GLOBAL BENEFITS AND OPERATIONAL CHALLENGES OF VESSEL RELOCATION

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ABSTRACT

Movement of moored floating production vessels, such as Spars, Semi-submersibles, Deep Draft Floaters and Floating Production Units, due to environmental loading is often considered a design challenge to be addressed during the design phase of a structure. Proactive vessel relocation through mooring line adjustment can be integrated as part of an operational method to improve and extend component lives. This method may be implemented during the initially planned life of the structure to overcome riser fatigue life challenges, or as one of the methods to extend service life. The benefits are particularly noteworthy for steel catenary risers and mooring systems and have been discussed in previous works. However, vessels often deviate from the original relocation plan in practice. This paper assesses the benefits of a vessel relocation program with conscientious focus on the associated operational challenges. Risks associated with vessel relocation are also investigated. Suggestions are made to optimize such a program and to minimize interruption to production.

INTRODUCTION

In the Gulf of Mexico (GoM), moored floating production vessels such as spars, semi-submersibles, deep draft floaters and floating production units are used to support tieback risers and withstand severe weather conditions such as hurricanes and strong loop currents.

Since the first steel catenary risers (SCR) were installed on the Auger TLP for export pipelines in the mid 1990’s, they have become a cost effective replacement for tensioned risers [1]. SCR design is often limited by achievable fatigue life at the hang-off and the touchdown zone. Hang-off fatigue can be partially addressed through more robust design of the top assembly and positioning of initial welds [2], but there are currently no effective operational methods to alleviate fatigue damage concentration at the top of the riser.

Fatigue in the touchdown zone (TDZ) arises from wave frequency, low frequency vessel motions (both from natural vessel drift and from hull vortex induced motion), and SCR vortex induced vibrations. There are a number of design options to increase fatigue life in the touchdown zone which are discussed in previous works [2] and [3], namely:

- The lazy wave riser configuration uses buoyancy near the riser TDZ to isolate the vessel motions from fatigue loading the TDZ.
- Increasing the riser departure angle can reduce the stress range in the TDZ; however caution needs to be practiced since this increases load at the hang-off connection.
- Significant fatigue life increase can be achieved by utilizing higher quality welds through pipe end machining and matching to reduce the stress concentration at the weld.
- The use of upset ends or titanium welding connections.

While sometimes effective, these design alternatives may not always provide the magnitude of improved fatigue life within the TDZ resulting in an acceptable design for a 25 year field life. In certain cases, it may be more appropriate to utilize an operational method to meet the riser design fatigue life requirements. Some common practices include operating at different drafts during production and extreme weather event
(which may achieve up to 50% load reduction according to [3]) and performing periodic planned vessel relocations.

The mooring system, while playing an important role during the design phase of the project, is often neglected once the facility is put into operation. It has been pointed out in previous studies that a number of mooring failures have occurred since 2000, many of which are attributed to lack of maintenance. The major causes of failure are wear and abrasion at the fair lead, corrosion of wire rope and chains (particularly at the splashzone), and out-of-plane bending of chains [4]. Periodic inspection, monitoring and maintenance of the mooring system can help extend the service life of the mooring components, thus reduce the frequency for component replacements. Active vessel relocation, in addition to benefiting riser TDZ fatigue life, is also proposed as a method to manage long term mooring integrity.

The global benefits of vessel relocation for the mooring and riser systems are briefly discussed within this work. Unfortunately, in practice, platforms often deviate from the designed vessel relocation plan during operation. This paper focuses on identifying the key risks and operational challenges of implementing vessel relocation and suggests solutions to balance the risks and benefits to ensure the success of a vessel relocation program.

**BENEFITS OF VESSEL RELOCATION**

Implementation of a vessel relocation program can help extend the riser and mooring service lives in both design and life extension cases.

**Fatigue and Wear Hotspot Dispersion**

The SCR fatigue benefits of vessel relocation are commonly understood and widely accepted. Even passive fatigue spreading in the TDZ due to normal vessel motions in wave fatigue analysis is accepted to meet design criteria. Active production vessel relocation is performed by adjusting the mooring line payouts to move the vessel from the design nominal position, or “neutral” position, to different stations throughout its service life. This effectively changes the SCR touchdown point, moving it along the length of the riser, thus the fatigue damage from the touchdown bending is dispersed along a greater length of the riser. For example, a 30m (100ft) in-plane displacement of the vessel in 1500m (5000ft) water depth can result in a 60m (200ft) shift in the TDP as represented in Figure 1. Relocating the vessel to two positions in addition to the Neutral Position can significantly spread the peak damage. Figure 2 demonstrates the spreading of a typical SCR TDZ peak fatigue due to wave loading. In this scenario, a 10-foot shift in the TDP is simulated in the far and near directions. It is assumed that the vessel spends equal time at all three positions. The fatigue damage with vessel relocation is approximated by averaging the independent TDZ fatigue for the three positions along the length of the SCR. The fatigue damage is normalized to the peak TDP fatigue without vessel relocation. It is considered prudent to return to the Neutral Position during the onset of a hurricane, which is discussed further in later sections.

It is recognized that relocating the vessel in the far direction increases the tension along the riser and particularly at the hang-off location. However, since bending is the primary contributor to fatigue damage, the increased tension does not drive the overall fatigue life of the riser system. These concerns would be addressed through additional fatigue analysis during the design stage of the vessel relocation program.
larger number of chain links or a greater length of the wire rope as shown in Figure 3. Fatigue in the touchdown point (i.e. mudline) transitions of the mooring legs also benefit from the periodic relocations. Furthermore, the payout adjustments allow for inspection and maintenance of components that may be previously inaccessible and ensure the onboard mooring handling equipment remains in functional condition [4].

**Figure 3 - EFFECT OF VESSEL RELOCATION ON MOORING FAIRLEAD WEAR POINT**

**Life Extension – Building Your Case**

With detailed planning, routine maintenance, condition monitoring and accurate record-keeping, vessel relocation may be a feasible option in extending the service life of a production facility. By vetting a well-executed relocation program and appropriate records, the evidence would be helpful in obtaining a life extension permit from the governing authorities. When assessing life extension of a field, operators sometimes face the decision of riser replacement if engineering shows the riser condition cannot meet the life extension target. Riser replacement, particularly export risers, is a costly operation. Not only does the cost include the design and fabrication of the riser itself, removal of the old riser and installation of the replacement riser requires support vessels and extended production shut-in up to one month. In this case, demonstrating that adopting a vessel relocation program can extend the original riser fatigue life can be more cost effective than the alternative of riser replacement.

Extending the service life of the mooring system delays or eliminates costly mooring component change-out and upgrade operations along with associated shut-ins. When the intended service life of a mooring system approaches the end, change-out operations must be considered if the field will continue to be produced beyond the originally selected service-life. These operations require the planning and purchasing of new components, installation aids and rigging, as well as chartering of vessel(s) to perform this work. The vessel(s) used at the time of installation for the original system may once again be necessary for disconnect and change-out of the system. During the change-out, which could take anywhere from a few days to several weeks, it may be prudent to shut-in drilling and production activities due to associated station keeping risks involved. This costly overhaul and subsequent production down time may be eliminated or at least delayed if good record-keeping and a thorough plan is in place to substantiate a proposed life extension.

**RISKS WITH VESSEL RELOCATION**

While the benefits of vessel movement are well understood in the industry and the method is adopted by multiple operators for its various applications, there are inherent risks associated with relocating the vessel from its designed nominal position. These risks require full understanding and thorough assessment prior to and during implementation.

**Effects of Severe Weather Events at Offset Locations**

When designing a production vessel and the riser, mooring and umbilical systems deployed from it, a nominal vessel position or “neutral” position is designated. Normal practice is to position the platform at this neutral position, so that it has the highest likelihood of surviving an extreme environmental event for which the system is designed. This position, along with the associated mooring payouts, pre-tensions, and riser configurations are typically the optimal arrangement which yields the greatest safety factors for the system. Intentionally offsetting from the neutral position may slightly reduce the effective safety factor should a storm hit while the structure is in an offset position since in some locations the riser and mooring tensions will be higher than in the “neutral” position.

Additional riser and mooring analyses may be required to verify the impact of additional offsets from the designed neutral position. The extra offset changes the configuration of riser, mooring, and umbilical hanging off from the platform, and may cause riser or mooring overstress and clashing concerns during extreme weather conditions such as tropical storms and hurricanes. Strength, fatigue, and clashing (i.e. interference) analyses may be performed using measured environmental data to assess the condition of the components. If determined that the vessel is limited to a “safe radius” from the neutral position during severe weather events, it may be necessary to plan for relocations only during non-hurricane seasons. Alternatively, plans need to be in place to return the vessel to within the safe radius when a hurricane is predicted to pass through the region. Special procedures to handle platform abandonment during hurricane events with vessel relocation may also be required.

Careful response planning is necessary to react to sudden hurricanes, which may develop quickly, leaving no time for the
vessel to return to its safe location before experiencing the extreme storm conditions.

**OPERATIONAL CHALLENGES TO IMPLEMENTATION**

Despite extensive assessment performed by the design team to ensure system integrity during vessel relocation, it is found that field implementation of vessel relocations often deviates from the plan due to the following factors.

**End User Perception of Benefits vs. Risks**

Due to the previously described risks of vessel relocation, the operations team may consider the risks to outweigh the benefits in certain situations. A potential factor leading to such perception is inadequate knowledge transfer during the project handover from the design team to the operations team. Projects are often handed over through the delivery of a final documentation package that encompasses all relevant reports including design analyses and specifications, fabrication records, and finally specific operational procedures built into the design. The immense information load makes it nearly impossible for the operations team to fully digest and implement during the race to achieve first oil. Those who work on the operations side may not come away from a reading of the documentation with the same ideas as the authors intended. Because of the many other demands on the operations personnel, each may only be able to focus on the documents relevant to their responsibilities. Therefore, the benefits and necessity of the designed vessel relocation plan may not be fully understood by the whole operations team.

**Knowledge Loss with Personnel Turnover**

Even if communication is effective during the project handover, ensuring knowledge continuity throughout the production lifetime of the development is another equally challenging obstacle. The majority of new permanent systems, including the moorings, risers, and structure, are designed for a useful service life of twenty-five (25) years or more. While a platform may remain in use throughout these 25 years, key personnel such as marine crews, offshore installation managers (OIMs), and operations managers will often come and go. Not to mention the design personnel quickly move on to new projects following closure of the previous. With the frequent personnel changes on the operations team, it is extremely difficult to ensure the successors inherit the full understanding of the vessel relocation and its importance in preserving the integrity of the risers and moorings. The newly appointed personnel have a large quantity of information relevant to all other parts of the facility operations, and frequently those items not directly linked to the processing or production of the oil or gas products from the well are overlooked. This turnover in key personnel often results in loss of knowledge about the system and understanding of how to properly maintain and care for it during the implementation of the vessel relocation program.

The knowledge loss due to project or personnel handovers is likely to further skew the “end user” perception of the vessel relocation program. The plan may be viewed as a hindrance to production rather than a critical part of maintaining safe production operations. Continuity in vessel relocation execution is therefore compromised.

**Balancing Benefits and Costs**

Theoretically, the more relocations a vessel undergoes, the greater the fatigue life can be achieved at any given point in the riser TDZ and the mooring system. However, the cost associated with vessel relocation quickly adds up when all financial factors are taken into account. Due to the physical risks associated with movement of the vessel, and depending on the operator’s policies for making adjustments to the mooring payouts and tensions, a pause in production may be necessary during the relocation activity. This could result in anywhere from a few hours to a few days of lost production time. Taxing the schedule even more, mooring adjustments may cause interruptions to simultaneous operations that the platform undergoes daily such as inspection, maintenance, repair (IMR) activities and supply deliveries.

Alternatively, too few moves may also cause problems. If mooring adjustments are not made for more than five consecutive years, the functionality of the tensing system may be compromised due to wear, corrosion, and effects of the marine environment [4]. If only two relocations are required during the 25-year design life of the platform to meet the fatigue requirements of the SCRs, the mooring tensioning system must be regularly inspected and maintained to ensure functionality.

Lastly, the probability of deviation from the original plan increases as a plan gets more complex. If a vessel relocation plan specifies complicated relocation sequences or relocations are too frequent, proper execution of the plan is less likely to occur.

**SUGGESTIONS TO MINIMIZE OPERATIONAL IMPACT OF VESSEL RELOCATION**

While a vessel relocation program may not be feasible for every platform or operator due to the above described challenges, there are practices which can be employed to optimize the benefits and minimize the operational disruption and costs.

**Design Phase – Cost Efficiency Study**

The cost of vessel relocation is a complex product of many factors. A cost efficiency study may help in determining the
optimal number of relocations necessary to balance meeting the riser fatigue life target, the mooring component benefits and the operational cost of vessel relocations. Due to the number of variables associated with each one of the cost contributors, the study can only be performed for a specific project based on its location, water depth, environmental conditions, and system configuration. Each relocation plan is as unique as the structure for which it is created and it is unlikely that one plan would be applicable to multiple locations.

**Design to Operation – Knowledge Transfer**

Knowledge transfer between the project design team and production operations team is crucial to ensure those implementing the vessel relocation program fully understand the need for and risks associated with the plan. Particularly, the operation team needs to be wholly aware of the consequences of deviation from the plan. Such consequences may include a need to reassess riser fatigue life, or to reassess the mooring integrity if the vessel exceeds the designed duration in an offset location.

The design team is often required to deliver an integrity management plan (IMP) to the operations team at project handover, detailing all necessary activities to be performed post installation to ensure the system is fit for service. The vessel relocation plan should be incorporated into the IMP to specify the time and position of each relocation. Verification of the planned relocations can be established as a key performance indicator (KPI), which can be tracked through monitoring of the vessel northing and easting using global positioning system (GPS) or the mooring link counts at each corner of the vessel. Similarly, if the vessel relocation program is being implemented as a life extension measure, the operational IMP should be revised to include the target relocation times and positions to ensure it is planned and tracked properly.

**Production Phase – Planning, Record Keeping and Knowledge Continuity**

Given sufficient lead time, vessel relocations may be scheduled to coincide with planned production shutdowns for maintenance and repair of safety critical equipment. As with all simultaneous operations (SIMOPS), it is crucial the planning involves all interested parties, (i.e. production, flow assurance, integrity management, and IMR groups) to ensure safety and minimize production downtime.

Execution of the vessel relocations should be monitored and verified as a KPI established in the IMP. Although the vessel GPS location gives an indication of the general position of the vessel, the normal vessel offsets due to environmental loading can sometimes drown out the intentional vessel offsets through mooring payout adjustments. Different riser configurations can result anywhere from a narrow peaked fatigue hotspot to a wide banded fatigue zone in the TDZ.

While a small vessel move may be sufficient to offset a narrow-peak hotspot, it may not be adequate to shift the wide-band zone. For this reason, tracking the mooring link count may be one reliable method to monitor the vessel location, supplemented by and cross-checked against GPS readings. This KPI should be assessed periodically, depending on the frequency of the relocations, and reported as part of the system overall integrity validation at least annually. The cumulative time spent at each relocation position should be tracked throughout the facility’s service life.

The mooring tensioning system must be regularly inspected and maintained in operational condition. Previous work has suggested best practices to prevent mooring fairlead failures [4]. Not only does this guarantee that the vessel relocation can be performed safely and on schedule, it also ensures the vessel can be moved back into the Neutral Position, or safe radius zone, during the onset of extreme weather events if the vessel is stationed in an offset position for an extended period of time.

In addition to thorough planning and monitoring, procedures must be established to react to unplanned events. Should sudden hurricanes develop before the vessel can move back within a safe radius from the Neutral Position, actions should be taken to best protect the system integrity and minimize the impact to the equipment and environment. The sudden hurricane assessment and response plan should be accounted for during the development of the vessel relocation program. Procedures should also be developed to specify the steps to follow when deviation from the plan occurs. Key personnel should be notified to determine the required assessments to be performed. Revisions to the original vessel relocation plan may be necessary and engineering assessments conducted to determine the impact of the deviation.

**Designating Responsible Party for the Asset Life**

In order to carry out a vessel relocation program, key personnel are required when the structure is accepted by regulators to implement the scheduled relocations as necessary and keep on-going detailed records of these activities. However, since turnover of personnel can be frequent and sometimes short-noticed, knowledge continuity can be difficult to maintain. Management of the vessel relocation program should be clearly defined for the role of the designated responsible party.

The mooring and riser designers are most familiar with these systems and how they will react in theory to changes to the relocation program. They are aware and understand the purpose of the program. They have a deep awareness of potential consequences should deviation from the plan occurs. In addition, if issues arise and a deviation from the plan is unavoidable, they can quickly assess the impacts of an alternate plan. They will check the proposed changes against their
models which have been benchmarked and fine-tuned using as-built data obtained during baseline inspection post-installation. However, availability and competing priorities render it difficult for the original design engineers from being the designated responsible party to oversee the relocation program through the life of the field.

Offshore operations or production crew onboard the vessel may be performing the actual mooring payout adjustments, but their priority is to keep production running at the highest capacity possible. Their routine maintenance and repair activities mostly focus on the topside equipment. The mooring system and the subsea riser system typically are managed by other groups. Again, the combined reasons above prevent the offshore operations and production crews from being designated as the responsible party to oversee the relocation program through the life of the field.

Considering the challenges faced by designers and operations personnel, it is recommended that the integrity management (IM) team, or onshore operations team, be designated as the responsible party to oversee the relocation program. Certain platforms may not have a separate IM team, but may have a designated group whose responsibilities include planning of IM activities and maintenance operations. The IM planner acts as an unbiased enforcer of all activities necessary to keep the system fit for continued service. They make sure that IM activities are carried out in a criticality based order and are scheduled on risk based intervals. They are well positioned to identify opportunities to match vessel relocations with planned shutdowns. Moreover, the IM team is responsible for periodically reporting the condition of the systems to upper management. This ensures the system health KPIs, which includes meeting target vessel relocations, is routinely monitored and assessed.

Depending on the size of the operator and their internal resources, it may be more cost effective to outsource the role of the IM team leader (or team member) to a third part familiar with the mooring and riser systems. This provides the added benefit of deeper operational knowledge of the equipment, payouts, and haul-ins required than might otherwise be achievable with internal resources.

Just as interaction between designers and installation contractors are highly beneficial and can impact future designs [4], interaction among the vessel relocation responsible party, operators, and offshore crew are essential to implementing a successful vessel relocation program. The responsible party should arrange for periodic review and reporting of overall system conditions to all parties involved in the production phase of the system. This is an opportunity to share knowledge between the different teams and promote knowledge continuity through the service life of the asset. A suggested implementation flowchart of a vessel relocation program is provided in Figure 4 for consideration.

CONCLUSIONS
By employing a vessel relocation program, life extension and overcoming design challenges on existing systems for both risers and moorings can be achieved. Although there are risks involved with vessel relocation plans, by recognizing and addressing hand-over obstacles between designers and operators, selecting a suitable responsible party to manage the relocation program, and maintaining a dynamic IM team, operators can reap the benefits of such a program. These include cost savings from extended service life, reduced risk exposure through fatigue dispersion for SCRs and mooring components, and increased operability of the mooring tensioning system.
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NOMENCLATURE
GoM – Gulf of Mexico
GPS – Global Positioning System
IM – Integrity Management
IMP – Integrity Management Plan
IMR – Inspection, Maintenance and Repair
KPI – Key Performance Indicator
OIM – Offshore Installation Manager
SCR – Steel Catenary Riser
SIMOPS – Simultaneous Operations

REFERENCES