In-service-experiences of anchoring systems in Norway 1996-2005

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ABSTRACT: The regulatory framework and the experience we have gained in recent auditing of anchoring analysis are presented briefly. The incidents involving loss of more than one anchor line are described individually, and general statistics of anchor system incidents are presented, based on incidents that took place on the Norwegian continental shelf from 1996 to 2005. The paper is based on 48 incidents of varying degree of criticality, as reported to the PSA in the period 1996-2005. The state of the art of risk analysis of anchoring systems will be given a short description of, too. Generic fault trees related to various root causes are presented also, with frequencies related to our experience.

1 INTRODUCTION

The safety of anchoring systems for use in the petroleum activities on the Norwegian continental shelf is regulated in the facilities regulations section 64 on anchoring, mooring and positioning, stating that the anchoring system for mobile offshore units shall be in accordance with the Norwegian Maritime Directorate's (NMD) regulations of 4 September 1987 No. 857 concerning anchoring/positioning systems on mobile offshore units. In addition, the anchoring system for facilities with production plants and facilities located adjacent to another facility, shall also be in accordance with the Norwegian Maritime Directorate's regulations of 10 February 1994 No. 123 for mobile offshore units with production plants and equipment. On such facilities, the calculations shall not include the advantage of active operation of anchoring winches.

The NMD regulations state, in general, that the environmental actions shall be stipulated with an annual probability of 10^{-2}, and a set of safety factors are stipulated. The main differences between the two NMD regulations, are different safety factors and the requirements to loss of anchor lines. While No. 857 require that the unit shall maintain position during loss of one anchor line, No.123 state that the position shall be maintained in case of two simultaneous line failures, if the facility in question is producing.

According to NMD, the drilling facilities will normally not have to comply with the No. 123 regulation, but pursuant to the PSA regulations, all facilities, be they mobile or not, comes under the No. 123 regulations if the facility operates adjacent to another facility. Hence, the main difference between the NMD and the PSA regulations is the requirements to adjacent facilities – as flotels. The PSA regulations require that the anchoring systems shall be analysed in the same way as the anchoring systems of production facilities. Our experience has shown that such a requirement is needed. In storms, a flotel is typically located 150 m away from the adjacent facility. Following multiple anchor failures we have had drifts of about 150 m.

Said regulations should prevent accidents to a reasonable degree. There have been too many incidents, however, but our conclusion is that this has very little to do with the regulatory requirements as such. It is more question of lack of compliance, so the industry has to improve the performance in this respect.

The purpose of this paper is to assist in such an improvement process.

2 AUDITS OF ANCHOR SYSTEM ANALYSIS

As a consequence of several incidents over the last few years, the PSA conducted five audits in 2004 and 2005, concentrating on site specific analysis of anchoring systems on mobile facilities (MOUs). Fifteen companies were visited all in all, oil companies, rig owners, consultants on anchoring analysis and suppliers of anchoring analysis software. The NMD took part in three of the five audits.

All of the audits made observations that were related to the quality assurance system. Typically, the traceability of the documentation of small consultancies was not up to par. We got the impression that analyses were the work of key staff only. They were very well qualified, though.

Quite a few of the operators did not do any verification of the analysis, as is required by the regulations. Some of the rig owners used a "Location Approval" system. In some cases, the Location Approvals did not verify the anchoring against the PSA regulations. Besides, according to our rules and regulations, this kind of approval often could not be regarded as verification.

Most technical audit findings had to do with anchoring and soil capacity. The MOUs in Norway use drag embedded anchors. In general, the capacity can be documented by either testing the anchor holding capacity to its maximum design tension, or, with knowledge of the soil conditions, to document the capacity by analysis. The analytical approach also makes it possible to calculate the drag length.

The calculation of the anchor holding test tension had not been done in all cases, and many companies did not comply with the requirements of the regulations, to test up to the maximum design tension. In addition, neither the assumptions made by the consultancies doing the analysis, nor the work done offshore, always comply with requirements. In one of the cases, the anchoring pattern was different to the calculations, and in several cases the tension used offshore was different to the assumptions in the analysis.

3 INCIDENTS INVOLVING MORE THAN ONE ANCHOR LINE

The requirement that loss of two anchor lines must be analysed for production platforms, was discussed in Norway, in connection with the introduction of ISO-DIS-19901-7. Our experience shows, though, that loss of two lines is a realistic possibility, and our regulations will uphold this requirement accordingly.

In a summer storm 13 June 2000, the Bideford Dolphin suffered three anchor line failures close to the Snorre facility in the North Sea. It was shackles (CR-links) that failed. The CR-links were used as connecting links between chain and wire in the mooring arrangement. Although the shackles were only two years old, they failed as a result of fatigue and tear-off fractures. The tension was about one third of it's the proven capacity. The facility drifted about 250 to 300 m from its target position, but the well was secured. The anchor lines crossed several export pipelines, but did not damage them. The ten minute average wind velocity was about 20 m/s, and the significant wave height was about 8.5 m.

On 11 November 2001, the Transocean Prospect was operating on the Heidrun field in the Norwegian Sea when two of the anchors dragged almost 50 m. They used eight 12 tonne Stevprice anchors. The 10 minute average wind velocity was about 21 m/s, and the significant wave height measured at the Heidrun facility, was around 13 to14 m (Haver & Vestbøstad, 2001).

The Scarabeo 6, while drilling on the Grane field in the North Sea, suffered anchor dragging on 24 December 2002. They used eight 15 tonne Bruce anchors. The tension was about 50 per cent higher than the test tension. Things got worse when a chain in the fairlead was fractured. According to the calculations, the line broke at around 80 per cent of its holding capacity. The fairlead had only five pockets, so some bending and a reduction in the breaking load of the link was anticipated. The ten minute average wind velocity was about 22 m/s, and the significant wave heights were 9 to 9.5 m. The well was secured, with the drilling riser suspended in the sea.

On 14 December 14 2004, an accident occurred on board the Ocean Vanguard drilling facility on the Haltenbanken in the Norwegian Sea. The brakes of two of the anchor lines failed almost simultaneously in a sea state of about ten metre significant wave height. The anchor winch was a Pusnes 750 CU. The band brakes malfunctioned. Because of the damage, it was impossible to know for sure whether the brakes had been correctly adjusted or not. Pusnes, the manufacturer, concluded that the springs in the brake cylinder did not function as intended. At an earlier stage they had recommended to change the brake band, but this had not been done. The pawl stopping mechanism did not work, since it had been installed in a wrong way, and not as specified in the instructions. The accident caused a temporary list of the facility, estimated to about ten degrees, and a horizontal movement of approximately 160 m. The movements of the facility lead to failure of the drilling riser and a total collapse of the tensioning system. The BOP on the sea floor suffered a permanent inclination of six degrees, the anchor winch system was damaged and the well was lost. The event was thoroughly investigated by the PSA (Solheim et al, 2005).

Of the four cases involving more than one anchor line, one was brake related, one line related, one soil related and one soil *and* chain related. Brake failures, line failures and dragging are also the three main failure modes of anchoring systems in storm conditions. Statistics of incidents caused be these failures, will be presented individually.

4 UNCONTROLLED CHAIN RELEASE

Most of the winches in use in Norway are manufactured by Norwinch or Pusnes. We do not have sufficient data to compare the two, with respect to the reliability of their products. Both of them use the band brake concept. A comparison of the incidents shows that malfunction of the band brake is the most common cause of failure, a most typical reason being wrongly adjusted band brakes and/or corrosion and wear. In one instance, the brakes did not hold more that 16 per cent of their documented holding capacity. In none of the incidents of uncontrolled chain release chain tension exceeded the theoretical holding capacity.

Figure 1 specifies the operational modes in which the winches failed. As expected, most of the incidents occurred during anchoring operations. In such operations, winches are activated by deactivating the brakes etc. Consequently, the system is vulnerable to both technical faults and operational errors.

The most common root causes in use are band brake failure and lack of maintenance. Other causes are incorrect operation by personnel, supplier instructions that are not being adhered to, and errors in procedures.

of wire failures in anchoring systems. Hence, wires will not be discussed any further.

Most often, chain failures are caused by sub standard quality of the chain at the time of failure. The causes may be said to be evenly divided between brittle fracture and fatigue. Some of the chains had been exposed to bending loads, but corrosion and loose studs had also taken a toll. The five inch fairleads were probably more exposed to bending, than seven inch fairleads.

We have had two fibre rope failures over the last three years. The fibre ropes are not as robust as chains, in terms of withstanding mechanical loads. In Norway, these ropes are normally used in a combination of chains and ropes, to protect pipelines against impact damage. For the last few years, around 20 fibre ropes have been used on the NCS. The failures are caused by trawl board wires from fishing vessels, by ROV wires and by wires connected to a hook.

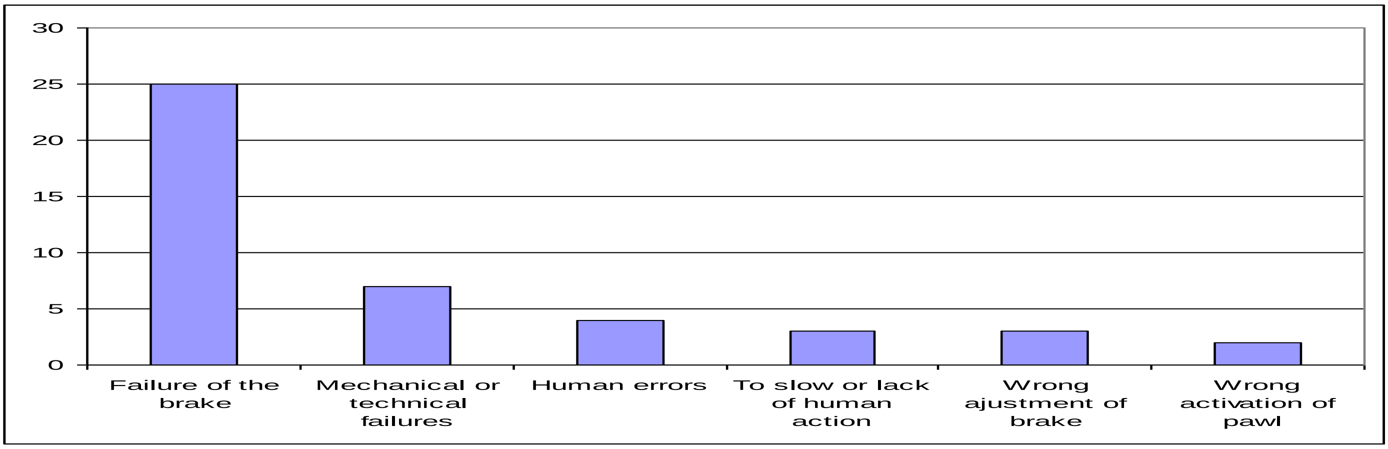

Figure 1: The number of loss of lines related to winches, and organized on type of error.

5 ANCHOR LINE FAILURES

In the period 1996-2005, ten Norwegian Continental Shelf (NCS) anchor line failures were reported to the PSA. Five chains failures, three losses of fibre ropes, and three shackle failures.

Shackles are used to connect line segments. According to experience that has been gained in the UK, failure frequencies of shackles are significantly higher than those of elements in the chain itself (Noble Denton, 2002). The Norwegian experience is very much the same. In two of the cases (CR links), it was a question of fatigue failures. Local stresses in the connection initiated fatigue cracks. The material impact toughness did not fulfil the requirements. In one of the cases, it was impossible to recover the shackle from the sea bed, to determine the cause.

Although we did an extended check of Norwegian data from 1990 onwards, we found no reports

Buoys are used to lift anchor lines across obstacles on the sea bed. Only a few cases of loss of buoys have been reported to the PSA in the period 1996-2005. The low number might be a case of underreporting as our rules are a bit vague as to the necessity of reporting such losses.

6 DRAGGING OF ANCHORS

Four cases of loss of anchor holding capacity were reported in the period. All the events occurred in stormy weather. The dragging events involved anchors from the manufacturers Bruce and Vryhof. We do not have sufficient data to give a reliable differentiation between the two suppliers. In the period 1996-2003, no storm dragging event was reported in the UK (HSE, 2005).

Dragging of anchors will occur if the line tension exceeds the holding capacity of the embedded anchor. Dependent upon the soil characteristics and the anchor design and fluke angle, the anchor could either be embedded further or dragged horizontally in the soil. In the first case, the holding capacity will increase, and the dragging could be stopped if the holding capacity equals the line tension. In the latter case, however, the anchor will continue to drag as long as the line tension is not reduced.

Normally, soil investigations are necessary to calculate the capacity with high accuracy. For exploration drilling, however, it has been accepted to use general information about soil conditions in the area when calculating holding capacity.

It is normal practice in the industry to pretension the lines to about 150-200 tonnes before mobile facilities (MOUs) start operation. Often, this is regarded as a verification of the anchor holding capacity. Nevertheless, as is also discussed in DNV-RP-E301 and HSE (1993), the test tensioning of the anchor lines verifies the anchor holding capacity *at* the applied test values only.

7 OTHER RISKS RELATED TO ANCHORING SYSTEMS

Anchor handling is a dangerous operation, and risks to personnel are generally high. Fatal accidents occurred on the anchor handling vessels Maersk Terrier in 1994, Far Minara in 1996, Maersk Seeker in 2000 and Viking Queen in 2001. The project "Working together for safety" will hopefully improve safety, mainly by introducing automation on the anchor handling vessels, and by improving work procedures. Incidents where anchoring systems have damaged equipment on board facilities and vessels, and on pipelines on the sea bed, have also been reported.

These “other risks” will not be discussed any further.

8 RISK ANALYSIS OF ANCHORING SYSTEMS OF MOBILE FACILITIES (MOUs) ON THE NCS

In the period 1998-2003, the NCS and the UK continental shelf (HSE, 2005) had about the same number of anchoring system failures, indicating that failure frequencies (as reported) are higher in Norway than in the UK, because the number of MOUs is lower. According to Norwegian data, the number of reported dragging events is significantly higher.

A total of ten quantitative risk analyses (QRA), six of mobile facilities, one of a flotel and three of production facilities, have been reviewed; the analysis of the anchoring systems being concentrated upon. The incident “loss of position” is not analysed detail in most of the QRAs. Many of the hazards that may lead to loss of position are not identified. Only one of the QRAs identified winch failures as a hazard. Other hazards that were not comprised by the majority of the QRAs are loss of buoys, fatigue, fishing equipment in contact with fibre ropes, and dragging of anchors. In quite a few of the analyses, the methods and the data applied are not well documented. Only three of the analyses specified the assumptions. Use of different data sources means large variations in calculated risk levels of similar systems. Fault trees are not used in the analyses. The gross error QRA of the Kristin facility (Lotsberg et al, 2005) is an example of a new approach, but more testing is needed.

9 USE OF FAULT TREES IN QRAs OF ANCHORING SYSTEMS

A set of fault trees has been prepared for QRAs of winch failures, for both active operation and storm conditions, line failures (chain or rope) and dragging of anchors. This paper presents generic fault trees of brake failure during storms (Figure 2), chain failure (Figure 3) and dragging of anchor (Figure 4). A fault tree for paying out the chain in marine operations can be found in Næss et al (2005). The fault trees are prepared in a process involving hazard identification and reviews of causes of incidents in Norway and those discussed in publications dealing with such incidents. Frequencies are calculated from Norwegian incidents data. The fault trees describe the causes leading to the top events.

The frequencies calculated from the modelled fault trees are lower than those calculated from the statistics of winch related failures. The frequency of brake failure from the fault tree (Figure 2) is calculated to 3.0×10^{-3} per winch year without the use of common mode failures. The observed frequency from the documented events is 8.4×10^{-2} per winch year. If common errors are modelled, the frequencies will be closer to the observed values. For details of the method and the individual frequencies of the fault trees, see Næss et al (2005).

From the fault tree (Figure 3), the frequency of anchor line failure is calculated to 2.2×10^{-2} per line year without the use of common mode failures. The observed frequency, from the documented events, is 1.0×10^{-2} per line year. If common mode failures are included, the results are similar to the observed ones.

The frequency of dragging of the anchor is calculated, from the fault tree (Figure 4), to 5.0 x 10-3 per anchor year without the use of common errors. Only a few incidents of loss of anchor holding capacity have been observed, however, so it is difficult to quantify the root causes. The frequencies are applied at high levels of the fault tree, and the frequency of the top event is consequently the same as the frequency calculated from the documented events.

To get good estimates from the fault trees, it is necessary to include common mode failures. It is then possible to get results that correspond, more or

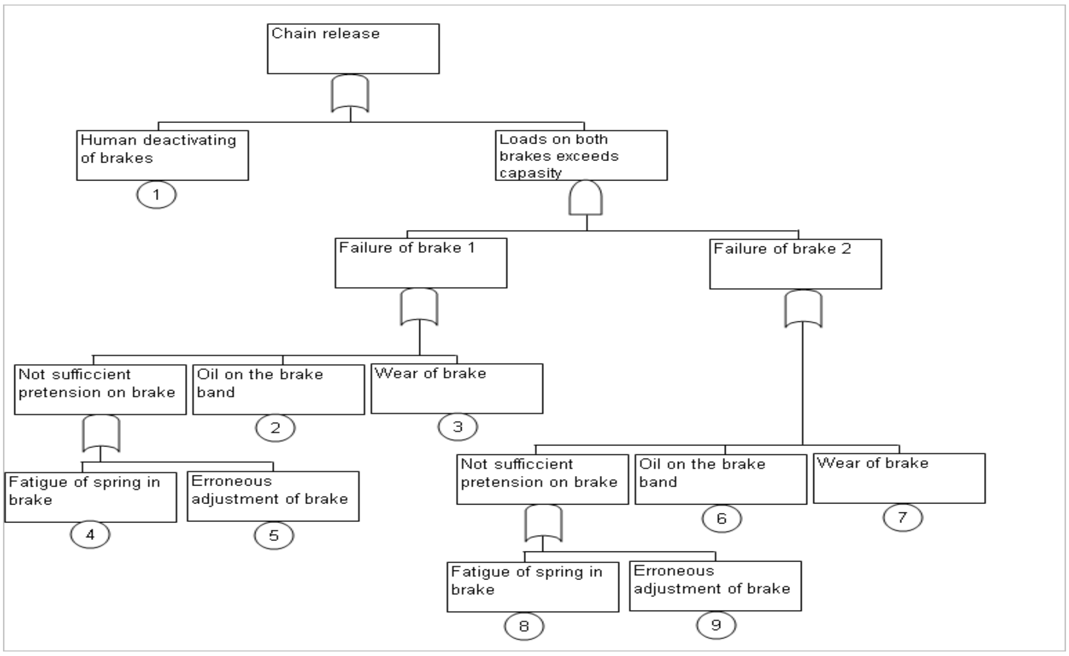

Figure 2: The modelled fault tree for the top event: Chain release from the winch, when the winch is in use and the brakes are static. The calculated failure frequency for this event is 3.0 x 10-3 per winch year. The circles are the input events in the fault tree.

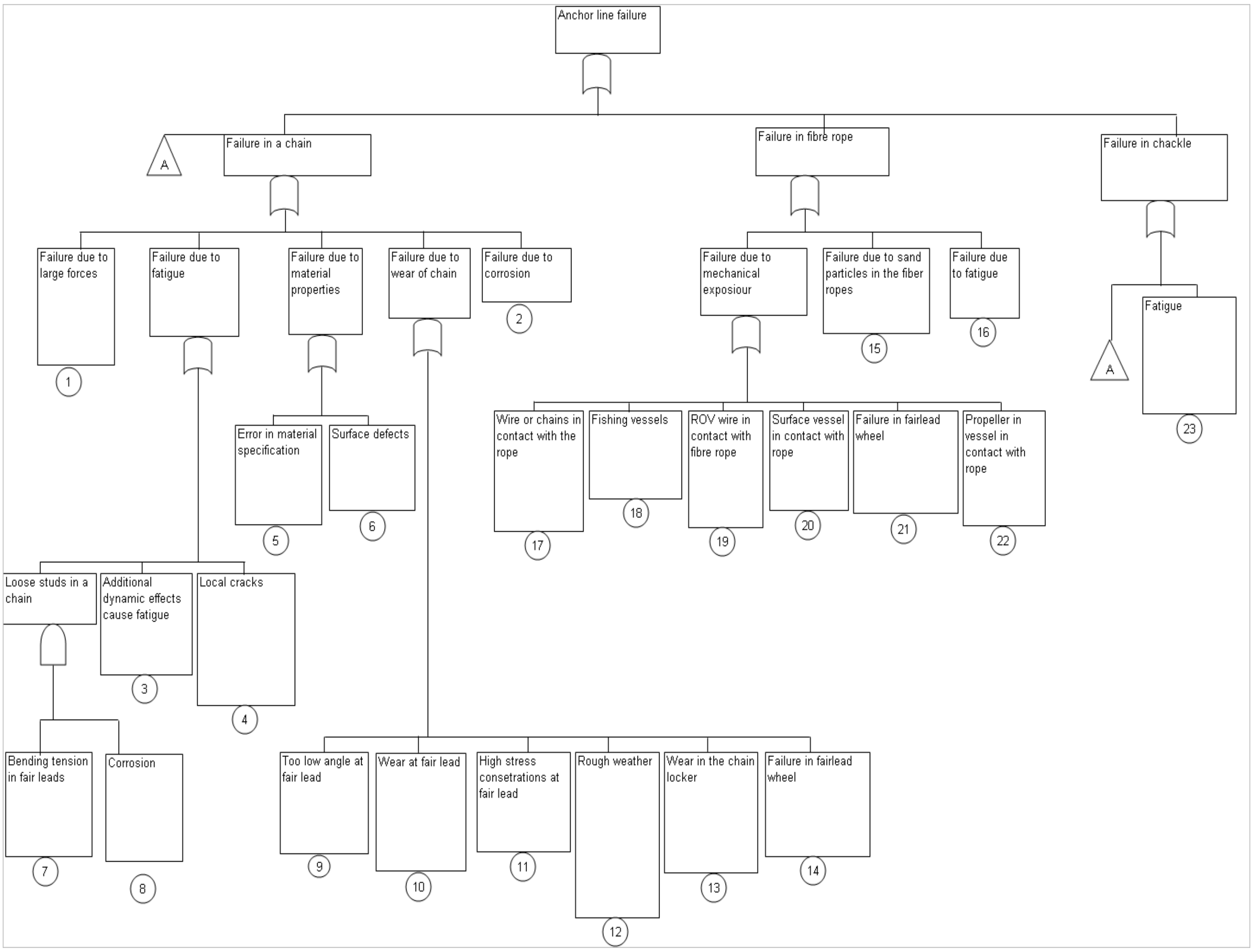

Figure 3: Modelled fault tree for the top event: Anchor line failure. The calculated failure frequency for this event is 2.2 x 10-2 per anchor line year. The circles are the input events in the fault tree and the triangles are transfer symbols.

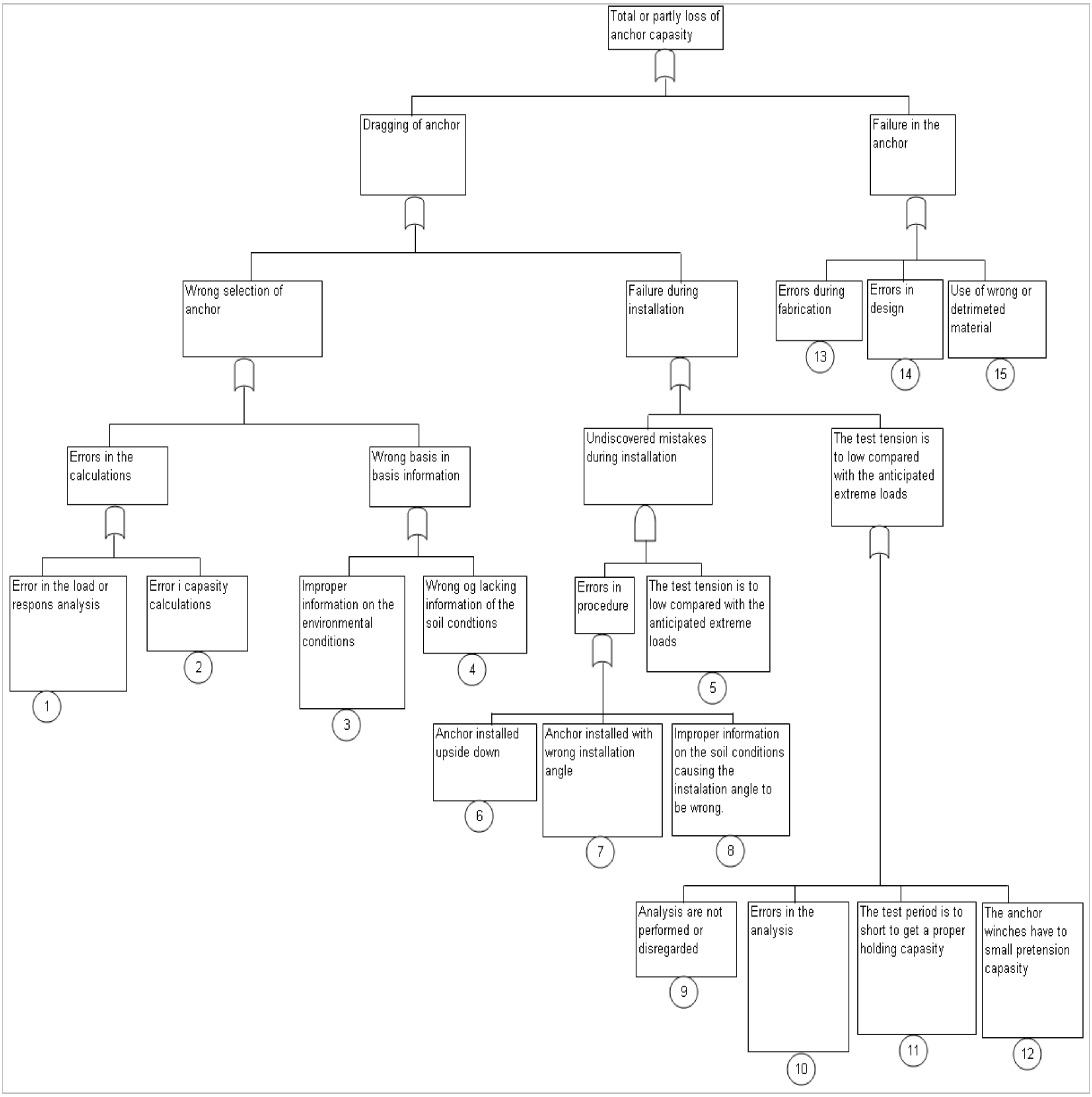

Figure 4: Modelled fault tree for the top event: Loss of intended anchor holding capacity. The calculated failure frequency for this event is 5.0 x 10-3 per anchor year. The circles are the input events in the fault tree.

less, to the observed data. It is recognized that the collected data is a relatively small sample, which should be increased in order to improve the reliability of the collated data. It is very challenging to collect data on common mode failures. The approach often used is to calculate such frequencies by some mathematical approximation.

10 DISCUSSION

On the NCS, the number of incidents related to anchoring systems on MOUs, is too high. From our point of view, training and organizational factors must get more attention. We believe that many incidents would not have happened if the industry had a better system of transferring experience, and the crew had more insight into and was more familiar with anchor systems and their function. Maintenance of such systems should also be given more attention.

We would like to point out that many of the incidents occurred during critical operations, when the facility was connected to the well or alongside another facility. Even though the anchoring system is designed to withstand a line failure, such an event is, nevertheless, undesirable.

Our regulations are accident preventive in nature, but do imply, of course, preventive action and improvements on the part of the industry in order to fulfil their intention.

The equipment on board the facility is the owner's responsibility, and the site-specific evaluations are the responsibility of the operator. The owners have, as a consequence, initiated work under the direction of the "Operations Committee for Drilling Contractors", and have proposed some measures aimed at reducing the number of incidents.

According to the regulations, two independent brake systems shall be in use at any time. Hence, in the event of incidents, both brakes have to fail. None of the reported incidents would have occurred if the winches had been in agreement with the regulations. It has not been possible to determine how often each individual brake system fails. The high number of incidents, however, involving failure of both brake systems with resulting chain deployment, indicates that the failure rate is high.

Failure of the anchor line itself is the most frequent cause of failures in the anchoring system in use. The quality and quantity of inspections and repairs in connection with the recertification of the chains are of major importance. Very much, so, because chains that are more than 20 years old, are still in use. Recertification inspections and repairs are therefore essential in ensuring that the chain satisfies the applicable quality requirements to the anchoring line. The chain owners must know the history of each individual line (cf. traceability) in order to ensure a successful recertification. Several fatigue failures have occurred recently on anchor chains, caused by bending stress. It is reasonable to assume that the bending stress has occurred at the fairleads. We believe this is a good reason to reconsider the design of the fairleads.

The number of shackle failures is about the same as that of chains, and the consequences of both types of failures are the same. Since the number of shackles is small compared to the number of chain links, the failure frequency of each individual shackle is significantly higher than that of chain links. We are of the opinion that special attention should be given to the selection of shackles, as well as to the assessments of the condition of the shackles.

In some cases, use of fibre rope in the anchor lines may be advantageous, both in terms of safety and operation. It should be taken into consideration, though, that fibre rope has proven to be very vulnerable to mechanical exposure, e.g. when in contact with wire. We believe, as a consequence, that operations carried out within the area of the anchor pattern, must be supervised better.

The number of dragging events shows the need for increased pretension capacity or use or other anchor solutions. Using present test tensioning capacity, it may be impossible to attain safe anchoring with traditional fluke anchors. The anchor holding capacity on mobile facilities must be calculated more accurately than typically done today. In the case of a mobile facility drilling an exploration well, a limited dragging of the anchor will not necessarily cause major damage, but dragging an anchor may lead to failures of the neighbouring lines. Often, mobile drilling facilities are anchored in locations with many subsea facilities, and a dragging anchor may damage these. Hence, there is a need to increase the anchors' test tension on mobile facilities. With good knowledge of soil conditions, even, it can be difficult to getting a fully satisfactory anchoring, when based on conventional anchors (drag anchors). Alternative types of anchoring should be evaluated then. Dragging anchors can only be accepted after a consequence assessment, - of the tension in the other lines, as well as the possibility of damage to subsea facilities and neighbouring facilities.

It goes without saying that practical anchoring work on facilities must correspond to the results of the anchoring analyses. It is the only way to enhance safety.

The quantitative risk analyses (QRA) are a common approach to find and quantify risk reducing measures. The QRAs we have reviewed have no detailed analyze of the anchoring. Several failure modes have not been identified or analyzed, nor have the analyses been used as a basis for reducing risk. Generally, all the QRAs were too coarse to be a basis for reducing risk. We have shown that failures of the anchoring system can be modelled by fault-trees. Further improvements and practical experience are necessary.

The verification required by the facilities regulations can assist in ensuring the desired level of safety to be provided by the anchoring analyses, but such verification must address all aspects associated with the anchoring. This means, inter alia, that the anchor holding power must be part of the verification.

11 CONCLUSION

On the NCS, the number of incidents related to anchoring systems on MOUs, is too high. Improvements are necessary.

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