, compliance with the DNV GL guidelines are from our point of view, a good starting point.

Hazard identifications (HAZID) should be performed to check if waves can hit vulnerable and weak elements as windows, pipes, port holes, power cables, water tight doors, engine exhausts or opening features. Local damage can threaten the weather tight integrity and safety critical functions. From our point of view, a reasonable robustness check for mobile semies should also include larger waves than with 10^{-2} annual probability. This is accommodated by our management regulation section 9 concerning risk analysis and acceptance criteria, and the ALARP principle. Some platforms have got additional watertight doors installed into the deck box, to ensure no risk to compromise the watertight integrity.

All our mobile semies are reanalysed according to the DNV GL guidelines. In addition, model tests have been performed on some mobile and production platforms. Most of the production platforms have detailed model testing from the design period both on 10^{-2} and 10^{-4} annual probability levels. However, additional model testing is performed, and some are scheduled for 2018. The analysis demonstrated that many of the mobile platforms have several meters of negative airgap in 10^{-2} annual probability conditions. Most of the production platforms have positive or small local negative airgaps, for horizontal wave hits in 10^{-2} annual probability conditions. Almost all our production platforms have negative airgap with 10^{-4} annual probability levels. The consequences of the analysis, is that most mobile platforms have done modifications as sealing off windows and portholes, some have strengthened bulkheads in the living quarters. In addition, changes occur in draft, criteria to change draft and restrictions in use of forward list. In addition, several platforms have got restrictions for personnel to be outdoor in storm conditions.

Model testing and offshore experiences demonstrate that the decks can be exposed to significant run-up jets. The effects should be properly accounted for in the local designs of the deck structures. Local run-up jets are rarely reported from model testing from Norwegian semis. The reason is probably that the measuring program has not been designed to examine the phenomena. However, Stansberg (2014 – his results on probe 4) described that his predictions close to the columns were lower than the measurements. Local run-up jets with a thickness of typically 1m (full scale) and water speed up to around 20m/s were also observed. They occurred in random waves and on aft columns in very steep wave conditions. Stenberg's figures indicate a run-up factor of near two on the significant wave height. In the offshore incidents, damage occurred from about five meter significant wave height. Several of the reported cases with hits on the lower deck level had a factor higher than two between the airgap and the significant wave height. Since many of the incidents occurred much higher than the lower deck level, the ratio between the damage location and the significant wave height have occasionally been significantly higher. Damage occurred on the Bideford Dolphin helideck 38m above sea level with a significant wave height of 12.3m, and on Heidrun at 35m level with a wave height of 10.3m. In both cases the run-up jet factor was above three. The factor of two, reported from one model test, is clearly not conservative for all cases. However, in most of the offshore incidents uncertainties exists on the actual significant wave heights, and the values should be regarded as estimates. In addition, we have no information on the shapes and properties of the individual waves. Local effects can probably be investigated by model testing, but scale effects and selection of model laws may influence the results. It is common to specify local vertical upward loads under the lower decks as a function of the distance from the columns, but based on the offshore incidents it is fair to assume that many specifications underestimate the run-up jets or do not take the effects properly into account. In practice, it is necessary to choose conservative design values.

When waves give horizontal loads on the deck structures, the loads calculated according to DNVGL-OTG-14 are significant. Non-linear structural capacity models are frequently necessary to demonstrate sufficient capacity. Non-linear analysis is not straight forward, but is usually done based on DNVGL-RP-C208.

Our facility regulation section five on design of facilities, state "*Areas occupied by personnel, or where safety-related equipment is located, shall not be exposed to waves with an annual likelihood greater than* $1x10^{-2}$." (PSA, 18.12.2015). The practical implication is that the design must avoid waves to hit personnel, or operational procedures must ensure that personnel are not present in areas influenced by waves.

Lightweight gratings should be used with care in areas influenced by waves. The gratings should have sufficient openings for water to pass or a good fixation system. Deck plates is also a good alternative to prevent waves to penetrate.

Operational precautions

If waves hit perpendicular to the main directions of the semi, the potential of high loads increases significantly. Some DP operated semies have changed their focus in storms to maintain a specific heading, and not holding position. Maintaining the position, may as on COSLInnovator, imply a forward speed against the waves and increased loads. The living quarters are normally located upwind, to prevent smoke to cover the living quarter in case of fire for the prevailing wind directions. The incidents demonstrated that waves could hurt personnel inside the living quarter. Proper protection of portholes and windows are necessary, but risk evaluations should discuss the orientations in storms, are the waves or fires most dangerous? The evaluation of the heading and position of the semis during storms, should use the knowledge of the behaviour of the specific semi in question.

COSLInnovator trimmed by about 1.5 degrees - deeper forward than aft. It contributed to reduce the airgap of the forward box girder. The effect of trimming was a reduction of about 1.2 metres in the air gap at the outermost edge of the box girder. Trimming should only be done with good knowledge of the behaviour of the specific platform.

Some platforms have changed their survival drafts to get a better situation. The designer should also specify clearly in the operational manual, which wave conditions the platform should change draft. Several of the incidents occurred in operational drafts, and not all platforms have had precise criteria.

We have one incident when foam stopped the engines of a helicopter on a semi. We also had a similar incident on Balder FPSO 19 December 2001 (Esso, 2001), where the pilots stopped the engines on the helideck. Events are rare, but should not be disregarded.

Waves have hit personnel outdoors on semis. This is not a phenomenon only related to semis. On the Skarv FPSO one person was hurt 20 December 2016 (Aker BP, 2016).

Good practice in front of a storm may include sealing of windows and port holes, limitations in access for personnel to exposed areas both outdoor and on lower floors, sea fastening and limitations in use of helicopters.

If larger waves than the design values are forecasted, precautions should be made. They can include removing the staff on board or moving the platform to sheltered areas.

To prevent accidents after periods of harsh weather, inspections should cover all affected areas.

CONCLUSIONS

Upward wave actions have caused pollution and damage on gratings, structures, production equipment, drilling equipment and lifesaving equipment. Waves have hit personnel, and been the root cause for a man to fall 13.5m to sea due to loss of gratings. Wave foam have caused problems for helicopters.

Horizontal wave actions have caused one fatality and four injured. They created large free water surfaces and significant damages.

Both the horizontal wave hits and the most significant vertical wave damages occurred in sea states with high average steepness.

Design of semis and planning of operations must include considerations of both horizontal and vertical wave actions on decks.

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ACRONYMS

ABS: American Bureau of Shipping; **BOP**: Blow out preventer; **DP**: Dynamic positioning; **FPSO**: Floating production; storage and offloading platform; **FSU**: Floating storage unit; **GRP**: Glass Reinforced Plastic; **MES**: Marine evacuation system; **MSL**: Mean surface level; **NCS**: Norwegian continental shelf; **NMA**: Norwegian Maritime Authority; **OTG**: Offshore Technical Guidelines; **PSA**: Petroleum Safety Authority Norway; **ROV**: Remotely Operated Underwater Vehicle; **TLP**: Tension Leg Platform.

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