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Study in the Petroleum Safety Authority Norway's report Trends in Risk Level in the Petroleum Activity (RNNP) 2013

"Causal relationships and measures associated with structural and maritime incidents on the Norwegian Continental Shelf"

This study forms chapter 10 of the Main report, RNNP 2013, published on 24 April 2014 at http://www.ptil.no/hovedrapport-sokkel/category1155.html

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10. Causal relationships and measures associated with structural and maritime incidents

10.1 Introduction

10.1.1 Background and objective

On the Norwegian Continental Shelf (NCS), there have been a number of incidents that may be linked to structures and marine systems. The most serious was the loss of Alexander L. Kielland in 1980, where a failure in a horizontal bracing led to the capsize of the platform, and 123 fatalities. The loss of West Gamma in 1990 while being moved from Ekofisk was caused by towing in poor weather and damage to tanks due to inadequate securing of one of the lifeboats. All 49 lives on West Gamma were saved. The loss of Sleipner A-1 in 1991 was primarily caused by errors in structural analysis. The concrete structure sank in Gandsfjord during testing, with no-one on board. Serious structural and maritime incidents have also occurred elsewhere, such as the Kolskaya accident in 2011, which caused 53 deaths, and the wrecking of P-36 in 2001, Aban Pearl in 2010 and Jupiter 1 in 2011. Kolskaya, Jupiter 1 and Aban Pearl had all previously operated on the NCS.

In 2013, the PSA instigated a study to examine DFU (defined hazard and accident condition) 8 - damage to platform structure/stability/anchoring/positioning fault. The background for the study was the negative trend in reported structural and maritime incidents on the NCS, as well as the serious incidents on Floatel Superior and Scarabeo 8 in 2012. The study is focused on incidents which might lead to major accidents. The objectives may be summarised as follows:

- To collect data from literature, investigations, interviews and questionnaires concerning causes and measures associated with structural and maritime incidents.
- To perform a complete assessment and analysis of human, technical and organisational causes and underlying factors. This will contribute to a better knowledge base than we currently have.
- On the basis of identified causes, to suggest areas for improvement and concrete measures which the industry should address.

This report presents the results of this work.

10.1.2 DFU 8 – Description and limitations

The study as performed is limited to DFU8 as described in the RNNP report. Figure 1 shows the number of reported incidents and damage events to structures and marine systems which conform to the criteria for DFU8 in the period 2000-2013.

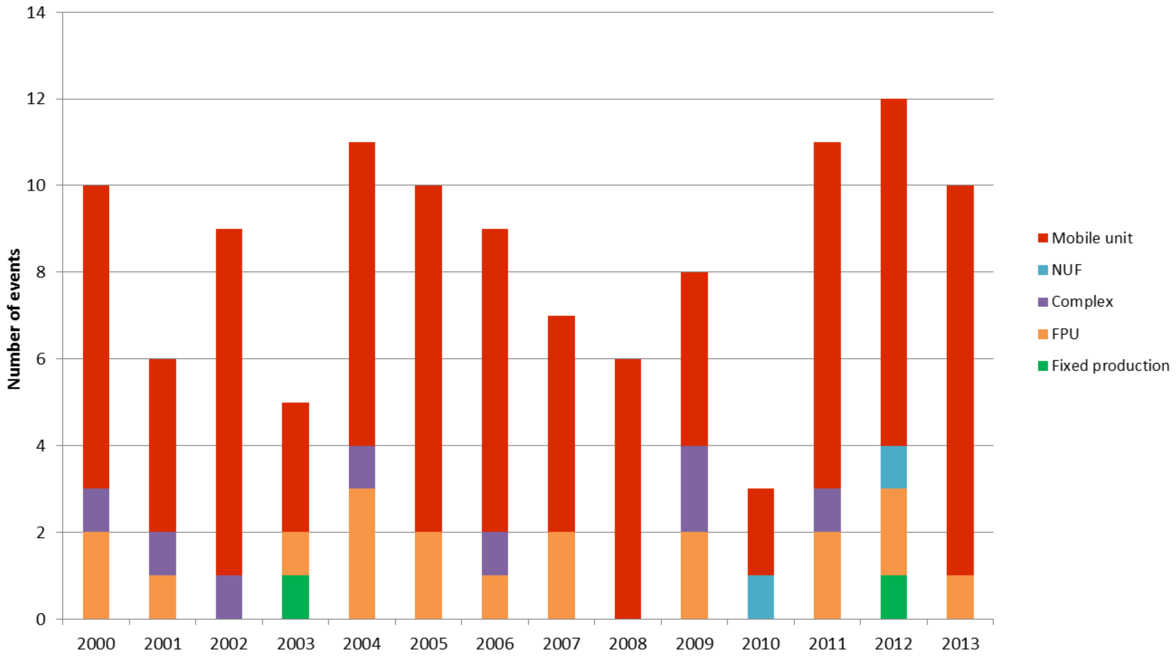

Figure 1 Number of reported incidents and damage events to structures and maritime systems and marine systems which conform to the criteria for DFU8 in RNNP[1]

Collisions with ships are a potentially important cause of this type of incident, but separate DFUs have been defined for ships on collision courses (DFU5), drifting objects [on collision courses] (DFU6), and collisions with field-service traffic (DFU7). Collisions as a cause are accordingly not included in this study. Moreover, a number of other studies have been performed of collision risk, especially for field-service traffic (Kongsvik, Fenstad, & Wendelborg, 2012).

DFU8 Figure 1 Number of reported incidents and damage events to structures and maritime systems and marine systems which conform to the criteria for DFU8 in RNNP concerns only incidents with a major accident potential. In simple terms, DFU8 includes incidents involving failures in main support structures which might contribute to the loss of carrying capacity of the entire structure or vital parts thereof (structural incidents), and incidents which involve the loss of position, stability and buoyancy (maritime incidents). The study differentiates between these two main types of incident.

The distinction is not necessarily completely unequivocal in all situations. For example, damage to or failure in structures may lead to water ingress which in turn may lead to loss of stability or buoyancy. This was the case with Floatel Superior in 2012, where external damage from an anchor caused flooding. In December 2002, a mobile facility suffered flooding in a horizontal brace due to a welding defect. If this had continued over some time, it could have led to a serious incident. The water ingress was however detected in good time, before the cracks had grown to a critical size. Both these incidents are examples of structural damage causing stability problems. It is therefore not always clear if an incident should be classified as a structural incident or a maritime incident.

The classification depends on what constitutes the major accident potential of the incident. If the structural damage is so serious that it could lead to a failure of the main support structure, the incident is classified as a structural incident. Conversely, if water

[1] NUF - "Normally Unmanned Facility"

ingress is the critical consequence, the incident is classified in this study as a maritime incident.

On this logic, Floatel Superior was classified as a maritime incident, since it is assessed as highly unlikely that the incident could have led to collapse of the structure. Alexander L. Kielland would be classified as a structural incident, since the triggering incident was fatigue and fracture of a bracing member.

The advantage of distinguishing between the incident types in this way is that improvement suggestions can be more clearly focused either on strengthening the structure, or on ameliorating issues of stability, buoyancy or flooding.

Figure 151 and Figure 152 show the number of reported structural and maritime incidents, respectively, in the RNNP reports from 2000 to 2013, by type of incident.

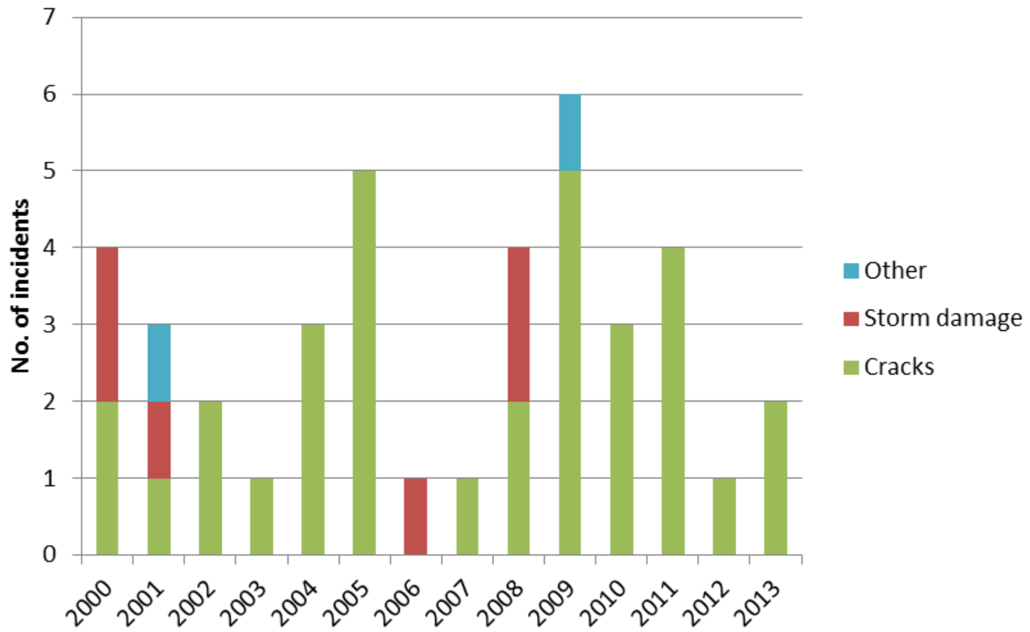

Figure 151 Number of reported incidents and damage events to structures which meet the criteria for DFU8 in RNNP

The figure shows that a total of 40 structural incidents were reported in the period.

Figure 152 Number of reported incidents and damage events to maritime systems which meet the criteria for DFU8 in RNNP

The figure shows that a total of 75 maritime incidents were reported in the period.

The study comprises, in principle, incidents occurring in all phases of a facility's lifetime, as long as they have a major accident potential. In practice however, the information we[2] have concerns, primarily, engineering and the installation and operational phases.

RNNP reporting to the PSA by the industry takes place annually. Reported incidents are assessed for criticality and incorporated in the RNNP statistics on the basis of the overarching requirement of a major accident potential[3]. In the period 2000-2013, 40 structural incidents and 75 maritime incidents were included in the DFU8 category. This forms the data base for this study. Ongoing reporting also takes place from the industry to the PSA's emergency response officer: reports in the emergency preparedness group's incident log are not classified in the same way as in RNNP, and are based on an immediate risk assessment whose status may subsequently change. In the period 2000-2013, 93 incidents with "structural damage" and 117 "incidents involving anchor lines and DP" were reported in the PSA's incident log.

10.1.3 Types of facilities

In some contexts, when presenting and discussing the results, it is natural to differentiate between different types of facilities. Accordingly, in the main, the report distinguishes between two groups:

- **Production facilities** – This term includes all facilities essentially designed to produce oil or gas from a field or which operate as storage. It may cover a range of different concepts, including structures fixed to the seabed and floating structures. Examples are offshore concrete structures, steel jacket platforms, tension leg platforms, floating production, storage and offloading vessels, semi-submersible facilities and so forth. Loading buoys may also be included in this definition, although we do not have data specific to this type of installation.

[2] "We" here refers to the group of researchers who conducted this study on behalf of the Petroleum Safety Authority Norway.

[3] Criteria for reporting structural and maritime incidents in RNNP are described in PSA (2012) "Methodological report – weighting of incidents relating to structurals and marine systems (DFU 8) in RNNP" at www.ptil.no.

- **Mobile facilities** – These will mainly be drilling facilities and some accommodation facilities that are not dedicated to a specific field, but which are moved from location to location. On the NCS, this applies to semi-submersible and jack-up facilities.

10.1.4 Parties

There are many parties involved in managing risks associated with structural and maritime incidents, especially when one also considers the potential underlying causes of such incidents. It is therefore natural to provide a brief overview of the most important parties. This description is not intended to offer a rounded view of the activities they perform, but rather highlights those aspects of their activities that are relevant for the topic under discussion here.

- **Operating companies** – Develop fields for production and thereby commonly requisition, own and operate production facilities. In most cases, operating companies closely monitor their facilities from choice of concept and initial design through to operation and, lastly, decommissioning. They also lease mobile facilities from rig owners for the drilling of wells.
- **Engineering companies** – Execute concept studies and develop design of offshore installations based on orders from rig owners, offshore/shipyards or operating companies. Design engineering is performed by Norwegian and foreign companies in various countries. There may well be different companies, in different countries, contracted to deliver different phases of the engineering. The engineering companies produce documentation as a basis for purchasing equipment and equipment packages, fabrication and subsequent operation. In many instances, engineering and fabrication are performed by integrated companies which then fulfil the yard function, but for the present purposes we have chosen to separate out these functions.
- **Yards (Offshore/ship yards)**– Build facilities on commission from operating or rig owner companies. Based on design prepared by engineering company, the yard may prepare some detail engineering and all fabrication drawings, order materials, equipment and equipment packages and perform mechanical completion. Depending on the contract, the yard also undertakes system completion in cooperation with the engineering/operating company. As a rule, the yard is responsible for supplying "as-built" documentation as a basis for operation. Fabrication of the facility takes place both in Norway and overseas. It is also common for different parts of the facility to be built at different locations, such as Poland and Korea, and then assembled at a third site.
- **Authorities** – In this instance, this comprises the Petroleum Safety Authority Norway, the flag states, the Norwegian Maritime Directorate and the classification societies. These agencies administrate their respective provisions and regulations and monitor compliance through audits and other measures. In addition, the classification societies have been delegated the authority to fulfil some of the authorities' remits.
- **Rig owners**– Order, own and operate mobile facilities and are responsible for manning the facilities with maritime personnel qualified to manage systems relating to, for example, stability and positioning. Most rig owners also undertake extensive monitoring of construction activities at the yards.

Other groups of participants are also involved. These include sub-suppliers to the yards, including equipment and systems suppliers, and service providers who deliver consultancy, analytical, inspection and maintenance services, and so forth. The classification societies and flag states, which issue maritime certificates, also contribute to the player landscape.

10.1.5 Theoretical basis

There has been much research on major accidents and a number of theoretical perspectives have also been published in the research literature. A comprehensive discussion of the most important of these may be found in, for example, Rosness et al. (2010). The choice of perspective may be very significant for the focus of the analysis and hence what are detected as relevant and interesting findings in a study such as this. An account of the theoretical basis is therefore necessary in order to put the results into a context.

One important theoretical framework has been James Reason's book "Managing the Risks of Organizational Accidents" (Reason 1997). Reason builds on the energy-barrier perspective instigated as far back as in 1961 (Gibson 1961, Haddon 1980), but makes an important extension by introducing the familiar "Swiss cheese model". This model illustrates that there may be active faults which cause barriers to fail, but there may also be latent preconditions with a potential for leading to failure. Reason points out that latent preconditions may be introduced a long time before an incident occurs, for example in the engineering or fabrication phase of a facility, or through modifications to or operation of a facility.

In line with Reason, "causes" is used in this context in a broad sense and not only in relation to factors that directly lead to an incident occurring. Causes may also include factors which are assessed as having had an influence on an incident by actually or potentially having contributed to increasing the likelihood of an incident occurring. Such an understanding of the concept of causation makes it natural to examine not only direct causes or triggering causes, but also to search further back along the incident chain to discover underlying causes. Such a broad interpretation of causation is also natural in the light of the PSA's principles for barrier management in petroleum activities[4] (PSA, 2013), which include a similarly broad understanding of barriers.

One challenge of such a perspective is that the relationships between cause and incident may be perceived as weak and indistinct. However, in the study it was decided to include such factors as long as it was also logically possible to argue for a potential relationship between cause and incident.

A natural consequence of the above description is that a man-technology organisation (MTO) perspective has been used in searching for causes, meaning that the study has looked for human, technical and organisational factors which may have affected, or which are capable of affecting, the incident types being studied.

Two other theoretical perspectives which have been significant for assessing the material are Turner's "Man-Made Disasters" (Turner and Pidgeon 1997) and Dekker's "Drift into Failure" (Dekker 2011). Turner concluded that serious accidents often had long incubation periods during which the factors developed negatively, until an accident actually occurred. One key element of Turner's theory was also that there were nearly always individuals or parts of an organisation who were aware that such developments were taking place. The challenge was to detect these trends, see them in context and correct them in time. Important and relevant factors in this perspective are information flow within and between organisations, and also an overview and understanding of relationships. This acquires extra relevance due to the complexity of organising, in particular, the engineering and fabrication of facilities. Many participants are involved, with varied experience from different countries and with diverse cultures. This may intensify potential problems with information flow.

Dekker's "Drift into failure" concerns slow trends in development that happen unawares because they progress so slowly that people are habituated to the small changes without

[4] http://www.ptil.no/getfile.php/PDF/Prinsipper%20for%20barrierestyring%20i%20petroleumsvirksomheten.pdf

seeing that, over time, these may entail major changes which negatively impact the risk profile. We were on the lookout for such development trends in the collected material.

One final theoretical perspective which it is relevant to mention is Rasmussen's (1997) article "Risk Management in a dynamic society: A modelling problem". Here trends are presented as a continuous tug-of-war between different objectives, such as safety versus costs or safety versus progress, and where one must constantly guard against imbalances. "Conflicting goals" is also one of the areas we particularly looked out for in the analysis.

10.2 Methodology

10.2.1 Overview

The study has been carried out by an interdisciplinary team of researchers with extensive experience from engineering science and social science research and consultancy work. Wide-ranging expertise within safety subjects in general, structural safety and maritime operations, risk analysis and investigations, safety culture, organisational and human factors was represented in the team. The PSA also assisted with structural- and marine expertise. The object of establishing an interdisciplinary team was to ensure that technical, organisational and human causes were all identified in the study. The entire team participated actively in the whole project, from the design and implementation of data collection activities to analysis of the individual sources, and collation and reporting of results.

The study was based on the collection of information from different types of data source and a subsequent analysis of the collected data. The use of several data sources allows for comparison and checking of different types of information against each other. The four main groups of information sources used were as follows:

1. Professional and research literature
2. Investigations of relevant incidents
3. Interviews with relevant experts
4. A questionnaire-based survey aimed at relevant experts

During the data collection phase, provisional results were used to target further work. For example, the interview guide was adjusted in order to obtain more complete information about topics identified in the first interviews. Similarly, the questionnaire was also created on the basis of, among other things, results from the other data sources. Information collection therefore developed as the work progressed.

The study was only possible due to the great willingness of individuals and companies. A central basis of the study is information collected from the professional community within the Norwegian petroleum industry[5], and which comprises key parties in the domain. A total of 85 people contributed to the survey (44 interviewees, 41 questionnaire respondents). This comprised a broad sample of those who are considered in the industry to be experts in structural and maritime specialisms. One indication of this is that interviewees were asked to suggest people who should be interviewed in their capacity as recognised experts. As the survey progressed, a pattern emerged that the names given were already on the list of contacts. Similarly, many of the people proposed as possible questionnaire respondents had already been interviewed.

It may also be mentioned that, in an international context, it is unique for companies to place at disposal investigation reports and informants. In connection with previous causal studies carried out under RNNP (2010 and 2011), the PSA has received feedback at presentations of findings at international conferences that it is "highly unusual" internationally for companies to assist with investigation reports and informants. It is

[5] The PSA offers its sincere thanks to everyone who contributed.

gratifying to see that the tradition in the Norwegian petroleum activities of sharing experiences and contributing to better insight into the causes of incidents with major accident potential has also continued in this study.

In the following sub-chapters, the work on the four data sources is described. By way of conclusion, there is a brief description of how the overall analysis was performed.

10.2.2 Literature study

In the literature study, relevant national and international research linked to structural safety and marine systems was identified and analysed. The objective was to investigate whether there was literature available to help improve knowledge of and insight into causal factors and preventive measures associated with structural and maritime incidents.

Using a list of search words, general search engines (such as Google Scholar) were employed, as well as searches in OnePetro, a database specially devoted to the oil and gas industry. In addition, a number of reports from various research organisations, consultancy firms and the authorities were used to identify items of literature. The main focus was directed at references from the oil and gas industry in the last 10-15 years.

A total of 145 reports and articles were identified. These were treated as follows:

- An initial rough sorting of the 145 identified data sources was carried out. This was mainly based on their titles. It was performed by the project team's specialists and reduced the number of relevant sources to 70.
- The summaries of these 70 sources were reviewed to further rank their relevance. The sources were also sorted by topic and type of facility.
- The sources assessed as being most relevant, totalling 48, were then reviewed in detail. Of these, 39 were published between 2000 and the present day. This detailed review entailed analysing the sources in terms of whether, and how, they shed light on causal factors for structural and maritime incidents.

10.2.3 Investigations

The review of investigations was based on 52 investigation reports received from the PSA. These investigations were carried out by operating companies, rig owners or the PSA itself following structural and maritime incidents on the NCS. Only investigations from 2000 or later were included. Before then, there were fewer investigations and a weaker analytical foundation. The base data was however extended to include the Sleipner accident in 1991. This was done because it is the last major accident caused by structural factors to have occurred in Norway, it is an accident for which a lot of information is available, and there have been few structural incidents with a major accident potential involving fixed production facilities.[6]

The investigations were analysed as follows:

- To begin with, a procedure was performed to ensure that the reports were relevant in relation to DFU8. For example, all reports dealing with collisions or near-misses, and reports concerning structural incidents not involving a primary structure were removed from the selection. Furthermore, the selection was limited to incidents that took place while the facilities were in operation (excluding Sleipner). In the end, 30 investigation reports were assessed as relevant and selected for further analysis. In addition, 18 investigations of uncontrolled anchoring deployments in RNNP were

[6] Note that the Sleipner incident is not represented in the data in RNNP, since it was not in operation at the time of the incident.

assessed as relevant for providing information about anchoring incidents, even though the incidents are not included in the data material in RNNP[7].

- A detailed analysis matrix was established in advance to be used for categorising and sorting findings and measures described in the investigation reports. This was used, even though it proved difficult to complete the matrix, since a number of the investigations did not contain information about underlying conditions.
- The investigations were first sorted and systematised, and relevant ones were then analysed.

10.2.4 Interviews

Interviews with the companies' experts in structures and marine systems constituted an important part of the core data for the survey. The interviewees were selected by asking the companies to indicate their principal specialists in the two domains. The purpose of the interviews was to gather experiences associated with causes, challenges and future measures within structures and marine systems. The invitation to participate in the interviews was written by the PSA, and included the following:

"In order to acquire comprehensive data, it is critical to gather information through interviews with relevant professionals who have knowledge and experience of engineering, risk management and operations associated with structures and marine systems. This offers an opportunity to acquire information which is rarely visible in the written material, such as perceptions of risk assessments, routines and practices which affect the risk of structural and maritime incidents."

Furthermore: "In terms of causes of the incidents, we are primarily looking for the companies' experts' views on what they themselves assess as being the most important causes. We would like (the research team) to be able to interview people in your company with in-depth insights into, and expertise and experience relating to, structural and maritime incidents. The Petroleum Safety Authority Norway therefore hopes that you are able to help select interviewees in your company."

It was also specified that it would be desirable to interview personnel with professional responsibilities within structural and marine systems from the engineering companies. From the operating companies, the wish was to interview people at several levels of professional responsibility for structural and marine systems, while from the rig owners we wanted to interview ballast operators/DP operators, stability managers and specialists onshore.

In total, 38 interviews were conducted with 44 industry specialists. There are grounds for assuming that the interviews represent a good selection of Norway's prime expertise in the area. The interviewees were asked whether they had suggestions for other people who should be interviewed. As a result, the number of interviews was expanded compared with the original plan.

Priority was given to employees of engineering companies (14), operating companies (12) and rig owners (11). In addition, the interviews cover a total of seven people from the authorities, a classification society, and the research and consultancy domains. Overall, the interviewees represented 14 organisations. The interview topics varied according to the subjects' background and expertise. For 12 interviews, structural incidents were the main topic, 12 dealt with maritime incidents and 14 with both. Most of the interviewees had technical expertise from engineering, structural, operations, consultancy or research, but there were also some who primarily had operational experience.

[7] Uncontrolled deployments are not normally part of the RNNP data basis. The reason why there are many investigations on uncontrolled deployments in this study is that last summer the PSA carried out a project about this type of incident.

The interviews were conducted between October and December 2013. 34 of the 38 interviews were conducted face-to-face with the remainder taking place by phone. With four exceptions, the interviews were conducted by two members of the research team. This was done so as to document the interviews satisfactorily without recording them, and to bring both engineering science expertise and social science expertise to the interviews. Each interview lasted about one hour.

Before the interviews began, an interview guide was prepared with a list of relevant questions and topics. In addition to specific questions and topics, the interviews also included completely open questions such as "in your view, where is the greatest risk in terms of structural incidents/maritime incidents" and "if you had all the necessary power and means available to you, what would you prioritise to improve safety within these areas?" By way of conclusion, interviewees were also asked if there were other topics they had expected to be questioned about, or whether there were other topics they would like to raise. This was done to ensure that it was not exclusively the interviewers' interests which determined which topics were raised.

Extensive notes were taken during each interview to provide a basis for writing minutes. After each interview, the interviewers produced a brief summary, identifying important outcomes from the interview. This was used as input for topics which should be followed up further in later interviews, and to refute or confirm earlier hypotheses and findings. Similarly, a summary was produced by the entire product team after around one third of the interviews had been concluded. This also produced input for new topics and further targeting of the remaining interviews.

10.2.5 Survey questionnaire

Interviews are an effective, but also time-consuming, method of collecting data. In order to ensure access to views from a wider sample of professionals, an electronic questionnaire-based survey was also conducted. The purpose of this survey was partly to supplement the data gathered through the interviews, and partly to investigate more closely some of the topics that the interviews had identified as interesting.

To procure relevant respondents for the survey, direct contact was made with a total of 17 operating companies, 14 drilling contractors, four engineering companies, three inspection and maintenance organisations, and five equipment suppliers. Contact was also made with classification societies and universities. All were requested to provide e-mail addresses of specialists within structural and marine systems respectively. Some companies chose not to participate in the survey. They stated that they did not have competence relating to structural and marine systems in-house. Some of the proposed names had already been interviewed and were not asked to participate in the questionnaire. 34 organisations in all responded positively to the invitation. These included 12 operating companies, ten drilling contractors, three engineering companies, two inspection and maintenance organisations, five equipment suppliers and two others. In total, questionnaires were sent out to 76 e-mail addresses and 41 responses were received (response rate 54).

The survey asked a number of open questions concerning causes and measures associated with structural and maritime incidents. These were answered as free text. Tickbox questions were also asked, where the respondents were requested to respond to statements concerning selected topics. The questionnaire was designed so as to present the respondents with questions adapted to the discipline they primarily worked in – structures or maritime systems. Here are some examples of open questions:

- In your view, where is the greatest risk in terms of structural incidents?
- What might be the underlying causes of the high incidence of anchor line failures, uncontrolled deployments or other incidents associated with anchoring?

Examples of tickbox questions (structural):

- Experiences from previous structural incidents are only given slight consideration in the choice of concept and in engineering.
- Adequate analyses and assessments are made before new concepts or solutions are implemented.

Examples of tickbox questions (maritime):

- Critical marine systems (such as ballast and DP systems) are simple to understand and use
- Factors relating to marine systems are an area that receives too little attention in safety work in the industry

The free text responses from the questionnaire were analysed in two stages. Firstly, they were sorted into thematically similar groups. Then the crux of each response was allocated to main MTO categories. The tickboxes were presented as descriptive statistics, and the responses used to illustrate key topics from the interview survey where appropriate.

10.2.6 Processing of collected data

Once all the data collection activities were underway (but before they were completed), a working meeting of the study's project team was held, at which provisional findings and conclusions from all the sources were reviewed and discussed. The purpose of this was primarily to see if there were obvious results it would be natural to highlight, if there were topics that should be pursued in further activities, and also if there was a need to adjust the data collection work in other ways.

A working meeting was then held of the entire project team to conduct a systematic review of the data from all sources in order to identify important findings and observations. This was done using two approaches:

- Firstly, the different phases in project execution were assessed to see if it was possible to associate observations with each of the phases. For this, assessments were made separately for field development versus construction of a drilling facility. For drilling facilities, by far the majority of findings related to operations, but for field developments this division into phases worked very well.
- For each phase, the different participants were assessed to see if there were observations that could be linked to different groups of participants, such as "operating companies" or "rig owners".

10.3 Results

The following sub-chapters discuss the results of the literature study, review of investigations and the questionnaire-based survey. The results of the interviews are discussed in sub-chapter 10.4.

10.3.1 Results from the literature study

As described above, a total of 145 sources were identified, of which 70 were selected for a closer review. Of these, 48 were thoroughly evaluated.

These 48 sources were divided into a number of different thematic areas[8]:

Topic	Number of sources and examples
Human and technical factors in engineering and operation of facilities	6 sources (e.g. Bea, 2002)

[8] A complete list of the sources that were thoroughly evaluated is given in the reference list.

Anchoring and anchoring difficulties	4 sources (e.g. Majhi & D'Souza, 2013)
Ageing problems and Structural Integrity Management (SIM)	8 sources (e.g. SINTEF, 2010)
Dynamic positioning systems (DP) and safety of mobile facilities	3 sources (e.g. Chen, Moan & Verhoeven, 2008)
Accident reports	7 sources (e.g. MMS, 2007 concerning Thunder Horse)
Different empirical studies	10 sources (e.g. Vinnem et al., 2000)
Uncategorised	10 sources

The overall result of the review is that the literature provides little aid in understanding relationships between triggering and underlying causes of structural and maritime incidents. Much of the literature deals with specific technical causes. In the sources where the authors pursue the triggering causes, this is often in the form of general considerations on the importance of preventing human error or on the relationship between organisational factors and the risk scenario. These discussions are of a general nature, and do not substantially link incident-specific human and organisational factors to causation. There may be many reasons for this. One proximate explanation is the lack of empirical evidence in the shape of good investigations.

This in itself is an interesting finding and is discussed later in the report. The literature which in different ways provides input into the topics discussed later will be highlighted where relevant.

10.3.2 Results from the review of investigation reports

One important part of this study was a review of available investigation reports. A total of 30 investigations of structural and maritime incidents from the NCS provided the foundation of this work. They are all, with one exception, from the period 2000-2013.[9] Four of them are investigations of structural incidents, and 26 of maritime incidents. In addition, the material comprised 18 investigations of uncontrolled anchor line deployments which are not part of the RNNP data. Where the investigations have been published, we have used the name of the facility in discussing the incident. All other incidents have been anonymised.

10.3.2.1 Maritime incidents

A list of the types of maritime incidents in the study, and which are included in RNNP, is shown in Figure 2.

[9] The investigation of the Sleipner accident, which occurred in 1991, is also included in the material.

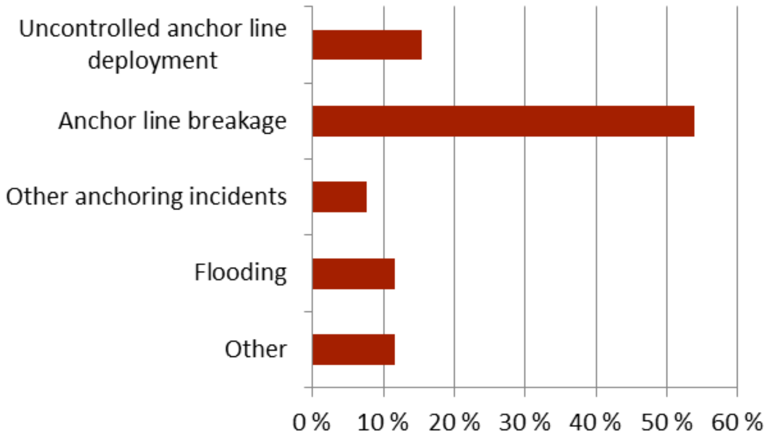

Figure 2 Lists of types of maritime incidents based on investigation reports in the period 2000-2013. The figures are percentages, N=26 (total number of maritime incidents in the material included in RNNP)

Uncontrolled deployments of anchor lines during operation comprised 15 per cent of the incidents, breaking of one of more anchor lines comprised 54 per cent, while other types of anchoring incidents comprised eight per cent. 12 per cent of the incidents involved the ingress of water in the structure, while 12 per cent were other types of maritime incidents.

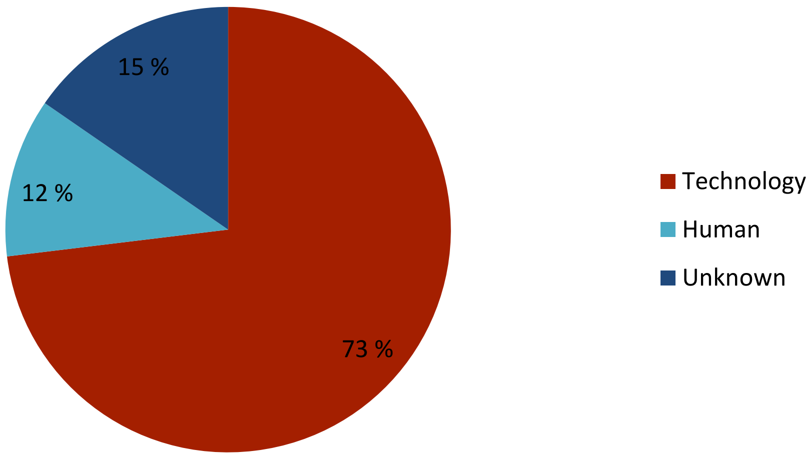

Figure 3 List of directly triggering causes linked to maritime incidents identified from the investigation reports

The directly triggering causes identified from the investigation reports are shown in Figure 3. Technical causes constituted 73 per cent and human causes 12 per cent. For four of the incidents (15 per cent), the triggering causes were not categorised since they were not clear from the investigations.

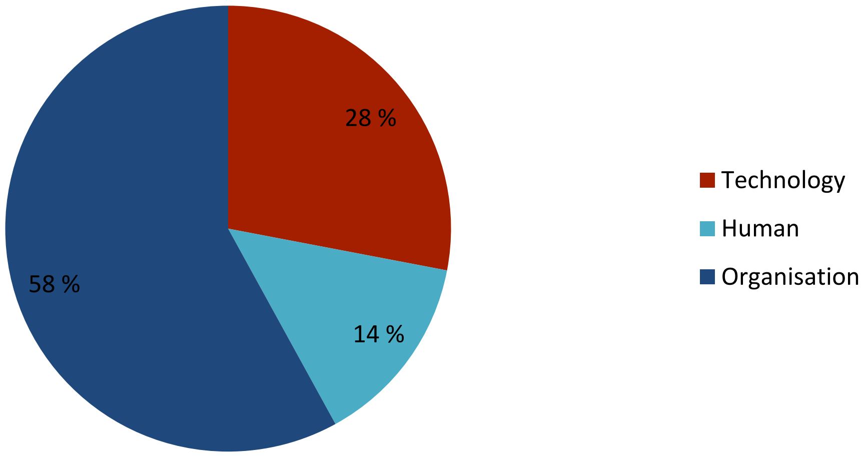

Figure 4 Underlying causes linked to maritime incidents broken down as human, technological and organisational

The underlying causes as identified from the investigation reports are shown in Figure 4. Note that this list involves a considerable degree of judgement. Such discretionary assessments were necessary since information about underlying causes was missing in 35 per cent of the investigation reports.

In an RNNP study on causes and measures associated with well control incidents (RNNP, 2011), a classification form was used to present triggering and underlying causes and types of measures. The form was based on a pragmatic adaptation of the categories defined for a similar causation study on hydrocarbon leaks (RNNP, 2010). Having assessed the quality of the investigations included in the selected material, the research team decided not to include such a presentation in this study. The presentation would have given an impression of a more reliable knowledge base than was actually the case. Information from the investigation reports about underlying causes has therefore been reproduced in this chapter in text form, and will be used in conjunction with other data sources as part of the discussion in sub-chapter 10.4.

As shown in Figure 2, maritime investigations are dominated by anchoring-related incidents – breaking of anchor lines, uncontrolled deployments and losses of anchor chains. These types of incidents can result in major accidents. Gryphon Alpha, an FPSO on the UK shelf, had a very serious near-miss in 2011 which illustrates the potential. Four anchor lines were lost in a storm with consequent damage to the ship, risers and production equipment. All non-critical personnel were evacuated by helicopter, and two tugs had to assist in holding the FPSO in position. It took nearly two years of yardwork before it was back in production. A similar incident occurred with Petrojarl Banff, an FPSO in production on the UK shelf in the North Sea. Banff lost five of its 10 anchors and drifted 250 metres out of position, with resulting damage to risers here too.

Breaking of anchor lines

54 per cent of the investigations concern breaking of anchor lines. In two of the incidents, two anchor lines broke, and in the remainder a single anchor line. The most common consequences were material damage, followed by drilling or production shutdown and what the investigation reports refer to as "no consequence".

With one exception[10], all the incidents were triggered by technical causes. The most common of these are described as:

- Excess loads on lines due to dynamic snap loads or unexpected weather conditions
- Fatigue fractures in chains
- Damage to fibre lines

There is great variation in the investigations in terms of descriptions of underlying factors and associated measures. It is therefore difficult to define a pattern but the following factors reappear in some of the reports:

- A lack of knowledge on actual loads in the mooring system
- Faulty or inadequate anchoring analysis with associated need for review and verification
- Weaknesses in the general principles for maintenance programmes and maintenance activities linked to anchoring systems, and a lack of emphasis on the significance of such systems
- Deficient competence, instruction and training in the handling of anchor systems

Uncontrolled anchor line deployments

15 per cent of the reported maritime incidents are associated with uncontrolled deployments of anchor lines. Including all available investigations of uncontrolled deployment incidents makes this proportion 50 per cent. Two of the incidents involved floating production facilities, the other involved mobile facilities. Many of the incidents occurred while facilities were being moved. The seriousness of the incidents varies, and in many cases is limited to the facility being displaced by a few metres. Some of the incidents must be characterised as more serious, such as the uncontrolled deployment of two anchor lines on Ocean Vanguard in 2004. This incident entailed considerable drift of the facility, failure of the drilling riser and BOP.

With one exception[11], all the incidents were triggered by technical causes. The most common of these are:

- Brakes failing to hold for various reasons
- Couplings which fail to hold or which slip
- Technical failures due to fractures, wear or hydraulic leaks

The investigations of uncontrolled line deployments are generally poor in terms of identifying and discussing underlying causes. The most common indications are of inadequate procedures or insufficient maintenance. There was also one case indicating inadequate design analyses.

The measures taken are essentially all technical in nature and directed at the causes mentioned above. Among the proposed organisational measures, a few types may be mentioned:

- Procedural changes
- Changes in maintenance routines/intervals
- Dissemination of information to relevant personnel and to other installations

[10] Faulty rigging of fibre lines
[11] Incorrect use of braking gear when running an anchor winch

Flooding
There were three investigated incidents in the period 2000-2013 involving the ingress of water into the structure. The research team considers two of these to have been the most serious maritime incidents investigated in terms of major accident potential.

In September 2012, the Scarabeo 8 semi-submersible drilling facility adopted an unintended list of seven degrees during drilling. The triggering cause was improper handling of the ballast system. The PSA's investigation report detected failures in conditions of importance for avoiding major accidents. These included the rig owner's ability to capture, evaluate and act on information about vulnerabilities in its own and the contractors' systems for ensuring adequate capacity and expertise among operational personnel. The report also pointed out weaknesses in the human-machine interface in the control room.

In November 2012, an unsecured anchor created eight holes in the hull of Floatel Superior causing flooding of two tanks and a list of about 5.8 degrees. There was also minor damage to three other tanks. The PSA's investigation report argues that puncturing of these tanks too was not unlikely and could have led to a list approaching the design limit of 17 degrees. The structures intended to secure the anchors while they were not in use had insufficient strength to withstand wave loading during transport and storm situations. An anchor came loose and damaged the hull. All the bolsters showed signs of similar damage. The investigation report gave a good picture of how these factors, in combination with a general lack of interaction and understanding in respect of the different participants' assumptions regarding the engineering, structural and operation of the facility, together caused this serious incident. The participants include engineering company, yard, equipment supplier, rig owner and operators organisation.

There was also a less serious incident involving a mobile exploration facility. The incident involved a hole in the hull due to corrosion and consequent ingress of water into the structure. The directly triggering cause of this incident was pitting in the bilge, which over time grew into holes. The investigation report, carried out by the rig owner, also points to a number of organisational causes which contributed to the accident. Among other things, during the last inspection, pitting was detected measuring up to 80 per cent of the plate thickness. The investigation group argues that when pitting of such an extent is detected, more intensive inspections or different maintenance routines should be implemented. That was not done here. The pitting that developed into a hole was in an area that was not monitored.

10.3.2.2 Structural incidents
There are four structural incidents included in this study. In addition, two of the incidents discussed in the previous sub-chapter may be viewed as structural incidents. With such a limited number of incidents, it is inappropriate to produce quantifiable lists of triggering and underlying causes. Below is a brief description of the incidents based on the investigation reports.

The most serious incident is the loss of the substructure of Sleipner A in Gandsfjord in 1991, shortly before its planned connection to the deck. During a test in which the structure was ballasted down to a low freeboard, an error in the engineering phase led to a rupture with major uncontrolled flooding in the D3 shaft. The shaft quickly filled and the structure sank, and was crushed on the bottom of Gandsfjord. All personnel were evacuated in time and the accident therefore only caused material damage. The financial consequences of having to build a new structure and of delayed production were substantial. The investigation showed that major errors were made in the engineering phase in the global finite element analysis of the structure, and this was the cause of inadequate reinforcement of the walls between the cells and the shafts. Furthermore, these flaws were not detected by quality control.

In 2006, a fixed production facility was struck on deck by a series of waves. The incident had a clear potential for personal injury, since the facility had not been shut down and down-manned following an extreme wave forecast. The investigation report did not detect damage to the primary structure. However, the incident did incorporate a potential for such damage. Under the PSA's categorisation of DFU8, this incident represented structural damage and it was included in RNNP as the only structural incident in 2006. The investigation report detected the underlying causes of the incident, including that understanding of the procedure for demanning and shutting down the facility in the event of bad weather was unclear. In addition, the investigation report noted that there was poor risk comprehension in respect of allowing personnel to remain active on deck. The offshore installation manager was new in the job and did not have extensive experience of offshore facilities, and adequate risk assessments for the facility had not been made.

In 2002, three continuous cracks were discovered in horizontal braces on a mobile drilling facility. The cracks were detected through the leak detection system recording water ingress. The facility was taken to shore as quickly as possible. The investigation discovered that the direct cause of the continuous cracks were cracks starting in welds in reinforcement plates in connection with a previous modification. The welding method did not match the engineering design expectations, and the report describes how this may indicate a failure in communication and quality control. It was further pointed out that the quality control of the drawings carried out by the classification society did not work as a barrier, since it did not detect a change between the engineering design drawing and the solution actually employed. In addition to short-term measures directed at the facility involved, the report recommends undertaking further investigations to establish underlying causes. The research team does not know if this was done, or what such activity may have resulted in.

The last incident in the material is also from 2002. Problems arose during work on installing five out of eight piles for a relatively small steel jacket platform. The problems arose during the installation phase, caused by a combination of minor manufacturing defects and an especially dense layer in the formation. The difficulties were resolved before production start-up and did not have a major accident potential. On this basis, the incident is not a structural incident, and was not examined further.

10.3.2.3 Differences between facility types

The presentation so far has described investigations of maritime and structural incidents, without differentiating between the types of facility involved. In this section therefore, the main types of structural and maritime incidents are broken down by facility type included in the study. The division used in section 10.1.3 was used as a basis, but the "Production facilities" group is divided into two: fixed production facilities, attached to the seabed, and floating production facilities.

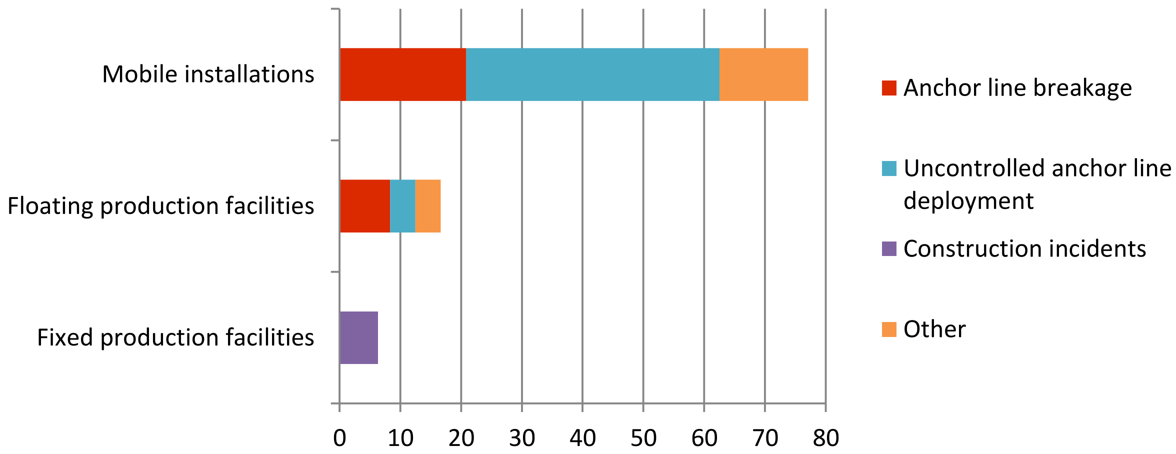

Figure 5 Percentage distribution of all structural and maritime incidents included in the study by type of facility (N=48)

Figure 5 shows the percentage distribution of all structural and maritime incidents included in the study by type of facility. Six per cent of the incidents involve fixed production facilities, 17 per cent floating production facilities and 77 per cent mobile facilities. Note that the figure and other descriptions in this section include all the investigations in the study, including the uncontrolled deployment incidents which are not part of RNNP.

For the fixed production facilities, there are three types of structural incidents: corrosion damage, fractures and waves on deck.

When a structural element corrodes, the plate thickness will decrease, and the element's resistance will be correspondingly reduced. Stresses will similarly increase. This leads to the margin between load and resistance being reduced and becoming potentially unacceptable.

Under fluctuating loads which create tensile stresses in a structural element, fractures may arise, as a consequence of fatigue. Relevant fluctuating loads will normally be generated by environmental forces, and for structures which are susceptible to fatigue, fluctuating loads often means primarily wave loads.

Waves on deck mean either that the distance between slack water and the underside of the deck has been reduced, or that the expected design wave has increased, entailing a greater risk of waves hitting the deck. The waves may cause local damage to the deck and inflict on the main load-bearing structure non-linear loads beyond those included in the original specifications, thereby reducing the inherent safety level. Reduced clearance between slack water and the underside of the deck has primarily been associated with subsidence of the seabed. This situation has been especially apparent on the Ekofisk and Valhall fields. For these fields, a number of compensatory measures have been used to counteract the effect or the consequences of subsidence: jacking-up of facilities, shutdown, and demanning when high waves are forecast.

In the investigations included in this report, there are a total of three incidents involving fixed production facilities; all of these are structural incidents (see 10.3.2.2).

There are eight incidents involving floating production facilities, six of which involve anchor line breakages or uncontrolled deployments. Serious structural damage to mobile production facilities which could have contributed to major accidents was not investigated in the period. One situation where an investigation could have yielded valuable learning involves a floating production facility which, after more than 15 years in operation, was closed down and demanned by the operator pending clarification of whether the deck should be strengthened or other measures implemented to extend the facility's life.

Most investigations are clearly of mobile facilities, a total of 37 in all. There are far more anchor line breakages on mobile facilities than on floating production facilities, with a total of 10 incidents of one or two anchor lines breaking. There are also far more incidents of uncontrolled deployments: a total of 20 for mobile facilities against 4 for floating production facilities. A systematic comparison is not available, but it may be noted that most floating production facilities have 12 or 16 anchor lines, whereas mobile facilities normally have 8 anchor lines. Many floating production facilities have passive anchoring systems (i.e. the lines are secured without possibility for continuous tightening or slackening), whereas mobile facilities have active systems.

The review of the investigations shows that uncontrolled deployments are associated to a considerable extent with the age of the facilities, especially when they are more than 25 years old. The distribution of ages at the time of the incident is as follows:

- 0-5 years: 16.7%
- 5-10 years: 0%
- 10-20 years: 3.3%
- 20-25 years: 36.7%
- 25-30 years: 33.3%
- >30 years: 10.0%

Overall the review shows that there are far more maritime incidents involving mobile facilities than floating production facilities.

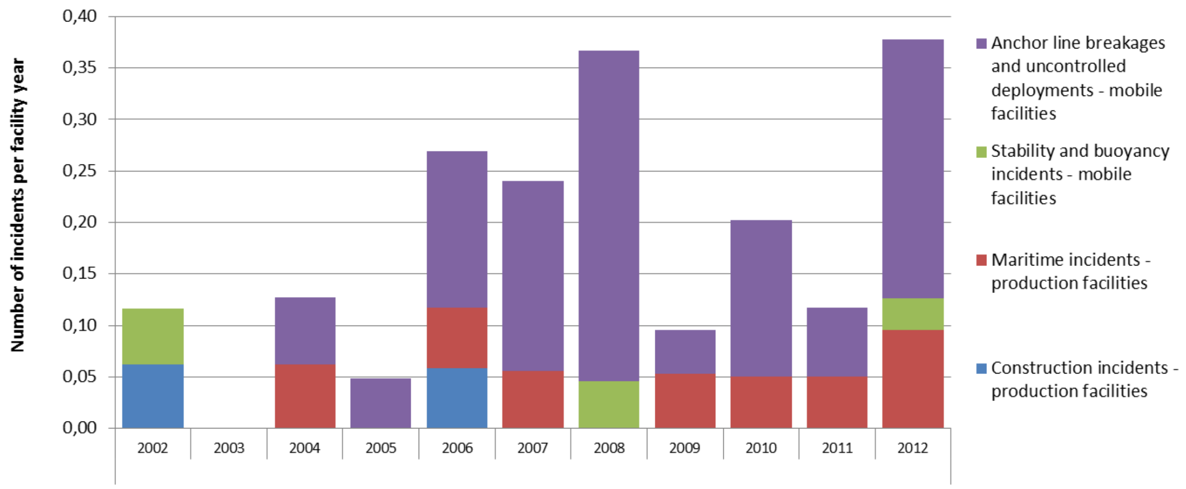

Figure 6 Overview of investigated structural and maritime incidents 2002-2012 by facility year

Based on all the investigations in the study, an overview has been produced of the number of investigations of structural incidents and incidents involving marine systems over time. Figure 6 includes separate categories for structural and maritime incidents by number of facility years for production facilities and mobile facilities. Maritime incidents for mobile facilities are further split into stability and buoyancy incidents, and breakages and uncontrolled deployments of anchor lines.[12] Because the total number of incidents is small, all the incident types have been summed in order to see if trends can be discerned.[13]

[12] For mobile facilities, only one structural incident has been investigated, and this is not included in the figure.

[13] Note that the loss of Sleipner in 1991 is not included in this overview since there are no other incidents in the sample between 1991 and 2002.

Figure 155 shows normalised numbers of incidents relative to number of facility years per year for production and mobile facilities respectively. This has been done by dividing the number of investigated incidents by the number of facility years for each year. The number of mobile units operating on the NCS has increased considerably in recent years. Accordingly, there is no clear trend in the figure when normalising the number of incidents against facility years. However, it is evident that the number of investigations of breakages and uncontrolled deployments of anchor lines for mobile facilities has increased since 2005.

On the basis of the data, it is not possible to explain all variations from year to year. Not all incidents are investigated, the number of annual storm days varies, and other arbitrary factors play a role. When there are relatively few incidents per year, the impacts may be as large as shown in Figure 155 without being statistically significant.

10.3.2.4 The quality of investigations of maritime incidents

In RNNP, since 2000, a total of 74 maritime incidents have been reported. This material includes 26 investigations and a further 18 investigations of uncontrolled deployments not included in RNNP.

The objective of using investigation reports was to identify causes of structural and maritime incidents. In order to gain insight into causation, the investigations must also be adequate in terms of underlying causes. Key causes are covered to varying degrees in the investigations in hand. This makes it difficult to produce full and trustworthy overviews and associated analyses of the relationship between triggering and underlying causes and of the quality of proposed measures.

Going back barely more than 10 years, there were few investigations carried out by the companies which contain information about human and organisational factors. The change can be traced back to the PSA's[14] Man, Technology and Organisation (MTO) project in the 2000s[15]. In this period, there was a clear trend towards more holistic thinking in relation to investigative activities in a number of industries. One reason why we still do not see consistently high quality investigations in this study may be linked to the nature of the incidents. It may be that the MTO perspective and Reason's theory on active and latent failures are primarily used for investigations of a restricted type of incident, such as hydrocarbon leaks and falling objects. Structural and maritime incidents have perhaps not been prioritised to the same extent as subjects for in-depth investigations.

It is a consistent trend in this study that investigations carried out by rig owners are primarily focused on proximate causes, especially technical ones. This is also true if the investigations of uncontrolled deployments are ignored. Investigations carried out by operating companies and the PSA include underlying causes to a greater extent. There is accordingly a poorer basis for evaluating underlying causes of maritime incidents. This indicates difficulties in relation to investigative expertise among the rig owners. The variation in the quality of investigations is an important finding of this study, and will be discussed more closely in sub-chapter 10.4.

10.3.2.5 Number of investigations of structural incidents

For structural incidents too, the research team encountered difficulties in terms of reviewing investigations. In contrast to the maritime incidents, it was not the variable quality of the investigations that was problematical, but the low number of investigation reports.

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[14] The PSA was part of the Norwegian Petroleum Directorate until 2004 and it was therefore formally the Directorate which instigated the project.

[15] The PSA commissioned J.P. Bento to analyse some ten incidents in order to demonstrate what an investigation with an MTO focus could provide; a compendium and a classification of MTO causes were also published (Bento, J.P, 2001).

In RNNP, since 2000, a total of 40 structural incidents have been reported. In this study, three investigations of structural incidents from the same period are included. This means that most reported structural incidents are not investigated.[16] One reason for this may be that many potentially relevant structural incidents do not occur frequently or have major actual or potential consequences.[17] As a rule, for example, fractures (which may be considered initiating incidents) are detected through ordinary inspection programmes long before they become critical, and followed up by corrective maintenance. Such incidents will not necessarily be investigated.

Systematic acquisition of knowledge of underlying causes for the occurrence of fractures requires reliable, comprehensive investigations to be performed in accordance with recognised methods. This does not happen if the non-conformity is handled by allowing the "incident" to fall into the maintenance programme instead of using it as a source of learning. In 2010, an extensive fracture was discovered in one of the simplest steel platforms on the NCS. It was discovered in a bracing that was not recognised as critically stressed, and was therefore not prioritised. This is the only known incident of such a serious nature in the period. Classification of structural elements in terms of criticality is done by the engineering companies during engineering, as a basis for inspection activities in the operational phase. The incident was not investigated and the information came out in an interview. The incident's potential is therefore unknown, but there is reason to assume that serious consequences could have occurred if the fracture had not been discovered. An investigation of the incident could have revealed this and provided valuable insight into triggering and underlying causes.

In this context, it should be mentioned that the problems with the Yme platform could also be seen as a structural incident, and, as such, a candidate for valuable learning for the industry, if it had been investigated as a structural incident.[18]

The difficulties surrounding investigations of structural incidents will be further discussed in Chapter 10.4.

10.3.3 Results of the questionnaire-based survey

As described in section 10.2.5, questionnaires were sent out to a total of 76 respondents. 41 responded, which is a response rate of 54 per cent.

There may be a number of reasons why the response rate was not higher. Since the companies had been contacted with a request to participate, there was generally widespread interest in the topic and a wish to put forward informants. At the same time, it was pointed out that there was a high level of activity on the NCS and associated pressure of work on key specialists. This may have affected the response rate. There were also five people who withdrew from the survey, since they did not consider their expertise to be relevant, and who said so in writing. It may be assumed that there were others who withdrew for the same reason, but without explicitly saying so.

Although the response rate could have been higher, the respondents constitute a refined selection, representing as they do the participating organisations' own experts in structures and marine systems. The informants cover all the participant groups invited to contribute, with the exception of inspection and maintenance.

23 per cent of the informants worked in the structural field, 45 in maritime systems and the remaining 32 per cent in both disciplines. 56 per cent were from operating

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[16] There is information in existence about incidents which are not investigated, but typically in the form of technical notes on triggering causes. This material does not form part of this study.

[17] Ref. Section 20 of the Management Regulations

[18] The Yme platform was to be commissioned offshore in 2012, but was never put into operation. It was evacuated in 2012 due to the discovery of cracks in the platform's legs. The facility is to be removed over time.

companies, 22 from rig owners, while the remainder worked in engineering companies, maritime equipment suppliers and universities.

10.3.3.1 Summary of free text responses

In the questionnaire, a number of open questions concerning causes and measures associated with structural and maritime incidents were asked. Of the 41 people who completed the questionnaire, 22 answered questions about structural incidents and 27 answered questions about maritime incidents. This means that 8 respondents answered both sets of questions, which the survey allowed. This sub-chapter provides a summary of the responses. We produce typical examples of answers to the different questions, and state what percentage highlighted the different topics. Since these were free text responses, the same respondent was welcome to refer to several topics.

Structural incidents

When the respondents were asked what they considered to be the most important causes of structural incidents in petroleum activities, the following causes were highlighted.

- Corrosion
- Fatigue, cracks and crack formation
- Unforeseen loading
  - For example "*Changes in use and unforeseen loads from the environment/weather*"[19]
- Deficient transfer of experience between different phases of a facility's life (engineering, fabrication, installation and operation)
  - For example "*Difficulties in experience transfer from project to operation, collective obliviousness, how can the organisation remember the facility's limitations*"
- Deficient expertise and experience, and a lack of awareness concerning the use of such expertise
  - For example "*Deficient expertise and awareness of the need to secure the right competence and technical quality control. The expert with professional integrity will be overruled. No procedure or management system can replace the responsible and competent professional.*"
- Subsidence
  - For example *"Subsidence of the platform and consequent wave loads on the structure"*

Corrosion was highlighted by 35 per cent of the respondents, as was fatigue. Unforeseen loadings, deficient experience transfer and lack of expertise and experience were in total highlighted by 25 per cent of the respondents.

In addition, other specific causes were mentioned, not least relating to the structural engineering profession itself and its status: "*Inadequate focus on structures and their maintenance/inspection. Low prestige of structural work compared with process work. Poor/low recruitment for working with structures.*"

It was also asked whether there were difficulties associated with quality assurance and follow-up of the construction phase that could have a negative effect on the risk of structural failure. The following factors were particularly emphasised by the respondents:

- Follow-up of foreign participants (suppliers and yards)
  - For example "*Deficient follow-up and presence of competent personnel for following up of the construction process*"
- Experience and expertise

[19] Direct (translated) quotations from free text in the questionnaire (written) or statements made during interviews (verbal) are in italics between quotation marks. Selected quotations are typical statements from the informants (show a pattern in the data material) or provide good insight into problems highlighted as important .

- For example *”The engineers' expertise in terms of large, complex structures subject to many different types of loads.”*

When asked about which risk-mitigation measures should be implemented to ensure the integrity of load-bearing structures on the NCS, the following measures were highlighted:

- Increased focus on inspections and condition monitoring of operational facilities.
  - For example *”Ensure that inspection programmes are established, that they are detailed enough to ensure that all important structural details are taken care of and inspected in the same way each time, that they are updated in respect of re-analysis results and life extension assumptions”*
- Stricter requirements and follow-up from the authorities.
  - For example *”Stricter requirements on life extension for installations*"

40 per cent of the respondents highlighted an increased focus on inspection and condition monitoring, while 15 per cent highlighted stricter requirements and follow-up from the authorities when answering about which risk-mitigation measures linked to structural incidents should be implemented.

It was also asserted that structural-related findings in the operations phase were not sufficiently analysed in terms of discovering causes.

Maritime incidents

When asked what the most important causal factors leading to maritime incidents were, the following causes were emphasised:

- A lack of maritime competence and experience among personnel on board the facilities
  - For example ”*The qualifications of personnel on board are often part of the causation scenario for maritime incidents. There are 30 people operating a control room over one year; it is difficult to monitor the maritime qualifications of such a large group*"
- Failures in anchoring systems
  - For example *”Anchor line breakage, dragging of anchors, uncontrolled deployment of chain”*
- Deficient procedures and deficient compliance with procedural requirements on board

26 per cent highlighted deficient expertise, 15 per cent failures in anchoring systems and 12 per cent deficient procedures.

In addition to highlighting deficient maritime expertise on board, it was stated that the operating companies attached too little importance to maritime training and expertise. A number of other factors were also mentioned, such as *"poor attitudes", "human factors" and "human failure*", as well as equipment failures.

As the review of the investigations clearly shows, there are many anchoring incidents on the NCS. We therefore asked about what may be the underlying causes of anchor line breakage, uncontrolled deployments and other incidents associated with anchoring. The following causal factors were highlighted:

- Deficient maintenance, inspections and condition monitoring of anchoring systems
  - For example ”*Lack of maintenance, ageing material and reduced capacity*.”
  - *”There are all kinds of factors, but it is quite difficult to perform exhaustive inspections of anchoring systems*”.
- Lack of expertise and experience relating both to the equipment in use and its actual use

  - For example *"Lack of experience of chain, fibre and wire for mooring operations*"
  - For example *"There is inadequate training of personnel on board"*
  - For example *"These are complex systems, it is difficult to create a good model of the waves and the unit's response"*
- Incorrect use of equipment/systems
  - For example *"Operator error during use of winches"*
- Fault/failure in technical equipment
  - For example *"Design or production error"*
  - For example *"Software fault in POSMOOR control system"*
- Overloading
  - For example *"Overloading of the anchoring systems"*

It is the first two points that were most frequently highlighted, with 41 per cent referring to deficient maintenance, inspection and condition monitoring of anchoring systems, and 37 per cent referring to insufficient expertise and experience.

When asked about which measures should be implemented to reduce the probability and consequences of maritime incidents, the following were highlighted:

- Strengthen maritime expertise both offshore and in the onshore organisation
  - For example *"Strengthen maritime expertise on board and increase training in crisis management within this expertise. Note also that there is a need for such expertise in the onshore organisation."*
  - For example *"Use of real-time simulators with scenario-based training on an annual basis"*
- Increased focus on maintenance, inspection and condition monitoring of mobile facilities during engineering, fabrication and operation
  - For example *"Continue focus on condition monitoring"*
  - For example *"Robust integrity and inspection programmes during fabrication and operation"*
- Improve and strengthen the authorities' regulations
  - For example *"More direct follow-up by the authorities of technical conditions, not just follow-up of management systems and procedures"*

33 per cent highlighted strengthening maritime competence, 22 per cent highlighted an increased focus on maintenance, while 11 per cent recommended improving and strengthening the authorities' regulations.

There were also a number of replies which suggested in various ways that it is necessary to increase the general attention paid to marine systems and operations.

The responses to the free text questions in the questionnaire are included as part of the analytical foundation of this study and are incorporated in sub-chapter 10.4.

10.3.3.2 Other questions in the questionnaire

In the addition to the free text responses, the respondents were invited to state their degree of agreement with a series of statements. A selection of the responses is illustrated in the following figures. We will not comment further on the responses here, but they form part of the basis of the analysis in sub-chapter 10.4, and will be discussed in more detail there.

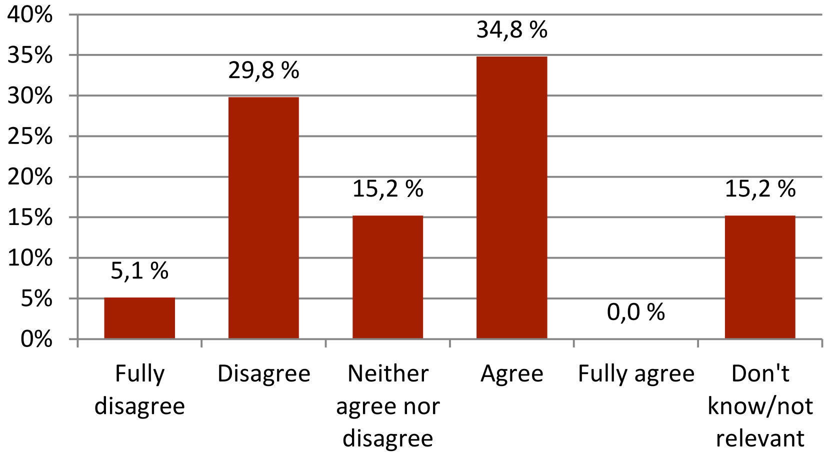

Figure 7 Experiences from previous structural incidents are only given slight consideration in the choice of concept and design (N=22)

34.8 per cent of the respondents stated that they agreed with the statement that previous experiences are only given slight consideration in the choice of concept and design.

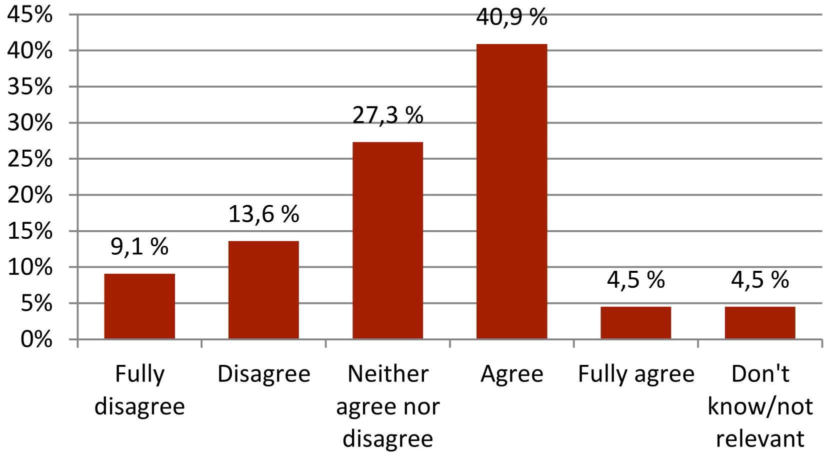

Figure 8 Better, more powerful analytical tools have led to less robust structures (N=22)

45.4 per cent stated that they agreed or fully agreed with the statement that better, more powerful analytical tools have led to less robust structures.

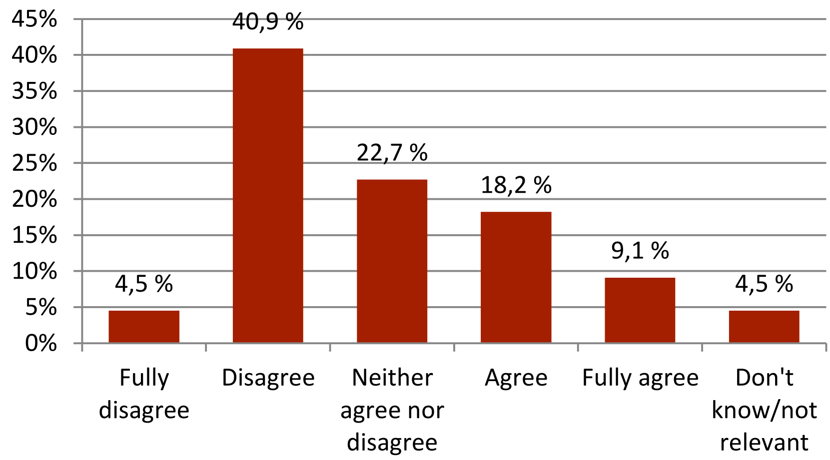

Figure 9 The construction process is properly monitored by operators and engineering companies (N=22)

45.4 per cent stated that they fully disagreed or disagreed with the statement that the construction process is properly monitored by operators and engineering companies.

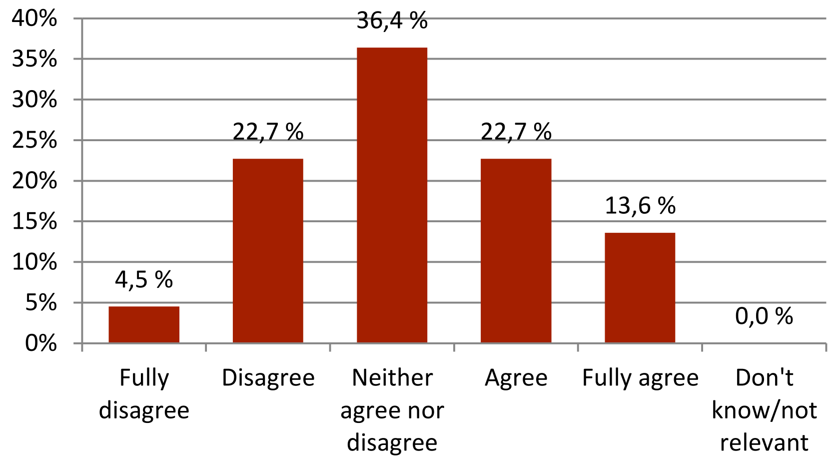

Figure 10 In my organisation, status is accorded to experts in structural engineering (N=22)

27.2 per cent fully disagreed or disagreed with the statement that status was accorded to experts in structural engineering.

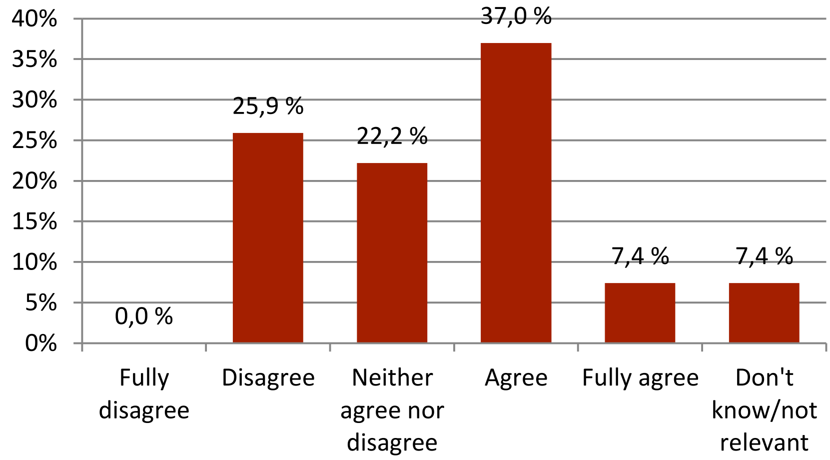

Figure 160 ***Critical marine systems (such as ballast and DP systems) are simple to understand and use (N=27)***

25.9 per cent stated that they disagreed with the statement that critical marine systems (such as ballast and DP systems) are simple to understand and use, while 44.4 per cent agreed or fully agreed.

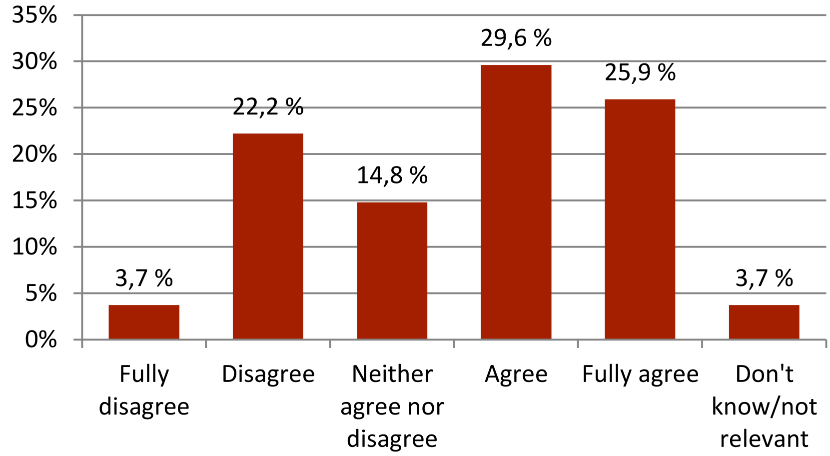

Figure 11 Factors relating to marine systems constitute an area that receives too little attention in safety work in the industry (N=27)

55 per cent of the respondents stated that they agreed or fully agreed with the statement that factors relating to marine systems constitute an area that receives too little attention in safety work in the industry.

10.4 Analysis and discussion

10.4.1 Introduction

As mentioned under sub-chapter 10.2.4, the interview material contains data from the participants' own experts in structural and maritime incidents. The interviewees are involved in the choice of concept and initial design, detailed design, and fabrication and operation of the facilities. Results from the analysis will be presented for each of these phases. We use the interviews as our basis and supplement them with relevant data from the literature review, questionnaire-based survey and relevant investigations in the discussion.

There is an essential difference between the two types of incidents analysed. Safety in respect of structural incidents, especially incidents with major accident potential, is largely a question of decisions associated with the choice of concept and engineering, rather than operation (even though inspection activities associated with condition monitoring of the facilities is an important activity in the operational phase). For maritime incidents, operational factors have a relatively greater significance for maintaining safety. The picture is of course somewhat variable. For example, sub-chapter 10.3 shows that the triggering causes of anchoring incidents are essentially all technical in nature. This may indicate that the fundamental choices linked to anchoring concepts and engineering of equipment affect the risk scenario. There are nonetheless clear differences between structural and maritime incidents.

In the analysis, we have also chosen to differentiate between production facilities constructed for a specific location (whether these are fixed or floating facilities) and mobile facilities (in practice, essentially mobile drilling facilities, but also some flotels). There are several reasons for this. Firstly, a production facility is dedicated to a very specific purpose and a specific location. Compared with mobile facilities, there is less opportunity for standardised solutions and the need for customisation is accordingly higher. This imposes different requirements on the different project phases and in the transitions between project phases than is the case for mobile facilities. Secondly, the scope of data available for the two groups of installations is different. As shown in sub-chapter 10.3, for example, the investigations carried out by operating companies (and the PSA) for production facilities are of better quality than similar investigations of mobile facilities carried out by rig owner companies. Thirdly, compared with floating production facilities, mobile facilities are more often onshore for such things as reclassification and modification. This provides easier access to relevant inspection areas, such as underwater structures and the splash zones, for monitoring structural integrity.

At the same time, it is also clear that there are a number of traits shared by these two main types of facility. We nonetheless consider that, for the purposes of this study, the best overview of the causation scenario underlying structural and maritime incidents and associated potential measures is provided by differentiating between production facilities and mobile facilities.

10.4.2 Production facilities

10.4.2.1 Choice of concept and initial engineering

One key topic for the informants, which they highlighted in the interviews, related to the importance of choosing robust design solutions in the early engineering phase. The interviewees used the concept of "robust" solutions with several meanings. At times, the concept referred to engineering the primary structure with good safety margins and so that it would withstand failures of individual components without catastrophic consequences (redundancy). This use of the term may also be associated with what we call passive safety[20], for example in semi-submersible production facilities. As an example of passive safety, several interviewees from engineering companies and operating companies argued for isolated ballast systems in the four quadrants of the hull. This makes it physically impossible to move ballast water between the quadrants, which in turn eliminates the potential of a type of operational error which can have serious consequences. For example, valves which are unintentionally open may lead to flooding and potentially worsen the situation. Conversely, it was asserted that such a solution involving isolated ballast water systems could prevent the flexibility that might be desirable in certain operational situations. Discussions are currently in progress between engineering companies and operators concerning this type of solution on the NCS.

The term "robust" was also used to characterise the structure's ability to cater for potential future needs linked to, for example, installing new and heavier production equipment on the facility. One interviewee expressed it like this: "*the platforms are constructed to be just too small for the needs right now*". Experience shows that, over time, production facilities will undergo a series of modifications due to new equipment, changes in production, new fields being tied in, etc. If account has not been taken of such future needs in design engineering, it may be difficult to modify the facility without exceeding the weight it was originally designed for.

A third use of the concept of "robust" was to engineer the structure to make the force distribution in the structureas simple as possible. It was said that this makes it easier to verify the soundness of a concept through manual calculations and good engineering expertise, which in turn is considered to provide extra assurance that safety has been provided for, compared with being completely dependent on detailed software calculations in order to verify the concept.

It was primarily informants from operating and engineering companies who discussed conceptual choices and initial design engineering. The following is a thematic review of the findings from these interviews, and associated results from other data sources.

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[20] Passive security is understood to mean built-in safety or robustness that does not need activating by operators or automation systems in order to function.

Conceptual understanding and engineering expertise
The informants were generally clear that good choices in the concept phase require access to highly qualified engineers with wide experience from offshore projects. A number of interviewees highlighted the expression "*conceptual understanding*" as a key one. This indicates the importance of one of the items referred to in the section above, namely the competence to be able to perform simple estimations of statics in a concept at an overalllevel, without having to undertake time-consuming and costly analyses. One example mentioned in the interviews was the engineer who could sit down for a couple of days in his office with pencil and paper and come up with a finished main concept. At the same time, according to the informants, conceptual understanding is important for understanding and evaluating the entirety of the structure to be built, precisely for ensuring that a sound solution is achieved. It was also said that good conceptual understanding is a prerequisite for being able to ask critical questions about the choice of concept at an early stage.

A number of interviewees stated that there were fewer engineers able to perform such manual estimations and that engineering expertise had increasingly shifted to performing heavyweight software-based analyses. In other words, there are signs that fewer people now have good conceptual understanding. It is important to emphasise that it is not only older engineers who express concern that there are fewer people in possession of the more "old-fashioned" engineering craft. It is not about "everything was much better before", but a concern that a lack of basic proficiency in calculations makes the structures over-analysed and under-designed.

Have the structures become less robust[21] as a result of more precise analytical methods?
Estimations and detailed software calculations were mentioned above, and one view put forward is that the transition to more detailed calculations has reduced the margins in the structure and thereby, in practice, reduced safety. However, the interviewees' feedback on this varied. Some supported this view, while others asserted to the contrary that this had produced safer solutions. There was no clear pattern when we investigated variations in the data from interviews and questionnaires across groups of participants. At the same time, the results of the questionnaire-based survey show that 46 per cent agreed or fully agreed with the statement that "better and more powerful analytical tools have led to less robust structures". Together with the results from the interviews on this topic, we take this as a sign that more knowledge is required about if and how analytical methods affect structural safety.

Poorer conditions for specialist structural engineering expertise
Several of the interviewees, especially from the operating companies, argued that there are mechanisms in the industry which make it more difficult to "stay the course" professionally and cultivate specialist expertise in structural technology. Some asserted that the career system in some of the companies does not reward continuity in respect of a single discipline, and some claimed that the status of employees with specialist structural engineering expertise has declined in recent years. Based on these interview findings, one of the statements for consideration in the questionnaire-based survey was "In my organisation, status is accorded to experts in structural engineering". 27 per cent of the respondents, representing both operating and engineering companies, disagreed or fully disagreed with this statement. This confirms that there are challenges associated with valuing structural engineering expertise.

[21] Note that the term "robust" is used here in the sense of "design the primary structure with good safety margins and so that it withstands failures of individual components without catastrophic consequences". Ref. NORSOK N-001 chap. 4.7 Robustness assessment

Some of the companies among the groups participating in this study have increasingly arranged for their employees to switch roles and work tasks at regular intervals. This is a positive measure in terms of developing professional scope, but it results in the creation of more professional generalists than specialists. Although the results from the questionnaire vary, we consider it important to listen to those experts who, in the survey and interviews, expressed concern for the status of their own specialism.

Changes in the burden of proof for assessing safety in structures
One key finding in the study is that several interviewees from engineering companies and operating companies are finding it more difficult to succeed in putting forward viewpoints critical of conceptual choices to their own organisation's management, or in the transition from one project phase to another. Illustrative statements emerged which indicate that conditions for "bringers of bad news" have deteriorated".

Examples of statements from the interviews concerning this include:

- "*Does the profession have a good enough status? No, there are many examples of technical specialists being overruled by the business admin side"*
- *"A culture which assumes that management should be able to override technical experts on technical matters"*
- *"When you have a team on site, and there's a visit from Norway, the management would rather hear the optimistic versions from the yard than bad news from the visitors from Norway"*
- *"The advance of the economists, much more focus on optimisation and immediate value than before."*
- *"It is optimism and positivity which are career-enhancing"*
- "*Now you have to prove that a solution does not work instead of having to prove that it actually does work*"

Based on the interview material, one may wonder whether over time there has been a slide towards a stronger focus on costs (present value) and progress in the projects. Key specialists in several operating companies have described that it is more difficult than formerly to adopt the role of devil's advocate and oppose critical questions about structural safety once the projects have passed the concept phase. This may contribute to weakening the control mechanisms aimed at detecting small faults before they are able to contribute to a major accident.

The industry has become more cost focused in recent years. This is among other things a result of an increase in the cost level associated with developments, so that profit margins are not the same as they were with earlier large developments. One measure of this is the trend over time in the oil and gas price that is necessary to make new developments profitable (the equilibrium price). Figures from the government white paper "An industry for the future – Norway's petroleum activities"[22], show that, whereas the equilibrium price for new field developments in 2004 was around NOK 100 per barrel, the equivalent price in 2009 was more than NOK 300 per barrel. In periods with important and natural needs to cut costs and increase efficiency, it is, as Rasmussen (1997) describes, especially important to maintain the right balance between safety on the one hand and costs on the other. Among other things, it is crucial to search for signs and signals of an incorrect balance, and it is important to maintain a safety culture where bringers of bad news are rewarded and heeded.

The research team wonders whether a certain distortion in the burden of proof linked to safety is in progress. Whereas specialists previously assumed that a structure <u>was not safe</u> until the contrary had been proved, key informants now say that is more a case of assuming that the structure <u>is safe</u> until one has proved that it is not.

[22] White Paper 28 (2010-2011)

This type of slippage in the burden of proof has been described in earlier accident investigations, including following the US Challenger spacecraft accident in 1986 (Vaughan, 1996). There appear to be differences between companies in this area. While some find that the situation has deteriorated significantly in recent years, others talk about organisations where there is a lot of scope for bringing up concerns about robustness, despite potential increased costs and delays. The data does not provide a foundation for drawing any clear conclusions about differences between and within groups of participants. The findings do however illustrate that the petroleum industry's focus on the safety culture should not be limited to operational personnel in the operations phase – decisions concerning choice of concept must also respond to conflicting goals of various kinds and will hence be capable of being influenced by the organisations' safety cultures.

Fabrication of offshore facilities in accordance to maritime regulations
In the choice between different concepts, Section 3 of the Framework Regulations allows for employing maritime regulations as the basis for building mobile facilities which follow a maritime operations concept. This includes a condition of having to undergo classification every 5 years. Several of the informants, primarily from the engineering and operating companies, were critical of this option in the regulations. The informants argued that it allows for choices of concept where structural safety is traded against the cost of solutions. The questionnaire respondents were not unanimous on this point. Around half agreed that it is problematical. In discussions with relevant authorities, it transpired however that building to maritime regulations does not entail lower levels of safety.

10.4.2.2 Detailed engineering, fabrication and installation
Decisions taken in respect of conceptual choices constitute important framework conditions for all subsequent phases. They will not be significant solely for the progress and cost of field development, but also for major accident risk. Progress and costs are affected due to faults being discovered that may require comprehensive redesign, which is both costly and time-consuming. The major accident risk is however also affected, due to the structurebeing less able to withstand faults that go undetected. In those cases where a concept with good passive safety has been chosen, it takes more for flaws introduced in detail engineering and fabrication to lead to a major accident.

Follow-up of detail engineering and fabrication
In recent years, there has been a tendency for more and more detail engineering and fabrication to be performed outside of Norway and for interaction between a multitude of stakeholders. There may be different engineering companies located in Oslo, London, India or Poland performing work on different phases of a project. There may also be several yards in different parts of the world involved in building in parallel parts of a facility. This is a complicated problem and the research team did not take a view on whether this is a good development or not. The interviews and questionnaire have however yielded some information about which problems need to be addressed and which may be relevant to major accident risk.

Much of the information that emerged relates to building in Asia, but there were also examples from engineering companies with similar problems in building and use of sub-contractors in other parts of the world, including Eastern Europe. Although the discussion primarily focussed on Asia, one should not underestimate the significance of similar challenges in situations where participants use suppliers with limited experience of supplying to the Norwegian offshore industry.

Follow-up of detail engineering and the fabricationphase was highlighted as the greatest challenge. This is raised by the engineering companies in particular, for example: "*Difficult and expensive to achieve good follow-up of yards in Asia – creates a poorer* *connection between engineering and yard*". Another similar example is: "*Building in the Far East requires a large team for follow-up*". The free-text answers to the questionnaire also include a number of similar statements, such as "*Operators do not devote enough resources to follow-up of yards with little building experience of relevant installations".* The participants in the questionnaire-based survey were asked their view on the statement "The fabricationprocess is properly monitored by operators and engineering companies". 45.4 per cent fully disagreed or disagreed with this statement, and these respondents were divided between operating companies, rig owners and engineering companies. Concerns relating to whether there is adequate follow-up in the fabrication phase therefore also emerged here.

The interviewees related their comments to both project progress and safety in the delivered facility. A lack of follow-up creates a need for both redesign and modifications, and this will lead to time pressure, which in turn may be to the detriment of quality in the engineering andfabrication . This is a classic conflict of goals as described by Rasmussen (1997): see sub-chapter 10.1.5. At the same time, it is apparent that a lack of follow-up represents both a safety and a financial risk.

The most important cause of interviewees perceiving an increased need for follow-up when constructing in Asia is foreign engineering companies' and yards' lack of experience with engineering and fabricationfor Norwegian conditions and in accordance with Norwegian requirements and standards. A lack of knowledge of NORSOK standards and Norwegian regulations, especially the background to the standards and regulations, was mentioned as one factor. Reference was also made to a lack of knowledge of the loads the structures have to withstand and the way they are used.

One possible interpretation might be that the significance for safety of the particular weather conditions on the NCS and the functional requirements of the Norwegian regulations were accorded too little attention in communications between requisitioners and suppliers in the planning, engineering and fabrication processes.

It must be noted that the interviewees did not necessarily assert that foreign yards did a worse job than Norwegian ones. Nor it is a case of foreign engineering resources being less competent than Norwegian engineers[23]. The research team's understanding is that it is a question primarily of less experience and that one would have probably found the same problems in choosing a Norwegian yard with no previous experience of offshore activities. One comment that may relate to this came from an interviewee who works for a rig owner: "*If you know what you want before you start, you build in Asia, otherwise you build in Norway*". This entails that standard solutions (which may well have been built before) and solutions where detail engineering is well advanced are more easily constructed in Asia.

One possible solution to the challenges outlined here, pointed out by many of the informants, is closer follow-up of the suppliers involved (both engineering companies and yards) until they have developed the necessary experience. For this, the companies need to possess and use resources in the form of personnel, time and competence for performing close follow-up of the executing party's competence, understanding of what is to be built and understanding of the loads the structures will be subjected to once fully installed.

In this context, it is also natural to mention the Norwegian Petroleum Directorate's report from 2013 on "Evaluation of projects implemented on the Norwegian shelf" (Norwegian Petroleum Directorate 2013). This report covers five projects with approved development

[23] The interviews produced examples of Norwegian solutions for use abroad having proved unsatisfactory due to a lack of knowledge of local environmental conditions and loads. This illustrates that it is more a question of familiarity with the environment that the structures will be erected in.

plans in the period 2006-2008 and with investments of at least NOK 10 billion. The report draws attention to underestimates of the need for follow-up of newbuilding projects abroad as an important cause of overruns and delays. The report also mentions a lack of NORSOK and regulatory experience among the yards building the facilities as important reasons. The Norwegian Petroleum Directorate's focus was on projects that suffered large delays or cost overruns, which confirms that follow-up is important for projects' finances as well as their safety.

Project execution and cultural differences
We would also like to emphasise certain factors relating to how projects are usually performed in Norway and in foreign yards.

It is well-known that there are national cultural differences between Norway and, for example, Singapore, Korea and China (see for example Hofstede, 1980). One key element is that, in Norway, it is usual to have flat, informal organisations, where everyone is able to put forward views and ideas, and where each individual has a large scope of action and much responsibility. In many Asian cultures, organisations are far more hierarchical, with managers who have absolute authority and employees who execute orders without asking questions. In terms of project execution, the interviewees said the following about conditions in Asia:

- "*Everyone expects to receive clear orders from their manager and to do their best to fulfil these orders to the letter*".
- "*One does not question orders received, regardless of whether they appear to be correct and sensible or not.*"

The research team does not take a view on what is a "correct" culture or not; the point is that it is different from what one is used to in Norway. Possible effects may include:

- Managers must be much clearer in their messages than in Norway. If orders are unclear or ambiguous, one cannot expect to be asked questions about what is intended, in order to clear up any uncertainties.
- Interdisciplinary cooperation cannot be expected to progress as easily as in Norway. The hierarchical structures can make this problematical.

Here too, closer follow-up and, not least, more resources for following up may help counter these problems.

10.4.2.3 Operations

Information exchange between phases and participants
A lot of information came out in the study to indicate that information exchange and learning between phases and participants could be improved. This was confirmed by both the interviews and the questionnaire. This subject was also of key interest in some of the investigations. The investigation of the structural incident with waves on deck showed for example how challenging it can be to ensure that the assumptions and results of risk analyses are communicated in a way that ensures that affected personnel understand the implications and act accordingly. Even though the platform management were familiar with the demanning procedure and had trained in such situations, they were not clear that the combination of wave height and forecast strong winds in the case required evacuation. In individual investigations of anchoring incidents with floating production facilities, the need for transmitting information back from the operational phase to the engineering phase was emphasised. This subject was also raised in many interviews. In particular, many of the statements from the engineering companies can be linked to this. From the theoretical perspectives outlined in sub-chapter 10.1.5, this may be associated with Turner's ”Man-made Disasters”, where deficient flow of information between organisations and phases is propounded as a potential source of major accidents.

The key point made is that the engineering companies believe they receive far too little information about how structures they have designed actually behave once they have been built and commissioned. The measures currently employed to feed information back are not perceived as adequate. Examples of statements include:

- *"No, in my experience, we get very little empirical data from the client. We never check the sums to find out if what actually happens out on the field matches our design analyses."*
- *"We get no feedback from the user organisations on how the structures are working. I often wonder how things have panned out for the structures over time."*
- *"Aside from the PSA's structural integrity seminar[24], there are no forums for information exchange."*
- *"When it comes to damage, we have had very little feedback about damage and corrosion to the structure. So, we don't know if the design criteria we use actually work."*

The questionnaire also involved this topic, and the following was stated in the free text replies:

- *"Relevant information about structural incidents is not adequately fed back to the design domains. Here the authorities (the PSA) have a job to do."*

The participants were also asked their views on the statement: "experiences from previous structural incidents are only given slight consideration in the choice of concept and design". 34.8 per cent of the respondents agreed with this statement, the majority of them representing engineering companies.

The engineering companies highlighted a lack of information exchange as a challenge since it may lead to the repetition of deficient solutions.[25] Systematic transfer of operational data over time can provide a basis for improvements in regulations, understanding of loadings and their effects on structures. The same applies to anchoring systems, where some of the interviewees from the engineering companies wanted data on actual loads on anchoring systems in demanding weather conditions. It was pointed out that such data is important for validating results from, for example, model tests. Similar recommendations concerning the transfer of experience from operations to the engineering domains are also to be found in a study of anchoring systems on FPS (Floating, Production and Storage) installations (Majhi, D'Souza & Granherne, 2013).

One proposal to have emerged from the interviews (mentioned by many) was that practice should be strengthened in terms of monitoring structures which are now being decommissioned to see where cracks have propagated as basis for checking assumptions and calculations made in the engineering phase. Section 50 of the Activities Regulations already contains a provision for this: *"When facilities are disposed of, the operator shall carry out studies of the structure's condition. The results shall be used to assess the safety of similar facilities."* Furthermore in the guidelines *"The examinations as mentioned in the fourth subsection, should particularly be carried out with a view towards projected new facilities and use of facilities beyond their original planned lifetime in mind."* It seems clear that this point is not well-known in the industry if suggestions are being made that it should become standard practice. It should be noted that this provision was introduced a relatively short time ago.

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[24] In recent years, the PSA has held an annual "structural integrity day", which the industry is invited to attend. This includes presentations tackling relevant problems associated with structures and safety.

[25] In a causation study of hydrocarbon leaks under RNNP 2010, 48% of triggering causes were associated with defective or poor design of the process facility. In following up this finding, the PSA contacted a number of engineering companies, who expressed a similar need for transfer of experience from the operating companies' running of the process facilities to the design domains, in order to prevent the repeat of inadequate solutions.

The interviews from the engineering companies also queried whether the knowledge possessed by the engineering teams concerning highly stressed nodes and elements on the facilities was adequately utilised. Inspection programmes are developed to monitor the condition of operational facilities. Examples were given of inspection programmes having been developed with a percentage coverage of the nodes that accorded with the engineering recommendations, but where the nodes that were actually inspected were selected on the basis of accessibility and not on the basis of the highest loading or criticality in terms of integrity:

"The nodes on the topsides were described in a report from [engineering company], which defined which were the most critical nodes. The inspection plan specified examining 5% of the nodes per year, but it was the same 5% that were inspected each year, and it was the most accessible and none of the most critical that were selected."

In the questionnaire, 40 per cent of the respondents highlighted an increased focus on inspection and condition monitoring of operational facilities in answer to the question about which risk-reducing measures should be implemented to safeguard the integrity of load-bearing structures. In the light of the discussions in this section, it is crucial that any increase in the level of activity in respect of inspections and condition monitoring also includes measures to ensure that information on the outcome of the activities reaches the relevant participant groups. This includes participants who prepare the foundation for inspection programmes (engineering or consultancy firms), those who evaluate results from the inspections (rig owners or operators) and the inspection enterprises who carry out the inspection work. This very point was highlighted by the investigation group in one of the investigations discussed previously. They describe that inspections of the hull detected considerable corrosion without this leading to changes in inspection routines or maintenance activities. The inspection report does not describe inter-relationships between participants but it nonetheless appears clear that the information flow between them (classification society, rig owner and yard) was deficient and that this contributed to the incident.

Statements also emerged from the operating companies which indicate that there is limited systematic transfer of experience and learning between the companies. A couple of assertions illustrate this: *"I have never met up with other operating companies to share experiences.". "I know people and we chat but there is no formal cooperation*".

Overall, there is much to indicate less exchange of knowledge and experience between the phases and the participants than is desirable. The only formal communications forums mentioned by the informants are the PSA's structural integrity seminars and Joint Industry Projects (JIP) for professional inter-company cooperation. It should be mentioned that other relevant specialist conferences are also organised in the petroleum industry but findings from the study may indicate that these on their own are not perceived as appropriate forums for the exchange of more concrete operational experience.

Challenges linked to the age of installations

In recent years, the Norwegian oil and gas industry has been preoccupied with challenges ensuing from the fact that many of the facilities have reached their original planned end-of-life, but are still wanted to be used for many years ahead. For example, ageing and lifetime extension were among the PSA's main priorities from 2005 to 2010, and in the literature review performed as part of this study, 8 out of 48 identified sources dealt with ageing problems and Structural Integrity Management. Against this background, it is interesting that challenges linked to the age of installations were not more prominent in the questionnaire or interviews. A possible explanation might be that the interviewees and questionnaire respondents consider these challenges to have been covered by the attention that the topic has received in recent years. Interviewees from one operating company explained that they had the ageing problem well under control and that the challenges were primarily linked to the quality of some of the documentation. At the same time, it is worth noting that, as previously mentioned, 40 per cent of the respondents highlighted inspections and status monitoring in answer to the question about which risk-reducing measures should be implemented to safeguard the integrity of load-bearing structures.

10.4.3 Mobile installations

As mentioned in the section on analytical methods, relatively little information has been gathered about the early phases of engineering and fabricationof mobile facilities, compared with production facilities. There are several possible explanations for this. As discussed previously, the engineering of drilling facilities is more standardised and there is therefore typically less scope for freedom in the choice of concept. To a certain degree, one may also talk about series production since there are often sister facilities.

The discussion in this sub-chapter is mainly focused on the operational phase of mobile facilities. All the same, a number of the issues raised previously concerning structural incidents may also be relevant for mobile facilities. For example, the investigation of Floatel Superior showed that the choice of design may influence the risk scenario to the greatest extent.

Competence, capacity and continuity

The high and increasing level of activity in the rig industry is a topic many are concerned with. It is already the case that the companies have problems retaining staff, and these are expected to increase in the years ahead since more mobile facilities are under fabrication and will arrive on the NCS in the next few years. This entails at least three problems concerning competence in the industry, both offshore and onshore. In the interviews, problems of competence and capacity were linked in particular to ballast systems.

In the first place, this applies to issues of formal competence in the fields of stability and positioning. Some of the interviewees from the rig owners criticised the quality of the current training programmes in Norway in stability for operators and stability managers. The training was described as outdated and inadequate, and a preference was stated for sending employees on comparable courses abroad.

Secondly, there are challenges in competence linked to the training in facility-specific equipment and routines. Interviewees in offshore roles in particular were concerned that there may be deficiencies in this area. In addition to the formal requirements that must be satisfied, time must be reserved for familiarisation, in order to get to know control room systems, other technical solutions and working methods and colleagues in the control room. In a pressurised manning situation, it was explained to us that the time spent on this type of training may be too short in the current pressurised market. The stability incident on Scarabeo 8 is a relevant example of this problem. The ballast operator had had very limited training on the facility in question before being left to manage the tasks alone on the bridge.

Thirdly, concern was expressed that personnel rise through the ranks much faster than before, so that staff in key roles possess less experience now than was the case just a few years ago.

This trend is significant for the major accident risk. Personnel working in stability and positioning have important roles, both for preventing maritime incidents and also for stopping those incidents that do arise from escalating into major accidents. If there are less experienced personnel in key roles, it is not at all unreasonable to assume that this affects the ability to avoid and, where necessary, manage critical situations.

The significance of competence for avoiding major accidents is also underpinned by the results of the questionnaire. Of the 26 people asked this question, 20 took a view on the statement that "a lack of qualified personnel entails an increase in the risk of major accidents". Of these 20, a clear majority of 14 agreed or fully agreed with the statement.

A lower level of competence and experience in key functions is inherently a cause for concern. Safeguarding safety-critical functions in a control room does not however solely depend on the presence of competent individuals in the room. It is also crucial that the control room *team* functions well and has properly established working relationships. A high level of turnover will represent a threat to crew's inter-relationships which are intended to ensure effective collaboration in demanding situations that may arise. It is important to find measures to counterbalance these problems. For example, a requirement for interaction training, so-called "Crew Resource Management", may be one instrument to counteract some of the adverse consequences of rapid growth in the rig industry. Experiences from other sectors, especially aviation, show that requirements for knowledge and expertise on cooperation and the utilisation of all available resources have been an effective means of reducing major accident risk. In the wake of the well control incident that escalated on Deepwater Horizon, recommendations have been issued by both the Norwegian Oil and Gas Association[26] and Oil and Gas Producers (OGP) on the use of Crew Resource Management training by relevant drilling personnel.

Control room design

One aspect which may worsen the situation of reduced competence is to do with the design of control panels in ballast control rooms. Although some interviewees believed that it was a lack of familiarity and not design that was the problem, and although they asserted that the control rooms had improved in recent years, many also had negative views of the actual design. A number of interviewees argued that standards (not specifying which) are not recognised, that there are large variations between the maritime systems and that different equipment from the same supplier sometimes has different human-machine interfaces in the same control room. One control room operator said: *"The siting of equipment is poor. The workplace design is not good. Built by mariners and assumes that the operator is going to sit right back. The planning phase and design phase are badly provided for."* In the questionnaire, 25.9 per cent of the respondents disagreed with the statement that critical maritime systems (such as ballast and DP systems) are simple to understand and use. Investigations of maritime incidents have pointed to incorrect operation of maritime systems, and to underlying causes in the shape of poor workplace design and human-machine interface (HMI). A good example is the PSA's investigation of the Scarabeo 8 incident, which states:

"The external HMI verification pointed out a number of weaknesses, such as the choice of background colours, poor screen contrast (legibility), shadowing, that the ballast images of the pontoons are not correctly positioned in relation to their actual orientation, and that operating ballast required having two screens up simultaneously, etc. The summary[27] discusses the presentation of safety-critical information on screen: "Several HMI shortcomings have been identified, especially with regards to legibility and to the way information of low operational value is emphasized on the safety system's HMIs." Challenges associated with the presentation of safety-critical information on the screens were known within the organisations, but not corrected."

Similar findings about control room design have been made on several occasions during the PSA's audits of mobile facilities. Typical findings include defective design of console workplaces, use of colours in screens, room lighting unsuitable for creating a good working environment in control rooms, etc. In a causation study linked to well control

[26] http://www.norskoljeoggass.no/Global/Publikasjoner/_H%c3%a5ndb%c3%b8ker%20og%20Rapporter/DWH%20rapporter/OLFs%20DWH%20rapport%20%202012.pdf

[27] Summary of ENI's HMI verification

incidents performed under RNNP in 2011, similar challenges linked to the presentation of safety-critical information for drillers and mudloggers, and poor workplace design in drilling cabins were identified. There will be differences between drilling cabins, mudlogger cabins and control rooms, but previous experiences from audits and investigations, of both maritime and well control incidents, show that poor HMI can increase the probability of incorrect operations.

There should now be good and mutually agreed understanding in the industry that errors made by qualified personnel in demanding operational situations must in the first instance be understood of signs of weaknesses in the system of which the human being is part. This is a key premise in safety research (see for example Dekker, 2006), and constitutes the foundation for regulatory conditions and for reduction in the risk of human error. There are also well-established standards and guidelines for how control rooms must be designed in order to provide the best possible support for decisions and work operations. Based on the major accident potential in events involving the interface between humans and control systems, there are grounds for wondering why human-centred design, including in respect of new facilities, is not adequately provided for, as confirmed by investigation and audit findings.

By way of conclusion, it may be noted that in several interviews (with both operational personnel and engineering employees) a clarification was sought of the relationship between the stability and ballast regulations in terms of restoring stability when dealing with stability incidents. The Stability Regulations require facilities to be capable of withstanding a list of 17 degrees[28]. It was claimed that there is a widespread perception that the Ballast Regulations require the facility to be righted within three hours. The reality is however that the requirements are that there must be the capacity to correct the list within three hours[29]. This interpretation of the regulations may create urgency in situations where it is crucial to be cautious, in order to ensure that the ballast operators do not make rash interventions that may worsen the situation.

As stated earlier, the project team had no data available from the choice-of-concept phase in respect of mobile facilities. But a few statements refer to it being usual to order "off-the-shelf" for maritime systems in control rooms. If so, this differs from the floating production installations, where it is usual for the builder to monitor that the engineering principles from the FEED phase are implemented in the detail engineering. The research team asked the PSA to evaluate this topic against relevant regulations[30]. The PSA judges the regulations to mean that all mobile facilities, including those whose technical solutions may be based on maritime regulations and supplementary classification rules, have an obligation to meet the other requirements in the petroleum regulations. This includes determining, evaluating and designing technical solutions in terms of how they interact with organisational and human factors, and fulfilling the functional requirements

[28] Regulation concerning stability, watertight subdivision and watertight/weathertight closing means on mobile offshore units, chapter VII Detailed requirements, stability, § 20, 1 a). (http://www.lovdata.no/dokument/SF/forskrift/1991-12-20-878?q=stabilitetsforskriften*)

[29] Regulation concerning ballast systems on mobile offshore units, Chapter V. Ballast pumps and piping, § 11, 1 and 2 (http://www.lovdata.no/dokument/SF/forskrift/1991-12-20-879)

[30] The Framework Regulations Section 3 on the application of maritime regulations in the offshore petroleum activities and the Facilities Regulations Section 1 on concerning the scope of the regulations allow, under certain conditions, mobile facilities to be subject to maritime regulations with complementary classification rules for relevant technical requirements. The Facilities Regulations can then be ignored as far as technical requirements are concerned, but not for requirements beyond that. Mobile facilities which comply with maritime regulations are obliged to take account of the petroleum regulations' requirements for analysis and operational factors when choosing technical solutions, which in practice entails the same functional level as applies to other facilities in the petroleum industry. For technical requirements for mobile facilities which adhere to maritime regulations, the following may apply: The regulations on ballast, stability and fire and the standards DNV-OS-D202 - Automation, Safety and Telecommunication and DNV-OS-D101 - Marine and Machinery Systems and Equipment apply in lieu of equivalent requirements in the Facilities Regulations. The requirement to ensure sound human-machine interaction, per Section 21 of the Facilities Regulations, applies for all types of petroleum facilities.

in the Framework, Management and Activities Regulations, as well as the requirements in the Facilities Regulations that go beyond purely technical requirements. The PSA therefore considers it inadequate to utilise exclusively the maritime regulations as a basis for designing technical solutions without viewing these in context with other requirements in the petroleum regulations.

Maintenance
Sub-chapter 10.3.2.1 shows that there have been in excess of 20 incidents linked to anchoring during the period. In addition the material covers a number of investigations of uncontrolled chain deployments. As mentioned, the investigations of such incidents for mobile facilities are generally of limited value, since they focus only in triggering causes. It has however been shown in sub-chapter 10.3.2.3 that 80 per cent of uncontrolled deployments have happened on mobile facilities which were more than 20 years old at the time the incident occurred. Deficient or non-existent maintenance therefore appears to be one possible relevant explanation, as also evidenced to some degree in the investigations. Maintenance is also the mostly frequently mentioned factor in the questionnaire in terms of causes of anchoring incidents (sub-chapter 10.3.3.1). It was also pointed out that good maintenance is demanding in a real-life operational situation with limited resources, pressure of time and other operational restrictions.

It should be noted that, as a result of the high level of activity in recent years, many old mobile facilities are operating on the NCS. If it is difficult to properly maintain the anchoring system, this suggests that this difficulty increases with the age of the installations.

Anchoring system challenges
Anchoring incidents was a topic in a number of the interviews, as shown by these examples. A representative of an operating company said the following: "*... 4-5 years ago, I said that anchor lines never went into overload. But in the last year, it's happened several times.*" A related statement was "*One should look at loads over time, and compare with analysed and experienced loads during the first year of operations. Discover where the faults are.*" Also concerning loads: "*Not everyone measures line tension; facilities under Norwegian flags are required to, but this requires monitoring by the authorities on first reclassification.*" [31]

A comment from a rig owner concerning operating conditions: "*Preventing anchoring incidents requires even more focus on the equipment and personnel. Some years ago, many people would wait as long as possible to disconnect from [the well]. And in the end you reach a limit where disconnection is no longer possible, and we've been there a few times. In this case, you need skilled people who have clout – to stand up to the oil companies and consultants. So, it's important to have expertise, so people can say no.*"

There were also interview comments about anchor chain manufacture, in this case from a representative of an engineering company: *"I am aware of many problems with material weaknesses, the quality of the steel in the chains and failures in quality assurance routines. A poor sampling philosophy. For us, follow-up of sub-suppliers on the anchoring side is extremely important. It's almost like we need three shifts for constantly following up. We would be very worried about getting new suppliers of chain in the dimensions we are talking about here. We are constantly pushing on size and it is not certain that larger dimensions on their own increase the breaking strength."*

The same interviewee made another comment: "*My thinking about drilling rigs is that there is a great push to not go beyond the conventional, while the rigs are just becoming larger and larger and moving out to deeper and deeper water. The thrusters will get*

[31] The Norwegian Maritime Directorate's requirements dictate that all facilities must have line tension measurement in the course of 2014.

larger but the anchoring system will ideally hold them on 8 lines as conventionally as possible."

A representative of an operating company was concerned with the problems of anchor lines on floating production facilities. *"There are two causes in play – there's the quality of the line, and the loads they are subject to. There are relatively large safety factors here, easily 2.2 for a production facility. One of the main contributors to the increased frequency of line breakages for mobile units is the increase in size of the units. These large rigs can be as big as the production facilities and they have fewer and smaller chains. They rely on thruster systems which are quite complex to analyse. There are a range of effects and forces which are difficult to control, especially when talking about shallow waters. The rigs are becoming larger and you're becoming dependent on DP system[32] that has to work."*

From reported incidents, we can see that there are many anchor line breakages and uncontrolled deployments on mobile facilities, and a number of comments indicating insufficient robustness in the choice of anchoring systems even though they meet relevant regulatory requirements. The potential outcome of a single line breakage may appear to be negligible, but there is major accident potential in these incidents, as with Ocean Vanguard where uncontrolled deployment of two anchor lines lead to significant drifting of the facility, a failure of a drilling riser and BOP.

Collating all the anchoring-related findings in this survey reveals that one possible explanation of the findings is that anchoring systems are insufficiently perceived to be safety-critical systems. There are no explicit statements propounding this in exactly these terms but this appears to be a natural observation encapsulating the different findings and comments. Unless anchoring systems are perceived to be safety-critical systems, they will be insufficiently maintained, there will probably be too little focus on avoiding maintenance backlogs, there may be a lack of expertise and inadequate emphasis on monitoring line tension.

Another key point concerns the choice of concept. Almost without exception, mobile facilities have only eight anchor lines – which complies with relevant regulations – while floating production facilities have 12 or 16, despite the fact that new mobile facilities are often as big as floating production facilities. A number of comments questioned the use of eight anchor lines on new mobile facilities, now that such facilities have become considerably larger, have more powerful thrusters, etc. At the same time, it should be said that it is not necessarily just the number of lines that ensures proper anchoring but that the anchor system in its entirety must be assessed when choosing a concept.

10.4.4 Challenges across DFU8

To conclude this chapter, important findings are summarised in the form of what the research team considers to be key challenges.

10.4.4.1 Status and awareness

One consistent impression from the literature review, the investigations review, the questionnaire-based survey and the interviews is that the status and awareness of the incident types included in DFU8 and the associated professional expertise are low relative to the potential in terms of both costs and risk.

There were a series of inputs from the interviews to the effect that the structural engineering domain has been weakened, and that it has become more difficult to cultivate specialist structural engineering expertise in the operating companies. Although

[32] Dynamic Positioning (DP) system, consisting of thrusters and possibly other propulsion systems, reference systems and a data-based control system to hold the facility (or ship) in a specific position. There are three classes, DP1, DP2, DP3, varying from no redundancy requirements to full redundancy for all systems.

the questionnaire responses nuance this view and demonstrate variation in perceptions of the status of this discipline, this remains an interesting finding. Similarly, the interviews with representatives of the maritime professions also claimed to feel their specialism had been downgraded. This is also reflected in the questionnaire responses, where 55 per cent of the respondents stated that they agreed or fully agreed with the statement that "factors relating to maritime systems constitute an area that receives too little attention in safety work in the industry".

The results of the literature and investigation reviews may also be viewed as saying something about the current status and awareness of these specialist domains. The project team had expected to find more literature linking the triggering and underlying causes of structural and maritime incidents, with this being done in line with best practice and experience. It was also thought-provoking to see how few investigations had been carried out of structural incidents and that there was a large, unexpected variation in the quality of maritime incident investigations. The project team also noted that there were operating companies with ongoing development projects on the NCS who declined to participate in the survey, explaining that they did not have their own structural engineering specialists.

Experience shows that, for different reasons, some incident types may receive a lot of a attention and that this may be at the cost of devoting attention to other types of incident. The best example is the strong focus there has been for many years on occupational accidents, which has been at the cost of major accidents (see, for example, the investigation following Texas City, Baker 2007). As a result, factors that clearly represent major accident risks have not been recognised and dealt with. For comparison, for example, in an eight-year period from 2002 to 2009 a total of 130 investigations of hydrocarbon leaks on the NCS were carried out, either by operating companies or the PSA (RNNP, 2010). This study shows that from 2000 to the present day, four structural incidents relevant to DFU8 have been investigated.

Through interviews and the questionnaire, many respondents commented that greater attention was given to hydrocarbon leaks than structural and maritime incidents. As one engineering company representative said, *"ballast and bilges are not such a hot topic as processing – where the value is created".* It therefore appears necessary to try in various ways to raise the status and attention given to structural incidents, structural engineering and similarly within the maritime domain, and to improve the understanding of risk at other levels in the organisations.

10.4.4.2 Prevention of major accidents

One other trait that the research team wishes to highlight is ostensible difficulties in the industry's policies and practice concerning prevention and management of major accident risk in respect of structural and maritime incidents.

By way of introduction to this study, we describe how the work of James Reason (1997) forms an important theoretical framework for the study. We also describe one of the challenges linked to this perspective, namely that correlations between causes and incidents may be seen as weak and unclear. At the same time, we emphasise that in the study we have chosen to include such factors as long as it is possible to make a logical argument for correlations between causes and possible incidents in the form of major accidents.

For structural incidents, interview data and results from the questionnaire derive from the sector's own experts in structural engineering. Although there are differences between engineering companies and operating companies in terms of the views expressed by the interviewees, we consider it important to take the concerns raised seriously. That the sector's own experts find it more demanding to be "bringers of bad news" about structural matters, and that questions may be posed about whether the burden of proof for assessing the safety of structures is in the process of changing are precisely matters that can be viewed as presenting the conditions for latent failures in Reason's terminology.

Bea (2002) describes how design-related threats to quality and reliability in offshore structures develop slowly. The slowness of the process helps mask the signs that such threats exist. This accords with the theories on man-made disasters (Turner and Pidgeon, 1997), and "drifting into failure" (Dekker, 2011), which both discuss and highlight the importance of detecting, understanding and correcting such negative processes in time. This requires a good safety culture at all levels of the operating companies, which requires good information flow between all participants. Last and not least, it requires a recognition of the significance of the capacity and willingness to constantly question whether the risk level is known and adequately managed, even after many years without serious incidents or accidents. This becomes particularly important when it applies to structural incidents which happen gradually and rarely.

The PSA has given notice that in 2014 emphasis will be attached to monitoring activities from a major accident perspective. This will be able to provide a good springboard for addressing the issues highlighted in this section of the study.

When it comes to maritime incidents, the challenges linked to thinking and practice concerning the prevention and handling of major accident risk appear to be somewhat different than for structural incidents. There is, for example, reason to question whether the weaknesses of the investigations carried out by rig owner companies indicate that this part of the sector needs to strengthen its understanding and practice in respect of understanding of risk and safety management from a major accident perspective.

One descriptive comment which emerged in the interviews was that "the maritime industry is doing the least it can get away with". This was used to illustrate a point that the industry positions itself at the level that standards and regulations require and that it does not have a tradition for implementing further risk-reducing measures beyond the regulatory requirements and requirements in standards. Against this backdrop, and as part of the analyses of the interviews with rig owner representatives, the project team therefore questioned parts of this industry's capacity and willingness to take responsibility for and ownership of the risk entailed by the maritime operations. The respondents advocated, for example, changes in the regulations for control room manning when using thruster-assisted anchoring; "position mooring" (posmoor). It was asserted that there is a requirement for two control room operators when operating on DP, but there was no similar clear requirement for the number of operators for operations using thruster-assisted position mooring. It was said that, as a result, some rig companies had only one control room operator for this type of operation. This was seen as undesirable, since the engine power of the thruster systems can often exceed the breaking strength of the anchor lines. If something unforeseen happens, the operator must react quickly to avoid damage to the anchoring system, and in that case a single person may not be sufficient, if they are preoccupied with other tasks. In this sense, from a major accident perspective, it may be detrimental to have only one control room operator on watch for this type of operation. From a safety perspective, it appears unnecessary to await regulatory amendments before rectifying such conditions. Further improvements in the work to manage major accident risk may require fundamental reflection and thinking about differences and interactions between prescriptive and functional approaches to risk management. In this context, the research team asked the PSA for a concrete assessment of the example reproduced above concerning the manning of POSMOOR operations. In the PSA's assessment, the example above clearly goes beyond the purely technical requirements in the maritime regulations, and the PSA's view is that control room manning will be subject to petroleum regulations. In addition, the mobile facility must comply with the national requirements defined by the vessel's flag state, which in Norway are the maritime regulations issued by the Norwegian Maritime

Directorate. Even if it were the case that the maritime regulations set a specific requirement for the number of control room operators, it is a breach of the regulations if this is insufficient for fulfilling the functional provisions relating to manning in the HSE regulations for petroleum activities[33].

In working on this study, the research team has reflected on the different professional traditions underlying structural incidents and maritime incidents respectively. Traditionally, both of these disciplines have their origins in traditional maritime activities, even though within structural incidents there is also an important contribution from structural analyses onshore. This shared background is however not necessarily a sign that safety is handled in the same way. This topic has only been touched on by way of introduction in commenting on the differences between structural and maritime incidents.

Structural safety has been and remains an engineer-dominated field with a clear academic character. The entire foundation for a safe structure is laid by the engineer doing a good job in the engineering design phase. Activities performed in later phases revolve around ensuring that the structure becomes what the engineers conceived (through its construction) and that it retains these properties (through inspection and maintenance). Relatively speaking, operational factors have therefore less significance for safety than the engineering design phase. With relatively little operational influence, it is perhaps not surprising that the MTO perspective has had little impact, and little concern has been accorded to underlying causes. The dominance of engineers and the small influence from operations both pull in this direction. Of course, this must not be interpreted to mean that safety is not taken seriously by engineers working on structures. On the contrary, the engineering of structures is a continuous balancing act to solve practical problems in a safe way.

Maritime incidents linked to stability, buoyancy and anchoring are even more strongly linked to maritime activities and shipping, but here the engineers' dominance is less clear. The systems must still be engineered to be safe, but safe operations also presuppose that those operating the systems perform their duties safely. The relative significance of engineering versus operations therefore constitutes a significant difference from structural safety.

In such a situation, one might expect that a more holistic approach to how human, technological and organisational factors affect safety (an MTO approach) would have had much greater impact but here the link back to maritime activities plays a role. In the research team's experience, traditional shipping does not yet have a clearly established tradition for thinking holistically about causes, and compared with offshore activities less attention is paid to underlying causes.

10.5 Conclusions and recommendations

The objective of this study has been to:

- To collect data from literature, investigations, interviews and questionnaires concerning causes and measures associated with structural and maritime incidents.
- To perform a complete assessment and analysis of human, technical and organisational causes and underlying factors. On the basis of identified causes, to suggest areas for improvement and concrete measures which the industry should address.

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33 For example, the requirements formulated in: The Management Regulations Section 14 concerning manning and competence defines requirements for adequate manning and competence in all phases of the activities, Section 12 on planning which sets out the responsible party's obligations to ensure that the resources necessary to carry out the planned activities are made available to project and operational organisations. The Management Regulations Section 13 on work processes which states that the interaction between human, technological and organisational factors shall be safeguarded in the work processes. A number of conditions formulated in the Activities Regulations, concerning, among other things, workloads and risk of mistakes, must also be assessed. This list of regulatory requirements is not exclusive.

Viewed in the light of the major accident potential, the focus on structural and maritime incidents and the disciplines involved is inadequate. The investigations of maritime incidents are of variable, at times poor, quality, while few structural incidents are investigated at all. Overall, the investigations contribute less than is desirable to a better understanding of underlying causes and to a basis for sound risk-reducing measures. Furthermore, the industry's own experts find that the status of the structural engineering profession has been diminished and that more attention needs to be focused on maritime systems and operations.

The following is a brief summary of the study's most important findings, followed by concrete recommendations.

Increase the quality of volume of investigations into structural and maritime incidents

One of the study's main findings is linked to the quality and quantity of investigations. Investigations are performed to map and describe triggering and underlying causes of incidents, and as a basis for preparing risk-reducing measures in order to prevent similar incidents occurring in future. Good investigations will also be able to contribute to organisational learning beyond the framework of the incident itself. If, for example, an investigative process of a structural incident results in better insight into the lack of experience transfer between participants, improvement work may be able to prevent a series of incidents caused by the same organisational failings.

From a major accident perspective, investigations also have a supplementary function. Major accidents are rare occurrences. Investigations of incidents and the ensuing information provided to relevant groups of participants therefore constitute an important tool for maintaining vigilance in safety work. There are also regulatory requirements demanding that safety-critical information is collected, processed and communicated, and that personnel must have received training in relevant risk factors. It is appropriate to use investigations for this purpose.

- Operating companies and rig owners, in cooperation with relevant authorities, should assess whether more structural incidents could be investigated. The criteria for when such investigations are undertaken should be reviewed, and an assessment made of which investigation methodology is best suited to yielding a better understanding of structural-related incidents.

- Measures should be undertaken to raise the quality of investigations of mobile facilities. Consideration should for example be given to establishing a shared pool of investigative resources which small and medium-sized rig owners could make use of. This could contribute to raising the expertise of all participants over time and may also improve the quality and utility of investigations from different companies.

Improve information exchange between participants and between different phases

The study has revealed a need to strengthen information exchange between participants and between different phases of a facility's life cycle. Efforts must be made towards improved information exchange between engineering companies and operating/rig owners through, for example, detailing how conceptual choices and technical solutions work in the field, or through strengthened practice in using data from decommissioned facilities as a source of empirical knowledge. Good information exchange between participants and phases also requires that there are adequate resources for performing good follow-up work in the design and fabrication phase.

- New forums should be created, or existing ones strengthened, for discussion and interaction between the participants in the structural engineering profession.

- More systematic transfer of experience from operating and rig owners to the engineering companies should be established. This will contribute to learning in the engineering companies and better structural solutions, both conceptually and at detailed design level. For example, there is a need for:

    - Information for the engineering companies about how the inspection work is performed in practice (according to which methods and measuring points)
    - Communication of findings from investigation reports
    - Communication of operational experience

- There is a need for better follow-up of engineering companies and yards from requisitioners of facilities. When contracts are awarded to engineering companies and yards that have little or no experience of the NCS, it is recommended to reinforce the follow-up of structural safety and marine systems.

- Opinions in the industry are divided on whether improved analytical tools produce more or less robust structures. It is recommended that the concept of robustness is clarified in the regulations and structural standards. It is in any case crucial to maintain engineering expertise in order to safeguard the understanding of the potential and limitations of the analytical tools.

Improve knowledge and practice associated with maritime systems
There is a need for improved knowledge and practice in terms of maritime systems. Such improvement will ensure that maritime systems receive the necessary attention and that the risk of maritime incidents will be reduced or handled better. In respect of anchoring systems, there is a need for more knowledge about actual loads, there is a need to evaluate the relationship between anchoring analyses and anchor line capacity for large mobile facilities, and it would be desirable to improve the maintenance of anchoring systems in mobile facilities. The stability incidents included in this study, together with results from the interviews, indicate a need for measures directed at the human-machine interfaces on mobile facilities. There is a need for improved competence in maritime systems, including collaboration in the control room. This could, for example, be in the form of training courses aimed at cooperation, communication and teamwork.

- Studies should be conducted to acquire better knowledge of the actual loads on anchoring systems.
- Maintenance of anchoring systems, especially on older mobile facilities, must be improved in order to reduce the number of uncontrolled deployments.
- On the basis of anchoring analyses, it must be ensured that adequate anchor line capacity is selected, especially on large semi-submersible mobile facilities.
- Screens and equipment for controlling ballast systems on floating rigs should be improved and designed in accordance with recognised standards and guidelines for control-room equipment.
- The competence of stability operators is a critical issue and the quality of training in Norway should be improved. In addition, their familiarity with facility-specific equipment and personnel must be secured. Furthermore, assessment should be given to designing and implementing training based on methods which emphasise team training, scenario-based training and simulator training.

Systematic safety work and major accident prevention

By way of conclusion, the study has pointed out the challenges associated with managing safety from a major accident perspective. For structural-related incidents, the study has identified that the structural engineering profession is under pressure. For structural-related incidents, there is a need to ensure that assessments from the structural engineering profession come to the fore in the organisations, so that dilemmas between, for example, costs and design choices are resolved appropriately and prudently and so that any tendency to drift into failure is detected and corrected.

For the maritime disciplines, the study has shown that different regulatory regimes create challenges, and more knowledge is required about the interface between maritime regulations and the petroleum regulations. A good understanding of a functional regulation should provide an adequate basis for preparing good risk-reducing measures regardless of the concrete detailed requirements in norms and standards.

- The petroleum industry should ensure that structural engineering expertise and evaluations are seen as key elements in major accident prevention work, and ensure proper handling of conflicting goals in structural issues is an integrated part of the efforts to create and maintain a good safety culture.
- The maritime section of the industry must ensure that activities are planned and executed in a manner compliant with the intentions behind function-based regulation of management and safety.

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