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Improving mooring reliability through risk-based monitoring and inspection

Marine technology is advancing rapidly to improve simulations, monitoring, weather forecasting, inspections and digitalization needed for safer mooring systems.

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Chain corrosion and fatigue are the primary causes of offshore mooring incidents, events that can cause costly line failures, pre-emptive replacements, downtime and severe degradation of asset security, according to a recent survey.

West Africa (where corrosion was the primary cause) and North Sea (fatigue) were the most common locations, suggesting site environments strongly influence the probability of failed mooring systems, often with expensive consequences (Figure 1). FPSO units were responsible for the majority (73%) of incidents covered in the analysis. In 2019 there were 225 FPSOs either in service (182), available (20) or on order (23) worldwide.

With the number of floating production installations on the rise, modern monitoring and inspection strategies are taking a key role in assuring dependable operations and worker safety. Most of the initiatives start with design assessments.

Assessing the design of a mooring system

The most effective way to assess the design of any mooring system is to verify the acceptance criteria for mooring loads in terms of strength and fatigue.

During the service life of the mooring system, demand for reassessments could be triggered by change of environmental conditions (relocation, etc.), life extension, detection of mooring system degradation or an anomaly, and/or other factors that could affect the safety of the system.

In general, the methodologies used to assess designs are well established, with industry guidelines and classification rules routinely applied by owners and operators. However, major challenges continue to arise from uncertainties associated with environmental conditions, advanced corrosion of mooring systems, shifts in operational conditions and transient responses that are difficult to detect at the design stage.

Environmental conditions at the FPSO site

The major environmental loads for mooring systems are caused by wind, waves and currents. In most cases, mooring line fatigue is caused by the impact of waves, which are cyclical and dynamic nature.

The severity of the wave environment can be measured by assessing the maximum wave heights over a specific period against the strength of the mooring line and wave energy where the line's fatigue load would be highest. These

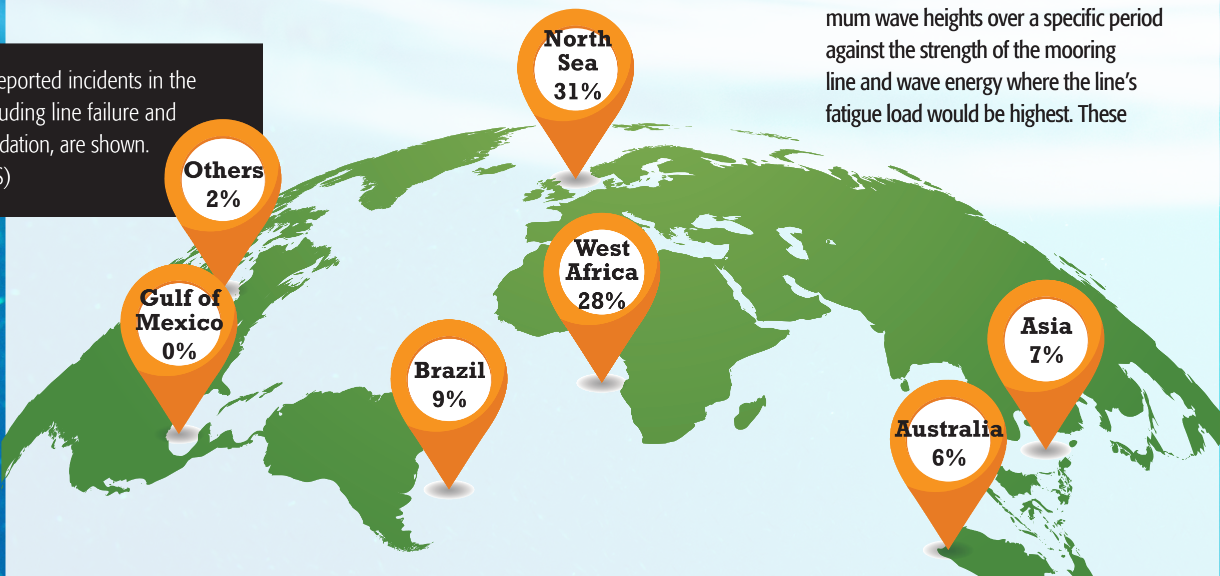

FIGURE 1. Reported incidents in the analysis, including line failure and severe degradation, are shown. (Source: ABS)

conditions are site-specific, even within recognized regions.

The wave environment in West Africa, for example, is comparatively benign. However, FPSOs in the region are prone to squalls that are characterized by sudden rapid increases in wind speed and shifts in wind direction.

For turret-moored FPSOs located in this region, it is especially important to simulate a time-domain analysis because sudden changes in wind direction could result in higher loads.

Mooring chain corrosion reduces the load-bearing area and increases levels of stress while changing its distribution. Levels of corrosion are mainly determined by water temperature, dissolved oxygen, velocity of the water particles, wet/dry cycles and nutrient concentrations, mainly dissolved nitrogen.

Corrosion rates, therefore, can vary at different locations on the mooring line, including at splash zones, middle sections, thrash zones and on the ground line, where segments are subjected to different temperatures, dissolved oxygen and nutrients.

Recent studies on the corrosion of mooring chains suggest dissolved inorganic nitrogen (DIN) is a critical water-quality measurement in assessing the potential for underwater corrosion. DIN mainly comes from nitrates, and its presence varies greatly across geographical locations and water depths.

In general, the solubility of nutrients decreases in deeper water, and the rate of their chemical reactions increases when water temperatures rise. Also, any discharge from local rivers can significantly affect the DIN levels.

The high level of nitrate discharge and other pollution in West Africa and Southeast Asia, together with the higher water temperatures, contributes to comparatively higher corrosion levels in these locations.

The major dynamic loads caused by any environment on an FPSO are transmitted to mooring lines through motions, offsets and accelerations. In general, ship-shaped FPSOs are subject to higher wave loads than other floating units due to their large water surface area.

FPSOs are also very sensitive to the directionality of environmental conditions. If the main environmental load is in the FPSO's beam direction, for example, the mooring system could potentially experience a very high level of stress.

Mooring systems are normally configured to ensure that the dominant direction of the environmental load is as close as practicable to the FPSO's longitudinal direction, namely, in its bow or stern directions, to minimize the environmental load.

Mooring strength and fatigue assessments are carried out, in general, by investigating the global performance of moored FPSOs to obtain maximum mooring line tension and produce a line-tension histogram, an approximate representation of the load distribution data.

Allowable line tension and accumulated fatigue loads are evaluated by calculating minimum breaking strength for the mooring line, fatigue capacity, corrosion allowance and safety factors such as a ratio of mooring line strength capacity to mooring line load.

For mooring chains that are designed with corrosion allowance, their minimum breaking strength is determined by removing the full corrosion allowance. For the fatigue strength assessment, half of the corrosion allowance associated with the design life can be used.

Unfortunately, compared with other marine assets, FPSOs have less historical data to analyze. Although there has been a significant increase in the asset class since 2000, the first FPSO installation was in 1985.

Aside from those associated with corrosion and fatigue, other challenges for current FPSO moorings include increased exposure to harsher environments, increased water depths and many are nearing the end of their service lives.

Digital models have the potential to help owners reduce uncertainties and **increase the integrity** of mooring systems.

Design development and innovation

On the positive side, the offshore industry has advanced in areas of monitoring, inspection and digitalization, which may serve to improve the reliability of mooring systems.

With increased computation power, performance simulations of mooring systems are commonly found tools that support the assessment of designs, particularly by increasing the transparency of forces from transient loads. Among other benefits, this provides better load histories for the fatigue assessments.

Real-time simulation models, or digital twins, incorporate information for real-time monitoring and/or assessments that allow vessel locations, headings and mooring line tensions to be incorporated in the system-fatigue analysis.

Technologies that can identify the failure of mooring lines by monitoring a vessel's offsets are also in development. An algorithm has been developed to predict excessively heavy loads for mooring systems based on historical experience, potentially identifying the probability of failure.

Digitalization

Digital models that include information on elements, such as the design of the mooring system, periodical inspections, operation performance and environmental conditions, have the potential to help owners reduce uncertainties and increase the integrity of the mooring systems. Monitoring and inspection strategies can be validated and improved by using data management systems to store, analyze, interrogate and identify trends. +

Acknowledgment:

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