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Moored MODU Risk Assessment

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Abstract

During the Gulf of Mexico (GoM) hurricane seasons of 2004, 2005 and 2008, numerous moored Mobile Offshore Drilling Units (MODUs) had complete mooring system failures and thus were later found to be adrift. Also, a few units suffered failure of one or more mooring lines but at least one line held to keep the unit from going adrift. As a result of these mooring failures, operators and rig owners expended much effort in recovering the vessels, the mooring components, and then in making the required repairs in order to restart operations. Other major consequences of the mooring failures were: direct damage to the industry's infrastructure such as pipelines and umbilicals, loss of production, and delays in several well programs.

MODUs in the GoM are a critical part of the necessary infrastructure for exploration and development of oil and gas. Industry standards that allow safe and economic operations of MODUs are important to the industry and regulatory authorities. Much work has been done since the events in the 2004 and 2005 GoM hurricane seasons to better understand the causes of moored MODU failures and learn from these failures. This knowledge has resulted in changes to the industry standards regarding mooring of MODUs. As an example, selection of the design return period is no longer prescriptive but based on performing a suitable risk assessment.

Using a Quantitative Risk Assessment (QRA) approach, the risk can be evaluated at every well location planned to be drilled during the GoM hurricane season. These results can be used to make more informed decisions regarding rig deployments during the GoM hurricane season.

In addition, the QRA methodology can be extended to more comprehensive considerations (e.g. all of the GoM) in order to better understand the risk posed by the moored MODU fleet to an operator's entire portfolio of deepwater facilities and infrastructure.

This paper describes a process that can be used to assess the risk associated with moored MODU operations and provides some examples to demonstrate the utility of the process.

Introduction

As a result of the numerous moored MODU failures during hurricanes Ivan, Katrina and Rita, the industry has reexamined the API guidelines for design of MODU moorings. Changes have been made to the current API guidelines as discussed in Refs. 1 and 2. The cornerstone of API RP 2SK, Appendix K (Ref. 3) is a risk assessment process to provide a consistent technical basis on which to make decisions of suitability of a particular rig at a specific site for a specific period of the GoM hurricane season. Per MMS NTL No. 2009-G09 (Ref. 4), a mooring risk assessment is required with every drilling permit. The QRA approach provides a means to rationally assess the risks, document the results, and compare the results to a company's internal guidelines in order to make better decisions regarding rig deployments. The process also provides a framework for consistently comparing the risk over multiple well locations.

An example site is presented herein that includes nearby surface and subsea infrastructure (at 10 miles or less) to demonstrate how the process works. Results are presented to particulary show the impact of drilling during the peak of the GoM hurricane season (approximately August 15 through October 15). Additionally, a second example shows the conclusions from a QRA that considers a comprehensive portfolio of deepwater infrastructure (surface facilities, pipelines and flowlines) being exposed to the fleet of moored MODUs during GoM (both peak and non-peak) hurricane season is presented. The second example further considers both the pre and post upgraded MODU mooring systems (i.e., relative to their 2004 condition). It is shown that proximity of the MODU to the infrastructure and the lost value placed on that infrastructure greatly influence the outcome of the QRA.

The process described in this paper can be useful in assessing the risks associated with moored drilling rigs operating during the GoM hurricane season. The approach provides more consistent quantification of the risks and software tools make this process efficient. The QRA process can also be used to identify the sensitivity of the risks to various factors and hence identify potential risk reduction measures. The objectives of the paper are to provide a better understanding of the relative risk associated with moored MODU operations in the Gulf of Mexico as well as provide information on how to apply a risk assessment process to supplement a Minerals Management Service (MMS) Application for Permit to Drill (APD).

Historical MODU Mooring Performance Overview

Hurricane Lili in October 2002 resulted in one moored MODU parting all of its moorings and drifting to shore. Another MODU broke some of its moorings but stayed on location. During Hurricane Andrew in September 1992, five MODUs went adrift with one resulting in the toppling of two fixed jackets. Also, there were 16 reported pipeline failures resulting from these drifting MODUs dragging anchors or anchor chain over the pipelines (Ref. 5).

During the 2004 and 2005 hurricane seasons, three major hurricanes, Ivan, Katrina and Rita, entered the GoM and passed over areas with extensive oil and gas infrastructure. Such powerful storms, in this area of the GoM, over roughly a 12 month time frame were historically unprecedented. The damage caused from these three storms was extensive. There were 23 reported MODU mooring failures caused by the three hurricanes. A few of these were partial failures where the MODU broke several but not all the moorings and stayed more or less on station. However, in the vast majority of failures, the moorings completely failed setting the rigs adrift in the GoM.

In 2008, hurricanes Gustav and Ike entered the GoM. These were considerably weaker (winds) storms than Ivan, Katrina and Rita although Ike had a large radius with relatively high wave heights on the strong side of the storm. Nevertheless, 4 partial and 2 complete failures occurred even though most of these rigs had upgraded mooring systems.

Historically, most of the mooring line failures have been at or near the fairlead. In the context of protecting subsea infrastructure, such fairlead failure is desirable compared to dragging of chain or an anchor. In 2004-05 hurricane seasons, some the mooring lines broke well below the fairlead and above the anchor. This resulted in wire or chain dragging on the seafloor as the MODU drifted off location; the consequence in some cases was a “sawing” effect from the mooring line as the MODU passed over a pipeline or an umbilical (Ref. 6).

Some of the mooring failures in 2004-05 were caused by failure of the anchors. The majority of the failed anchors were drag embedment type anchors and in a few cases they were Vertically Loaded Anchors (VLA’s). In the cases where drag anchors failed, roughly half of the rigs dragged one or more of their anchors for at least a few thousand feet. However, in two cases the rig traveled much further: one traveled 1.5 miles and the other traveled 25 miles. For the VLAs, one rig held and the other reportedly dragged one VLA for 120 miles.

Fortunately, there were no moored MODU collisions with a production facility during the 2004-05 and 2008 hurricane seasons. However, the incidents of pipeline and umbilical damage (caused by the anchors, wire, or chain dragging) resulted in major interruptions to the oil and gas industry.

Present Design Rules

API RP2SK 3rd Edition (2SK) (Ref. 7) is the industry guideline for designing both mobile and permanent moorings in the GoM. For permanent moorings, API RP2SK recommends using the 100-year return period environment as the design condition. If the offshore installation design life is substantially less than 20 years, a shorter recurrence interval is allowed if it is supported by a risk assessment, i.e., taking into consideration the potential consequences of the mooring failure.

For mobile offshore drilling units operating away from other facilities, the return period of the design environment, pre-2005, was recommended to be 5 years. The API Recommended Practice (RP) also allowed for the return period to be reduced if a risk analysis is performed (but in no case could the return period be less than one year). In cases when a MODU is operating in the vicinity of other facilities, the return period of the design environment was recommended to be at least 10 years. Moorings designed using this criterion and 2SK safety factors can anticipate failure when exposed to hurricanes with wind and waves in the range of 50-100 years return period.

At the time when 2SK was originally developed, there were several reasons for the API committee to judge that the risk of a MODU mooring failure was low and hence to recommend a lower return period for MODU mooring design:

1. Until recently, few MODUs were operating in deepwater Gulf of Mexico.
2. MODU personnel are always evacuated prior to hurricanes.
3. Until recently, there were few deepwater facilities in the Gulf. Therefore, in the case of a MODU being adrift, the probability of damage to a deepwater facility or its wells and flowlines was judged to be low.
4. Most MODUs were operating in deepwater and, in the case of a MODU going adrift, the probability of the MODU traveling long distances to the shelf and causing damage to a fixed facility was judged to be low.
5. The early generation MODU fleet had limited mooring capabilities and this issue was taken into consideration in setting the mooring design criteria. In effect, at that time higher design criteria would have excluded most MODU’s from operating in the GoM.

There are two noteworthy changes in recent years that have completely changed the MODU mooring failure risk picture in the GoM. First, more moored MODUs have come into the fleet and are now operating in the deepwater GoM. Second, the infrastructure (floaters, subsea hardware, flowlines, and pipelines) in deepwater GoM where most of these MODUs operate has expanded significantly. Therefore, the higher probability of MODU mooring failures (due to the increase in rigs) coupled with an expanded deepwater infrastructure (i.e., increased consequences) has resulted in more mooring failure risk much different from a decade ago.

Another factor at work involved the industry's metocean design criteria for the GoM. In effect, the occurrence of three severe hurricanes (Ivan, Katrina and Rita) with very long predicted return periods in two years led to a reevaluation of the GoM MODU mooring design criteria and a major increase in the design environmental conditions, particularly in the central GoM (the region between longitude 87 and 90 degrees. (Ref. 8). Coincidentally, this is also an area of the GoM where there is extensive infrastructure.

Fortunately, the industry acted quickly on several fronts to reduce the risk. The MODU owners voluntarily elected to upgrade the vast majority of the moored MODU fleet operating in the Gulf. This meant that the typical 8 and 9-line mooring line configurations were increased to 12-lines. Additionally, the API committee worked to develop improved design criteria and MODU mooring guidelines for the industry (Refs. 1, 2 and 8). Numerous companies supported a Joint Industry Project (MODU JIP), managed by ABS Consulting, investigating Moored MODU Strength and Reliability Issues. All of these efforts moved the industry forward in achieving the objective of reducing the risk of damage due to MODU mooring failure.

Approach to Assessing Moored MODU Risk

The new edition of 2SK recommends risk assessments as a means of assessing a mooring system design and thus this approach can be adopted to evaluate well sites to be drilled during the hurricane season. 2SK Appendix K prescribes a process whereby one considers the characteristics of the area near the rig location, identifies options related to mooring component selection, mooring system design, and mitigation opportunities prior to finalizing the mooring design and installing the mooring system. For the planned MODU operation, the mooring system should be associated with acceptable risk parameters, by minimizing potential consequences of mooring component failure and / or by reducing the probability of mooring component failure.

Risk is defined as:

Risk = [Probability of an adverse event occurring] x [The consequences associated with that event]

The risk can be reduced either by reducing the probability of experiencing an incident, i.e., prevention, or by reducing the consequences of that incident should it occur, i.e., mitigation.

A QRA is a way of assessing the risk. Although the probabilities calculated by the QRA methodology are notional and have an associated uncertainty band, the approach allows the risks of different mooring options and/or different well locations to be compared using a consistent and documented process. For example, the process can be used to evaluate the risks and merits of the following options:

1. Use of a polyester mooring system versus the rig's conventional steel catenary system.
2. Upgrading the rig from an 8-line to a 12-line mooring system.
3. Conducting the drilling operations during different times of the year, e.g., the peak months of August, September and October versus off peak months.
4. Use of suction piles or Suction Embedded Plate Anchors (SEPLAs) versus drag anchors when pipelines flowlines and subsea infrastructure are of concern.

Although the QRA approach allows an operator to manage the risk of its own (leased) moored MODUs during the hurricane season, there can be substantial residual risk to an operators's infrastructure resulting from MODUs that are operated by other companies. Thus, operators will likely be interested in quantifying and evaluating such residual risk Accordingly, an extension of the QRA methodology and the development of applicable software tools is a natural outcome.

Overview of Risk Assessment Process and Event Tree Approach

The Quantitative Risk Assessment (QRA) approach first evaluates the two dimensions of risk (i.e., probability and consequence) separately and then evaluates the risk itself via the use of a conventional risk matrix that has probability and consequence as its two dimensions. Depending on the probability and consequence, a given risk can be categorized as low, medium or high. The consequences can be categorized by potential impact (e.g. health/safety, environmental, company and industry reputation, financial, etc.). In this process, the consequence categories are addressed separately.

As described below, there are four major steps in performing a QRA for a moored MODU:

1. Data gathering
2. Hazard Identification (HAZID)
3. Mooring Assessment and Reliability Analysis
4. Probabilistic Calculation (e.g., via an Event Tree Analysis) and Risk Assessment

<u>Data Gathering and Review</u> – This involves collecting all the information required for performing the mooring analysis and the risk assessment: well location, seafloor bathymetry, location, type and throughput of floating facilities and/or subsurface infrastructure within a certain distance from the well, metocean conditions, mooring configuration,

<u>Hazard Identification</u> – A HAZID workshop may be held using various experts representing several disciplines who are involved in the proposed operations (mooring, subsea, drilling, risk engineering, etc.). The primary objective of the HAZID workshop is to identify and define the potential mooring failure scenarios and the potential consequences of each scenario. This information is then used to develop event trees of the individual scenarios.

Another objective of a HAZID is to ask the participants to estimate certain probabilities based on their collective experience and judgment. For example, since it is not possible to analytically calculate the probabilities of operational failures, such probabilities can be estimated by experts in a HAZID workshop. The objective in this case is to estimate the order of magnitude likelihood of a given event. If possible, a given failure or event can be broken down into sub-events to obtain a better estimate of its likelihood of occurrence.

Mooring Assessment and Reliability Analysis – A deterministic analysis of the proposed mooring configuration is performed to determine its resistance with respect to site-specific mooring conditions. In almost all cases, the mooring resistance is dependent on the direction of the winds and waves. In the reliability assessment, it is assumed that failure of the most heavily loaded line during the hurricane will lead to progressive failure of the mooring system and loss of station keeping. This assumption is supported by historical experience during the 2004 and 2005 hurricane seasons. Thus only complete mooring failure is assumed for hurricanes.

The probability of failure for the most heavily loaded line, Pf, can be written as:

$$P_f = \int F_R(R < s \mid S = s)\, f_S(s)\, ds \qquad (1)$$

Where R is the resistance of the line, S is the wind, current, and wind induced loads on the line, $F_R(.)$ denotes the conditional cumulative density function of R and $f_S(.)$ denotes the probability density function of loads.

In performing a reliability analysis in hurricanes, one typically needs to model the joint probability distribution of winds, waves, and currents. However, hurricane wind induced loads are dominant in design of MODU moorings. In addition, wave and current induced loads during a hurricane are highly correlated with wind loads. Therefore, the hurricane event can be simply modeled in terms of its wind probability distribution. The line tension T can then be assumed proportional to wind speed (V_w) to an exponent (α) as follows:

$$T \propto V_w^{\alpha} \qquad (2)$$

The line tension, T, is then related to the Factor of Safety (FOS) by the following equation:

$$FOS = R / T \qquad (3)$$

Combining the above two equations, the following expression results:

$$1 / FOS \propto V_w^{\alpha} \qquad (4)$$

From the mooring analysis, the exponent α can be calculated. This exponent is a measure of mooring line tension sensitivity with respect to increase in the environmental loads.

Equation 1 can be solved numerically using First Order Reliability Methods and Second Order Reliability Methods (FORM/SORM) techniques. In this case, the probability distribution of hurricane wind loads has a much higher uncertainty compared to the resistance of a line and therefore further simplifications can be made to solve the probability in Eq. 1. Following the method developed by Cornell (Ref. 9), the probability of failure can be estimated as:

$$P_f = F(V_{w,fail}).\exp(0.5 k_1^2 \sigma_{LnR}^2) \qquad (5)$$

Where

$F(.)$	is the Complementary Cumulative Distribution Function of the wind speed
$V_{w,fail}$	is the wind speed that results in a safety factor of 1 for the most heavily loaded line
k_1	is an inverse measure of the variability of the wind speed distribution
σ	is the coefficient of variation of the logarithm of resistance (R); assuming a lognormal distribution for R, σ is the same as the coefficient of variation of R.

Using the GoM seasonal metocean statistics, the annual failure probability results are further divided into pre-peak season (beginning of June to mid-August), peak season (mid-August to mid-October) and post-peak season (mid-October to end of November). From historical hurricane data, the probability of getting a strong storm that would cause mooring failure is approximately 10 times higher in the peak season versus the off-peak season. This allows evaluating the risk associated with operating in different months of the hurricane season.

<u>Event Tree Analysis and Risk Assessment</u> – The risk assessment focuses on the in-place risks associated with the MODU mooring system and not on installation risks. The in-place risks represent two cases; 1) operating, and 2) evacuated. The two cases are treated differently because there will be different responses and safeguards in place. The evacuated case is usually of most concern as it represents a situation where the vessel is exposed to extreme environmental conditions and thus the potential for failure escalation (i.e., complete mooring system failure) is much greater than for the operating case.

Assuming that a sequence of events would be initiated by the failure of one or more mooring lines, the event tree is a convenient method for systematic evaluation of all the possible failure sequences and identification of their respective consequences. An example event tree for the mooring failure during an evacuation is shown in Figure 1. In Figure 1, the probability of mooring failure during a hurricane (i.e., the initiating event) is estimated from the reliability procedure described above. As shown in Figure 1, typical questions that are then asked and appear at the top of the event tree may be as follows:

1. What is the likelihood that one or more lines fail at the bottom? The likelihood of damage to subsea infrastructure depends on whether a line chain or a line anchor is dragged over the flowlines and equipment, otherwise mooring failure at the fairlead does not pose a threat to subsea infrastructure.
2. What is the likelihood that the MODU would drag its lines or anchors for a given distance and damage flowlines or subsea infrastructure?
3. What is the probability of collision with a nearby facility?

In order to estimate the probabilities asked in the questions above, the experiences from the recent MODU mooring failures (Ref. 10) gathered as part of the MODU JIP are used. The JIP collected MODU failure data from the 2004-05 hurricane seasons and general statistics for each type of failure and the approximate drift distances were developed based on this data. The probability of a given event sequence in Figure 1 is then the product of all the event probabilities in that sequence.

Results from the event tree quantify the likelihood and consequence of each sequence of event. These results can then be compared to a company's corporate guidelines. As for the consequence, the cost of production downtime is also included. As part of this task, the entire set of assumptions and the process is documented for future reference. If better information becomes available, it can be incorporated in the future risk assessments and hence this becomes an evolving process which improves the quality of the results.

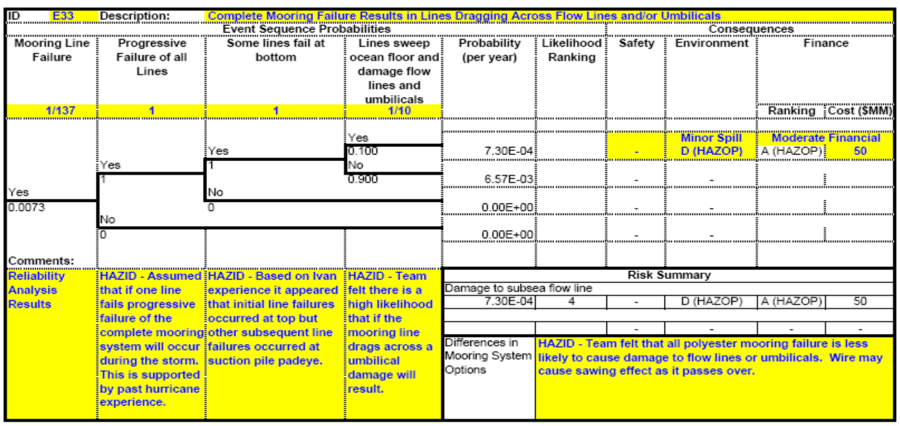


Figure 1. Example Event Tree.

QRA Example Site Location

Consider a moored MODU in a Mississippi Canyon location, and assume a desire to drill during most of the hurricane season. A detailed QRA assessment for the proposed drilling location can be performed to determine that the MODU mooring system design is consistent with applicable corporate guidelines.

Location – There is no subsea infrastructure inside the MODU's mooring pattern. Flowlines and umbilicals tying two fields back to a nearby truss spar, which is approximately 5 miles South-Southeast of the drilling location, are within a mooring diameter of the proposed drilling site. The truss spar's export lines are also within one mooring diameter. Other flowlines and umbilicals extend in most of the Northeast quadrant. About 15 nautical miles East and West are two other facilities. Figure 2 shows the infrastructure within approximately 15 nm.

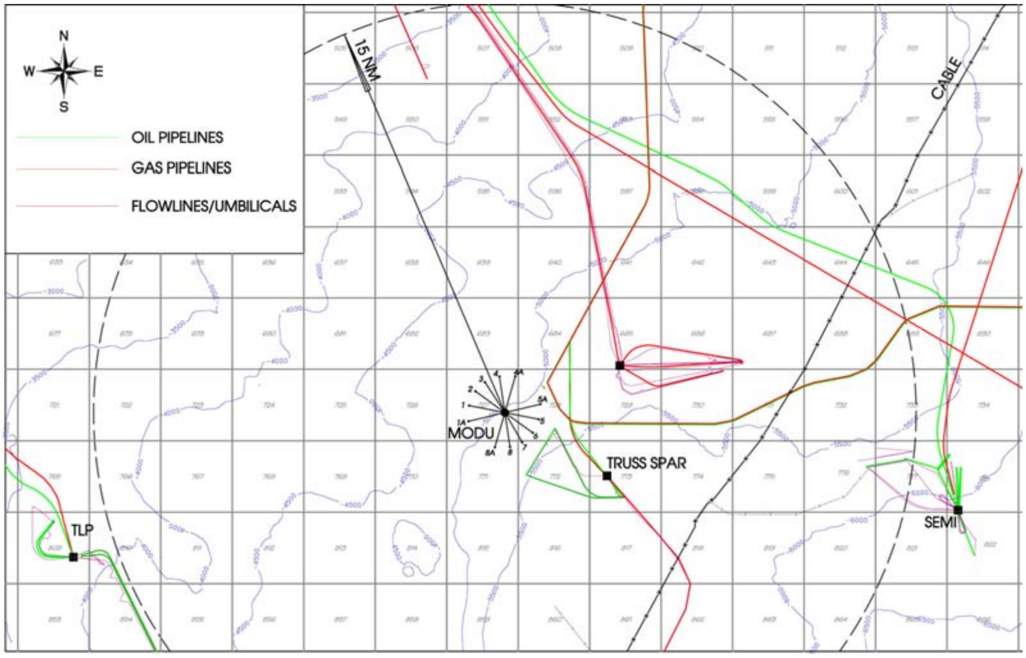


Figure 2. Infrastructure around example location.

Mooring Analysis – This location falls within the Central Region as defined in API 2INT-MET (Ref. 8). The mooring analysis uses site specific metocean criteria from a nearby block . This study compares the following 12-point mooring systems:

- Steel mooring line with drag anchors
- Polyester taut mooring line with suction piles

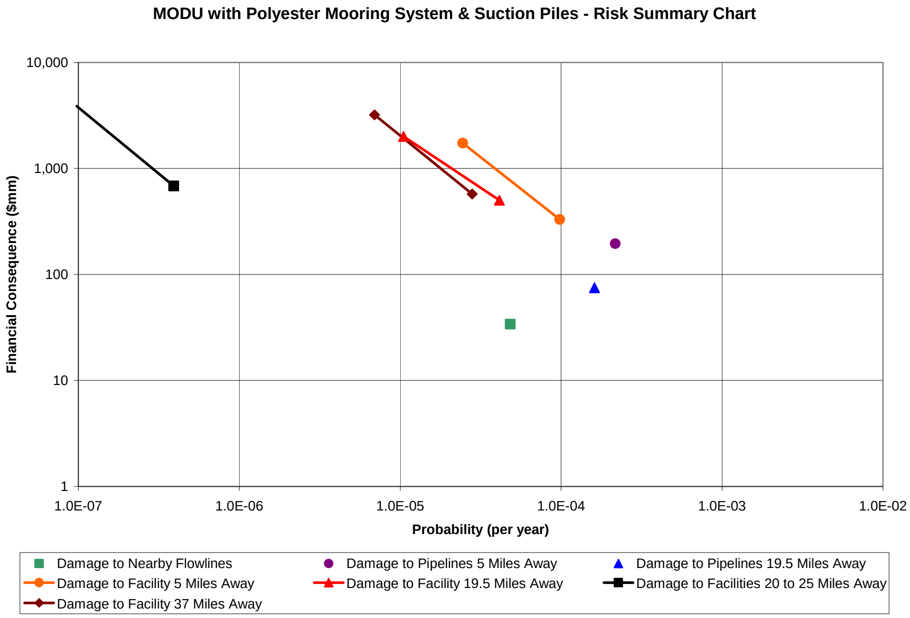
The performance of the polyester mooring system produced an intact return period of 23-years at an API Factor of Safety of 1.67 and damaged return period of 22-years at an API Factor of Safety of 1.25. At an intact factor of safety of 1.2 (a approximate limit state check), the polyester system achieves a 107-year return. The performance of the all steel mooring system (rig based) is similar to the polyester producing an intact return period of 31-years at an API Factor of Safety of 1.67 and damaged return period of 29-years at an API Factor of Safety of 1.25. At an intact factor of safety of 1.2, the steel system achieves a 105-year return.

Risk Assessment - The objective is to determine the risk to nearby deepwater facilities, flowlines, and export pipelines. The risk assessment is focused on the in-place risks associated with the MODU mooring system, not including the installation risks. Events identified in the HAZID once complete mooring system failure occurs include:

1. Damage to floating production systems (collision or interaction)
2. Mooring line / anchor damages to export pipelines
3. Mooring line / anchor damages to trees, flowlines or umbilicals

For the events listed, an annual probability and cost to repair the damage resulting from such an event can be estimated. The risk results are then compared.

The results indicate that the steel system has a higher risk compared to the polyester system because of the mooring line / anchor related events. Hence the steel mooring system may be rejected as an option. The annual probability of the events and their estimated consequence for the polyester mooring system are graphically shown in Figure 3. Events that control the risk are collision or interaction with nearby floating facilities. The highest probability event for the polyester system is calculated to be approximately 10^{-4}.



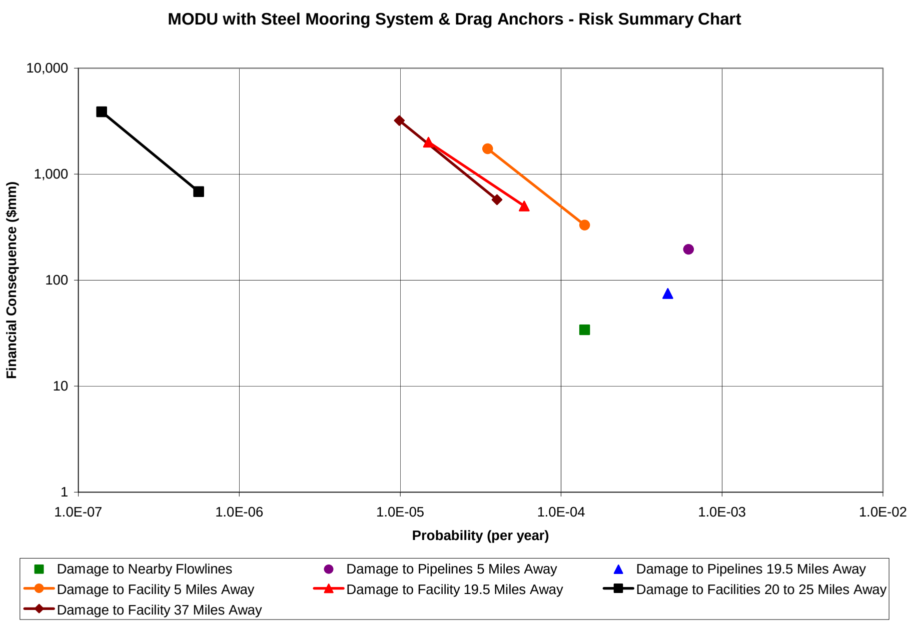


Figure 3. Risk results displayed on diagram for polyester and steel mooring system.

Risk Reduction Measures **-** Several alternatives to reduce the risk can then be explored. For example, using polyester mooring systems with suction piles:

- Eliminate the possibility of dragging an anchor
- Greatly reduce the risk of seafloor infrastructure damage because polyester does not have the sawing effect of steel chain

- Lower the probability of line failure compared to steel chain-wire.

Also, from an analytical point of view, accounting for MODU drift directionality reduces the calculated probabilities because:

- The closest facility is in the less probable Southeast drift direction.
- Facilities in a more likely drift direction are further away

Therefore the QRA allows the risk to be systematically assessed and the results used to make informed decisions. Such results, with proper documention, are also required as part of the APD submittal to the MMS.

Risk Posed by Moored Rigs in the GoM

Assume your company operates multiple major deepwater facilities in the GoM and exports the oil and gas from these facilities via pipelines to shore. MODUs operated by others close to your facilities present residual risk. In order to better understand this residual risk, a study may be performed by extending the risk assessment methodology described in the previous sections to all of the rigs operating in the GoM.

Figure 4 shows seven typical deepwater facilities in the GoM and the associated pipelines which carry the oil and gas from these facilities to shore. Also shown in Figure 4 are the path of Katrina and the locations of the 21 moored rigs operating in the GoM during Katrina (The number of moored rigs in the GoM has been relatively stable and has stayed around 20 since Katrina).

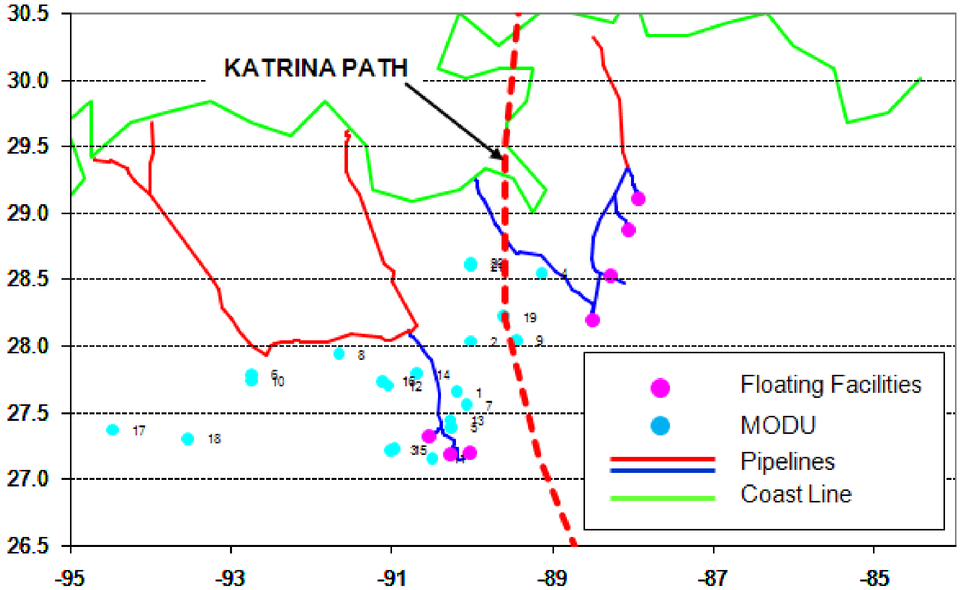


Figure 4. Snapshot of Moored Rigs Operating in GoM during Katrina Around Some Typical Infrastructure.

As Figure 4 shows, some of the 21 rigs are operating relatively close to the deepwater facilities or pipelines. It is noteworthy that this situation has been more scrutinized and is changing due to the new API guidelines and the MMS regulations regarding the operations of moored rigs during the hurricane season, in particular during the peak of hurricane season. Although the snapshot of rigs in Figure 4 is not representative of the risk that may exist today, it is still worthwhile to study this snapshot to better understand the risk posed by the fleet of moored rigs in the GoM.

The probability of damage caused to a facility by any of the rigs operating in the GoM is the Boolean union (OR) of damage due to all of the rigs. In order to determine the collective probability of damage to one facility from several moored rigs, one has to account for correlations amongst the potential damages caused by the rigs. If one considers the risk of damage due to two different rigs, there is a degree of correlation between the two events because they are caused by the same hurricane entering the GoM. If all of the uncertainty in damage is due to the environmental conditions caused by the hurricane, then the correlation coefficient is 1.0. However, the correlation coefficient is lower than 1.0 since uncertainties in the independent resistances of the two mooring systems and directionality also contribute to the probability of damage. For a given hurricane entering the GoM, simulations show that there is a moderate degree of correlation (in the range of 0.6-0.7) between any of the two damage events. In this study, a correlation coefficient of 0.65, along with second order bounds proposed by Ditlevsen (Ref. 11), can be used to calculate the probability of damage to a given facility from all the rigs operating in the GoM.

A detailed evaluation can be performed to determine the mooring resistance for each of the rigs operating in the GoM. For example, during Katrina, all of these rigs operated with either 8 or 9 lines. However, most were later upgraded to 12 lines (if an upgrade was feasible).

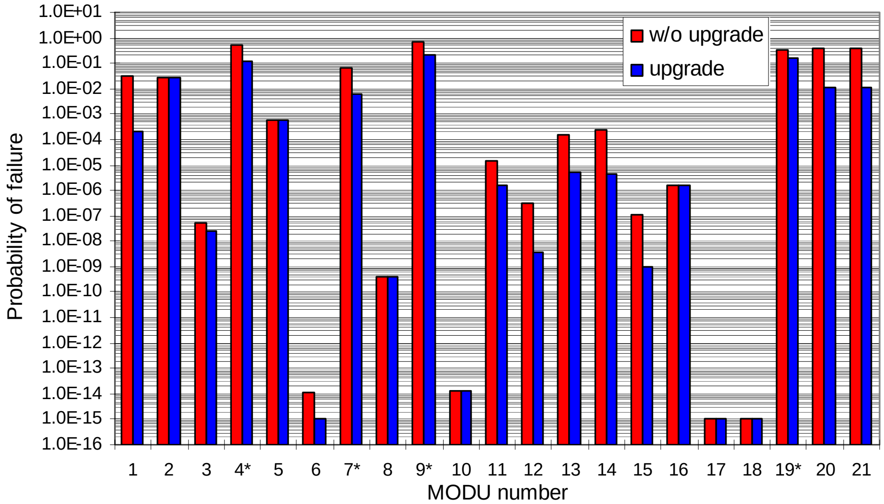


Figure 5. Probability of Failure during Katrina with and without Upgrade
(MODU's adrift are indicated by an asterisk)

Comment [BU1]: This chart quickly points out which rigs you want to be using or to be present near a facility. Need to think about what we are trying to accomplish with this paragraph.

Figure 5 shows the conditional probability of station keeping failure for the 21 rigs during Katrina assuming both 8/9-line and 12-line, upgraded mooring systems. The rigs that actually lost their station keeping are indicated by an asterisk next to their number along the x-axis. In Figure 5, the rigs that could not be upgraded have the same probability of station keeping failure for the upgrade and without upgrade case. Rigs 20 and 21 in Figure 5 are DP MODUs which were moored in shallow water undergoing repairs and hence should not be considered representatives of deepwater MODUs. Excluding these two rigs, all of the rigs with calculated probabilities of failure in the range of 0.1 or greater lost their station keeping. It is also interesting to note that, in most cases, there is approximately an order of magnitude reduction in the probability of failure due to the mooring upgrade from 8/9 to 12 lines.

The Katrina results in Figure 5 can be extended to determine the risk to a given deepwater facility and the pipelines at issue. Evaluation of the results reveal that major contribution to the risks were invariably due to rigs operating at close distances to production facilities. Assuming an upgrade to 12 lines, the residual risk for the same set of conditions does improve by approximately an order of magnitude. A similar exercise was also performed for the snapshot of rigs operating during hurricane Rita with similar results and conclusions.

An analysis of the risk of damage to pipelines results in the same conclusions as the risk to deepwater facilities. In effect, while upgrading the rigs to 12 lines reduces the risk, a more significant risk reduction measure is to increase the distance from the rig location to the operating pipeline (or choice of anchor type used as presented in the above site example). In the case of pipelines, keeping the moored rigs at a relatively large distance is even more important since a pipeline represents a large target for any dragging lines of a drifting MODU.

Prior to 2004-05 hurricane seasons, it was common to operate MODUs within a mooring radius of deepwater facilities or pipelines. Sensitivity analyses performed herein shows increasing such distance from one mooring radius to 15 miles would reduce the probability of collision with a facility or damage to a pipeline by roughly an order of magnitude. Hence a minimum operating distance of 15 miles has a similar risk reduction effect as upgrading the mooring systems from 8 lines to 12 lines.

Another risk reduction measure is to avoid operating moored rigs close to deepwater facilities or infrastructure during the peak of the hurricane season. Sensitivity studies were carried out where the risk to the deepwater facilities was recalculated assuming that the GoM moored rigs were not present during September. The results showed that, eliminating the risk during September, the probability of collision with a deepwater facility or damage to a pipeline can be reduced by a factor of 5-10.

In short, a Gulf wide study of these 7 deepwater facilities and pipelines performed concludes the following:

- The risk posed by moored rigs during the hurricane season is primarily controlled by their distance to deepwater facilities or pipelines. A distance of 15 miles to a deepwater facility or a pipeline can reduce the likelihoods of collision or damage by an order of magnitude relative to rigs that are at a mooring radius of the facility or pipeline.
- Recent upgrading of mooring systems from 8/9 to 12 lines has reduced the probabilities (of collision or infrastructure damage) by roughly an order of magnitude. However, the risk can still be relatively high due to proximity of a rig to a deepwater facility or a pipeline.
- There is a small to moderate increase in the probability of damage to a facility or a pipeline due to the cumulative effect of roughly 20 rigs operating in the GoM.
- An effective risk reduction measure is to avoid operating moored rigs close to deepwater facilities or pipelines during the peak of the hurricane season. It is shown that avoiding the month of September has the effect of reducing the probabilities (of collision or infrastructure damage) by a factor of 5-10.

Conclusions

The basic methodology to perform a Quanatative Risk Assessment on a moored MODU is outlined. Such a method can be readily implemented to perform similar assessments as required by API RP 2SK and the MMS NTL. An example is presented to illustrate the process. The QRA process was also extended to examine the risk of the moored MODU fleet to a sample of facilities and infrastructure in the GoM. The results shed light on the benefits of the upgrades the MODU owners have made to their mooring systems, the effect of MODU distance to a facility or a pipeline, and on the seasonal variation of risks.

Acknowledgement

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