PETROLEUMSTILSYNET

Investigation report

Report	
Report title Report from the investigation of the listing of *Floatel Superior*, 7 November 2012 on the Njord field	Activity number 420001003

Security grading		
X Public	☐ Restricted	☐ Strictly confidential
☐ Not publicly available	☐ Confidential	

Summary

An unsecured anchor caused water intrusion in two tanks on *Floatel Superior* during the night of 6-7 November 2012, leading to a list of 5.8°. The extent of the damage and the potential consequences of further water intrusion then prompted a decision to evacuate. The evacuation of 336 people was carried out by helicopter. None of the 374 people on *Floatel Superior* suffered any personal injury as a result of the incident.

Involved	
Main group T-Floating installations	Approved by/date Odd Rune Skilbrei
Members of the investigation team Terje L Andersen, Jan Erik Jensen and Arne Kvitrud	Investigation leader Arne Kvitrud

Figure 1: *Floatel Superior* at survival draft (13 metres). The air gap is 14.5 metres from sea level to the underside of the topside (beneath the text "FLOATEL SUPERIOR" in the photograph). Spray from the wave in the foreground reaches the drum of winch 4 (with anchor line 8) on the forward port column. The photograph was taken during an earlier episode of bad weather. Copyright Erik Sevaldsen[1].

[1] http://www.tk.no/naring/article6343656.ece. Permission to use the photo has been obtained from Sevaldsen.

Contents

Figure 2: A 12-tonne Bruce anchor from *Floatel Superior*. The photograph shows anchor 1 from the starboard side after removal. The scratch marks where marine fouling (the blue-black colour of the mussels) has been removed show that the anchor has rotated as well as moved from side to side (see the fan shape on the right-hand side of the fluke, arrowed). See also Figure 14, which shows various positions taken by the anchor. The anchor fluke is the large plate topped by two points. The photograph was taken by the PSA on 14 November 2012 in Kristiansund.

Figure 3: Anchor 8 and the damage above the waterline, here at transit draft. The anchor which caused the damage and the partly destroyed bolster are visible. The photograph was taken by the PSA on 10 November 2012 in Kristiansund.

1 Summary

An unsecured anchor created eight holes in the hull of *Floatel Superior* during the night of 6-7 November 2012, causing water to enter two tanks and producing a list of about 5.8°. It was then on the Njord field in the Norwegian Sea. In addition, the anchor caused local damage to a third tank and scraped the outside of two others. We feel these might well also have been punctured. The overall list could then have come close to the design limit of 17°.

In heavy seas and during transport, all eight anchors have repeatedly hit fixing surfaces and structural components on the bolsters. Damage at various stages of development has been found on all four bolsters.

An anchor bolster lost three braces on the night of the incident as a result of damage which had occurred and developed over time. After these had fractured, the remaining bolster components were unable to prevent the anchor from hitting the hull directly. The anchor was left hanging free, struck the hull repeatedly during heavy seas, and made seven holes. The final hole was created when a damaged part of the bolster suffered a fatigue fracture.

The incident is primarily the result of the design choices made and wave conditions which prevailed during the transport of *Floatel Superior* to Ølen.

One design assumption was that *Floatel Superior* would maintain its position with either mooring or dynamic positioning (DP). In the latter case, the anchors were stowed in positions exposed to weather on the bolster without adequate account being taken of this placement. Inappropriate choices made include:

- the anchors could not be adequately secured to the bolsters
- the bolsters were not dimensioned for the loads to which they were exposed
- the doubling plate did not function as a weak link
- the hull was not dimensioned to withstand blows from an anchor.

A general deficiency was cooperation between and understanding of the preconditions applied by different players when designing, constructing and operating the facility.

Floatel Superior had suffered damage before being taken into use on the Norwegian continental shelf (NCS). This was caused by transporting it in higher waves than the operations manual and analyses permit. The operations manual for transit draft specifies the maximum significant wave height at three metres, while much of the voyage across the Indian and Atlantic Oceans took place in waves above this criterion.

Safety-critical observations, such as the motion of anchors in the bolsters and alarms on the winch system, were not followed up in a satisfactory manner by Floatel International.

The hull damage occurred between 01.30- 03.30. When it was discovered, steps were take to prevent it getting worse. The crew believed that the damage was limited (to the puncture of one tank), and they observed around 03.45 that the anchor was motionless. A later assessment of the extent of the damage led to the discovery around 08.45 that a second tank had been punctured. The investigation shows that it should have been possible to detect this wider damage earlier.

The scope of the damage and the potential consequences of further water intrusion provided the basis for an evacuation decision. The evacuation of 336 people was executed quickly and efficiently with the aid of helicopters. No personal injuries were suffered by the 374 people on *Floatel Superior* as a result of the incident. In our view, the position on board was handled well. Many good and well-considered decisions were taken during the incident, in strong winds and high waves.

2 Introduction

The Petroleum Safety Authority Norway (PSA) resolved on the day of the incident to carry out its own investigation of the incident. Members of the investigation team have been:

- Arne Kvitrud - structural safety (leader)
- Terje L. Andersen - structural safety
- Jan Erik Jensen - emergency preparedness

Figure 4: Three of holes in tank 10A viewed from inside. The photograph was taken in Kristiansund during November 2012 by the PSA.

Floatel Superior is a semi-submersible floating unit with hotel facilities and topside storage to support offshore installations for hydrocarbon recovery. Operated by Floatel International AB of Gothenburg, it was designed and built by Keppel FELS in Singapore.

The construction contract was entered into on 4 May 2007, the keel was laid on 21 May 2008 and the unit was delivered by Keppel FELS on 18 March 2010[2]. The flag state is Bermuda. The unit is classed by Det Norske Veritas (DNV) with the class notation 1A1 Column-stabilised Accommodation Unit (N) HELDK E0 DYNPOS-AUTRO POSMOOR-ATA BIS [26]. *DYNPOS-AUTRO* specifies the highest level of redundancy for the dynamic positioning system (also called *DP3*) and *POSMOOR-ATA* specifies that the mooring system has automatic thruster support [26].

We have used the following abbreviations and designations:

CEN:	chief engineer
DNV:	Det Norske Veritas
DP:	dynamic positioning (computer-controlled propulsion machinery)
ECR:	engine control room
Heading:	direction of the bow (forepart) of the unit in relation to north
Heave:	vertical motion of the unit, up and down (measured in metres)
Hmax	highest individual wave in sea condition (measured in metres)
Hs	significant wave height (measured in metres)
HTO:	human, technology and organisation
IMO:	International Maritime Organisation
LBO:	Linjebygg Offshore AS
List:	transverse inclination of the hull
MOB:	man overboard (MOB boat)
NCS:	Norwegian continental shelf
NDT:	non-destructive testing

[2] http://www.offshore-technology.com/projects/floatel-superior/.

NMA: Norwegian Maritime Authority
NPD: Norwegian Petroleum Directorate
PA: public address system
POB: people on board
Pitch: motion of unit, up-down at bow/stern (measured as an angle) (see Figure 5)

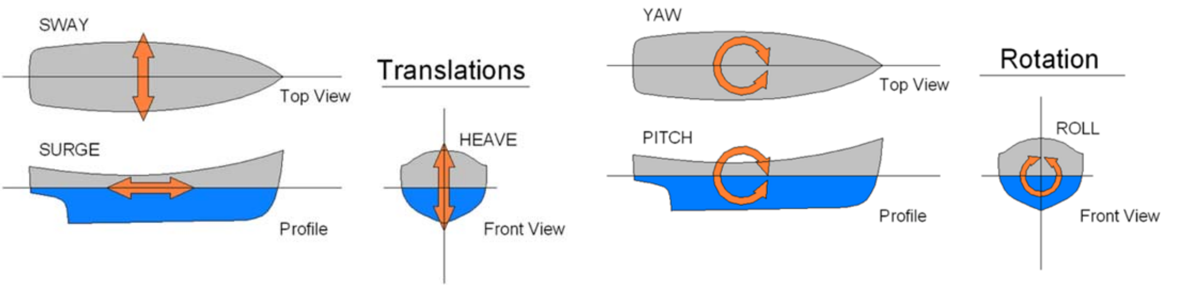

Figure 5: Degrees of motion for a vessel. *Floatel Superior* uses the same definitions, but has a virtually quadratic topside. The bow (forepart) is by the gangway, and the hotel section is aft (stern section) on the topside. The degrees of motion are measured as translations in three directions – *surge* (x), *sway* (y) and *heave* (z). Rotations around the three axes are termed *roll, pitch* and *yaw*. This report uses the terms heave, roll and pitch. The figure is from Wikipedia.[3]

Tp: peak period, when the level of energy is at its highest
PS: port side
PSA: Petroleum Safety Authority Norway
Roll: Rolling of the unit from side to side, also known as list or inclination (measured as an angle) (see Figure 5)
SAR search and rescue
SFO: safety officer
Trim: difference between the fore and aft draft of the vessel
UTC: universal time convention
VDR: voyage data recorder
VRS: vessel reference system from Kongsberg Seatex

Norwegian time is used in the report. This is UTC plus one hour. Levels are specified from the bottom of the pontoons.

2.1 Execution

The purpose of the investigation has been to clarify HTO causes, as well as the processes and levels where these causes made themselves felt, which barriers failed and which functioned, reasons why barriers failed and which barriers should possibly have been established, and to contribute to lessons leant on a broad basis from this incident.

An inspection of *Floatel Superior* was conducted by the investigation team from 12-15 November 2012, when the unit was berthed in Kristiansund. External damage was surveyed with the aid of the unit's MOB boat. Tank 10 was inspected from the inside. The operating house for the anchor winches was inspected and error message logs from all four winches examined. The anchors, which had been removed and stocked on the quay, were also inspected. Spot checks were made of five earlier deficiencies in maritime equipment cited by the NMA in its verification of October 2010.

[3] http://en.wikipedia.org/wiki/File:Translations.PNG.

Samples of mussels were taken from the damage sites for dating. These have been dated by the Norwegian Institute for Marine Research in Bergen. See appendix B. Appendix C specifies where the samples were taken.

We had conversations on *Floatel Superior* with selected crew members and representatives from Keppel FELS. Conversations were also held with Floatel International at its Gothenburg offices on 4-6 December 2012. Talks took place with personnel at Floatel International in Gothenburg, DNV (video conference), Maschinenfabrik Bröhl and Keppel FELS (teleconference). On 7 December, we talked with two guests evacuated from *Floatel Superior* who worked for the LBO and Reinertsen companies. A conversation took place on 4 January 2013 with Statoil’s representative on board. See the list of participants in appendix A. We also had brief telephone conversations with Rolls Royce on 30 November 2012, Viking Seatech on 12 December 2012 and Kongsberg Seatex on 22 January and 1 February 2013 to obtain information. In addition, we had contacts along the way with DNV and the NMA concerning regulatory requirements.

We have received and gone through the documents listed in chapter 8.

A timeline of “events” has been constructed, from the ordering of the unit in 2007 until it arrived in Kristiansund for repair. This forms the basis for chapter 3 on the course of events. Based on the timeline, an assessment has been made for each incident concerning the presence of barriers or opportunities for assessing faults at the time. These are indicated in the timeline as “barriers” and form the basis for chapter 5. Furthermore, an HTO analysis has been conducted using a simplified method based on Jean-Pierre Bento’s HTO classification [130]. Using that classification, we have counted the HTO observations and identified which are dominant. The results are presented in appendix D. We have also done a causal analysis with the use of a causal chart, see appendix E. This method has been developed by Statoil [131]. Both analyses have been used as aids for the investigation. We have made a physical model of the bolster in a scale of 1:200 to illustrate the damage and the course of events.

2.2 Mandate

The investigation mandate written on 13 November 2012 includes the following duties for the investigation team [141].

1. Clarify the scope of the incident and its course from the start and until the facility left the Njord field, with an emphasis on the safety, working environment and emergency preparedness aspects.
2. Assess actual and potential consequences:
    a. harm caused to people, material assets and the environment
    b. the potential for harm to people, material assets and the environment.
3. Assess direct and underlying causes, with an emphasis on HTO, from a barrier perspective.
4. Discuss and describe possible uncertainties/ambiguities.
5. Identify non-conformities and improvement points related to the regulations (and internal requirements).
6. Discuss barriers which functioned (ie, those which helped to prevent a hazard developing into a major accident or which reduced the consequences of the event).
7. Assess the investigation report produced by the player.
8. Prepare a report and covering letter (with possible proposals for taking action) in accordance with the established template.

9. Make recommendations and contribute to further follow-up.

Particular conditions to be assessed in the investigation
The investigation team must verify that a sample of technical conditions of a maritime nature identified in earlier reports from the PSA have actually been corrected as described in correspondence from Floatel International. The team will determine which conditions it wants to verify, but must include aspects related to stability and the ballast system.

3 Course of events

3.1 Course of events after the damage was discovered

Water intrusion was observed soon after 03.00 on Wednesday 7 November 2012 in the forward port column on *Floatel Superior*. The first sign of an undesirable condition was the automatic bilge alarm in the ECR. This sounded at 03.11.58 to indicate water intrusion in the forward port column shaft.

At that time, *Floatel Superior* was on the Halten Bank close to Njord A. The bridge to Njord A had been disconnected on 6 November (at 08.20), and *Floatel Superior* was in a stand-off position at the time of the incident about 250 metres north-north-west of Njord A (see Figure 6 and Figure 16). According to the DP log, draft had been reduced from normal operation (18 metres) to survival (13 metres) at 18.50 [19]. Survival depth provides the best possible clearance to avoid waves hitting the topside in high seas[4]. Unit and crew were prepared for bad weather, in part through securing cargo and loose equipment.[5] *Floatel Superior*[6] was laid bows-on to the weather so that the waves would hit the forward port side at an angle. See also Figure 16 for the relative location of the facilities.

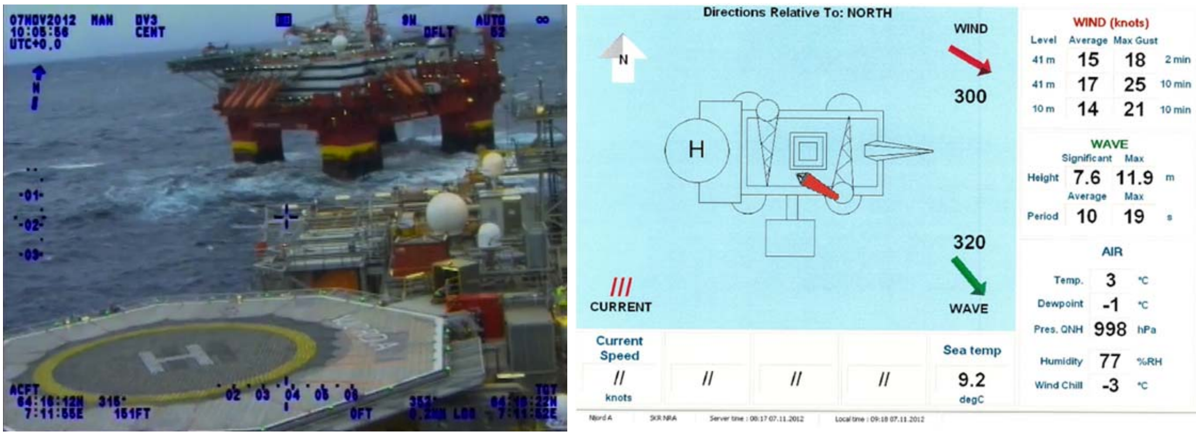

Figure 6: Position and weather information for Njord A on the morning of 7 November. Left: still photo from the rescue helicopter flown by the Norwegian air force's 330 squadron.[7] Right, status information from the emergency response room on Njord A, 7 November 2012 [120]).

[4] DP log [19] 6 November 2012 states: "Started pumping at 14.00, 13m 18.50".

[5] No information has been found in the course of the investigation concerning other measures, such as securing the anchors in the bolsters, inspecting the position of the anchors or additional anchor-related preparations for the storm. Anchor motion had earlier been discussed by the maritime crew on board in connection with bad weather.

[6] Heading is the direction of the vessel. Note that ships normally lie bows-on to the weather, while semi-submersibles have quieter motions and less stress with the weather (partially) on their side.

[7] http://www.youtube.com/watch?v=fQcngxXRD58.

DP was being used at the time to maintain position, and this is also the normal operating mode for the facility. In the stand-off position, the DP system was set to “low gain” on the thrusters in order to achieve calmer operation in bad weather and consequently provided less precise position control (not “chasing” the waves). Operating on DP in high seas in survival mode brings anchors and bolsters[8] into the splash zone and exposes them to heavy loads.

The incident occurred at night in bad weather. According to data from the wave radar [116], the waves reached their maximum height around 00.00. At 23.40, the Hs was 10.9 metres. The 10-minute mean wind speed at a height of 10 metres was about 20 metres per second (40 knots) at 01.00 and about 15m/s when the damage was discovered at 03.20. More details on weather conditions are provided in chapter 9.1.

Motion on the helideck meant that helicopters could not land on the night of the incident. The last helicopter took off at 13.37 on 6 November, when the wind was at gale force. The waves had not built up to more than Hs = 4 metres at that point, but were rising.

After the bilge alarm at 03.11 in the forward port column, the crew immediately investigated the column shaft. Water intrusion was observed from the manhole hatch in the forward bulkhead between shaft and ballast tank 10 outer port, plus water on the pontoon deck (level 8 625 millimetres). One member of the crew on board indicated in conversation with the PSA that the water volume on the deck at the bottom of the shaft was about two cubic metres[9], and the leak has been estimated at about five to 10 litres per minute – not a hazardous level. Only one of the two hatches into tank 10 was leaking; the one in the port bulkhead was tight. Both hatches were accessed from the stair landing, level 11 106 millimetres, and thereby on a level with the lowest threshold of the manholes[10] at about 11.5 metres. The engine room personnel reported the observations from inside the forward port column to the control room at 03.12 and to the bridge at 03.13. The crew then began tightening the bolts on ballast tank 10 outer port [1]. The engine room began pumping bilge overboard at 03.14. According to the ballast plan, ballast tank 10 should not contain water[11], but the ballast system did not sound an alarm. The bridge checked the stability programme at 03.14 [1]. The DP log recorded at 03.18 that “tank 10 outer PS” was full because of assumed damage by the anchor [19].

The master was off watch and had gone to bed earlier in the evening. He and the first officer were rung up from the bridge at 03.18. The master took command on the bridge at 03.22 [1] and established that the facility had developed a list assessed as 4° following water intrusion in tank 10. No other alarms were given. There were not considered to be signs of further

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[8] A *bolster* is a structure intended to hold one or more anchors along the side of the facility when they are not in use, to prevent them damaging the hull. Other names for it are a *rack* or a *cow catcher*.

[9] Water about eight centimetres on half the deck along one bulkhead: $½*10m*5m*0.08m = 2$ cubic metres.

[10] *Floatel Superior*’s draft was set at 13 metres. When the stability report at 03.29 showed a mean draft of 16.85 metres for the forward port column because of the listing [12], this was assumed to be the mean water level outside the damaged tank with a variation from rolling of about $\pm\tan(5^\circ)*30m = \pm 2.6m$. The top of tank 10 is at a level of 15 metres, and the tank can therefore be assumed to be completely waterfilled after submersion. Maximum pressure on the lower edge of the hatch was roughly 16.85+2.6-11.5 = about eight metres. The load on the hatch was $0.25m^2*8m*1025kg/m^3*9.81m/s^2 = 20kN$.

[11] Information from conversations with crew on *Floatel Superior*.

listing. Heave was about 14-15 metres, pitch about 7˚ and roll about 10˚. The position was not regarded as acute[12].

The first officer reached the bridge at 03.21 and went through the check list for stability incidents (see [90]). This included checking watertight doors and initiating the closure of one showing as "open" on the bridge overview. The stability margin was assessed as good, and barriers against further water intrusion were in place with little leakage through the seal around the manhole hatch[13]. A printout from the ballast computer at 03.29 showed tank 10 to be completely filled with 111 tonnes of water, and the calculated stability margin was good (1.951 metres from the table-defined design limit for the draft). The trim angle was given as 6.959˚ and the list angle as 2.345˚. The mean draft was given as 13.591 metres. The total heel of *Floatel Superior*'s deck was specified as 7.3° towards the forward port column according to the stability analysis [12]. Pumping from tank 10 failed to have any effect, and was abandoned at 03.37, after which pumping began from tank 1 outer port to restore the facility to an even keel. That was achieved at 04.25 [19].

Stability analyses at 03.29 [12] and 05.09 [13] show that the ballast was adjusted from 5 433 tonnes to 4 982 tonnes. The 451 tonnes pumped out and further changes of 13 tonnes in other tanks meant that the draft changed from 13.591 to 12.945 metres.

It has been reported[14] that tank 3A outer port was water-filled before the incident, and that tank 10 outer port was the only one to fill with water. We dispute this and conclude that tank 3A filled with water between 01.40-02.15, when the facility altered its mean list from +1° to -3.75° (our reasoning is provided in chapter 9.2).

Checks made in connection with the investigation show that *Floatel Superior* had experienced several cases of alarms for high anchor line tension in bad weather. From before 21.40[15] on the incident night, a long sequence of overload alarms were logged on winch 4, which operates anchors 7 and 8 on two drums. Drum 2 held the line for anchor 8, so the alarm shows that the anchor was experiencing a minimum tension of 71 tonnes. At a tension of 78 tonnes, the control system freezes and the winch becomes inoperable, so the crew were unable to reduce the load. The alarms stopped around 23.40 on Tuesday 6 November[16]. We interpret this change as a possible indication of the (first) structural fracture on the bolster during the incident night. On that basis, the assumed development of the bolster damage started about 3.5 hours before the bilge alarm led to the leak in the column being located.

The storm reached its peak around 23.40 on 6 November 2012. This weather was the direct cause of movement by anchor 8, which led in turn to a number of cases of structural damage. During two hours of bad weather, between 23.40-01.40, the damaged bolster structure was broken up and the anchor could freely hit the hull.

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[12] Conversation on *Floatel Superior*. The text refers to personal observations by crew on board during the incident and later related from memory. Figure 20, Figure 21, Figure 22 and Figure 23 show the measured values on board which were subsequently processed during the investigation.

[13] According to Floatel International, the seal was defective. When this happened is not known. The last time tank 10 was opened prior to the incident was 29 May 2012 [61].

[14] Conversation on *Floatel Superior*.

[15] The log stores 500 entries using the method whereby the earliest entry is deleted when a new one is made once the 500 limit has been reached. The earliest stored entry in the log was at 21.40.

[16] Registered at 22.55.05, but with the clock set to the wrong time.

No alarms notified water intrusion in tank 3A between 01.40-02.15, nor did any alarms report a substantial change in the facility's mean list. Tank levels are transmitted continuously to the Lodic programme pursuant to section 15 of the ballast regulations. The facility's motion is measured and stored in the on-board VRS pursuant to section 12 of the ballast regulations. Simple changes to the software could have helped to sound the alarm for the incident earlier, and its scope would have been more clearly understood by those involved[17].

After damaging tank 3A with its rear side and knocking away the brace attached to tank 3A, the anchor has hung with its flukes against the hull. The damage could have developed quickly at roll angles of ±5˚, with the anchor swinging pendulum-fashion and hitting the hull. Five holes and deep scratches have subsequently been found in this area. The circular form of the damage and paint removal shows that the flukes have been moving for some time. Scraped-off mussels clearly reveal that the top of the shank, the shackle and the cable eye have moved by and large symmetrically between the remaining brace and the missing upper brace (see Figure 7). We regard this symmetry as a sign that the torn-off topmost brace was in place during the time when the anchor swung freely against the port side of tank 10. In other words, the topmost brace is assumed to have been ripped off immediately before the anchor ceased to swing freely along the hull, began to hit the forward part of the column, and then become wedged fast in the bolster where the crew could observe it from about 03.45. The uppermost brace was torn off with the doubling plate, so no significant damage was caused to the actual hull there. A possible penetration at the brace's fixing point would have caused a new hole in the already-damaged tank 10.

[17] Figure 20, Figure 21, Figure 22 and Figure 23 in this report could theoretically have been produced at the same time as data acquisition to the VRS, and could thereby have been used to warn of the list before 02:00.

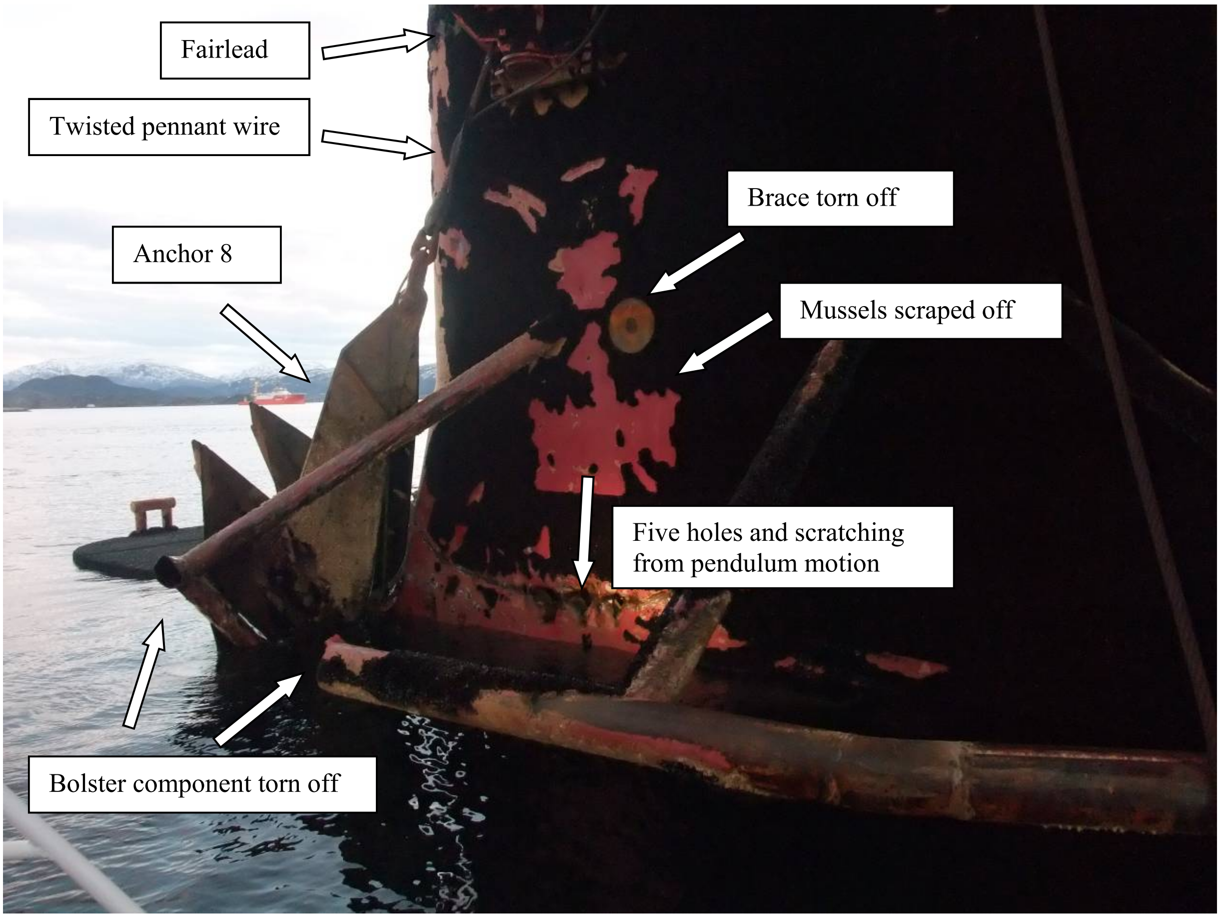

Figure 7: The damage site at anchor 8 after arrival in Kristiansund on 10 November 2012. Anchor 7 has been removed from its place to the right of the picture. Five holes can be seen in the hull just above the waterline (see arrows). The circular mark has been left by the torn-off brace. The black areas are covered with mussels and the hull is painted red. Red areas show where mussels have been peeled off from contact with the anchor and lines. The anchor is rotated, with a twisted pennant wire. The facility is in its transit draft of about 8.5 metres. At survival draft, the mean waterline is at the uppermost fixings of the bolster, to the right at the top of the picture. The photograph has been taken by the PSA.

At 03.12, when the crew became aware that something was wrong, the other tank had begun filling with water. Based on the comments in chapter 9.2, tank 3A had already taken in some 360 tonnes of water at that point. Between 03.00-03.20, tank 10 took in 111 tonnes of water after the anchor had pierced it in several places immediately above the pontoon deck. The 1.7˚ change in list corresponds to a water intrusion of about 130 tonnes[18], which is roughly 30 tonnes more than the maximum capacity of tank 10.[19] This could partly be explained by the inaccuracy of the estimated calculation of the listing effect of water (about 1.3˚/100 tonnes), which depends to a great extent on the location of the water in the facility. The discrepancy could also partly be explained if the water in the column shaft exceeded two cubic metres. In any event, the agreement between the rough estimate of 360 tonnes plus 130 tonnes of water intrusion in tanks 3A and 10 and the 464 tonnes of ballast plus fuel removed is so good that we regard the description of the course of the tank filling as certain.

[18] The approximate water intrusion in the second listing increase was 1.7˚/(1.3˚/100 tonnes) = 130 tonnes.

[19] Storage capacity in tank 10 outer port is 111 tonnes [7].

Figure 8: Hatch from the central column to ballast tank WB TK NO 10 OUTER-P. Marks from the reinforcement temporarily welded on during 7 November 2012 are visible where the paint has gone. Seal and bolts are removed. Photograph taken by the PSA in Kristiansund on 12 November 2012

Crew in the forward port column had heard noises and blows from outside the hull, and continued to investigate what had caused the water intrusion in tank 10. On deck, it was reported at about 03.45 that the railings on the stern side of the operating house for anchor winch 4 had been damaged [1]. From the observation point beside winch 3 (the level below the cabin), the bolster at anchor 8 was seen to be damaged and anchor 8 was not in its usual place (was gone). The sight line from anchor winch 3 to anchor 8 runs along the side of *Floatel Superior*. Anchor 8 was located from the observation point at winch 4 (the level below the operating house for that winch). At that time, the anchor was at rest on the wrong side of the bolster brace, wedged between the forward side of the column, the pontoon deck and the bolster structures[20]. That location corresponds roughly to what could be observed on arrival in Kristiansund, see Figure 7.

The incident report from the ECR describes the course of events briefly as a big leak at 03.12, further reporting to the bridge at 03.13, pumping at 03.14 and rousing the CEN at 03.15. The latter was in the engine room at 03.20, when the leak had been reduced to about two litres per minute through the efforts of mariners and electricians [8]. Guards were detailed to monitor the anchor and water intrusion in the column. Crew from the day shift were called out to help the night shift. Guards took it in turns to monitor damage, work and take breaks.

Those we have talked to did not regard the position as hazardous. No significant listing was experienced, since the facility was rolling a good deal in the heavy seas, which is thought to have “camouflaged” the list. Earlier, around 03.05, somebody in the ECR called the bridge to get the listing reduced because the scuppers were overflowing[21] [1]. No adjustment was noted in the DP log [19], but the report from the ECR specifies, without citing a time, that many reports were being received from catering personnel about overflows from floor drains in the laundry and cabins on green deck (the main deck at a level of 35.2 metres) [8].

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[20] Conversation on *Floatel Superior*.

[21] *Scuppers* are small openings in the gunwales of large vessels. They often have a cover hinged at the top so that it opens outwards. This means that more water flows out from breaking waves than can reach the deck over the gunwale. Without these covers, the deck would often be filled with water for long periods.

Statoil's representative on board was informed at 03.22, and came onto the bridge at 03.25. At 03.40, the Statoil representative notified the control room on Njord A and asked that the platform manager be mustered. The emergency response leadership on Njord A was established at 03.50, and the second-line emergency response organisations at Statoil and Floatel International informed of the position [1]. The PSA was notified at 04.16.

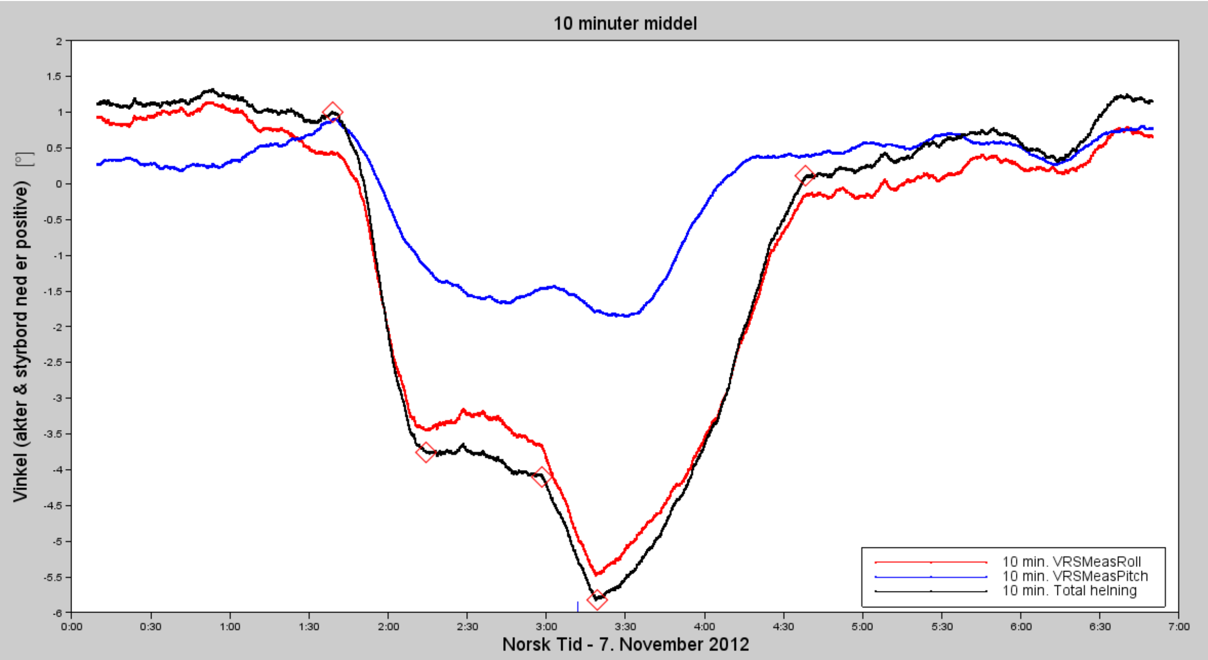

Figure 9: Calculated mean listing history from measured roll and pitch motions on the incident night. The diamond symbols mark the times when clear changes occur in the graphs – about 01.40, 02.15, 03.00, 03.20 and 04.40. These incidents and times are discussed in the text. The figure has been produced by the PSA on the basis of data files from Floatel International [56 and 57].

After printing out the status from the stability programme at 03.29, the first officer acted as on scene commander on deck. He inspected the damage and made a detailed report to the bridge at 03.45 [1]. The pennant wire[22] for anchor 8 was damaged, the fairlead[23] for anchor 8 was facing forward, the safety glass in the operating house was broken and the railing partly damaged [1]. It was impossible for the first officer to see anything from the operating house, and he had to stand outside and shine a torch down[24]. He determined that the anchor was not swinging freely, but lay relatively motionless at the forward end of the bolster. He and the deck crew considered the chance of improving matters by operating the anchor winch. In addition, the first officer and the master considered opportunities for turning the facility so that the damage site was on the lee side. It was decided that doing anything to secure the anchor would be too risky. Consideration was also given to leaving the damage site (anchor) in the same position, facing into the weather, in order to minimise its motion. *Floatel Superior* was therefore kept in the same position, with the damage site facing the weather.[25]

[22] The pennant wire is a steel rope attached to the anchor and used for handling it. It was attached by a two-part cock's foot to the anchor, with the other end hung aft of the operating house for anchor winch 4 in order to be transferred by crane to the anchorhandling vessel.

[23] A fairlead is a wheel which the line passes over where it changes from its vertical descent from the winch to connect with the anchor. The fairlead's orientation is adjusted by anchor tension and position. With normally stowage in the bolster, it will extend almost perpendicularly from *Floatel Superior*'s side.

[24] Conversations on *Floatel Superior*.

[25] Conversations on *Floatel Superior*.

At 04.25[19], the facility was ballasted to an even keel. The stability analyses nevertheless showed a minor list of 0.9° at 05.09 [13].

Work began at 07.00 to reinforce the manhole hatches by welding two steel bars horizontally across each of them so that they were fixed to the bulkhead. The two hatches were reported reinforced at 11.28 and 11.57 respectively [19].

Stril Poseidon was called up and asked for assistance at 04.45. Its estimated arrival time was then 08.00. POB at 07.35 were reported to be 374. *Stril Poseidon* arrived at *Floatel Superior* at 07.55.

A status meeting took place on the bridge at 04.45. Information was given to guests by the master and Statoil's representative in the cinema at 05.05 for the night shift and 07.00 for the day shift. The guests were asked to pack a bag each which they could take with them in the planned **personnel removal** by helicopter shuttle. Preparations for a reduction of POB in suitable weather had thereby been made. Helicopter fuel had not been available because of maintenance work, but was prepared for use at 06.05.

The master and Statoil's representative held meetings with Statoil's second line at 05.30 and 06.30. A status meeting was also held with Floatel International's second line at 08.00.

A "worst case" scenario analysis, with water filling the whole inner column, was conducted on board at 07.30 [1]. This analysis concluded at 07.56 that the facility would sink[26] if that happened [15]. Tests with deballasting tank 3A outer port at 08.45 failed to remove the water. The conclusion was then reached that two tanks were damaged. The master noted that the facility was at its design limit with two damaged tanks. The potential hazard was considered to have increased. The master accordingly wanted to remove the guests as quickly as possible. Thinking moved from controlled removal of personnel to planning of an **evacuation**. The consequence of water filling engine room 4 was analysed at 10.01, with the conclusion that one of three independent thruster "families" would be lost [1].

Another status meeting took place at 09.00. At 09.20, an emergency response leadership was established on *Floatel Superior*. The decision was taken to evacuate by helicopter in accordance with the lifeboat muster plan. People were asked over the PA system to put on warm clothes and a survival suit and take a bag of personal effects. *Floatel Superior*'s response leadership met at 09.40, with the information that helicopters were still unable to land (pitch 3.9˚, roll 4˚ and heave 5.6 metres). It was decided to sound a general alarm for mustering at the outdoor muster stations, and proceed if necessary to the lifeboats. The master spoke over the PA at 10.00, ahead of the alarm. The personnel were then no longer allowed to take bags or other equipment with them because this could not be accommodated in the event of evacuation by lifeboat or helicopter winching, or with available helicopter types. The general alarm was sounded immediately after this announcement, around 10.00.

A proposal from the second line to evacuate by winching from helicopters was discussed, but not approved by the master. Winching was expected to take in the order of one minute per

[26] The analysed position is far outside normal operational criteria, and the Lodic programme accordingly cannot be expected to provide exact results. Damage cases can be analysed in Lodic's stability programme on *Floatel Superior* using its emergency response function. This is not intended for operational use, but can be used when preparing for exercises or training, and for post-event analysis of damage conditions like the incident in question [136, and conversations with Kongsberg Seatex].

person, and it was felt that this evacuation would take considerable time and be a bigger risk than remaining on board and taking if necessary to the lifeboats.

After a successful trial landing with an SAR helicopter on Njord A, this machine first touched down on *Floatel Superior* at 10.14. A total of 23 landings by the SAR helicopter (16) and 330 squadron's Sea King (seven) took place over an hour and 22 minutes.[27] POB after the evacuation totalled 47 (later adjusted to 48). Those we have spoken to considered the process very efficient and controlled. A status meeting between *Floatel Superior* and the emergency response leadership took place at 12.10. The final post-evacuation POB was determined to be 48 at 12.48. A total of 326 people were evacuated.

Flotel Superior's heading was changed at 13.33 to prepare for leaving the field. Departure took place at 13.50 with a speed of 0.2 knots. *Floatel Superior* left the 500-metre zone around Njord A at 14.50. An additional helicopter landing at 14.58-15.01 took off another 10 people, leaving 38 of the maritime and catering personnel for the voyage to land. The master chose to sail "with the sea" using as little engine power as possible since he did not know the extent of the hull damage. The "restricted manoeuvrability" navigation light was turned on at 17:00 on Wednesday 7 November, and the DP log specifies "streaming south" [19].

The facility sailed to land under its own power, with assistance from various vessels. It halted at 09.15-10.20 on 8 November so that *Normand Ferking* could close on the port side to check the damage. The damage picture at that time was roughly as shown in Figure 7.

3.2 Conditions related to *Floatel Superior* in transit

The construction contract was entered into on 4 May 2007, the keel was laid on 21 May 2008 and the facility was delivered by Keppel FELS in March 2010.[28] *Floatel Superior*'s first job was in the Timor Sea for three months until June 2010, when DP was used. It was then transported to Ølen, partly by towing and partly under its own power. See chapter 9.3 for further details.

The transport procedure [73] specified that: "The *Floatel Superior* limitations are described in Marine Operations Manual Part 1.A Section 1. At no time the vessel shall be operated beyond these limits. Loads on hull structure impose limitations with respect to sea state and roll motions. The unit is to be ballasted down to survival draft when environmental conditions exceeding those specified in the operations manual . " The operations manual [69] states that: "The maximum significant wave height for transit condition is: Hs = 3.0 m. If the wave height is exceeded, the vessel shall be ballasted to survival draft." Floatel International reports that the whole transport from Australia to Europa took place at transit draft.[29] No halts were called en route as a result of weather conditions. The three-metre limit was set out of consideration for the hull rather than the bolsters.[30]

The daily log recorded wave heights of well over three metres on a number of days. A log entry was made every day. As a result, the waves have hit the anchors on many occasions and

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[27] A video of the evacuation can be viewed here: http://www.nrk.no/nyheter/distrikt/nrk_trondelag/1.8388317 and at
http://www.vg.no/nyheter/innenriks/artikkel.php?artid=10047927

[28] http://www.ptil.no/nyheter/tilsyn-med-boliginnretningen-floatel-superior-article7329-24.html.

[29] Conversations with Floatel International on 4 December 2012 in Gothenburg.

[30] Conversation with Keppel Fels.

placed undesirable loads on bolsters and hull. It is accordingly highly probable that *Floatel Superior* was damaged before arriving in Ølen.

Samples of mussels were taken by the PSA in Kristiansund at the points shown on the drawing in appendix C. The Institute of Marine Research [31] analysed these samples and established that the mussels were of the *Mytilus edulis* species, which is common in northern Europe, around the British Isles and along the whole Norwegian coast. This species relies on external fertilisation, followed by a period as free-swimming larvae. Many weeks can pass before these begin their attached life. The Institute of Marine Research has assumed that the mussels have settled (become attached) during June and July. That is the most important period for settling, but some also occurs in the spring and during the autumn. Mussels in all the samples have a smooth shell form and surface. That normally indicates very good growing conditions. Mussels in sample 1 were about five to 10 millimetres long and have probably settled in 2012. The size of the mussels in samples 2, 3 and 4 and in the reference sample varies (about five to 40 millimetres), but the biggest of them probably date from 2011 [31]. Fouling from Singapore, the Timor Sea and the transport to Europe vanished when *Floatel Superior* reached colder waters. The mussels on *Floatel Superior* became attached in Europe, at the earliest in Ølen from 26 October 2010. The mussel samples from the cracked braces support the view that several of the bolsters have had cracks in June-July 2011, in an environment with adequate water and nutrient flow to provide good growth conditions for mussels.

Four anchors were removed in Ølen [67 item 2.4]. It is normal practice for crew on the anchorhandling vessels to inspect the anchors visually and report on their condition to the bridge[31]. Whether this was done in Ølen is unknown. Floatel International writes that no documentation is available on whether an anchor inspection occurred [67 item 27].

Floatel Superior arrived in Ølen on 26 October 2010,[32] and left there on 27 April 2011. After Ølen, it had an assignment on Oseberg from May 2011-August 2012, and at Njord A from August until the incident of 7 November 2012. The mussels have probably settled in the damaged structural components in June-July 2011. Most of this damage probably occurred en route to Ølen. Some damage could nevertheless have been suffered on Oseberg. The bolsters lie just below the waterline in survival condition. Waves and hull motion accordingly impose substantial loads on anchor and bolster. See also chapter 5.1.1.

In addition, *Floatel Superior* was at transit draft on 7 November 2012 in considerably higher waves than the operations manual permits. According to the DP log, *Floatel Superior* was deballasted to 8.5 metres at 14.10 [19]. The highest Hs was seven metres [123]. [33]

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[31] Conversation with Viking Seatech, 12 December 2012.

[32] http://www.westconyard.no/Article3.aspx?NodeId=c04a252d-8869-4465-b83f-bfd9307dd565.

[33] In this case, it was sensible in our view to exceed the limits. An anchor was loose, with a full damage potential of damaging five tanks and a 17° list. *Floatel Superior* sailed to land with the anchor raised as high as possible to limit wave loads on it, low speed and “riding the waves” to avoid loading on the hull. The navigation light for restricted manoeuvrability (because of a damaged facility) had been lit and the facility had accompanying vessels.

4 Actual and potential consequences of the incident

4.1 Actual consequences

The incident did not cause personal injuries on *Floatel Superior*.

No harm was caused to the natural environment, but part of the bolster remains on the seabed. Three steel tubes are left on the seabed within the safety zone on Njord after the incident. Statoil does not intend to remove these [119]. How they are lying on the seabed is unknown. Statoil initially reported that the flotel withdrew to an area without infrastructure in the form of lines, pipelines or subsea systems [34], but reported later that the facility withdrew to the north-north-west. Statoil has confirmed that there was no infrastructure there [115].

The following were identified after the incident.

- Holes in the hull penetrating tanks 3A and 10, both on the outer port side.
- Damage to all four bolsters.
- The beginnings of hull damage at two other bolsters.
- Local damage to all eight anchors.
- Damage to the anchor line and pennant wire.
- Damage to the railings and a broken window in the operating house at winch 4.
- The need to take the facility to land, with the loss or postponement of revenues for Floatel International. All guests on the facility were evacuated on 7 November. The facility was back on the field on 29 November 2012.
- Delays to work on Njord A, and a delayed start to production [139].

Figure 10: Damage to anchor 8 on *Floatel Superior*, photographed in Kristiansund on 14 November 2012 by the PSA.

During the evacuation, all helicopter landings were handled by the same helideck team on Njord A. All eight of them were exposed to noise above the recommended maximum daily dose. Five cases of mild hearing damage or mild worsening of established damage were identified, one case of moderate damage and two cases of serious damage [138]. Following consultation with the commissioning authority, events on Njord A are considered to lie outside the mandate of this investigation.

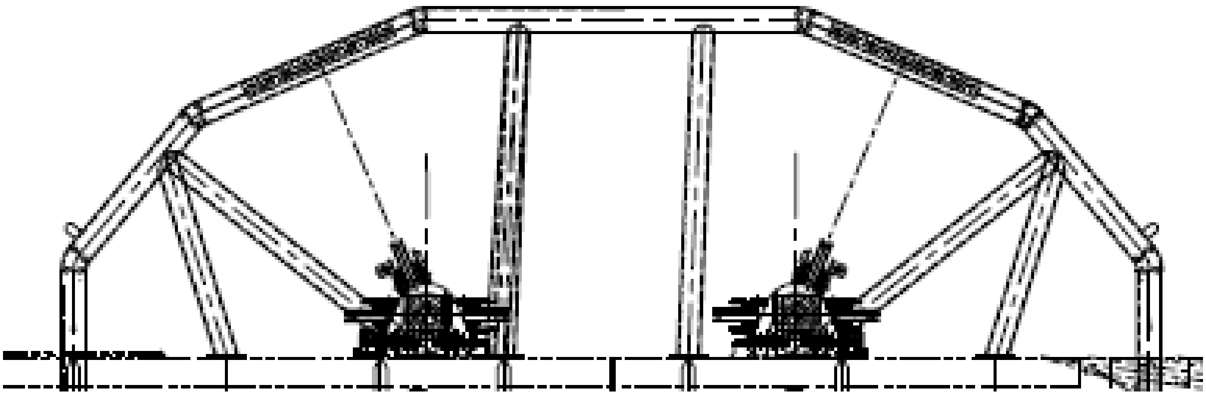

Figure 11: A drawing of the bolster on *Floatel Superior* produced by Keppel FELS [58]. It consists of 14- and 16-inch steel tubes welded together. The anchors are attached to the wear surfaces identified by black infill. The dotted lines show the wire ropes from the winches to the anchors. The latter are not shown, but their intended positions are indicated by the wire ropes. Anchor position 8 is on the right-hand side of the figure and 7 to the left. See also Figure 12, which shows the same bolster after the damage.

Figure 12: The bolster after the damage. Line 7 is to the left and line 8 on the right. Line 7 has been used here for mooring to land. The line running across the picture is the pennant wire. A comparison with Figure 11 shows which components have fallen off. The photograph was taken in Kristiansund on 13 November 2012 by the PSA.

A more detailed description of the damage is provided in chapter 9.4.

4.2 Potential consequences

The amount of water pumped out (and fuel consumed) to get the facility on an even keel was 464 tonnes. During the incident, the maximum list was 5.8°. At the same time, the 12-tonne anchor was displaced somewhat, causing a slight change to the lever arm, but we regard the effect as small and disregard this change. Three steel tubes from the bolster fell off, making the facility somewhat lighter. We have estimated their weight at three-four tonnes. For calculation purposes, we assume that changes in water volume in this part of the facility give in the order of 1° of list per 80 tonnes of weight change.[34]

In addition to puncturing tanks 3A and 10, the anchor also scraped the outside of tanks 2 outer port, 11 outer port and 3B outer port. See Figure 35. These could easily also have been punctured.

- Tank 2 outer port. The anchor has scraped this tank's wall and removed a good deal of the wall thickness. It could hold 541 tonnes of water, and already contained 11 tonnes. Filling it with water could have caused about 530/80 = 6.6° additional list. Together with the 5.8° actually experienced, this would have been substantial.
- Tank WB TK 11 outer (P). According to the tank plan [7], this had the same volume as WB TK 10 outer (P). The list could then have been about 1.5 ° higher.
- Tank WB TK 3B outer (P). According to the tank plan [7], this has a volume of 367 cubic metres. At 03.29, it contained 65.5 cubic metres of and could then have accommodated another 301 cubic metres. Estimates show that this would have given 3.5° of additional list.

Figure 13: The hull at the front of the column outside tank 10. A simple penetration before the anchor has become wedged between hull and bolster components. Note the bent plate marked with an arrow in the left-hand picture. The picture to the right shows extensive wear on hull plates outside tank 2. The photographs have been taken by the PSA in Kristiansund on 12 November 2012.

A not wholly unrealistic scenario involves the anchor puncturing all three of these tanks in addition to the two which were punctured.[35] The total additional waterfill would then have been 1 500 tonnes (see Figure 35). At a rough estimate, this would have given a list close to the design limit of 17°.[36] Note that the facility, in addition to its mean list, was also rolling +/-

[34] 464 tonnes/5.8° = 80 tonnes per degree. By comparison, *Scarabeo 8* could have developed 1° of list when filling 97 tonnes at the very end of one pontoon: $1189m^3$ /12.2° = $97m^3$ per degree [145].

[35] Statoil [139, page 32] describes this as something which could have happened "under slightly different circumstances".

[36] We have calculated the list as 5.8 + 6.6 + 1.5 + 3.5 =18.4°. Statoil [139] has calculated the additional effect of tanks 2(P), 3B(P) and 11(P) as 10.6°. In addition to 5.8° (our calculation), this gives 16.4°. Floatel

5-6° throughout the incident night. Weathertight openings might then have been flooded at a mean list of 11-12°.

Based on observations of the damage site, the master resolved *not* to change the direction of *Floatel Superior* after the damage had been discovered. That was to ensure that the anchor remained where it was. A change of direction could have caused it to come loose and do more damage. At the same time, more anchors could have come free from some of the other bolsters which were already damaged. Had other ballast tanks been punctured, the list might have increased and made evacuation of personnel on the facility more difficult. We have not discussed this in more detail, but note that the most likely heading would have brought the forward starboard column onto the weather. This is also where the most extensive damage to the other bolsters was observed in Kristiansund.

Had the weather been worse and lasted considerably longer, several anchors at other corners may have come loose and created more holes in the hull. The likelihood of several simultaneous incidents is considered small but, as mentioned above, an active change in the facility's position could have posed the threat of similar damage to the forward port column. Active decisions on board may therefore have prevented an escalation of the damage.

When the pennant wire broke free and tore off part of the railings, personnel could have suffered serious harm had they been present at the operating house for the anchor winch or on the anchor winch deck. Because the railing was lost at the best point for standing to observe the damaged bolster, a danger also existed that people might have fallen into the sea at a later time while in the area to inspect/assess the damage in bad weather. A man overboard was thereby a relatively likely potential event on the night of the incident.

The pennant wire from line 8 might have become entangled in one thruster, but not in two. That might have made one thruster unusable. Experience exists of a wire rope stopping a thruster on *Far Grimshader*, which led in turn to a collision with *Songa Dee* on 18 January 2010. The consequences of losing a thruster on *Floatel Superior* are regarded as small because of the redundant DP3 system.

When the outer hull was punctured, one barrier remained against the large inner column shaft – both a watertight hatch, secured by 22 bolts (Figure 8) with a seal, and the actual inner bulkhead were intended to prevent further water intrusion. This barrier is regarded as robust, providing all the bolts have been properly tightened. Some of the bolts had broken [104]. In our view, a leak through the seal alone is unlikely to have caused a serious incident. The emergency response leadership on board carried out stability analyses [17] which showed that filling the inner column could have caused the facility to sink. However, this would have happened slowly, since pumping and ballasting could have delayed listing.[37] The inner bulkhead and hatches are dimensioned to withstand water in the tanks right up the air ventilation and with a one-year wave height [38], and represent a highly reliable barrier. A case

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International [104] has calculated the effect in each direction as 5.57° and 10.01°. That gives an overall list of 11.5° ($\sqrt{[5.57^2 + 10.01^2]}$). Such estimates function best with small inclination angles, and are given here solely as an indication of the size involved.

[37] The column has two ballast and one bilge pumps with a capacity of 335 tonnes per hour [139]. We have not assessed whether this is adequate pursuant to section 11 of the ballast regulations on capacity requirements.

[38] A one-year wave is a wave with an annual probability of 10^0 for being exceeded. This requirement follows from the maritime regulations. The concept is defined in the same way as the hundred-year wave, but the wave height is a good deal lower.

can be envisioned in which the manhole hatches had not been closed after the previous inspection. It is unlikely to have been possible to close the hatch(es) afterwards. We have found one example since 2000 of a reported incident, when a tank on *Transocean Winner* with a volume of 75 cubic metres became filled with water in 2011 because a manhole hatch was not closed.

About 1 200 tonnes of fuel [12] and some lubricating oil was carried on the facility but, since this is a flotel, it did not contain other substantial quantities of hydrocarbons which could pose a threat to the environment.

Floatel Superior had an external hull and inner bulkheads 1.5 metres apart, pursuant to the requirements of the NMA. The anchors were so constructed that they penetrated about as deep into the hull as the opening was wide. Since there were stiffeners about 0.6 metres apart, the intrusion was confined to 0.6 metres. We consider it unlikely that the anchor could have damaged the inner bulkhead.

Since *Floatel Superior* is a DP3-class facility, we consider a collision with Njord A or B to have been unlikely except in a scenario with a massive inflow of water which shut down all propulsion machinery. DP3 means that *Floatel Superior* has substantial redundancy in relation to an engine breakdown. This is considered in greater detail in chapter 5.2.4.

The move from Njord to Kristiansund was made at transit draft in waves above the design limit of three metres Hs. That could have put some additional strain on the hull. The log on board indicates that the facility streamed with the sea at low speed in order to minimise hull loading.

5 Observations

Our observations are divided below into the following categories:

- nonconformities from the regulations
- improvement points where we see deficiencies, but lack sufficient information to be able to establish a breach of the regulations
- lessons learnt and other observations.

5.1 Nonconformities

5.1.1 Inadequately dimensioned bolsters

Nonconformity

Floatel International has utilised bolsters which have been underdimensioned for coping with tension from the anchor winches and wave loads.

Grounds

The anchor winches were so constructed that they could cope with tensions up to roughly 78 tonnes. Dimensioning of the bolsters was based on a characteristic load of 21.8 tonnes.[39] A safety factor of two was applied at 21.8 tonnes, so that the dimensioning load was 43.6 tonnes. The difference between 43.6 and 78 tonnes is considerable.

Bolsters on *Floatel Superior* are dimensioned for waves pursuant to DNV-RP-C205.[40] This gives the pressure on the anchor, which can theoretically be infinitely high for a horizontal surface. A drag coefficient[41] of Cd = 5.15 has been used.[42] DNV-RP-C205 states that Cd = 2π = 6.28 must be used as a minimum, but can well be larger. Bruce [133] wrote that "The gross area of the fluke of the 12mT Bruce FFTS GP anchor is 15.8 m^2". The analysis used 15.14 m^2.[43] The difference probably arises because dimensioning was based on Steveprice anchors,[44] but Bruce units were chosen after tendering. The anchor was changed to a Bruce model with a larger area without taking account of the consequences. Taken together, the coefficient and area variations mean that the dimensioning load is roughly 21 per cent too small.[45]

The biggest nonconformity nevertheless lies in the way wave particle speed is calculated. Keppel FELS has applied a vertical wave particle speed of 2.7m/s for calculating wave loads on the anchor. Hull motion has not been taken into account. Assuming deep water and a wave height of 30 metres, the wave particle speed at the bolster is about 5m/s. On the same assumptions, the highest wave on 7 November 2012 (Hmax = 19.5 metres) had a wave particle speed of about 3.7m/s at the bolster – considerably higher than the figure applied by Keppel FELS. We have also calculated an example which combines a hull heave of plus/minus five metres with the wave particle speed, and find that this yields a substantial

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[39] Bröhl reported in the conversation that it had asked Keppel Fels for loads, but received no response. Keppel Fels had applied its interpretation of possible tensions in the Bröhl documentation to dimension the bolsters.

[40] Keppel Fels reported that it used the 2007 edition of DNV-RP-C205. The relevant chapter in the 2010 edition is 8.7 – wave impact loads on plates.

[41] The drag coefficient, area and speed are used to calculate the load = 0.5*Cd*area*speed*speed.

[42] Telephone conversation with Keppel Fels.

[43] Telephone conversation with Keppel Fels.

[44] Telephone conversation with Keppel Fels.

[45] $= (6.28/5.15) * (15.8m^2/15.14m^2) = 1.27$. Furthermore, 1-1/1.27 =0.21, or 21 per cent.

increase. In addition come roll and pitch motions.[46] When the speed contribution is squared, the difference in wave loads becomes considerable.

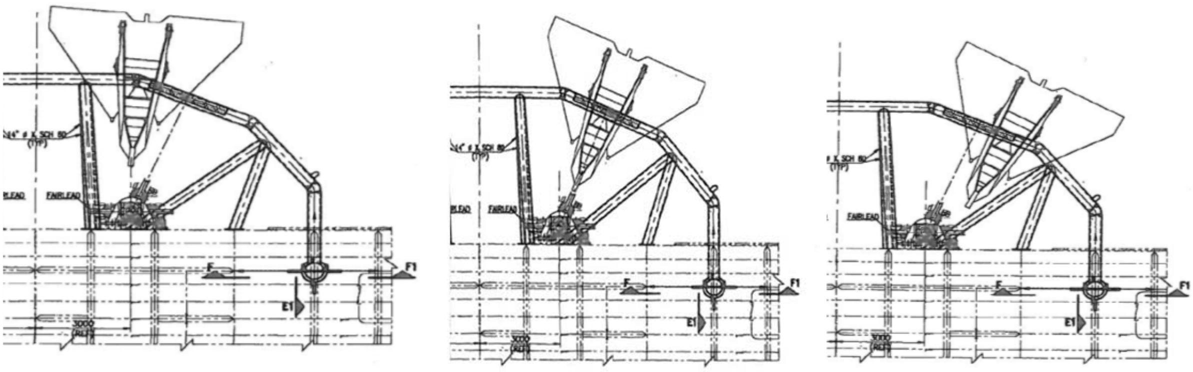

Figure 14: Drawing of the anchor positions: Centre: correctly stowed in contact with the wear surface on the bolster and with a short line (about 22 metres[47]). Left: against the bolster's aft brace. Right: against the forward brace. The bolster section intended to hold the anchor is roughly right-angled at the shortest distance from fairlead to hull side under the fairlead (centred). If displaced in the order of one metre to either side, the contact points on the anchor reach the bend on the bolster and the line is lengthened by about 50 millimetres[48]. That causes the active part of the wire to be elongated by 50/22000 = 0.3 per cent. Our estimate for the increase in line tension to reach this geometry is 44-63 tonnes[49].

Keppel FELS has subsequently calculated[50] that, when the anchor moved from its intended position and towards the brace, the line must have elongated by the equivalent of 44 tonnes of tension. That is substantially larger than the load applied by Keppel FELS in its wave analyses.

Keppel FELS[51] considered that the tension and length measurements for the *Floatel Superior* winches were wrong. With the anchors removed, the tension measurements still showed a substantial load. This is discussed in greater detail in chapter 9.5.

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[46] Statoil [139] has estimated the sum of all the motions to be 6.1m/s.

[47] Active line length is assumed to be a half-turn of the drum (five metres), free vertical length (13 metres) and angled line from fairlead to anchor (four metres). Total L = 22 metres active wire length with parked anchor.

[48] Estimated geometry change for the wire rope from anchor movements in the bolster. Vertical distance from bolster level to fairlead: eight metres. Horizontal distance from hull under fairlead to bolster: five metres (line angle from horizontal plane is estimated at (8/5) = 58˚). Nominal length from fairlead to anchor contact with bolster is $\sqrt{(8^2+5^2)} = 9.434$ metres. Horizontal displacement means that the new length from fairlead to bolster is $\sqrt{(8^2+5^2+1^2)} = 9.487$ metres. The elongation (taken up by the line since the anchor is much stiffer) is about five centimetres. Line elongation with 22 metres of active line is about 50/22 000 = 0.3 per cent. Keppel Fels reported in a phone conversation that it had calculated this to be 46 millimetres.

[49] The anchor line is a 6x49IWRC type with a diameter of three inches = 76 millimetres. *Floatel Superior*'s anchor line had an elasticity module of E=68GPa [98], and the purchase documentation [68] specifies the mean breaking load as MBL = 490 tonnes. The cross-sectional area of the steel wire rope is about $A=0.85*39^2*\pi \approx 4*10^3 mm^2$. With 22 metres of active line, stiffness at the anchor in the bolster is about $K=E*A/L = 12.4*10^9 N/m$ ~1.26 tonnes/mm. HSE specifies [151] the typical stiffness of wire rope as a function of its elongation: $E=1.21*10^5*(load/MBL)^{1/3}$. At a load of 50 tonnes, this corresponds to E≈57GPa => K=1.06 tonnes/mm. A five-centimetre elongation can thereby cause an estimated increase in tension of 53-63 tonnes in the anchor line. Keppel Fels reported in a phone conversation that it calculated about one tonne per millimetre, and estimated a load increase of 44 tonnes.

[50] Telephone conversation with Keppel FELS.

[51] Telephone conversation with Keppel FELS.

As detailed in chapter 9.8, facilities other than *Floatel Superior* have suffered damage to bolsters and anchors.

Requirements

Section 25, first paragraph, of the activities regulations on the use of facilities, see section 3 of the framework regulations on the application of maritime regulations in offshore petroleum activities, see section 6, sub-section 1.1, of NMA regulation 0856 of 4 September 1987 on the construction of mobile offshore units: "The unit shall be constructed in such a manner as to be strong enough to withstand the weather and wind conditions which may be anticipated ... The unit shall be of sufficient strength to withstand the most unfavourable combination of maximum environmental and functional loads."

5.1.2 Inadequate hull dimensioning to withstand an unsecured anchor

Nonconformity

Floatel International has taken the hull of *Floatel Superior* into use without this structure having adequate strength. Anchor movements caused several holes in the hull in two tanks, which put the facility in danger.

Grounds

Several holes were caused in ballast tank 10 outer port from many direct blows on the external hull. Two holes were caused in tank 3A outer port – one penetration from a direct hit by the rearmost corner of the anchor and another caused when a brace hit (repeatedly) by the anchor was torn free of the hull along weld seams. The hull has not been sufficiently robust to withstand loads from an unsecured anchor.

DNV-OS-E301[52] states: "Anchor bolsters shall be efficiently supported to the main structure. However, if the anchor bolsters are damaged or torn off, the main structure shall not be significantly damaged." This is achieved in practice by installing a doubling plate between the bolster and the hull, without any assessment of the consequences of the anchor then being unsecured.

The doubling plate is dimensioned as a weak link, so that the hull does not suffer harm if the bolster is damaged. On *Floatel Superior*, the one fracture of the hull was caused by fatigue cracking, which is outside the calculation base. As an example, section 7.13 in Norsok N-001 on design of weak links states that "In special cases a weak link may be introduced in a design in order to obtain a prescribed failure mode. If a weak link is used in a structure, due considerations shall be made to determine geometry and material properties such that that the intended structural behavior is achieved for all possible design conditions." At a functional level, this text is also appropriate for fatigue cracking without mentioning fatigue specifically. The DNV standard does not include a corresponding text.

DNV considered the use of a doubling plate sufficient to ensure a weak link.[53] During design work, the design office has carried out a simple comparison of weld dimensions as the basis for expecting a fracture to occur on the bolster side of the doubling plate.[54] This analysis has not included the possibility of crack propagation from fatigue loads.

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[52] DNV-OS-E301 position mooring, October 2010 Ch 2 Sec 4, O103.

[53] Conversation with DNV from Gothenburg.

[54] Conversation with Keppel Fels from Gothenburg.

Requirements
Section 25, first paragraph, of the activities regulations on the use of facilities, see section 3 of the framework regulations on the application of maritime regulations in offshore petroleum activities, see section 6, sub-section 1.1, of NMA regulation 0856 of 4 September 1987 on the construction of mobile offshore units: "The unit shall be constructed in such a manner as to be strong enough to withstand the weather and wind conditions which may be anticipated ... The unit shall be of sufficient strength to withstand the most unfavourable combination of maximum environmental and functional loads", see DNV-OS-E301 on position mooring, October 2010 edition. Ch 2 sec 4, O103, which states: "Anchor bolsters shall be efficiently supported to the main structure. However, if the anchor bolsters are damaged or torn off, the main structure shall not be significantly damaged."

5.1.3 Inadequate protection of personnel from the pennant wire

Nonconformity
The pennant wire and the area around its holder were not adequately safeguarded to prevent personal injuries.

Grounds
The holder for the pennant wire was at head level when crew members were attaching the wire to the crane hook.

The pennant wire tore with it the railings, which landed on the platform on the inside of the original position of the rails. The wire or railings then hit the winch operating house and broke its window.

How far into the platform and operating house a person would have been affected is uncertain.

The wire holder was designed in such a way that a fracture would cause damage to railings and cabin, which must be well protected pursuant to the regulations. No weak link or other safety device could have isolated the damage and reduced the damage potential. Similar damage could have been caused by a possible emergency release of the anchors from their stowed position (in the bolster with the pennant wire in the holder).

No solution is available to ensure that consequential damage from uncontrolled anchor deployments or displacements will be limited.

Figure 15: An intact pennant-wire holder on *Floatel Superior*. The wire is freed by lifting the loop away from the hull with a crane. The whole steel structure for wire 8 was ripped off, including holder and railing. The photograph was taken by the PSA in Kristiansund on 13 November 2012.

Requirements
Section 25, first paragraph, of the activities regulations on the use of facilities, see section 3 of the framework regulations on the application of maritime regulations in offshore petroleum activities, see NMA regulation 0998 of 10 July 2009 on positioning and anchoring systems on mobile offshore units (anchoring regulations 09). Section 12 (1) on operation, instrumentation, signs and alarms requires that "[it] shall be possible to operate the mooring winches from a well protected separate operating house by the winch. From the operating house it shall be possible to survey the anchor handling vessel, anchor line, anchor winch and anchor chain/steel rope stoppers/pawl to ensure that a safe laying out and heaving in can be performed. The house shall be located so that it will not be hit by the anchor line in case of release of the whole length."

5.1.4 Inadequate securing of anchors in bolsters

Nonconformity
Floatel International has used a solutions whereby the anchors could not be adequately secured to avoid movement.

Grounds
The anchors display damage from moving horizontally and striking the braces. Several braces have damage from being hit by anchors.

Crew have reported that several of the anchors were observed to have moved. Nothing was done when it became known that the anchors had moved en route to Europe. The matter was nevertheless raised again later. The minutes from the offshore meeting of 28 October 2012 [74, item 1.33] states: "Should we remove anchor? The risk to remove 29.04. Ongoing 11/5 No news 12/6 Plans for conservation of the winch. 22/7: No news from ... 5/9 Plan is to remove when we do next "yard" stop, on yard list. 28/10: No news."

A person on board wrote in September 2012 [42]: "Chafing of anchors on the bolster: Problems have been experienced with anchor chafing on the bolster. This could be the reason for the extra tension induced, resulting in overload protection." The writer had two proposals for action, one of which was: "Removing anchors, cutting socket and securing wire on drum. Fairlead to be interlocked in stowing position. This will remove limitations in anchor winch maintenance and remove risk of having anchor chafing and inducing overload." We regard this memo as clear evidence that the maritime crew understood the damage potential, even if they say they thought that the design could withstand what it was subject to.

It was decided on 5 September to remove the anchors during the next yard stop, which was scheduled for the first quarter of 2013 [104].

DNV-OS-E301[55] states: "The anchors shall be effectively stowed and secured in transit to prevent movement of anchor and chain due to wave action". How large the load on the winch must be to achieve this, and how the anchor should otherwise be secured is left to the designers and users. See also the discussion in chapter 5.3.1. The tension used has proved to be inadequate for keeping the anchor in position.

Requirements
Section 25, first paragraph, of the activities regulations on the use of facilities, see section 3 of the framework regulations on the application of maritime regulations in offshore petroleum activities, see section 6, sub-section 1.1, of NMA regulation 0856 of 4 September 1987 on the construction of mobile offshore units: "The unit shall be constructed in such a manner as to be strong enough to withstand the weather and wind conditions which may be anticipated ... The unit shall be of sufficient strength to withstand the most unfavourable combination of maximum environmental and functional loads", see DNV-OS-E301 on position mooring, October 2010 edition. Ch 2 sec 4, O103, which states: "The anchors shall be effectively stowed and secured in transit to prevent movement of anchor and chain due to wave action."

5.1.5 Deficient logging of line tension

Nonconformity
It was not possible to acquire data on tension in the anchor lines.

Grounds
Floatel International reported on 2 December 2012 that "No log exists for this"[64 no 28].

Floatel International wrote to Keppel FELS: "We changed (upgraded) the mooring winches to meet the new NMD requirements on brake holding power during the construction phase ..." Keppel FELS then responded: "It was in the original contract and the AoC documentation shows compliance with NMD 2009 edition" [103]. Bröhl nevertheless wrote that "The winch is manufactured according to DNV class rules and regulations" [49]. The NMA has stricter requirements than DNV. It is unclear whether the upgrade has been confined to the brakes. Logging of the line tension is not included

Requirements
Section 25, first paragraph, of the activities regulations on the use of facilities, see section 3 of the framework regulations on the application of maritime regulations in offshore petroleum activities, see NMA regulation 0998 of 10 July 2009 on positioning and anchoring systems on mobile offshore units (anchoring regulations 09). Section 12 (4), sentences 1 and 2 on operation, instrumentation, signs and alarms, which requires that "continuously manned

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[55] DNV-OS-E301 position mooring, October 2010 Ch 2 Sec 4, O101.

control room shall have instruments for reading the length laid out, and continuous reading and logging of line tension. The line tension shall automatically be saved and the information shall be accessible for at least the next 30 days."

5.1.6 Deficient safety equipment for lifeboat coxswains

Nonconformity
It was not possible to safeguard coxswains adequately during evacuation by lifeboat.

Grounds
During the conversation with a lifeboat coxswain, it emerged that the height of the coxswain's headband could not be adjusted. This meant that the person concerned was too short to protect their head with the installed band. The coxswain sits facing the sea even during the drop.

A "stop card"[56] had been issued because the headband intended to protect lifeboat coxswains was too high up the chair for all users [92 og 93]. Floatel International raised this issue with lifeboat manufacturer Norsafe, which said that it did not have equipment which could be used by short coxswains.[57] Floatel International had not converted the lifeboats by November 2012, but it emerged during the investigation that a tender for the work was obtained from the lifeboat supplier on 18 September 2012 [149 and 150]. The scope of the tender has not been described in detail, but covered improvements related to the headband issue.

A number of cases of injury when using freefall lifeboats have been published. For information, we briefly describe some we know of. The IMO[58] describes five injuries on freefall lifeboats in 1998-2001: whiplash (M/V *Rigoletto*), back pain (M/V *Don Quijote*), serious injury from not wearing the seatbelt (M/V *Elektra*), boat entering the sea with slight list causing a number of minor injuries (M/V *Titus*) and back/thigh pains (M/V *Boheme*). Tsychkova[59] writes further that 34 500 people had participated in freefall lifeboat tests in Norway up to 1998, with three reported injuries: two from banging into VHF radios and one for a person without his head held to the chair back. Nutec in Bergen had 59 176 course participants in 1985-92, involving 16 injuries in falls from 28 and 12.5 metres.

Requirements
Section 4 of the management regulations on choosing technical solutions which reduce the probability of harm, errors, hazards and accidents.

Section 3 of the framework regulations on the application of maritime regulations in the offshore petroleum activities, see section 9, sub-section h, on requirements for designing life-saving appliances in the NMA regulations on evacuation and life-saving appliances on mobile offshore units.

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[56] Stop cards are a scheme which allows employees to notify undesirable incidents and monitor their colleagues.

[57] Conversations in Gothenburg on 4 December.

[58] IMO: Measures to prevent accidents with lifeboats, draft amendments to Solas regulation III/19.3.3.4, 18 December 2003.

[59] Tsychkova, Elena: Evaluation of adequacy of current design criteria for free-fall lifeboats – literature overview, annex to IMO: measures to prevent accidents with lifeboats, 2 November 2004.

5.1.7 Inadequate documentation

Nonconformity
Documentation was inadequate on the use of bolsters, anchors, anchor winches and stability analyses.

Grounds
Floatel International has taken the winches into use without the necessary documentation. Information was missing, for instance, on what the alarms meant, as was a figure which showed what needed lubricating regularly in the winch and details of tensions on the winch when the anchors were stowed in the bolsters. The overview of alarms received by Floatel International after the incident [59] was not very informative. Floatel International has not registered this as a nonconformity and had the deficiencies corrected. It received verbal information on the tensions to be used, but not in the documentation.

Crew on *Floatel Superior* discovered that the anchor winches cut out when loads exceeded 71 tonnes. Bröhl maintained that this first happened at 78 tonnes. The documentation did not show that the load was then significantly above that used in dimensioning the bolsters. Neither Keppel FELS nor Bröhl had provided information on this. Nor was there a safe way of reducing the tension when it had become so high.

Documentation delivered to the facility for Lodic's stability analysis software was a 2006 draft. The Lodic software delivered to Keppel FELS for *Floatel Superior* contained specific documentation for the facility, which was not correctly installed on board.

The operations manual specifies that the anchors must be stowed in the bolsters during transit [25] and when not in use [97]. However, the manual is deficient with regard to such aspects as

- which operational conditions underpin the analyses concerning tension on the anchor winches and the weather conditions in which the bolsters could be used
- measures to be adopted ahead of storms
- measures to be adopted when observing that anchors have come loose in the bolsters.

Requirements
Section 6, paragraph 3, of the management regulations on management of health, safety and the environment requires that "the necessary governing documents shall be prepared ..."
Section 23, paragraph 1, sentence 1, of the framework regulations on general requirements for material and information requires that "the responsible party shall prepare and retain material and information necessary to ensure and document that the activities are planned and carried out in a prudent manner."
Section 90 of the activities regulations on position, with guidelines, see section 16 on [the] procedure [for] the anchoring operation, item (4), of NMA regulation 998 of 10 July 2009 on positioning and anchoring systems on mobile offshore units (anchoring regulations 09), which requires that "information necessary for the safe operation of the anchoring/ positioning system shall be given in the operations manual. The consequences of failure in the positioning system shall be known. The guidelines necessary for the operation of the systems shall be given so that the safety is ensured and that the requirements in this Regulation are complied with at all times."
Section 15, first and second paragraphs of the management regulations on information, which state that "the responsible party shall identify the information necessary to plan and carry out the activities and improve health, safety and the environment. It shall be ensured that the necessary information is acquired, processed and communicated to relevant users at the right time."

5.1.8 *Floatel Superior* was operated beyond its design assumptions

Nonconformity
Floatel International operated *Floatel Superior* beyond its design assumptions without assessing the consequences of such operation for the facility's integrity.

Grounds
The operations manual [95] and information provided by DNV and Keppel FELS[60] make it clear that the assumption during the design phase was that *Floatel Superior* would not stay at transit draft if Hs exceeded three metres. This limit was set with regard to the hull rather than the bolsters. Operating at transit draft in higher waves would exceed hull capacity.[61]

As noted in chapters 3.2 and 9.3, *Floatel Superior* has been operated at transit draft in higher waves than those specified in the operations manual.

We have not seen documentation which indicates that the consequences of operating beyond the design assumptions have been clarified and assessed.

Requirements
Section 25, paragraph 1, of the activities regulations on use of facilities requires that "use of facilities and parts of these shall be in accordance with requirements stipulated in and in pursuance of the health, safety and environment legislation and any additional limitations that follow from fabrication, installation and commissioning. The use shall at all times be in accordance with the facility's technical condition and the assumptions for use that form the basis of the analyses, cf. Chapter V of the Management Regulations."

Section 16, paragraph 4, of the management regulations on general requirements for analyses states that "criteria shall be set for carrying out new analyses and/or updating existing analyses as regards changes in conditions, assumptions, knowledge and definitions that, individually or collectively, influence the risk associated with the activities."

5.1.9 Deficient risk understanding and compliance with requirements

Nonconformity
Deficiencies existed in identifying risk and in complying with requirements and preconditions for using *Floatel Superior*.

Grounds
Floatel International is a new player on the NCS and *Floatel Superior* is its only facility subject to Norwegian regulations. Since *Floatel Superior* was taken into use in May 2011, the PSA has received reports of seven undesirable incidents on board. One of these (8 December 2011) was a serious incident which has been investigated by Statoil [117]. While bad weather was developing on 8 December 2011, the bridge from *Floatel Superior* to Oseberg B went into autolift mode (automatic disconnection) while people were on it. Statoil also knew that there had been three other autolift incidents. One of Statoil's conclusions[62] accords with our observations concerning Floatel International in this report concerning deficient or inadequate risk identification.

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[60] The conversations in Gothenburg

[61] The conversations with Keppel Fels from Gothenburg.

[62] Chapters 1.3 and 7.1.

Floatel Superior was towed in higher waves than specified in the operations manual or assumed in the hull analyses. No nonconformity process was conducted with associated risk assessments and the adoption of compensatory measures for this condition. That also applies to nonconformity 5.1.6 (safeguarding of lifeboat coxswain).

The crew observed that the anchors had shifted as early as the transit to Europe, without any check being made of the consequences for the bolsters. The latter were assumed to be sufficiently robust. Neither bolsters nor anchors were checked in Ølen. When the issue of unsecured anchors was raised again, it was decided that they would be demounted when the facility next came to land. A number of alarms were sounded from the anchor winches. These alarms were logged without anything being done about their cause. Bröhl was called to check and carry out maintenance on the winches. The consequences of the alarms were not understood by those involved, and nothing was done about their causes.

Requirements
Section 19, paragraph 1, letter a), of the management regulations on collection, processing and use of data states that "the responsible party shall ensure that data of significance to health, safety and the environment are collected, processed and used for ... monitoring and checking technical, operational and organisational factors."

5.2 Improvement points

5.2.1 Deficient updating of information on the bridge

Improvement point
The system clocks were not updated on a number of systems. Information in and about the stability programme was wrong.

Grounds
Floatel International had chosen[63] not to have synchronised clocks for the onboard systems. Problems were observed with obtaining the correct time history from a number of systems because clocks had various inaccuracies and settings, such as Norwegian, UTC and Singapore time, and went wrong with varying inaccuracies.

Printouts from the Lodic programme during and after the incident show that the anchor information was incorrectly specified. All the stability analyses presented are calculated on the basis of eight 25-tonne anchors. Eight 12-tonne anchors were installed on 7 November. The anchors were removed after the repairs in Kristiansund, but the Lodic programme continued to register 25 tonnes. The correct anchor weight can be entered by an operator who knows the password. The anchor tension was also incorrect. See chapter 9.5. Mooring loads are calculated on the basis of the paid-out line, water depth and tension measured at the winch. At short line lengths ("paid-out-line under threshold" – value not specified), only the weights of the wire rope on the drum and the anchor are used.[64]

Requirements
Section 15 of the management regulations on information states that "The responsible party shall identify the information necessary to plan and carry out the activities and improve

[63] Conversations on *Floatel Superior*.
[64] Conversation with Kongsberg Seatex (formerly Lodic).

health, safety and the environment. It shall be ensured that the necessary information is acquired, processed and communicated to relevant users at the right time."

5.2.2 Releasing anchor winches after overload

Improvement point
When the control system for the winches locked at a tension of 78 tonnes, the load could only be reduced by emergency disconnection. The limit was set to prevent winch overload.

Grounds
Bröhl recommended that the emergency disconnection system should be used to free up the anchor winches on *Floatel Superior* [41].

Bröhl was on *Floatel Superior* on 14 September 2012 [41]. According to the photographs in its report, the tension in line 8 was then 79 tonnes. Bröhl wrote on 14 September 2012 it would not release the highest tension in bad weather because of the safety risk. Bad weather is when the highest loads can be expected.

In our view, the emergency disconnect system is unsuitable for such operations, and many incidents involving uncontrolled deployment have occurred.[65] Such deployment of the anchor line on *Floatel Superior* could have caused damage because the pennant wire would have accompanied it. Nineteen cases of full or partial uncontrolled anchor deployment have occurred since 2006,[66] most of them probably in connection with winch operation.

An emergency disconnect also puts the pennant wire holder, the railing and the operating house at risk in the event of an uncontrolled anchor deployment. See also chapter 5.1.3.

Requirements
Section 4, paragraphs 1 and 2, of the management regulations on risk reduction state that "In reducing risk as mentioned in Section 11 of the Framework Regulations, the responsible party shall select technical, operational and organisational solutions that reduce the probability that harm, errors and hazard and accident situations occur. Furthermore, barriers as mentioned in Section 5 shall be established."

5.2.3 Stability programme and motion measurements

Improvement point
The analyses in the stability programme fail to provide an accurate picture of stability in damaged condition.

Grounds
A programme called Lodic, delivered by Lodic AS, has been used on *Floatel Superior* to calculate stability. The version utilised is 5.23.0004.

[65] When the anchor line is deployed in an uncontrolled manner from the anchor winch into the sea.

[66] The incidents of uncontrolled deployment we have registered on the NCS since 2005 are 13 July 2012 on *Scarabeo 5*, 7 March 2012 on *Bideford Dolphin*, 28 May 2011 on Njord A, 13 October 2010 on *Songa Trym*, 18 July 2010 on *Transocean Winner*, 4 August 2009 on Veslefrikk B, 12 August 2009 on *Aker Barents*, 16 December 2008 on *Scarabeo 5*, 5 December 2008 on *Transocean Winner*, 7 December 2008 on *Polar Pioneer*, 14 November 2008 on *Bideford Dolphin*, 4 October 2008 on *Deepsea Trym*, 9 September 2008 on *Polar Pioneer*, 22 August 2008 on *Polar Pioneer*, 28 December 2007 on Njord A, 8 April 2007 on *Songa Dee*, 24 November 2006 on *Borgland Dolphin*, 31 October 2006 on *Bideford Dolphin* and 26 May 2006 on *Polar Pioneer*.

When calculating actual and potential damage, no account was taken of changes to the waterline area in the event of damage. The intact stability of floating units is governed by GM, which is the distance between the centre of gravity (G) and the metacentre (M) as follows[67]: GM = KB + Iw/V - KG. Damage to the waterline reduces the water area. The inertial moment in the waterline area (Iw) accordingly declines, and causes a similar reduction in GM. The effect is that listing with minimum potential energy will occur around an axis system which rotates in relation to the intact symmetry axis [146]. These analyses can give a false sense of security.

The Lodic programme on board does not calculate the correct total inclination angle, but uses the square root of sum of squares (SRSS) method. The inclination angle is calculated as ≈ $\sqrt{(\text{roll})^2 + (\text{pitch})^2}$. This only provides a reasonable approach for small inclinations. The error is particularly visible in the stability analysis performed at 07.56, where trim = (pitch) = 69.1˚, list = (roll) = 82.6˚. The correct total inclination angle in the analysed case is 83.0˚, and not the 107.6˚ shown in the Lodic printout. That exceeds 90˚ and does not accord with the other information in the graph and figures in the printout.

As we note in chapters 3.1 and 9.2, the arithmetical signs and directions have changed placed in Lodic's stability analyses compared with the VRS system.

The Lodic printouts specify loads from line tension, but it is unclear to the operator how far these are incorporated in the ballast analyses. Nor is the limit for including anchor tension clear in the Lodic manual [136]. Lodic has explained in conversations that loads are not included for short line-outs, and should thereby not have given errors in the stability analyses on the incident night. Mooring conditions in Kristiansund have not been taken into account in that connection. This could mean that some loads appear erroneous in the analyses, depending on the length of the lines laid out and how far the measuring equipment functioned or was damaged, as mentioned above.

Requirements
Section 25, paragraph 1, in the activities regulations on the use of facilities, see section 3 of the framework regulations on application of maritime regulations in the offshore petroleum activities, see the NMA regulations on stability, watertight subdivision and watertight/weathertight closing means on mobile offshore units, sections 15 concerning the calculation of daily loading conditions and section 17 on loading conditions.

5.2.4 Positioning *Floatel Superior* in disconnected condition

Improvement point
Floatel Superior was positioned during the incident in a way which could have allowed it to drift onto Njord A.

Grounds
During the storm, *Floatel Superior* was positioned partly upwind from Njord A and B, so that it would drift between the two installations should power be lost in the forecast weather.[68]

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[67] K specifies the keel point, B the buoyancy point, G the centre of gravity. KB is thereby the distance from the keel to the buoyancy point, KG the distance from keel to centre of gravity. The distance from the buoyancy point to the metacentre is KB = Iw/V. KB, volume displacement (V) and inertial moment of the waterline area (other area moment, Iw) all change if the hull is damaged at the waterline.

[68] Conversations on *Floatel Superior*.

Analyses by the joint rescue coordination centre (JRCC) around 08:00 on 7 November showed a 50 per cent chance of colliding with Njord A with free drift [132]. The centre conveyed this to Statoil, but the information was not passed satisfactorily to Njord A or *Floatel Superior* [139]. If the emergency response management on *Floatel Superior* or Njord A had received this information, they could have given the *Floatel Superior* crew a better basis for assessing the facility's position. Statoil [139] maintained that, had this information been received on Njord A, it would have demanded that *Floatel Superior* be moved to another position without a collision risk.

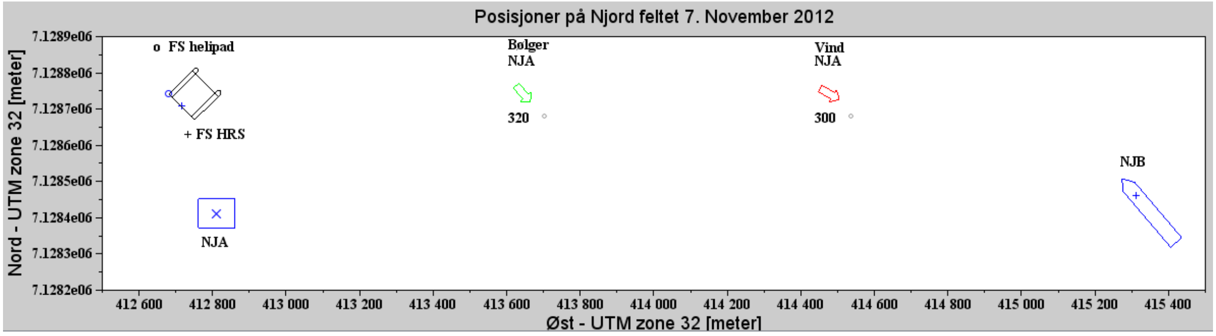

Figure 16: Position of the facilities on the incident day, 7 November, with wind and wave directions. The arrows point in the direction of the weather. The coordinates for Njord A (NJA) and B (NJB) are from the Sisu database. Those for *Floatel Superior* labelled as *FS helipad* (indicated by 0) are from the video during the evacuation,[69] and the point marked *FS HRS* (indicated by +) are the coordinates specified by the JRCC at 03.59 on 7 November 2012. We have positioned *Floatel Superior* in relation to these two positions. The coordinates have been transformed to UTM zone 32 by the NPD.

The drift calculations are uncertain. Information received by the JRCC from the second line for the drift calculations was inaccurate about the size and draft of *Floatel Superior* [132]. The JRCC log does not show whether it had access to current data, which make an important contribution to the loads.

Statoil wrote to us: "We can confirm that the flotel withdrew to the west when it disconnected on 6 November ..." [114]. The position was later changed, so that it corresponds with Figure 16 [124].

Statoil wrote in the application for consent [137] that "The location of the Flotel is based on the most favourable position [with] regards to drift off and gas dispersion/exposure. The gas release hitting the Flotel will be wind driven. Thus, the strategy will be to move the vessel perpendicular to the wind direction off the present position." From the time of disconnection, movement could have accorded with the description in the consent application. On the other hand, the facility was not moved again as the wind changed direction. *Floatel Superior* has not been moved in accordance with the description given by Statoil in its application.

Requirements

Section 4, paragraph 3, of the management regulations on risk reduction: "The solutions and barriers that have the greatest risk-reducing effect shall be chosen based on an individual as well as an overall evaluation."

[69] http://www.youtube.com/watch?v=fQcngxXRD58.

5.2.5 Communication systems

Improvement point
Technical communication systems failed or revealed deficiencies during the incident.

Grounds
It emerged from interviews that communication between the first and second line emergency response leadership, and from the first line leadership to the crew in the forward port column, where the damage had occurred, was not clear, unambiguous and consistent.

The phone connection between *Floatel Superior* and the second line at Floatel International in Gothenburg was lost several times.

It emerged from interviews that satellite phones were not used during the incident.

UHF communication was not in place between the bridge and those working on the leak or on duty in the inner column on the port side.

Requirements
Section 80 in the activities regulations on communication, which requires that necessary communication must safeguarded at all times, including in hazards and accidents.

5.2.6 Shielding the leadership on board from meetings with the second line

Improvement point
The robustness and efficiency of the first line emergency response team and leadership on *Floatel Superior* was weakened by a heavy burden of status meetings with the land organisation.

Grounds
It emerged from conversations on *Floatel Superior* that the first line emergency response leadership on the facility was not dimensioned or organised to handle a big demand for information from the land organisation. It emerged that key members of the first line leadership were unreasonably burdened in updating the second line on land.

Requirements
Section 75, paragraph 1, of the activities regulations on the emergency preparedness organisation requires this to be robust and able to handle accidents in an efficient manner.

5.2.7 Deficiencies in training and exercises

Improvement point
Deficiencies in the execution of training and exercises

Grounds
It emerged from conversations that mustering exercises took the form of the crew going to their muster stations at the lifeboats, but not entering the boats. Nor had systematic training been conducted to ensure that guests and crew members were practised in entering the lifeboats.

While bad weather was developing on 8 December 2011, the bridge from *Floatel Superior* to Oseberg B went into autolift mode (automatic disconnection) while people were on it. This incident was investigated by Statoil. One of its conclusions was also lack of exercises related to autolift [117, page 35].

Requirements
Section 23 of the activities regulations on training and drills requires that necessary training and drills are conducted so that the personnel are always able to handle operational disturbances as well as hazards and accidents in an effective manner.

5.2.8 Deficiencies in signage at the muster areas

Improvement point
It was difficult to see the signs in the outside muster areas.

Grounds
This observation is based on reports during the conversations.

The outside muster areas were designated by paint marks on the deck for each lifeboat. When the areas are filled with people, these marks cease to be visible and conducting the muster can take a long time.

Requirements
Section 3 of the framework regulations on the application of maritime regulations in the offshore petroleum activities, see section 19 on marking of evacuation routes in NMA regulation 0853/07 on evacuation and life-saving appliances on mobile offshore units, and section 15 on marking, warning signs and notices in NMA regulation 0859/87 on protective, environmental, and safety measures on mobile offshore units.

5.2.9 Classification and first-year inspection of bolsters

Improvement point
Insufficient inspections have been carried out to identify damage after unintended anchor movements have been observed.

Grounds
Pursuant to DNV's[70] classification, the bolsters are auxiliary structures. This means that they receive little follow-up from the classification societies. It has been demonstrated that anchors stowed in the bolsters can cause damage to the hull.

Section 50 of the activities regulations on special requirements for technical condition monitoring of structures, maritime systems and pipeline systems states that "technical monitoring of new structures and maritime systems shall be carried out during their first year of service". DNV-OSS-101 B annual survey provides details which we regard as industry practice. As part of the maritime operating concept (see section 3 of the management regulations), it requires during the annual inspection that[71]: "Accessible and visible parts of the unit's permanent towing arrangement and temporary mooring system shall be inspected. If the temporary mooring system is part of the mooring system for position keeping on location, then accessible and visible parts of the position mooring system shall also be inspected." DNV-OSS-101[72] states with regard to the annual inspection: "The towing and mooring

[70] According to the conversation with DNV on 5 December 2012.
[71] DNV-OSS-101 Ch 3 Sec 4, B306.
[72] DNV-OSS-101 Ch 2 Sec .4 on renewal survey, D210 and L401.

equipment shall be surveyed as follows: – all chain lockers and anchor stowage arrangements shall be surveyed …" This involves a requirement to inspect the bolsters every fifth year. In our view, the requirement in the DNV rules to inspect every fifth year is normally adequate with ordinary use of the bolster, providing the programme includes more frequent inspections if the anchors are found to have moved. If, on the other hand, the anchors are stowed in the bolsters during storms – as in this case – more frequent inspections are needed.

Requirements
Section 50 of the activities regulations on special requirements for technical condition monitoring of structures, maritime systems and pipeline systems states that "technical monitoring of new structures and maritime systems shall be carried out during their first year of service".

5.3 Important lesson learnt

In our view, the incidents also provide a basis for learning lessons in a number of areas which are valid beyond *Floatel Superior* and Floatel International alone.

5.3.1 Anchor stowage during DP operations

DP-operated facilities with anchors stowed in bolsters over lengthy periods are particularly vulnerable to heavy loads. As shown in this report – see chapter 9.8 – a number of incidents have related to anchors stowed in bolsters. That applies both while the facilities have been in transit and while the anchors have been stowed for long periods. Long-term storage of anchors in bolsters at or close to the sea surface increases the risk of damage to the facility. See chapter 9.6.

5.3.2 Safety reports

We inquired on *Floatel Superior* on 14 November 2012 whether Floatel International could issue a safety report to other players about the incident. This request was repeated a number of times without Floatel International producing a report. As a consequence, we produced a brief report which was circulated to the industry [147].

5.3.3 Hearing protection for helideck personnel

All landings during the evacuation were handled by the same helideck personnel on Njord A. All eight were exposed to noise in excess of the recommended maximum daily dose [138].

5.3.4 Measurements and alarms with unintended filling of tanks

Tank 3A unintentionally filled with water without the bridge noticing. The tank was equipped with devices for measuring water level, and the data were transmitted to the stability programme on the bridge. When the latter was not in use, however, the water intrusion was not observed because the measurements did not trigger any alarms.

Measuring the water level in tanks is a regulatory requirement. The present regulations do not require alarms to be triggered when the tank fills unintentionally. Alarms were installed on *Floatel Superior* in Kristiansund after the incident. These will help to ensure earlier discovery of unintended tank filling. After the incident, Floatel International introduced alarms at 10 per cent filling of tanks. These alarms must be acknowledged. The requirement, pursuant to section 3 of the framework regulations and section 39 of the facilities regulations, see section 20, sub-section a) on requirements for tank level indicating systems in NMA regulation 0879 of 20 December 1991 on ballast systems on mobile offshore units, is to "indicate liquid levels in all ballast tanks. A secondary method of determining levels in ballast tanks shall also be provided, i.e. sounding pipes or other measuring equipment."

5.4 Good solutions and assessments

In our view, alerting, mustering and evacuating guests on board functioned very well. Some of the guests noted that they were initially asked to pack a bag which they would be able to take with them. When they then were ordered to muster on the weather deck at 10.00, they were not permitted to take their luggage with them. The reason was that the damage was then considered to be significantly more serious, and evacuation had to be conducted as soon as possible. The first decision to allow a bag to be taken was based on using passenger helicopters, which had plenty of room. When the evacuation took place, SAR and rescue helicopters with no space for luggage were used.

Immediate action was taken when the alarm sounded for water intrusion in the central shaft (bilge alarm), and the cause of the damage was established as far as possible. Efforts were made to reduce water intrusion. The hull exterior was inspected to identify the reason for the damage, and guards established at manhole hatches and anchors. The hatches were also reinforced later by establishing extra barriers. The hatches were sealed and attached to the bulkhead by 22 bolts, which provided substantial capacity.

The solution with a double hull separated by 1.5 metres functioned as intended, and prevented the anchor from damaging the inner hull. Similarly, the manhole hatches in the inner bulkhead functioned, even though there was some leakage.

In our view, the helicopters used as the main means of evacuation functioned well. We have noted, above, a weakness in the headband for lifeboat coxswains which could have been significant in a possible lifeboat evacuation.

The decision to evacuate was taken after the discovery that tank 3A outer port could not be emptied, which meant there were two damaged tanks. It was furthermore based on a new stability analysis which showed that filling the column shaft would have serious consequences. Filling the shaft would have been counteracted by pumping and ballasting, but evacuating the guests proved in practice to take one and a half hours by helicopters. Hoisting them into the helicopters was expected to take several hours. Lifeboats were available, but not a preferred evacuation method. In our view, the decisions taken on the evacuation and the choice of evacuation method were correct.

Figure 17: The muster for evacuating *Floatel Superior* on 7 November 2012. A still from the video "Evacuating *Floatel Superior*" during evacuation by 330 squadron's Sea King helicopter on 7 November 2012.[73] The photograph was taken by 330 squadron of the Norwegian air force.

5.5 Correcting deficiencies related to maritime conditions

The PSA conducted an audit of *Floatel Superior* on 4-6 October 2010 with support from the NMA in connection with an application for an acknowledgement of compliance (AoC) for the facility. Twenty observations related to maritime conditions were conveyed to Floatel International on 15 October 2010 [108], and an explanation of how the conditions would be dealt with was requested. Floatel International's response was received on 1 November 2010. This response, including the specification of plans and deadlines for correcting the identified conditions, was considered satisfactory by the PSA. Apart from one condition where a permanent exception was granted, Floatel International confirmed that all identified maritime-related conditions would be corrected before the facility was taken into use. Floatel International received an AoC for *Floatel Superior* on 22 December 2010.

In accordance with our mandate, we looked at some items Floatel International had confirmed to be corrected. Selected as a random sample, these were item numbers 4 on VDRs, 6 on toggles, 8 and 13 on emergency power, and 17 on emergency lighting in the NMA's list. All five items Floatel International had confirmed as corrected were found to be in order in the inspection of 15 November 2012.

6 Other experience

A number of incidents where semi-submersible units have either sunk or had big problems with flotation stability. *Alexander L Kielland* in 1980 and *Ocean Ranger* in 1982, with a total

[73] http://www.youtube.com/watch?v=fQcngxXRD58.

of 207 fatalities, are the most serious of these. Incidents since 2000 include *Petrobras 36* (sank in 2001), *Thunder Horse* (21° list in 2005), *Aban Pearl* (sank in 2010), *Deepwater Horizon* (sank in 2010) and *Jupiter 1* (sank in 2011). In addition come many smaller stability incidents. Most of these cases are not generally known. With the world fleet of semi-submersibles averaging about 150, the frequency of incidents involving more than 17° of list has been roughly $19*10^{-4}$ per unit-year since 2000. The damage frequency has not declined over the past decade. Norway has not experienced such incidents since *Alexander L Kielland* and *Henrik Ibsen* in 1980. A semi-submersible is more vulnerable than a ship, for example, to faults associated with stability. Maintaining stability on such units is accordingly a demanding task. It calls for a high level of crew expertise, particularly in handling accidents. Norway experienced two serious stability incidents in 2012, first on *Scarabeo 8* and then on *Floatel Superior*. These are Norway's most serious stability incidents for many years.

We have searched in our databases for incidents since 2005 without finding ones involving damage to both bolster and hull. On the other hand, a number of incidents were related to bolsters. We have mooring lines which parted on or near bolsters, damage to bolsters, and anchors which have damaged hulls. See chapter 9.8 for more details. A number of other incidents exist where anchors have damaged bolsters and hulls. *Floatel Superior* is not unique in stowing its anchors in the bolsters when operating in DP mode. Using 40-50 tonnes of tension on the winch is normal, but reports have even then been received of anchors shifting in the bolsters. Wave loads on the bolsters also reduce the fatigue life of the lines.

7 Assessment of investigation reports from the players

7.1 Assessment of Statoil's investigation report

The mandate was issued by the relevant executive vice president on 13 November 2012 [33]. A union representative and a representative from Floatel International were included in the team. The deadline for the final report was 25 January 2012.

We received the report on 20 February 2013 [139]. Statoil's assessments differ from ours on some points. Naturally enough, a number of conditions are not covered in both reports. The differences in viewpoint include whether tank 3A was waterfilled before the incident. See our Figure 23 with associated text, and the function and manner of working of the doubling plates. Statoil has also focused on the importance of a proactive emergency response leadership, and recommended an earlier muster in order to gain control over personnel on board. We agree with this while understanding the decisions taken on board.

In our view, important conditions not discussed by Statoil including wave impact during transit, damage caused by the pennant wire and the communication shortcomings.

7.2 Assessment of Floatel International's investigation report

The mandate was issued on 20 November 2012 by a member of the four-strong executive management team at Floatel International. A union representative was included on the team, which included personnel with maritime and emergency response expertise. Its mandate was to investigate the incident with the emphasis on structural damage and emergency response [40]. The mandate is shorter than usual in the industry, and excludes such underlying causes as organisational factors, investigation of lessons from earlier incidents and barrier breaches. That Floatel International did not plan to assess barriers in investigations was noted in the

PSA's audit of Floatel International on 27-30 September 2010 [142 item 5.3].[74] Floatel International replied [84] that "Procedure for Accident Reporting and Investigation No 1000-220-16 is being updated to comply with all notified items".

The deadline for the final report was 15 January 2012. We received it on 26 February 2013 [104]. Floatel International's report covers most of the issues we also raise. It does not discuss underlying causes such as organisational conditions and investigating lessons for earlier incidents. Floatel International takes a different view from us of such issues as the damage sequence, water intrusion in tank 3A, *Floatel Superior*'s motion and weather conditions during the incident. In our view, important issues not discussed include wave action during transit and communication weaknesses.

8 Documents utilised by the investigation

The following documents have been utilised in the investigation. Reference is made to each document in the text by the number placed next to it.

1. Floatel International: *Abstract from different log and verbal statement* (3 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727 no 7 sequence 1, pp 15-17.
2. Floatel International: *POB 08 Nov 2012* (2 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-1_s18-19.
3. Floatel International: *Emergency preparation plan: DFU 6 Loss of stability* (2 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-1_s20-21.
4. Floatel International: *Principal particulars* (1 page). *General Arrangement Side View, Portside.* Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-1_s23.
5. Floatel International: *Drawing over bolsters* (1 page). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-1_s22.
6. Floatel International: *Tank arrangement plan* (1 page). I Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-2.
7. Floatel International: *Tank capacity plan* (1 page). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-2.
8. Floatel International: *Statement from Engine personnel on duty* (1 page). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-1_s2.
9. Floatel International: *Chief engineer report* (2 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-1_s3-4.
10. Floatel International: *Event List Engine* (6 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-1_s5-10.
11. Floatel International: *Weather* (4 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-1_s11-14.
12. Floatel International: *Stability report First print damage, time 03:29* (5 pages) . Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-3.

[74] "Nothing was said about the investigation reports including a description of which barriers functioned and which did not."

13. Floatel International: *Stability report damage, time 05.09* (6 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-4.
14. Floatel International: *Draft survey time 05.10* (1 page). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-5.
15. Floatel International: *Stability report flooding port inner column, time 07.56* (6 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-5.
16. Floatel International: *Stability report damage, time 09.19* (4 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-6.
17. Floatel International: *Stability report damage Transit, time 11:51* (6 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-7.
18. Floatel International: *HS, Wave graph* (4 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-8.
19. Floatel International: *Copy of DP log* (5 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-9.
20. Floatel International: *VRS sensor* (3 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-10.
21. Floatel International: *Print over Ballast tanks time 05.06* (2 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-10.
22. Floatel International: *Print outs mimic display bridge* (3 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-11.
23. Floatel International: photographs (26 pages). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-7-12.
24. Floatel International: *Emergency Response Teams Floatel Superior 06.11.2012 09.43*). Information received at the kick-off meeting for the investigation on 12 Nov 2012. PSA reference: 2012/1727-22-1.
25. Floatel International: *Floatel Superior. Navigation, transit, towing and anchoring procedures*, Document No 2000-317-01. Dated 4 Jan 2010. We took copies of three pages on the bridge of *Floatel Superior*.
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27. Norwegian Meteorological Institute: *Informasjon vedr været under hendelse på Floatel Superior på Njordfeltet natten 08112012*. PSA reference: 2012/1727-10.
28. Norwegian Meteorological Institute: *Vindmålinger vedr hendelse på Floatel Superior på Njordfeltet natten 08112012*. PSA reference: 2012/1727-11.
29. Norwegian Meteorological Institute: *Fwd: Gransking av en hendelse på Floatel Superior - bølgedata fra Oseberg og Njord-feltene fra 2011 og 2012*, e-mail, 29 January 2013. PSA reference: 2012/1727-69.
30. Norwegian Meteorological Institute: *Re: Hindcast tilgjengelige for lokasjoner i Indiske hav og Atlanterhavet?*, e-mail 28 February 2013. PSA reference: 2012/1727-111.
31. Norwegian Institute of Marine Research: *Vurdering av alder på blåskjell ifm granskning av hendelse på Floatel Superio*r, Bergen, 21 Nov 2012. PSA reference: 2012/1727-18.
32. PSA: *Beredskapslogg, Flotell Superior ved Njord - slagside 7.11.2012.*
33. Statoil: *Mandat og liste over deltagere i granskingsgruppen til Statoil vedr Floatel Superior*, dated 13 November 2012. PSA reference: 2012/1727-97.

34. Statoil: RE: *Granskingen Floatel Superior-hendelsen - potensielle konsekvenser*, e-mail to the PSA, 19 November 2012.
35. Floatel International: *Informasjon om status, i sak nr 2012/ 1727, på tiltak som er gjennomført før Floatel Superior i dag returnerer til Njord A*, e-mail, 26 November 2012. PSA reference: 2012/1727-23.
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37. Floatel International: *Drill/training report*, 1 November 2012. PSA reference: 2012/1727-24.
38. Floatel International: *Training and drill plan 2012*, Excel spreadsheet, undated. PSA reference: 2012/1727-24.
39. Maschinenfabrik Bröhl: *AW: Floatel Superior*, 13 November 2012. PSA reference: 2012/1727-24.
40. Floatel International: *ACC2012-0018 Terms of reference*, Document No 2007-410-01, 20 November 2012. PSA reference: 2012/1727-24. *Mandat for granskingen til Floatel International.*
41. Maschinenfabrik Bröhl: *Service report,* undated. PSA reference: 2012/1727-24. Probably written some time between 18 September and 7 November 2012.
42. Floatel International: *Floatel Superior – Anchor Windlass Status And Deficiencies*, undated. PSA reference: 2012/1727-24-9. Probably written in September 2012.
43. Floatel International: *Floatel alert anchor, cradles & winches - inspections*, 19 November 2012. PSA reference: 2012/1727-24.
44. Statoil: *Bridging document for emergency response between Njord and Floatel Superior, Work process requirements, WR2540*, final version 1.01, valid from 31 July 2012. PSA reference: 2012/1727-24.
45. Statoil: *Operational Bridging Document Between Njord and Floatel Superior,* Rev 7 - 10 September 2012. PSA reference: 2012/1727-24.
46. Floatel International: *Status på intervju,* e-mail 13 November 2012. PSA reference: 2012/1727-24.
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53. Floatel International: *Oversikt over spm./ dokumentasjon som Ptil etterspør i forbindelse med sak nr. 2012/ 1727,* 14 December 2012. PSA reference: 2012/1727-40.
54. Floatel International: *04 eksempel_stabilitetsdata_tank_10*, 14 December 2012. PSA reference: 2012/1727-40.
55. Floatel International: *04 stabilitetsdata_Njord_*, 14 December 2012. PSA reference: 2012/1727-40.
56. Floatel International: *05 Mail 22 11 12 Ptil dok FloatelDPHeavePitchRoll 07 11 12*, 14 December 2012. PSA reference: 2012/1727-40.

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59. Maschinenfabrik Bröhl: *11 Alarm Messages B302*. PSA reference: 2012/1727-40.
60. Maschinenfabrik Bröhl: *Mooring winch 188kN – lefthand design*, drawing 123046-01L, revision 02, sheet 1. PSA reference: 2012/1727-85.
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65. Floatel International: *PSA_e-mail_22.11.12 with answer*, 14 December 2012. PSA reference: 2012/1727-40.
66. Floatel International: *PSA_e-mail_22.11.12 with answer*, 14 December 2012. PSA reference: 2012/1727-40.
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69. Floatel International: *Procedure Floatel Superior Passage Plan Mauritius – Walvis Bay*, document number: 2002-401-01. Undated. PSA reference: 2012/1727-43.
70. Floatel International: *Emergency Response Teams Floatel Superior*, 6 Nov 2012, 09.43.
71. Floatel International: *Document Control Manual*, 18 May 2010. PSA reference: 2012/1727-43.
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74. Floatel International: *Møtereferat Bi -Weekly Offshore SBM*, 28 October 2012. PSA reference: 2012/1727-43.
75. Floatel International: *Drill / training report Floatel Superior*, 1 Nov 2012. PSA reference: 2012/1727-43.
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86. Floatel International: *2.2 Comments 2000-263-DG-H602-R00*. PSA reference: 2012/1727-60.
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89. Floatel International: *2.7_Service Report 2010-11-18 (3)*. PSA reference: 2012/1727-60.
90. Floatel International: *2.20_Flooding (2)*. PSA reference: 2012/1727-60.
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92. Floatel International: *Safety Observation Card: SOC2012-0395, Floatel Superior*, 6 May 2012. PSA reference: 2012/1727-73.
93. Floatel International: *Safety Observation Card: SOC2012-0397, Floatel Superio*r, 8 May 2012. PSA reference: 2012/1727-73.
94. Floatel International: *Pkt. 2.13 bilder av tavler for 2. linje i Gøteborg* (4 photographs). PSA reference: 2012/1727-74 og 2012/1727-75.
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99. Floatel International: 02_Manual_Mooring, 31 Jan 2013. PSA reference: 2012/1727-82.
100. Floatel International: *Deres referanse 2012/1727: FS Daily Voyage Reports*, 1 Feb 2013. PSA reference: 2012/1727-83.
101. Floatel International: *Manglende dokumentasjon etterspurt av Ptil ifb med gransking av stabilitetshendelse på Floatel Superior november 2012*. PSA reference: 2012/1727-84.
102. Floatel International: *FW: Angående Brukerbeskrivelse/-manual for LODIC-programmet, som brukes for stabilitetsberegninger*, e-mail, 31 January 2013. PSA reference: 2012/1727-86.
103. Floatel International: *Dokumentasjon i forbindelse med sak: 2012/1727*, e-mail, 19 February 2013. PSA reference: 2012/1727-102.
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119. Statoil: *RE: Skadeanalyser av Floatel Superior*. E-mail, 10 January 2013. PSA reference: 2011/1422-52.
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122. Statoil: *Loggføring/observasjon fra Operation Manager (2)*. PSA reference: 2011/1422-57.
123. Statoil: VS: *Granskingen Floatel Superior-hendelsen - Værforholdene på Njord og Oseberg*, 25 January 2013. PSA reference: 2012/1727-65.
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144. PSA: *Rapport etter tilsyn med bærende konstruksjoner og maritime systemer på Rowan Norway*, 31 October 2012. PSA reference: 2012/995-24.
145. PSA: *Rapport etter gransking av hendelse på Scarabeo 8, 4. september 2012, med varsel om pålegg*. PSA reference: 2012/1427.
146. PSA: *Stabilitet og ballastering av halvt nedsenkbare innretninger*, 23 August 2010. PSA reference: 2010/113. http://www.ptil.no/getfile.php/Tilsyn%20p%C3%A5%20nettet/2010_113_Stabilitet%20og%20ballastering%20av%20halvt%20nedsenkbare%20innretninger.pdf.
147. PSA: *Informasjon om skade på bolster på halvt nedsenkbar flyttbar innretning på norsk sokkel,* 13 December 2012.
148. ROV films (3) of damage to *Floatel Superior*, filmed 9 November 2012. Abyss. PSA reference: 2012/1727-53.
149. Norsafe: *Quotation S12-4165-162578*, Færvik, 18 September 2012. PSA reference: 2012/1727-73.
150. Norsafe: *Quotation SC12-441-162828*, Færvik, 21 September 2012. PSA reference: 2012/1727-73.
151. HSE: *Wire Rope Offshore*, OTH 91 341. Health & Safety Executive, UK.
152. Floatel International: *Stabilitetsanalyser utført ombord Floatel Superior for verifisering av krengning ved vannfylling av tanker*. PSA reference: 2012/1727-94.
153. DNV: *Analysis of Failed Parts From Floatel Superior,* Report No/DNV reg no: 2013-0162 / 163GBM0-4, REV 0, 21 February 2013. PSA reference: 2012/1727-110.

9 Appendix – supplementary comments on points in the report

9.1 Ref chapter 3.1 – weather conditions

The incident occurred during bad weather at night. Our sources on the weather are forecasts (from 23.45 UTC on 6 November 2012) and observations by StormGeo [11], observations and maps from the Norwegian Meteorological Institute and instrument observations on Njord. Two types of instruments are used: 1) a radar on Njord which sweeps the sea and interprets the images as waves, and 2) a wave buoy in the sea which converts motion to wave height. The radar comes from Miros and is positioned on Njord A. The buoy comes from Fugro Geos. As expected, differences exist between data from these instruments because of differing measurement principles.

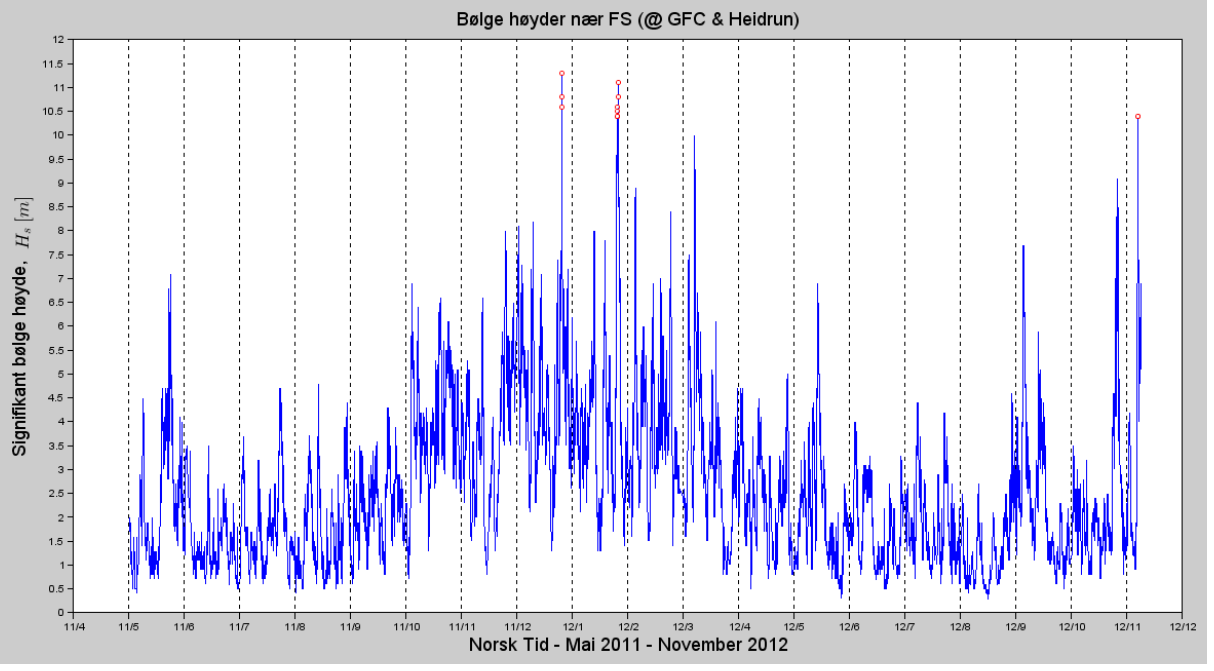

Figure 18: Wave conditions in locations close to *Floater Superior* when operating on the NCS (measurements from Gullfaks C from 1 May-31 July 2011 and Heidrun from 1 August 2011-8 November 2012). The weather on 7 November was registered as Hs 10.4 metres at 00.00 and 01.00 (on Heidrun). *Floater Superior* has only experienced worse seas in two previous storms: 25 December 2011 with maximum Hs = 11.3 metres and 26 January 2012 with maximum Hs = 11.1 metres. Observations of Hs = 10.4 metres and above are marked with red circles. Information from Statoil [124].

According to the Miros radar [116], waves peaked around 00.00 Norwegian time. At 23.40, the peak Hs was 10.9 metres. Data from the Fugro Geos [18] wave buoy show rather higher figures than the radar, with maximum Hs = 11.5 metres and Hmax = 19.5 metres. Hs was measured above 10 metres until 03.20, med peak periods typically of 16-17 seconds. Ten-minute mean wind speed at a height of 10 metres was about 20m/s (40 knots) at 01.00 and roughly 15m/s when the damage was discovered at 03.20. It is assumed below that Hs = 10 metres and 10-minute reference mean wind speed (10 metres above the sea) = about 15-20 m/s – in other words, close to fresh gale – are descriptive of weather conditions from 23.00 until the damage was discovered around 03.20 Norwegian time. The wind was stronger on the helideck, and has been referenced as 40 knots (20m/s). The weather came stably from the north-west, around 300°, and the wave periods were stable at around Tp =16 seconds for most of the night [27, data file for Njord]. A brief period of wind at full gale had blown from the south-south-west earlier in the day, peaking at about 09.00 on 6 November 2012 [27, data file for Njord]. Around 05.30 on 7 November 2012, Hs was down to about nine metres.

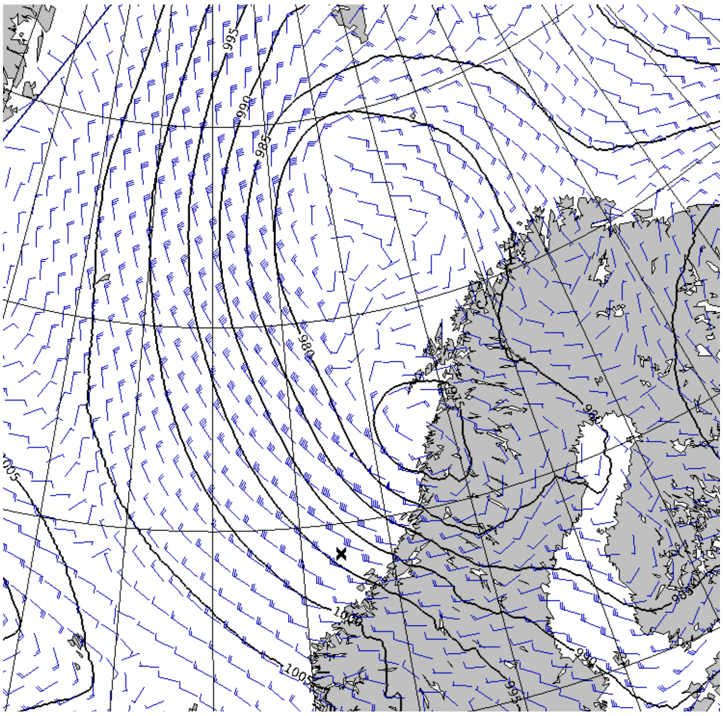

Figure 19: Weather map at 01.00 Norwegian time on 7 November 2012. *Floatel Superior*'s position is marked by a cross. The solid lines show air pressure in millibars. The blue arrows show wind directions and speeds. Three feathers on an arrow show a fresh gale with wind speeds of 13.9-17.1m/s at a height of 10 metres. The map is produced by the Meteorological Institute [27]. A low-pressure centre of about 975 millibars was roughly 400 kilometres north-east of Njord at 01.00 Norwegian time. Atmospheric pressure on Njord was about 995 millibars, giving a pressure gradient of roughly five millibars per 100 kilometres.

Motion on the helideck mean that helicopters could not land on the incident night. The last helicopter took off at 13.37 on 16 November 2012, when the wind was at gale force. The waves had not built up to more than Hs = 4 metres at that time, but were rising.

9.2 Ref chapter 3.1 – Course of events after the damage was discovered

The stability analyses at 03.29 [12] and 05.09 [13] show that the ballast was adjusted from 5 433 to 4 982 tonnes. The 451 tonnes pumped out and the further change of 13 tonnes in other tanks altered the draft from 13.591 to 12.945 metres. The change in draft corresponds to about 700 cubic metres per metre draft, and accords with the area of the four column shafts[75]. It also corresponds to information from the Lodic stability programme on board, which gives about seven tonnes per centimetre of altered draft [14]. To get the facility on an even keel and a draft close to the original value[76], about 464 tonnes of ballast had to be pumped out. Tank 3A outer port was reportedly[77] waterfilled before the incident, and only tank 10 outer port filled with water. We disagree with this assessment, and our reasons are spelt out below.

Measurement data recorded on the incident night permit reflections on the passage of time before and after the incident which the crew on board were unaware of[78]. Figure 20 shows roll measured and stored in the VRS system on *Floatel Superior*. Figure 21 shows the

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[75] The area of the four column shafts is about 4*14m*12.5m = 700 square metres.

[76] The DP log recorded at 18.50 that the draft was set at 13 metres in anticipation of the weather.

[77] Conversation on *Floatel Superior*.

[78] Part of the information could have been acquired by the crew with a clearer presentation of real-time measurements made on board.

corresponding pitch, both measured in degrees. Ten-minute mean values are marked on both graphs, and ignore wave motion (10-18 second periods are typically recorded for heave). Figure 23 shows the overall list picture for the facility on the basis of the two sets of separate roll and pitch measurements. Four incident points are marked on the graph for mean list. In addition, the observation time at 03.12 is marked on the time axis. The graphs show a relatively stable facility from 00.00 to about 00.45. This is followed by a period of roughly an hour when a change occurs in the relationship between the facility's heading and its direction to the wind and waves[79]. From having the weather to port, the heading altered to bring it closer to bows-on. This is shown by the fact that wind pressure caused a roll to starboard early in the period, and later pressed on the superstructure aft at around 01.40.

A significant change in the facility's list occurred from about 01.40-02.15. The average list altered by about 4.75° in this period, corresponding to roughly 8˚ per hour. Between 02.15 and 03.00, the list increased moderately by 0.35° (0.5˚ per hour). Around 03.00, it again began increasing sharply. Up to 03.20, it rose by 1.7° (5° per hour) to the **maximum mean list of 5.8°**.[80] During this final period, the crew had been alerted at 03.11 by the bilge alarm in the forward port column, which had then reached a mean submersion/draft almost four metres greater than intended (16.85 metres [12] compared with 13.00 metres [12]). The facility had an overall mean draft of 13.59 metres at 03.29 [12].

The deballasting which began after the crew discovered the problem is clearly visible on the list graph in Figure 23. Between 03.20-04.40, the facility was righted by 5.9˚ to roughly even keel – 0.1˚ (4.4˚ per hour)[81]. Stability reports before and after deballasting show that the facility was lightened by a total of 464 tonnes, including 451 tonnes of ballast water.[82] The latter comprised 226 tonnes from tank number 1 outer port, 115 tonnes from 5B outer port, 47 tonnes from 10 outer port (punctured, but partly above water), 33 tonnes from 2 outer starboard and 23 tonnes from 3A outer starboard. In addition come several minor tank adjustments.

Crew on the bridge had access to the stability computer on the incident night, and documented the position before and after deballasting through printouts. It was stated in a number of post-incident conversations that the facility rolled before and during the incident. This observation

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[79] It is not clear to us whether the facility was moved by direct intervention from the DP personnel on the bridge or whether the weather shifted direction at the location.

[80] The stability analysis at 03.29 shows a list of 7.3°[12]. The developer of the Lodic programme reports that the analyses become increasingly inaccurate at higher inclinations, and should normally not be used above 2-5°. Measurements by the VRS system are thereby regarded as the most significant when assessing actual list angles.

[81] Assuming that the mean volume removed is positioned roughly like the intruding water, the estimated effect of the water intrusion and deballasting can be expressed as: 5.9˚/464 tonnes = 1.27˚ ≈ 1.3˚ per 100 tonnes. At our request, stability analyses were conducted in the Lodic system's planning mode aboard *Floatel Superior* on 7 February 2013 [152]. These indicate that listing as a result of water intrusion in tanks 3A and 10 was about 1.9° per 100 tonnes of water. That diverges substantially from observations, and both methods contain inaccuracies. The measured values are used for estimating on the assumption that the centre of gravity is the same for water both intruding and being pumped out. The analysed values use a linearised approach for small inclination angles. Some calibration discrepancies could also exist between measured angles and analysed estimates

[82] About 451 tonnes/(1.025 tonnes/cubic metre) = 440 cubic metres of ballast water were discharged between 03.29 and the next ballast report at 05.09 [12 and 13]. Applying the times of the registered movements, the pumping interval runs from 03.20 to 04.40, and the pumping rate can then be estimated as 451 cubic metres/80 minutes ≈ 5.6 cubic metres/minute.

is supported by data logging in the VRS, where Figure 20 clearly shows a higher mean angle and larger fluctuations in terms of roll than is measured in the pitch direction and reproduced in Figure 21. The stability report before deballasting, at 03.29, specifies trim as +6.959˚ and list as +2.345˚ [12]. These values from the Lodic programme do not accord with the motions measured and described for the facility. An analysed condition which does not take account of the effect of wind load must be expected to show some discrepancy from the values actually measured. Note nevertheless that Figure 23 shows roll of about -5.0˚ and pitch of roughly -1.6˚ at the same point in time. The Lodic printout clearly shows the arithmetical sign applied. Real-time measurements stored in the VRS system have not defined directions, but applied the general notation which indicates that the measurements follow the definitions described in Figure 5. The fact that two available systems use opposite conventions for arithmetical signs could be unfortunate in circumstances where the right decision depends on clear information. Note further that the two systems appear to show the biggest motion in two different directions. This suggests that one of them is reporting inaccurately. That is corrected in the figures by presenting Lodic's trim values in the diagram for roll and its list values in the graph for pitch. According to a conversation with the programme developer at Lodic AS (part of Kongsberg Seatex after 1 January 2013), the Lodic system on *Floatel Superior* assumes that the facility operates with small inclination angles. Discrepancies because of the effect of level measurements in partly filled tanks and of wind pressure can cause inaccuracies in the analysed values[83]. The Lodic system utilises tank level measurements from the Kongsberg Seatex system on board and is connected to sensors in accordance with the Kongsberg Seatex documentation[84]. But the possibility of a faulty connection which swaps roll and pitch cannot be excluded without verifying the physical connections on board.

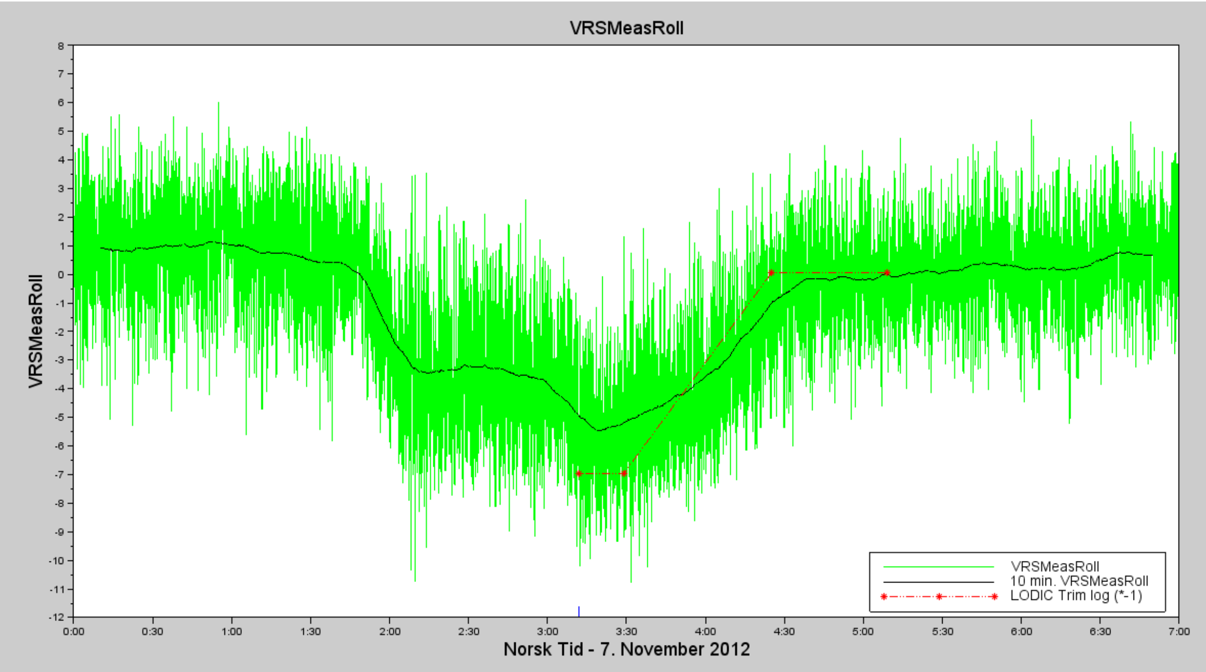

Figure 20: Registered roll on *Floatel Superior* in degrees. The horizontal axis shows Norwegian clock time from 00.00 on 7 November. The vertical axis shows roll in degrees. Red stars show trim from the stability programme (with opposite sign) [12 and 13] at times specified in the DP event log [19]. The graph has been produced by the PSA on the basis of data files from Floatel International [56 and 57].

[83] The Lodic manual for *Floatel Superior* [136] specifies that the error is in the order of 0.1° at inclination angles greater than 2-5°. The discrepancy at higher inclination angles is not specified, and is regarded as outside normal operation.

[84] Information from a conversation with Kongsberg Seatex.

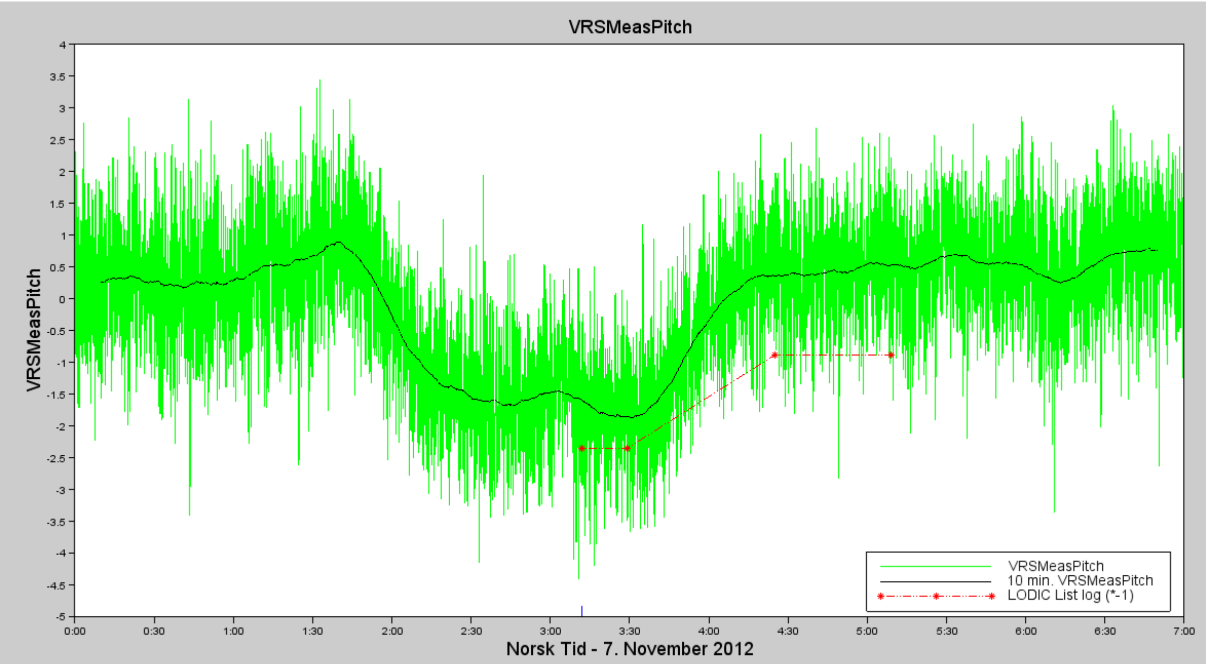

Figure 21: Registered pitch for *Floatel Superior* on the incident night. The horizontal axis shows Norwegian clock time on 7 November. The vertical axis shows pitch in degrees. Red stars show list from the stability programme (with opposite sign) [12 and 13] at times specified in the DP event log [19]. The graph has been produced by the PSA on the basis of data files from Floatel International [56 and 57].

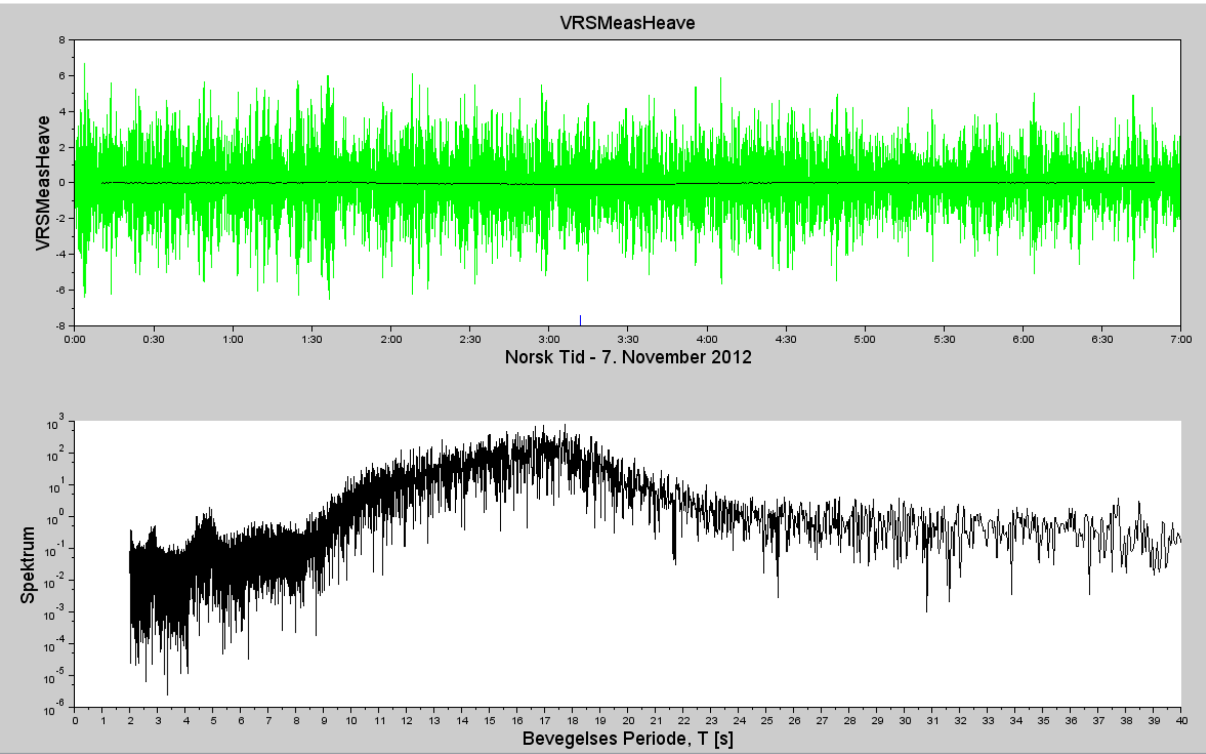

Figure 22: Registered heave for *Floatel Superior* on the incident night. The topmost graph shows the timeline. The horizontal axis shows Norwegian clock time on 7 November. The vertical axis shows heave and the 10-minute mean line. The graph above shows wave energy spectral density on a logarithmic scale as a function of the motion period. Note that motion in the 10-18 second interval is dominant, and at peak is at about the 17 second period in accordance with the weather information about Tp. The figure has been produced by the PSA on the basis of data files from Floatel International [56 and 57]. According to the marine operations manual [95], the natural period for roll and pitch for *Floatel Superior* lies between

48 and 77 seconds at drafts from 16.0-20.5 metres, and is thereby far outside first-order wave influences. The natural period for heave is given as 18.7-19.0 seconds, and is thereby very close to the dominant Tp on the incident night. Nevertheless, no clear spike can be seen in the spectrum which shows any marked dynamic amplification.

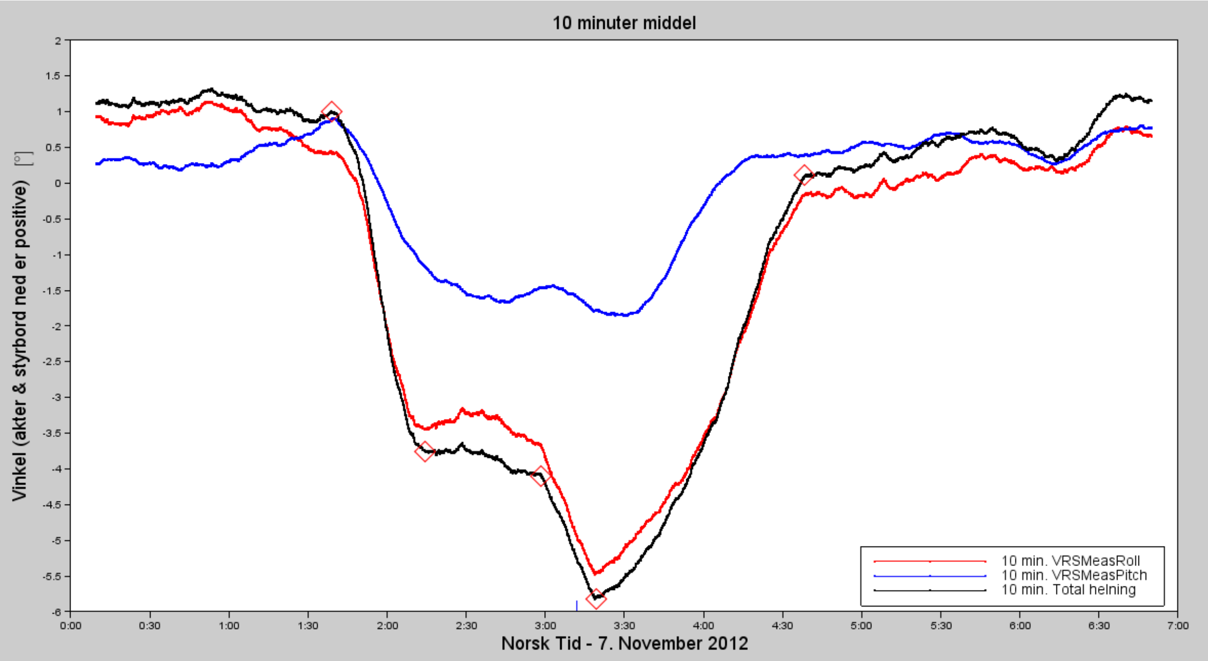

Figure 23: Calculated averaged list history from measured roll and pitch on the incident night[85]. The diamond symbols mark times when clear changes occur in the graphs – about 01.40, 02.15, 03.00, 03.20 and 04.40. Incidents and times are discussed in the text. The figure has been produced by the PSA on the basis of data files from Floatel International [56 and 57].

It is emphasised that the crew, from the sounding of the bilge alarm at 03.12 until after deballasting (right up to 08.45), were convinced that only one tank had been damaged. Given the information presented above, it can be stated that tank 3A outer port was punctured at 02.15. It was then virtually empty but according to the crew should have been full[86]. The tank took in some 360 tonnes of water[87 and 88] over 45 minutes (eight tonnes per minute). See also chapter 5.3.4 on measurements and alarms in the event of unintended tank filling.

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[85] The size and direction of the inclination angle are calculated from the roll and pitch data sets, with vector analysis and sign definition from the VRS data logger [56 and 57]:

- Roll is defined as positive for starboard down and port up.
- Pitch is defined as positive for bow up, stern down.
- List is defined in accordance with roll and pitch as positive for starboard stern (column) down.
- Normal unit vector for the global horizontal plane, MSL: $\underline{n}_{MSL}$ = [0, 0, 1]
- Normal vector for facility's topside: $\underline{n}_{FS}$ = [tan(pitch), tan(roll), 1]
- The vector must be scaled to unit length: $\underline{n}'_{FS}$ = 1/norm($\underline{n}_{FS}$) x $\underline{n}_{FS}$
- List angle is determined as the inverse cosine of the vector dot product: $|(\text{list})|$ = acos($\underline{n}_{MSL} \cdot \underline{n}'_{FS}$)
- The list is positive where: (roll)+(pitch) > 0, and otherwise negative.

Note that the Lodic programme on the facility does not calculate the correct inclination angle. See chapter 5.2.4.

[86] The officer of the watch reportedly thought 3A outer port (one specific tank out of 68 ballast tanks in all) was completely waterfilled in normal operation and in the relevant survival condition. On the basis of stability reports before and after deballasting [12 og 13], it can be seen that tank 3A outer starboard, placed symmetrically on the opposite side of the facility, was only about seven per cent full throughout the sequence of events.

[87] 4.75°/ (1.3° / 100 tonnes) = 365 tonnes.

[88] Capacity of tank 3A outer port is 360 tonnes, according to the tank layout and capacity plan [7].

The bolsters were damaged before tank 3A was punctured, and this damage probably developed over a number of months. Damage of varying extent and stage was observed on all the bolsters after the incident. Given the symmetric damage to the bolster for anchor 1, the lowest brace for anchor 8 is assumed to have been completely disconnected at the intersection where the anchor flukes[89] have been able to strike the brace over a long time. The lowest brace can therefore be assumed to have been cantilevered[90] from the wall of tank 3A before the 7 November incident. Biological dating of mussels in the damaged structures suggest that the damage has developed since June-July 2011 [31]. In addition to direct puncture of tank 3A by the anchor fluke, it has also been established that the brace attached to the hull outside this tank has been ripped off, creating a circular hole in the hull around the doubling plate.[91] The form of the fracture suggests that a fatigue crack could have originated before the incident night. Corresponding damage development was found on two other bolsters during repairs in Kristiansund.

On the basis of the observable damage to the other bolsters, the initial damage can be assumed to have arisen because of horizontal anchor movement along the bolster bar and hammering on the braces below. The crew have reported that anchor movement was observed as early as the transit around the Cape of Good Hope. The only opportunity for securing the anchors to the bolsters was to haul in with the winch. The winch has a design tension capacity of 71.4 tonnes on the outermost layer, reducing to 30 per cent for the final metres. This means that the parking load has been in the order of 21.4 tonnes. The anchors have also been subject to wave loads, see chapter 5.1.1. The parking load is relatively small[92], and the incident shows that wave loads have moved the anchors. The bolster geometry is such[93] that horizontal movement in the anchors causes a small but nevertheless significant elongation of the relatively elastic[94] wire rope. Horizontal movement of an anchor on its bolster means, as a second-order effect, that the steel wire rope is stretched. Elongation of this line means that the load from the wire rope rises, which increases the load on the bolster. As a result, the effect of horizontal movements of the anchors includes an increase in the intended parking load on the bolster. In this way, relatively minor horizontal displacements have yielded large extra loads which cannot normally be expected to be incorporated in a linear (first order) analysis. This means that the horizontal movements, in addition to fracturing the horizontal components of the bolster, have also increased the wire rope load to almost 78.5 tonnes (according to the supplier, the winch is able to hold 110 per cent of 71.4 tonnes before releasing the wire rope).

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[89] The anchor fluke is illustrated in Figure 3. See also the associated text.

[90] A cantilever is a slender structural component attached at only one end. It is fully or nearly horizontal.

[91] A doubling plate is a steel plate welded to the hull, to which the bolster is then welded. The idea is that the connection between bolster and plate will be the weak link and break first without damaging the hull.

[92] The parking load is small in relation to the normal practice of about 50 tonnes. See chapter 9.8.

[93] The design could have applied this geometry in order to centre the anchors in the parked position, since the load increase described can be expected to pull the anchor towards the central point on the bolster. This has not been the effect in practice, with the increased load actually serving to overload the bolster structure.

[94] Relative to chain. The elasticity of the wire rope depends on its tension, and converges towards $E=1.21\cdot10^5$MPa at mean breaking load (MBL) [151]. Chain links have individual stiffnesses close to that of the steel material ($E=2.1\cdot10^5$MPa). The steel wire material has a higher floating tension than normal chain steel, and accordingly needs a smaller cross sectional area (A) than chain. Overall stiffness ($K=E\cdot A/L$) for a short tensioned length (L) of a steel wire rope is therefore substantially lower than for chain.

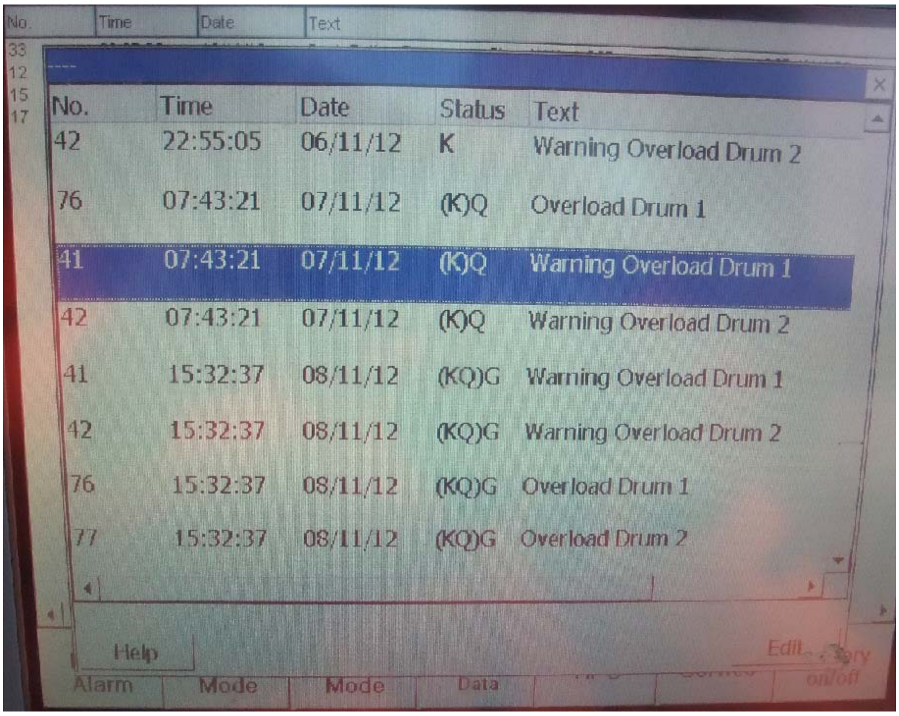

Figure 24: Anchor winch 4 for operating anchor lines 7 and 8. Anchor 8 is on drum 2. Before 22.55.05, the overload alarm repeats continuously. The change logged at 22.55.05 occurred around 23.40 Norwegian time (clock inaccurate). Photograph taken by the PSA in Kristiansund on 13 November 2012.

We have identified a number of cases of alarms for high anchor-line tension on *Floatel Superior* in bad weather. A long sequence of overload alarms was logged before 21.40[95] on the incident night on winch 4, operating anchors 7 and 8 on two drums. Drum 2 held the line for anchor 8, and the alarm shows that this anchor has been under a minimum tension of 71 tonnes. At 78 tonnes of tension, the winch freezes and becomes inoperable, so that crew have been unable to reduce the load. The alarms ceased around 23.40 Norwegian time on 6 November[96]. We interpret this change as a possible indication of a (first) structural failure in the bolster on the incident night. The assumed development of damage to the bolster began about three and a half hours before the bilge alarm led to the localisation of the column leak, and this coincides with the highest waves on the relevant night

The gale peaked around 23.40 on 6 November 2012, and was the direct cause of the movements in anchor 8 which led in turn to several incidents of structural damage. During two hours of bad weather between 23.40-01.40, the damaged bolster structure broke up and the anchor was free to hit the hull. The loss of bolster elements[97] and displacement of the centre of gravity of anchor 8 cannot be expected to be observable on the graph in Figure 23, since it probably corresponded to a change of 0.1° and is likely to have occurred at different times. The information was thus camouflaged in variations caused by the mean values for wind and waves.

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[95] The log stores 500 entries using the method whereby the earliest entry is deleted when a new one is made once the 500 limit has been reached. The earliest stored entry in the log was at 21.40.

[96] Registered at 22.55.05, but with the clock set to the wrong time.

[97] The first element ripped off the bolster was about 5.5 metres long, with a diameter of 16 inches SCH80 and with a wear surface of 2.5 metres diameter 18XS. Its total weight was about 1.5 tonnes.

9.3 Ref chapter 3.2 – early damage development

The construction contract was awarded on 4 May 2007, the keel was laid on 21 May 2008 and the facility was delivered by Keppel FELS in March 2010.[98]

9.3.1 Transit

Floatel Superior had a first assignment in the Timor Sea for three months to 21 May 2010, during which it was positioned with the aid of DP.

It was then transported, partly under tow and partly under its own power, to Ølen. *Floatel Superior* called en route at the following ports [73]:

- Dampier in Australia, arrived 5 July 2010,
- Port Louis in Mauritius, 10 August 2010,
- Walvis Bay in Namibia, 30 August 2010, departed 2 September 2010
- Las Palmas in the Canaries, 3 October 2010.

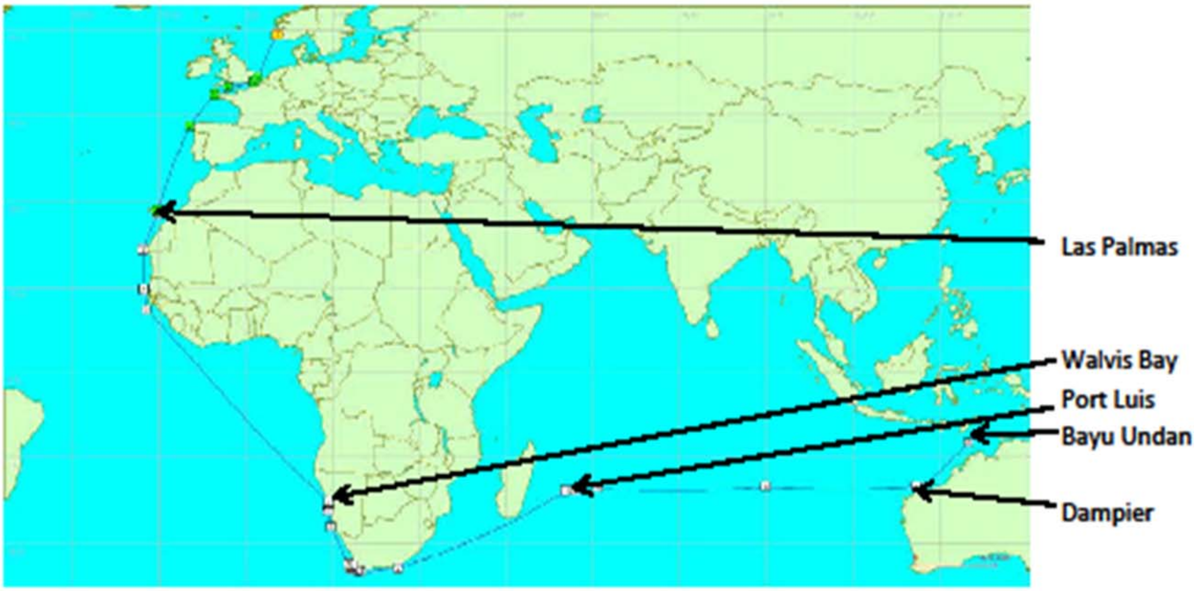

Figure 25: *Floatel Superior*'s route from Dampier to Ølen [73] from July to October 2010.

The transport procedure [73] stated: "The *Floatel Superior* limitations are described in Marine Operations Manual Part 1.A Section 1. At no time the vessel shall be operated beyond these limits. Loads on hull structure impose limitations with respect to sea state and roll motions. The unit is to be ballasted down to survival draft when environmental conditions exceeding those specified in the operations manual." The operations manual [69] states: "The maximum significant wave height for transit condition is: Hs = 3.0 m. If the wave height is exceeded, the vessel shall be ballasted to survival draft". Floatel International reports that the whole journey from Australia to Europe was conducted at transit draft.[99] There were no halts because of weather.

The three-metre limit was set with regard to the hull rather than the bolsters.[100]

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[98] http://www.ptil.no/nyheter/tilsyn-med-boliginnretningen-floatel-superior-article7329-24.html.

[99] Conversations with Floatel International on 4 December 2012 in Gothenburg.

[100] Conversation with Keppel Fels.

Keppel FELS did not anticipate wave damage to the bolsters at an Hs of three metres.[101] The transit draft is about 8.5 metres, see Figure 42. The attachment lug on the bolster was about 1.7 metres above transit draft,[102] and the anchor a little lower. To reach the anchor, wave amplitudes and *Floatel Superior*'s motion must be greater than about 1.5 metres. In a seastate with an Hs of three metres, the highest waves will have an amplitude of about 2.5-3 metres.[103] *Floatel Superior*'s motion comes in addition. On 17 July, for example, the daily log noted a pitch of 5.5° and a roll of 5° [100], with Hs of four metres. Vertical motion of the anchors was then considerable, and they were exposed to wave loads. Anchor movement on the bolsters was also observed during the journey, see also Figure 26.[104]

A simplified calculation of the force required to move the anchors horizontally can be based on a winch tension of 21.4 tonnes less the anchor's own weight (12 tonnes), which gives a tensioning force between anchor and bolster of 9.4 tonnes. Assuming a friction coefficient of 0.3 between the two steel surfaces, this means that a horizontal wave load of 0.3*9.4 tonnes = 2.8 tonnes is sufficient to move the anchor horizontally. This corresponds in order of magnitude to an anchor area of about four square metres being subjected to a drag load with a drag coefficient of two and a fluid speed of 2.6m/s (five knots). Applying a horizontal load of this magnitude or greater to the anchors could put them in motion, and these movements could be reinforced by repeated loads. The biggest effect occurs at the anchor's natural period. Since the latter is influenced by many parameters, it is difficult to calculate exactly. A very simplified estimate can be obtained by regarding an anchor as an ideal pendulum with a length corresponding to the distance from the fairlead to the bolster (9.4 metres). The natural period of this pendulum is about six seconds. Comparing this with a typical long wave with a period of about 16 seconds, for example, shows that long waves are not expected to pose the biggest danger for resonance with the anchors. Sailing with or against the waves will affect the wave period experienced. Assuming a wave with a period of T = 8 seconds at length[105] L=100 metres, it will propagate at a speed of 12.5m/s. When moving against the wave at 2.5m/s (4.9 knots) , the experienced wave speed will be 15m/s and the wave period T'=6.7 seconds. Without having determined the natural period of the anchors more exactly, wave periods deviating by one-two seconds from the anchors' natural period can be expected to have a big damage potential for the bolsters because of anchor movement.

Floatel Superior's voyage began in the Indian Ocean monsoon belt, with the dominant wind direction from the south-east. At this time of year, the seas around the Antarctic are characterised by powerful low-pressure activity which generates big waves. These come generally from the south-west – in other words, across *Floatel Superior*'s direction of travel during its transit of the Indian Ocean. When it reached the North Atlantic and Europe, the waves came mainly from the west/north-west. Data from various positions during the transport[106] show that the waves at periods were significantly higher than an Hs of three metres, which was the condition for operating at transit draft.

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[101] Conversation with Keppel Fels.

[102] Deduced from drawings by Keppel Fels [58].

[103] Calculated the highest wave of a three-hour storm as about 1.55-1.6 * Hs with an amplitude of about 55-60 per cent of the highest wave.

[104] Conversations on *Floatel Superior*.

[105] Wave length is assumed empirically to be $L \approx (1.25 \cdot T)^2$ and wave propagation speed: $c = L/T$.

[106] We have compared with data from windguru.cz.

The daily log has recorded wave heights well over three metres on a number of days. A log was produced every day. The waves have accordingly had many opportunities to hit the anchors and put loads on the bolsters. Some of the conditions where waves exceeded three metres are shown in Table 1. A comparison of hindcast data[107] from the Meteorological Institute [30] indicates that the values in the logs do not always correspond.

Table 1: Positions for *Floatel Superior* between Australia and Ølen where Hs was well above three metres, together with wave heights as logged on board [100]. The right-hand column shows hindcast data from the Norwegian Meteorological Institute [30].

Position north or south (in degrees)	Position east or west (in degrees)	Date	Wind sea reported in the log (in metres)	Swell recorded in the log (in metres)	Calculated wave heights (in metres)[108]	Hs from the Metrological Institute (in metres)[109]
20° 6.8' S	98° 20.3' E	17.7.10	2.5	4	4.7	5.6
20° 6.8' S	98° 20.3' E	18.7.10[110]	2.5	4	4.7	5.9
20° 10.0' S	93° 55.8' E	19.7.10	2	3.5	4.0	5.1
20° 11.6' S	91° 31.3' E	20.7.10	2	3.5	4.0	4.3
20° 28.8' S	65° 48.7' E	1.8.10	2	4	4.5	5.0
31° 17.2' S	30° 56.7' E	18.8.10	2.5	3.5	4.3	2.3
32° 33.2' S	29° 12.5' E	19.8.10	2.5	4	4.7	4.1
34° 27.0' S	26° 35.0' E	20.8.10	2.5	3.5	4.3	3.2
33° 46.9' **N**	13° 20.2' **V**	9.10.10	1-2	4-6[111]	4.1-6.3	5.7
35° 16.3' **N**	12° 36.3' **V**	10.10.10	1.5	3.5	3.8	5.7

Floatel Superior sailed at variable speeds, but up to 9.8 knots on 20 August 2012, with Hs > 3 metres. It travelled under its own power apart from the Mauritius-Namibia stretch, where tugs were used in addition.

The operations manual [95] states: "The maximum significant wave height for transit condition is: Hs = 3.0 m. If the wave height is exceeded, the vessel shall be ballasted to survival draft ... In calm water (no wind, waves or current) a maximum transit speed of

[107] Hindcasting involves calculating past weather conditions on the basis of observed values and with available physical models. This differs from forecasting, which looks ahead to future conditions.

[108] Calculated by us as the square root of (wind sea^2 + swell^2).

[109] Highest Hs per day. Wave data from ECWMF. Wave data are provided at 00.00 06.00, 12.00 and 18.00 UTC for the relevant days at the model point closest to the specified positions.

[110] The same coordinates as the day before, probably incorrectly entered in the log.

[111] The log provides conflicting information on the largest values.

approximately 8.5 knots is expected." The conclusion is that *Floatel Superior* has operated beyond its design assumptions.

Figure 26: Detail from a photo which shows one anchor (anchor 1 at far right) out of position with its fluke against the lower brace on the bolster while under tow at transit draft on 24 August 2010. Photograph: Floatel International [73].

9.3.2 Determining the timeline for damage development

We took samples of mussels in Kristiansund as indicated on the drawing in appendix C.

- Sample 1 was taken inside the broken brace aft of anchor 1.
- Sample 2 was taken inside the broken brace aft of anchor 2.
- Sample 3 was taken inside the damaged horizontal brace to the right of anchor 8 when facing the hull (aft of the anchor position).
- Sample 4 was taken inside the damaged brace aft of anchor 6.
- A reference sample was taken up on the starboard pontoon at the fixing point for the bolster near anchor 3.

The Institute of Marine Research [31] analysed the samples, and determined that the mussels were *Mytilus edulis*, a species common in northern Europe, around the British Isles and along the whole Norwegian coast. This species relies on external fertilisation, followed by a period as free-swimming larvae. Many weeks can pass before these begin their attached life. The Institute of Marine Research has assumed that the mussels have settled (become attached) during June and July. That is the most important period for settling, but some also occurs in the spring and during the autumn. Mussels in all the samples have a smooth shell form and surface. That normally indicates very good growing conditions. Mussels in sample 1 were about five to 10 millimetres long and have probably settled in 2012. The size of the mussels in samples 2, 3 and 4 and in the reference sample varies (about five to 40 millimetres), but the biggest of them probably date from 2011 [31]. Fouling from Singapore, the Timor Sea and the transport to Europe vanished when *Floatel Superior* reached colder waters. New fouling settled on *Floatel Superior* in Europe, at the earliest in Ølen from 26 October 2010. The mussel samples from the cracked braces support the view that several of the bolsters have had cracks in June-July 2011.

Four anchors were removed in Ølen [67 item 2.4]. It is normal practice for crew on the anchorhandling vessels to inspect the anchors visually and report on their condition to the bridge[112]. Whether this was done in Ølen is unknown. Floatel International writes that no documentation is available on whether an anchor inspection occurred [67 item 27].

[112] Conversation with Viking Seatech, 12 December 2012.

Floatel Superior arrived in Ølen on 26 October 2010,[113] and left there on 27 April 2011. After Ølen, it had an assignment on Oseberg from May 2011-August 2012, and at Njord A from August until the incident of 7 November 2012.

The table below lists the number of days when Hs has been greater than seven and 10 metres respectively [29].

Table 2: Days with Hs greater than seven or 10 metres on Oseberg and Njord before the accident night of 6-7 November 2012. Data from the Miros wave radar are used. Our extract from [29].

Months and year	Location	Days with Hs > 7m	Days with Hs > 10m
May-June 2011	Oseberg	1	0
July-August 2011	Oseberg	0	0
September-October 2011	Oseberg	0	0
November-December 2011	Oseberg	12	1
January-February 2012	Oseberg	8	1
March-April 2012	Oseberg	2	0
May-June 2012	Oseberg	1	0
July-August 2012	Oseberg	0	0
September-October	Njord	3	0

If the mussels had settled in the damaged structural components during June-July 2011, and the damage occurred on Oseberg, the most likely day is 24 May 2011, which then had an Hs of 7.5 metres. As table 1 shows, a large number of days followed when waves were equally high as well as days when they were significantly higher. The level of waves on the incident night (about 10 metres) can be seen to have occurred earlier. It was probably a matter of chance which gale caused the hull damage.

The bolsters lie just below the waterline in survival condition. Waves and hull motion accordingly impose substantial loads on anchor and bolster. See also chapter 5.1.1.

9.4 Ref chapter 4.1 – actual consequences

Anchor 8 caused substantial damage to bolster, hull and superstructure at anchor winch 4 on the incident night. The sequence of images below with the associated texts seeks to describe the course of events chronologically.

[113] http://www.westconyard.no/Article3.aspx?NodeId=c04a252d-8869-4465-b83f-bfd9307dd565.

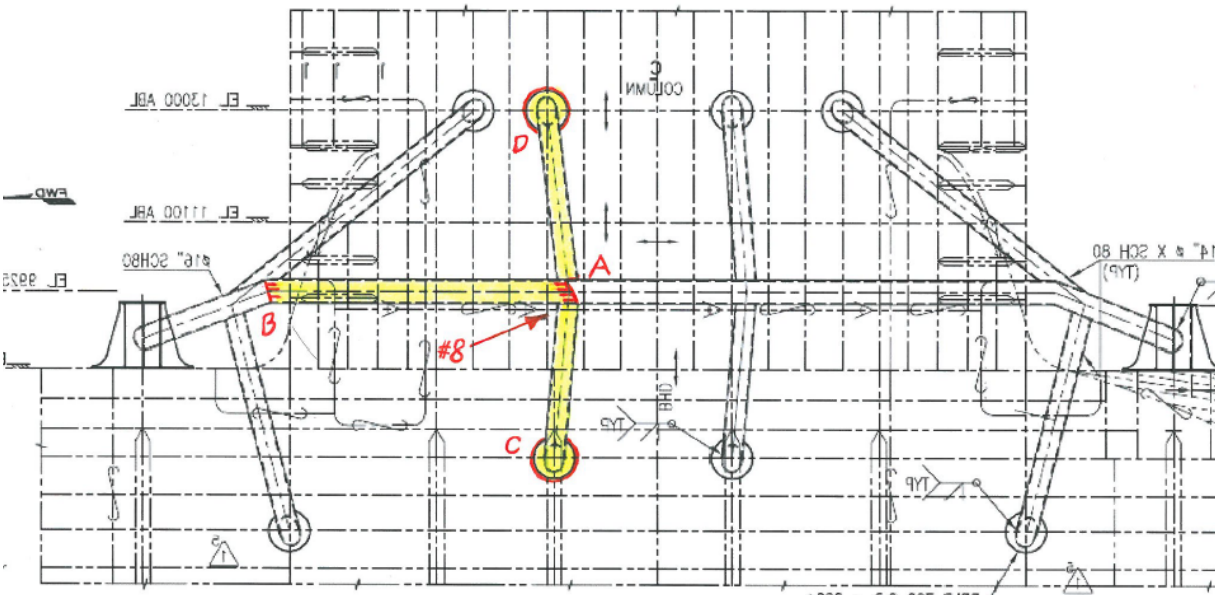

Figure 27: Detail of drawing with the extent of the damage to the bolster at anchor 8 sketched in. Arrow marked #8 indicates the most likely position of the anchor before the damage developed. A, B, C and D show the four fractures in the bolster structure. Yellow indicates which components fell off. From the Keppel FELS design drawing [58] with our notations in yellow and red.

Figure 28: The bolster on the forward port side. Anchor 1 has hit the brace under the bolster bar. Note that the lower brace has been disconnected completely and shifted about one diameter aft (to the right in the photo), and is thereby attached only at a point on the side of tank 3A starboard. The damage is not the outcome of a sudden fracture, but has big deformations from action over a long time. The bolster at anchor 8 (A in Figure 27) has probably suffered similar damage on the evening of 6 November 2012 (all the anchors have damaged bolsters). The photograph was taken in Kristiansund on 13 November 2012 by the PSA.

Figure 29: Bolster 4 with damage A (see Figure 27). Three components are missing at this point. The first fracture on the incident night is assumed to have occurred here at 23.40 on 6 November, when overload alarms on the anchor winch ceased. Until then, the anchor could have pulled with a load of 70-80 tonnes in the horizontal bolster bar A-B (see Figure 27). The fracture has developed from the earlier damage, which is thought to have occurred in the lower brace (see Figure 28). This fracture caused a reduction in the anchor load, and allowed the anchor to start moving. The bolster bar between A and B may have remained for a time. After about two hours, the anchor has been able to hit the hull. Before that, the bolster has suffered yet another weld fracture at B and the bar – weighing about 1.5 tonnes – has fallen to the seabed. Both braces have been present until 01.40, with the upper probably still attached to point B (where the hand in the photo is holding a component which was bent after 01.40. The photograph was taken in Kristiansund on 12 November 2012 by the PSA.

Figure 30: Wear damage where anchor 7 has been wrongly positioned on the bolster (towards the aft of *Floatel Superior*) and worn bolster material and wear surfacing on the edge of the wear surface (left). Note also the surface which as been scraped smooth on the bolster base material to the right. These observations are interpreted to mean that anchor 7 (and other anchors similarly) moved for long periods outside the dedicated position on the bolster's wear surface. In addition, the local wear on the edge of the wear surface is interpreted to show that the anchor has been "locked" in this position and that a high contact pressure has led to extensive local wear. With movements of the anchor from the centre of the wear surface, the geometry of the bolsters causes the wire rope to elongate. This design is intended to

centre the anchors when being stowed in the bolsters, but the use of wire rope rather than chain has made movement possible, and geometry changes have caused an elongation of the anchor line with increased load as a consequence. The anchor has been “hung up” on the wear surface’s edge, and the high tension has had a local effect on a set of welds. Welds, wear plates and base materials all show cracks. Various stages of this damage were observed on all the bolsters. The bolster at anchor 8 has clearly suffered corresponding damage, and the reduction in winch load (alarm cessation) at 23.40 could have been caused by a fracture developed from the edge of the wear surface, where the anchor is thought to have been lying on the incident night under a tension of 70-80 tonnes as well as wave loads from passing repeatedly through the wave zone. The photographs were taken in Kristiansund on 12 November 2012 by the PSA.

Figure 31: Facture surface B on the bolster, see Figure 27. The fracture has developed from the circumferential weld at the bend in the bolster geometry. Note that the final stage of the fracture could have developed as a tension fracture from the anchor tension (along the arrow), and the cross section has been deformed to a straight section before this component was torn off and the A-B bolster section fell off shortly before 01.40. The photographs were taken in Kristiansund on 12 November 2012 by the PSA.

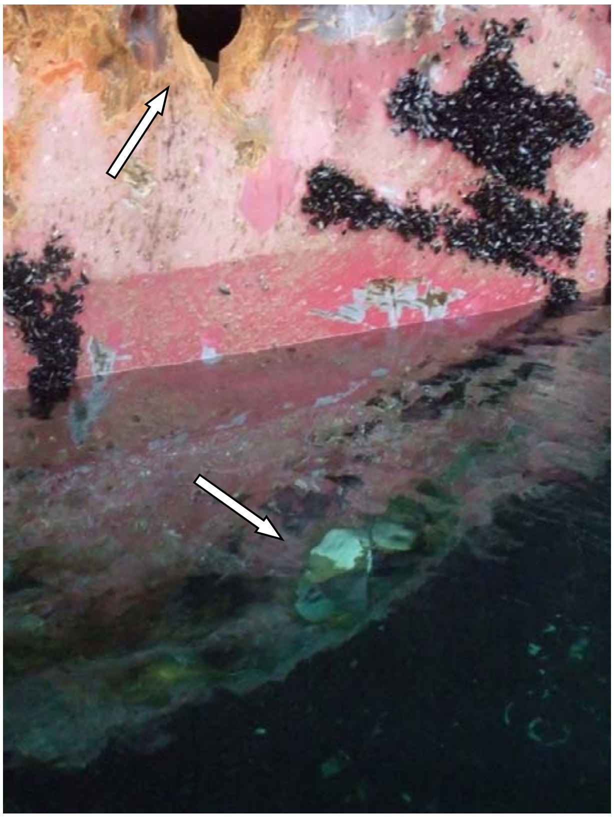

Figure 32: Hole beneath the waterline at bolster damage C (see Figure 27), where the doubling plate has been ripped off, leaving a hole in the hull's outer plating. Note the bottom edge of the anchor penetration at the top of the photo, and the waterline with transit level in the middle. The photograph was taken in Kristiansund on 12 November 2012 by the PSA.

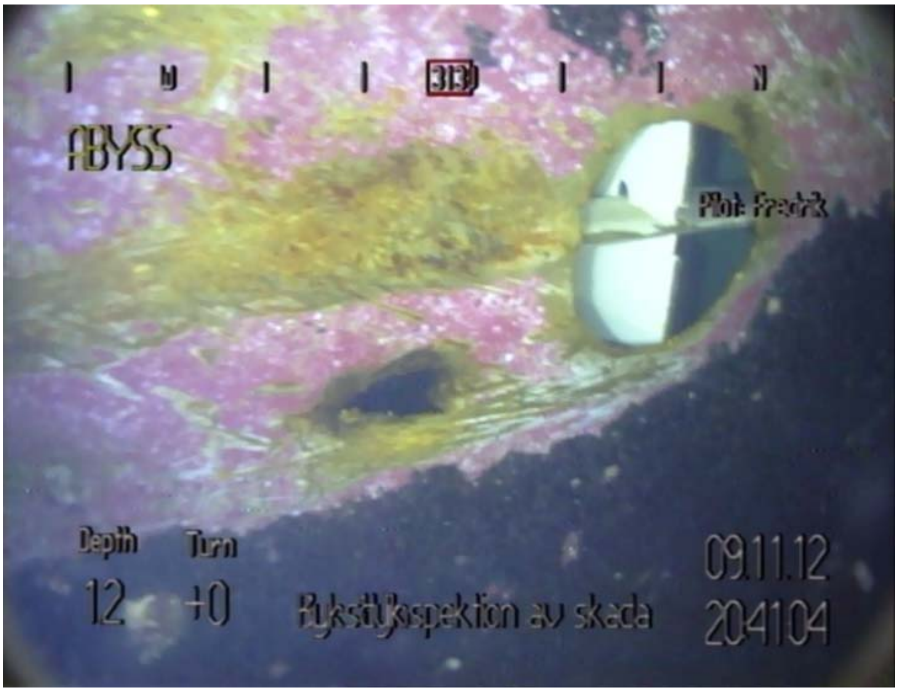

Figure 33: The two holes through the hull into tank 3A. Most clearly visible is the circular hole where the C brace fixing (see Figure 27) has broken off from the hull, with the development of cracks along the weld between doubling plate and hull. Observe that the cross-stiffening with L profiles remains in place on the inside of the hull. The hole diameter is 700 millimetres. To the left can be seen the hole created by the rear part of the fluke of anchor 8 penetrating the hull. The damage is assumed to be the first penetration (about 01.40), and has occurred while the anchor has had its "back" to the brace which was later torn off.

The scrape marks caused by the anchor while it had its back to the hull and clearly hit the brace can be seen to the left of the circular hole. Since the brace had probably been broken at the other end weeks or months before the incident night, it fell off after a short interval and sank to the seabed (possibly about 01.50 when the list changes increase. See Figure 23). The still photograph is from the ROV inspection film taken on 9 November 2012 [148].

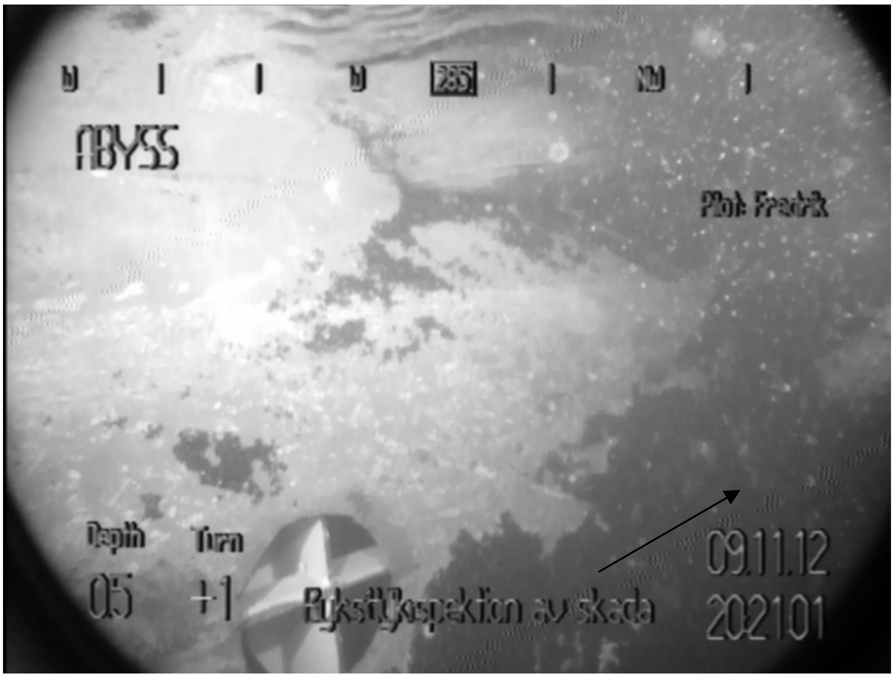

Figure 34: Scrape marks on the hull between anchor positions 8 and 7. Note that the lower brace for the bolster at anchor 7 can be discerned at the far right (see the arrow). The still photograph is from the ROV inspection film taken on 9 November 2012 [148].

After the lower brace was torn off, tank 3A filled with water within about 30 minutes. At 02.15, the facility stabilised at a list of about 3.5˚. The anchor probably had its "back" to the hull and flukes facing out until about 01.50. Figure 36 shows the areas on the hull where anchor and line have scraped away the mussels. The slanted markings at bottom right in the otherwise rectangular scraped area behind the upper brace are interpreted to be where the anchor did not scrape the hull after the lower brace was torn off. Scraped-off mussels in the direction of anchor 7 show that the anchor has moved past the point where the lower brace was ripped off. Because of the list after the water intrusion, the anchor moved further from the hull in its mean position, and thereby changed its behaviour. It hung throughout like a pendulum and moved relative to the hull under the influence of the sea and the facility's motion. Because of the large anchor-fluke area (15.8 square metres), the waves put big loads on the free-hanging anchor and were able to toss it around. At one time, the anchor rotated so that the points of its flukes went right into the hull, and the top of the shank with its line attachment was held between the upper braces. During this period, the flukes made the characteristic scrape marks seen in Figure 36. After repeated blows, yet another hole was made in the hull, which possibly caused moderate water intrusion in tank 10 between 02-15-03-00. At 03.00, the damage was so extensive that tank 10 filled with water in about 20 minutes.

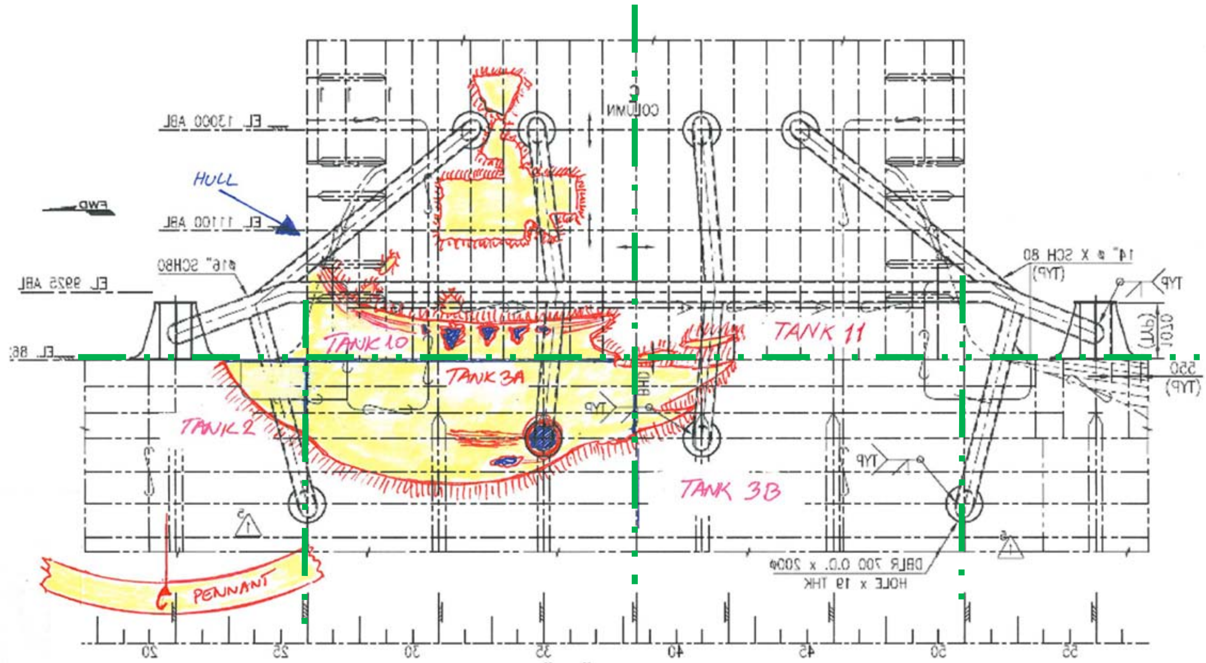

Figure 35: Drawing of part with areas of the hull sketched in where mussels were scraped away by the anchor and the damaged pennant wire holder. These are marked in yellow. Seven of the eight holes in the hull are marked in blue. The eighth was on the front of the column close to the 11 100 millimetre level (see arrow). Note that the drawing has been mirrored from a typical detail design to show the damaged area correctly. Scratch marks are found on the outside of tanks 2, 3A, 3B and 10 and small marks on tank 11. The total ballast weight for these five tanks is 1 500 tonnes. The boundaries between the tanks are shown by dotted green lines. Keppel FELS design drawing [58] with our markings in red, blue, yellow and green.

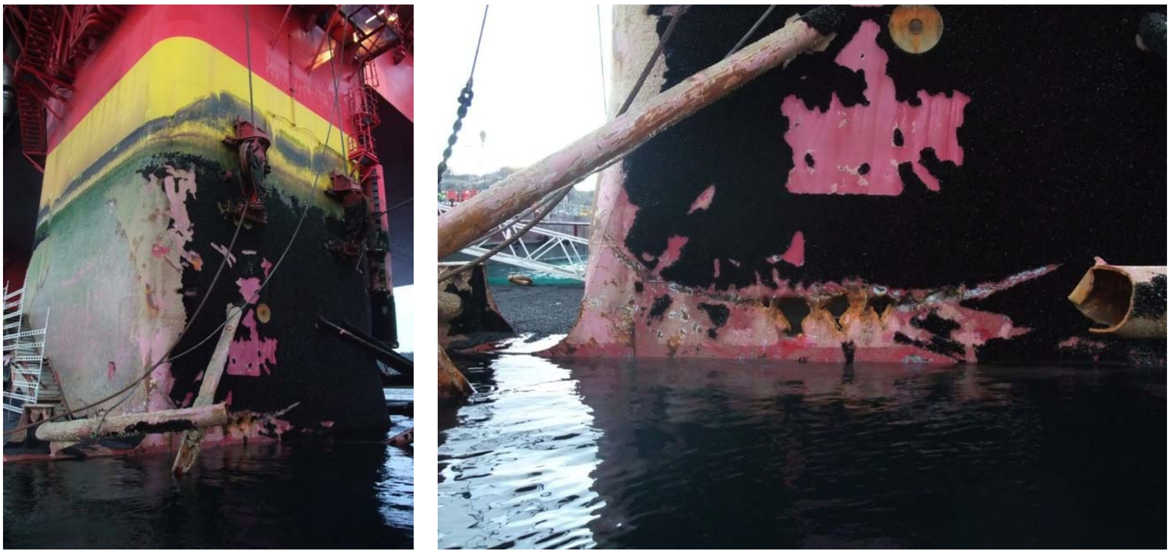

Figure 36: Damage above transit draft, with five holes in the hull side and one on the front of the column. All six were caused by penetration from the anchor fluke's points. Note that the areas where the anchor and the wire rope have moved are clearly delineated (red areas) by scraping away mussels (black area). The photographs were taken in Kristiansund on 12 November 2012 by the PSA.

Figure 37: Five holes through the hull into tank 10. Note the clear marks from repeated blows. The hull between the holes is stiffened on the inside of the tank, and these stiffeners (about 0.6 metres apart) have absorbed the anchor's blows and prevented deeper intrusion to the tank's inner bulkhead (1.5 metres in). The photograph was taken in Kristiansund on 12 November 2012 by the PSA..

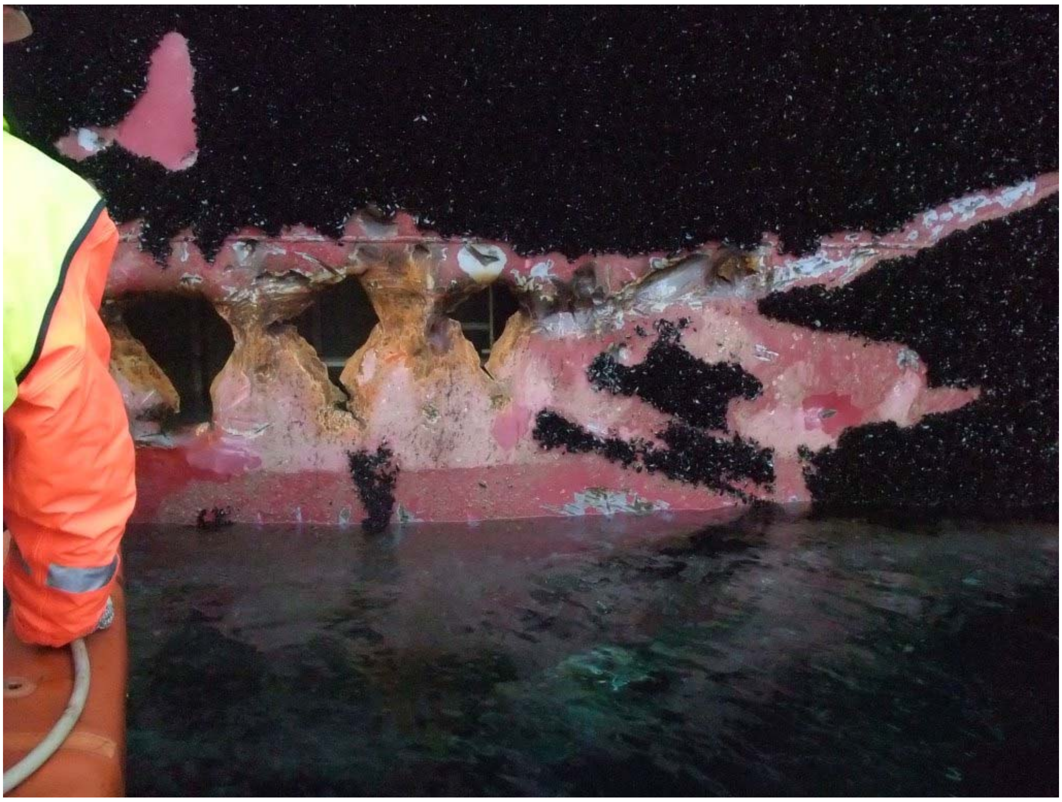

Figure 38: The holes and remaining mussel growth (black). The slanted scratches caused by the flukes towards the upper right provide clear signs of the anchor's pendulum motion. The photograph was taken in Kristiansund on 12 November 2012 by the PSA.

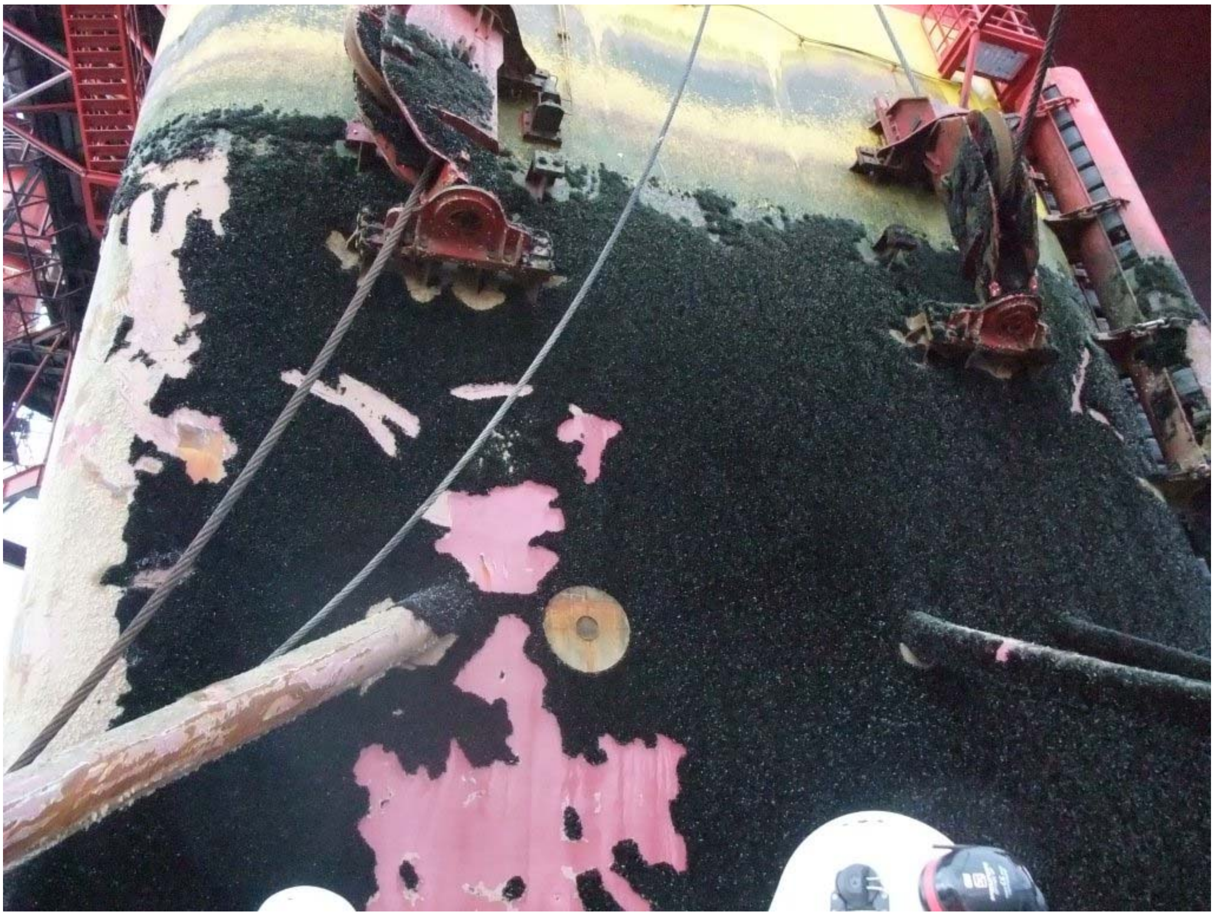

Figure 39: Bolster damage D, see Figure 27. The circular mark in the centre of the picture is where the brace was torn off with the doubling plate welded to the skin of the facility. Note that the doubling plate has been welded both around its exterior and in an inner ring (the plate was doughnut-shaped). The fracture has clearly propagated along the welds, and no noticeable bulging or plastic deformation has occurred on the hull plate, which indicates that this was not a ductile fracture. The internal stiffener cross can be observed, probably because welding heat during fabrication has penetrated the plate. Crack propagation in the doubling plate's weld to the hull rather than in the weld to the brace shows that the plate did not perform its intended role as a structural weak link. The mussels have not been scraped away around the doubling plate after it was ripped off, which is interpreted to mean that the anchor moved forward on the bolster at the same time, or possibly before. See also the scrape marks on the brace to the left of the photo. The photograph was taken in Kristiansund on 12 November 2012 by the PSA.

Figure 40: The forward port column on arrival in Kristiansund on 10 November 2012. Anchor 8 is wedged in the bolster and the hole into tank 10 (arrowed) is clearly visible. Some scrape marks at the bottom of the column show that the anchor has moved in the area. The pennant wire twined around the anchor line (above the anchor) shows that the anchor has rotated. The photograph was taken by the PSA.

Figure 41: The pennant wire holder for anchor 8 after it had been torn free and damaged the railings and operating house. The overview photo on the left shows that the pennant wire must have become caught up in the railings or something else on a level with the anchor winch and drums (see Figure 42, where the positions are marked). The pennant wire hangs from a position above the top of the photo and down to the anchor, and also down to the damaged holder. The wire has apparently become wedged in the bumper[114], and the terminal cable eye has come out of the holder. It appears to hang usually with a security lashing, which the crew reported was normal in order to secure the end of the pennant wire. The photograph was taken by Floatel International personnel on board during the incident day on 7 November.

[114] The bumpers are fenders intended to limit the consequences of collisions.

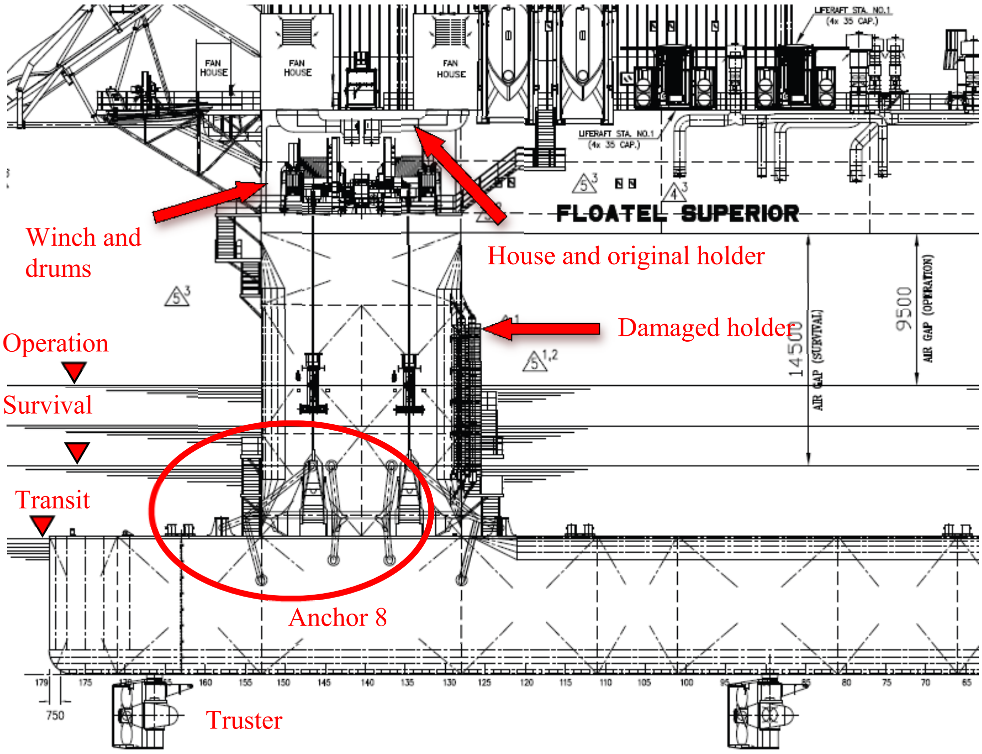

Figure 42: Detail from the side of *Floatel Superior* which shows the forward port column with anchor position 8 circled. The topmost arrow shows the operating house with railing where the pennant wire was positioned before the incident. The bottom arrow shows the final position where the ripped-off wire holder was found after the damage. At far left, the markings for operating (top – 18 metres), survival (centre – 13 metres) and transit (bottom – about 8.5 metres) draft are shown by red triangles. Two of the six thrusters are seen under the pontoon. If the pennant wire had not been caught up in the facility after being ripped from its holder, it could have hung 15-20 metres beneath the keel. That would have given it the potential to be drawn into the forward thruster on the port pontoon. The drawing shows anchors of another type and a different position in the bolsters than those which were actually installed. From Keppel FELS' drawing [58].

Figure 43: The area by the operating house where the pennant wire destroyed its holder, the railings and the operating house window. The damaged window is covered here with a wooden sheet. The holder for pennant wire 7 remains. The photographs were taken in Kristiansund in November 2012 by the PSA.

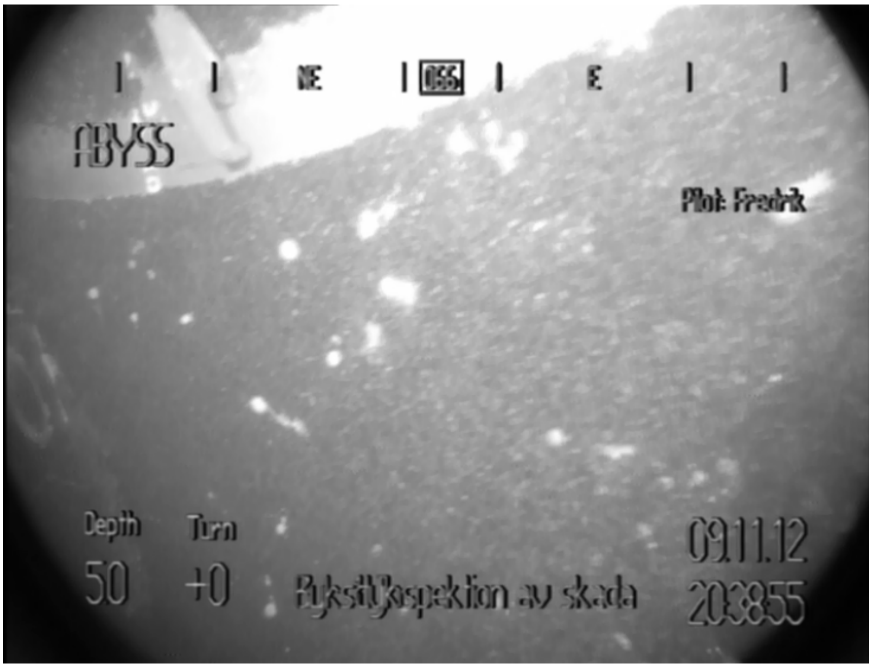

Figure 44: Still from the ROV inspection film of 9 November 2012 [148]. The damaged part of the cock's foot for attaching the pennant wire to anchor 8 can be seen at the top. The cock's foot hung down from anchor 8 after the incident. The cable eye is broken, probably because of a blow or a skewed or twisted load rather than wire tension. See location in Figure 27.

9.5 Ref chapter 5.1.4 - Inadequate securing of anchors in bolsters

During the conversation with Bröhl in Gothenburg on 5 December 2012, the latter explained how the winches functioned. When paid-out anchor line is less than 10 metres, as was the case with the anchor in the bolster, the winch load on active tension is reduced to 30 per cent of nominal capacity for the outermost layer on the drum. Nominal holding power is 71.4 tonnes [48, page 44]. During winch operation, the tension on the bolster will accordingly be 0.3*71.4 = 21.4 tonnes. If the load on the line exceeds 100 of nominal winch load (71.4 tonnes), the system will give a warning.[115] Should the load increase to 110 per cent – in other words 1.1*71.4 tonnes = 78.5 tonnes, the band brakes will operate automatically and the system will electronically prevent winch operation. In order not to destroy the winch, line will then be paid out. The supplier guarantees a holding load of 78.5 tonnes, but this can be up to 83 tonnes. Should that limit be reached, the system gives a new warning. [116] Emergency anchor deployment is then the only way to reduce tension. The winch will normally only be able to pull at 30 per cent of maximum holding load, or 0.3*71.4 tonnes = 21.4 tonnes for the final 10 metres of winding in. In practice, it is possible to pull a few tonnes more, perhaps to 25 tonnes. Bröhl [48, page 25] writes in the documentation that accuracy for line tension measurements is two per cent of the 0-280 tonne interval.

A functioning counter on the winches is significant for measuring the length of paid-out line. When the anchors were removed after the incident, several counters were damaged by rust on an internal "bicycle chain". This corrosion has arisen through inadequate lubrication of the chain. Maintenance programmes on *Floatel Superior* and at the supplier referred in the text to such lubrication and to a specific drawing/figure. But the referenced drawing which was supposed to show the lube point was not included in the maintenance manual on board or at

[115] Warnings 41 and 42, see Figure 24.

[116] Warning 76, see Figure 24.

the supplier. Such lubrication was therefore not included in Floatel International’s maintenance programme for *Floatel Superior*.

An enquiry sent to land from *Floatel Superior* in September 2012 [42] included the following: “AW 3 and 4: Winch blocked due to overload >73 ton measured. This inhibits any use of the winch. This prevents any operation and sufficient maintenance. To release this function either the Emergency Release function has to be activated or the winch operated in service mode to bypass the safety functions. (Broelh technicians statement was that overriding the safety functions creates the risk of components failing, possible VFD trip) AW 3 clutch have to be manually disengaged prior.” Further that “AW 3: Faulty load cells. These have to be replaced when no or little tension on the winch. Previous issue is again the limiting factor”. Winch 4 is for lines 7 and 8. Winch 3, with damaged load cells, is for lines 5 and 6. Two load cells on two different drums were faulty as early as September 2012. Bröhl explained in conversation with us that the load can be measured with one cell, but that two gives greater accuracy.

The preserved error messages begin at 21.15 local clock time on 6 November with alarm number 42 – which shows that tension exceeded 71 tonnes. Only the final 500 messages are preserved. Alarms (number 42) then repeat at intervals of a few seconds for an hour and 40 minutes. Tension has then repeatedly exceeded or remained above 71 tonnes, without reaching 78 tonnes (alarm number 77). See also chapter 9.5.

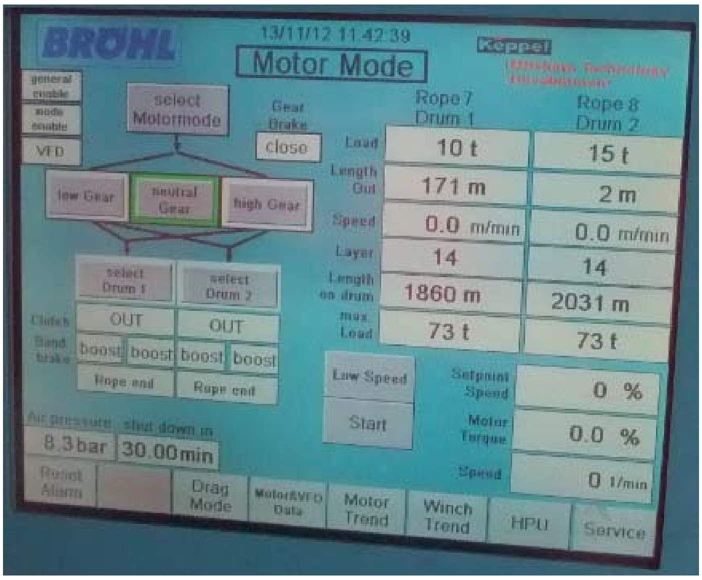

Figure 45: The control panel showing line tension on winch 4. Line 8 had 15 tonnes of tension after the anchor was taken off, which shows that the tension was erroneous. Line 7 was moored to land when the photograph was taken by the PSA in Kristiansund on 13 November 2012.

Keppel FELS used the values in the printout from the stability analysis to explain that the line tension was wrong.[117] The stability analysis specifies 17 tonnes from line 8 at 03.29, 05.09 and 11.51 on 7 November 2012. The same value is also included in the stability analysis at 19.37 on 29 November 2012 after the anchor had been taken off [12, 13, 17 and 152]. The anchor tension was probably included as a fixed load of 17 tonnes in the stability analysis, and accordingly says nothing about the actual tension. According to Lodic, the load should not be included in the stability analysis with short wire rope lengths paid out, so the error is unlikely to be significant. But it helps to make the overview less clear than it should be.

[117] Conversation 5 December 2012.

Similarly, the 15 tonnes of tension observed on 13 November (see Figure 45) is clearly wrong since the anchor was not attached. The load cell on line 8 measured 15 tonnes too much at virtually zero load, but the size of the error at higher loads is uncertain. Lines 1-4 had tensions on 14 November which looked realistic without anchors. We have calculated the necessary elongation of the wire rope for an anchor to reach the braces while stowed in the bolster. See chapter 5.1.1. To reach that elongation, a load of 53-63 tonnes would be required. Without calibrating the gauges, nothing more specific can probably be said beyond the fact that the tension in line 8 during the period before the bolster broke was 53-78 tonnes.

9.6 Ref chapter 5.3 – anchor stowage during DP operations

As shown in chapter 9.8 of this report, a number of incidents have occurred involving anchors getting stuck in bolsters – both while the relevant facility has been in transit and when anchors have been stowed in bolsters for a long time during DP operation. Long-term anchor stowage in bolsters, which are placed at or near the sea surface, increases the risk of damage to a facility.

Achieving a sufficiently stiff system which can keep the anchor secured is difficult. Satisfying the requirements in the DNV standard that the hull must withstand anchor damage is also hard. Removing and re-installing the anchors between each operation requires various considerations to be weighed against each other.

If the anchors are to be stowed in the bolsters during storms, the kind of loads the anchors could be subject to must be carefully calculated.

Designing a hull to withstand direct blows from and anchor could call for large dimensions. Simply installing a bolster solution with a more robust structure is insufficient under today's regulations [118], but will in practice be a way to enhancing protection against anchor damage. A number of bolsters on other facilities have an additional horizontal brace between the wear surface and the hull. This could delay the anchor hitting the hull, but an unsecured anchor could "sail" over the extra brace. The effect of the latter would then be small.

Floatel Superior used steel wire anchor lines, which meant the system was not sufficiently stiff to hold the anchor place. On the subject of using a length of chain between anchor and wire rope, DNV-OS-E301[119] states: "A minimum length of chain to the anchor is required". The design of the fairlead on *Floatel Superior* would nevertheless restricts the length and thereby the effect of a chain. Wire rope was not optimum solution for keeping the anchor in place.

Another key element is the tension to be used to keep the anchor stowed. Industry practice is to maintain 40-50 tonnes of tension at the winch on anchors stowed in bolsters. See chapter 9.8. Even then, there are reports of anchors moving in the bolster. Supplementary measures are therefore essential. As the anchor supplier for *Floatel Superior*, Bruce recommended [133] "We recommend that a 'parking' load of twice anchor weight be maintained with a Blake screw slip to prevent movement of the anchor on the bolster bar during transit." In this case, with a 12-tonne anchor, Bruce believed that 24 tonnes of tension was sufficient with a stopper. A tension of 21.8 tonnes was used on *Floatel Superior*. The difference is small, and using 24 tonnes is unlikely to have made any difference to the incidents. A Blake screw

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[118] See DNV-OS-E301 on position mooring, edition October 2010 Ch 2 Sec 4, O103.

[119] DNV-OS-E301 Ch 3 Sec 2.

slipper is a method for securing chain. Similarly, Bruce [134] recommended for wire rope that "Carpenter's stopper may be used in conjunction with a bottle screw. The winch would pull twice the anchor weight to hold the anchor firmly on the bolster bar while the Carpenter's stopper is attached to the taut wire. The bottle screw is then turned to take out slack in the bridle attached to the stopper before the winch pull is decreased to transfer the holding tension to the stopper. Release is later achieved by re-establishing winch tension to take the load off the stopper to allow it to be taken off the wire prior to paying out wire from the winch to lower the anchor." These methods for securing or lashing anchors are impractical on a semi-submersible because the area between fairlead, anchor and bolster lacks crew access.

Insufficient attention has been paid to winch tension, and, viewed in conjunction with the location of the anchor in relation to relevant drafts on the facility, to securing the anchor to the bolster and to bolster design. The designer has not specified the tension in the operations manual. Given the assumptions involved in combined DP/anchor operation, today's requirements in DNV-OS-E301 will not be fully adequate. Where stowing and securing anchors are concerned, the standard covers only transit of facilities.

An upgrading of the bolters to "secondary structures" would increase their follow-up.

In addition to repairing the damage, Floatel International took several sensible steps to prevent similar incidents in the future, including [35] the removal of all four bolsters.

9.7 Ref chapter 6 – other experience with suppliers

Keppel FELS is an experienced supplier of facilities to the NCS, mainly jack-ups. It designed and fabricated the bolsters on *Floatel Superior*, while Maschinenfabrik Bröhl designed and built the winches and operating house. Keppel FELS and Bröhl have a collaboration agreement dating from 2004 [129]. Bröhl delivered four double winches to *Floatel Superior*.[120] In other words, these players have produced products for the offshore industry over many years.

Keppel FELS and Bröhl have supplied winches for several semi-submersibles [129], including:

- *Safe Concordia* from 2005. This has four wire anchor lines and operates in benign waters.
- *Mærsk Developer* in 2008. Operates off the USA. It has four double winches for chain.
- *Mærsk Discoverer* and *Mærsk Deliverer* from 2009 and 2012 respectively, which operate off Egypt and Angola.
- *Ensco 8500* to *8506* from 2008. Operate off the USA. They have four winches[121].

Floatel Superior appears to be the first facility with this type of winch for use in north European waters. None of the other facilities have DNV class. The winches for *Floatel Superior* are not type-approved by DNV, but approved specifically for this facility. Without access to technical documentation for the other units, it is not possible to assess how alike they are. Keppel FELS [103] reported that the same type of bolster has been used on nine other semi-submersibles. These are the Ensco facilities listed above, *Seadrill West Jaya* and *PV Drilling V*. All have ABS class. They have not been used in north European waters.

[120] http://www.broehl.de/pdf/references/offshore.pdf.
[121] http://www.broehl.de/pdf/references/offshore.pdf.

The PSA has audited design work at Keppel FELS on a few occasions, but not in connection with *Floatel Superior* or other semi-submersibles.

An audit was conducted by the PSA at Keppel FELS and OTD in Singapore [143] on 3-4 May 2011, related to documentation of maritime systems and support structures for Rowan Stavanger. Documentation and quality control of analyses were found to be deficient. Findings included:

- no check was made for the most critical load cases for fatigue
- one analyses used outdated DNV regulations
- jacking system analyses did not comply with the NMA's regulations
- OTD lacked check lists to show what been checked.

Another audit was conducted at Keppel FELS in Singapore [144] on 17-18 October 2012, related to documentation of maritime systems and support structures for Rowan Stavanger. Findings then included:

- fatigue analyses were not conducted for the cantilever which supports the drilling derrick, or for the derrick itself
- analyses of vortex-induced cross-vibrations were not carried out in accordance with the latest edition of the DNV standards
- no NDT of secondary structures.

The PSA has not conducted audits of Maschinenfabrik Bröhl.

9.8 Ref chapter 6 – Other experience

We have searched our incident databases since 2005 without finding incidents involving damage to both bolster and hull. On the other hand, a number of incidents related to bolsters are recorded. We have anchor line ruptures in or close to the bolsters, damage to bolsters, and anchors which have damaged the hull. A brief summary of these incidents is provided below.

Cases where anchor lines have parted:

- Some time between 18-20 June 2010 [109], an anchor (Delta Flipper 12 tonnes) stowed in a bolster on *Regalia* fell off. Hs was around 6.2 metres. The wire rope (86 millimetres) parted just above the anchor. This line was connected directly to the anchor via a socket, and had a breaking load of 528 tonnes. The anchor was attached at a tension of 40-50 tonnes [127]. Inspection of the break site on the line showed that five of the six strands had ruptured and the core was destroyed just above the socket. The sixth strand was pulled out of the socket, when it and the anchor fell into the sea.
- On 4 October 2005 [110], *Eirik Raude* had drilled on DP with the anchors suspended from the sides. A 15-tonne anchor fell off during the concluding work. The chain was cut just beside the fairlead. The owner concluded that it parted because of fatigue under high torsion because of twisting in the line and under high loads because of heavy swell.
- On 9 January 2005 [111], an anchor on *Eirik Raude* was stowed in the bolster. This was a 15-tonne Steveprice unit secured with 50 tonnes of tension [125]. The anchorhandling vessel was to pass the pennant wire to *Eirik Raude*, but high waves caused the vessel – with the aid of the pennant wire – to destroy the final chain link before the anchor shackle. The anchorhandler reported that it was pulling with 82 tonnes. That came in addition to the tension. The anchor fell off the bolster and hit the seabed.

Cases where the anchor system has damaged the hull include:

- On 14 December 2009 [112], the external side of a small-volume tank in the bottom of *Aker Barents* was found to have a dent with a crack which caused water intrusion from the sea. The leak site was about two metres below water, with a leak rate of six-seven litres per minute (0.36-0.42 cubic metres per hour). The crack was close to the fairlead. The fairleads were protected by tension on the anchor chair from anchors stowed in the bolsters. Anchor movements meant that the fairlead was not protected in the proper way. The waves worked with the anchor, causing motion from side to side. The dent could have been caused by collisions between fairlead and the main structure by the tank. When all four fairlead support tanks were checked for damage, three similar dents were found on the starboard side in exactly the same spot. The anchor was stowed with a tension of 50 tonnes.
- On 6 April 2007 [113], a leak and a crack were discovered in a ballast tank on *Polar Pioneer*. The leak was estimated at 10-20 cubic metres per hour. The crack probably started during anchorhandling on 21 March 2007, when the anchor had to be raised and lowered several times because of problems stowing it in the bolster in high seas. This could have caused the pennant wire to stretch and the anchor to swing against the ballast tank while being lowered.
- Damage to two braces, directed towards the hull, was discovered on *West Hercules* [128] on 1 July 2012 after deballasting. Flanged anchor 5 had hit one of the braces. About 30 centimetres of a brace was also missing in front of anchor 6. When deballasting the facility, anchors 5 and 6 hung very slack. Anchor 6 was not stowed in the bolster at all. Unlike *Floatel Superior*, the bolster on *West Hercules* has an extra brace between the bar with the wear surface and the hull. The anchors were attached with chain. The damage on *West Hercules* had much in common with that found on *Floatel Superior*.

Figure 46: Brace cut off on the bolster on *West Hercules* 1 July 2012. Photograph: Seadrill [128].

The conclusion is that other cases are known of anchors damaging bolsters and hulls. *Floatel Superior* is not alone in having the anchors hanging in the bolsters while in DP mode. Using 40-50 tonnes of tension in the winch is normal practice, but even then reports exist of anchors moving in the bolsters. Wave loads on the bolsters also reduce the fatigue life of the lines.

10 Separate appendices to this report

10.1 Appendix A: Overview of conversations.

10.2 Appendix B: Letter from the Institute of Marine Research, 21 November 2012.

10.3 Appendix C: Drawing which shows where mussel samples were taken.

10.4 Appendix D: HTO incident and causal analyses (Bento’s method).

10.5 Appendix E: Causal analyses (Statoil’s method).