

THE CHANGING MOORING ENVIRONMENT

Dustin Heins, Samson, USA, outlines the critical need for more stringent safety evaluations of new mooring line products, in order to ensure safe and successful operations.

The selection of mooring lines based solely on reported strength is no longer acceptable. The LNG transportation industry has now come to recognise the critical role that rope design can play in ensuring safe and successful operations. Purchasers have an abundance of available and legacy product solutions to choose from and need to investigate the pros and cons of each of the options available to them, with the aim of fulfilling and maximising safe operating practices. When CAPEX, OPEX and, above all, crew safety are considered as part



of the selection process, it is critical to know how to evaluate potential solutions against your own operating requirements.

Rope designs vary significantly, but are generally organised into four pillars that influence the final performance of a rope (Figure 1):

- Base material – The specific fibres utilised to achieve the desired characteristics.
- Finish coatings – Design elements chosen by the rope manufacturer to produce specific performance benefits.
- Structural configuration – What macro-level construction of the mooring line is selected.
- System integration – How the line fits into/interacts with the rest of the mooring equipment.

Design choices affect a mooring line's performance, lifetime, and resilience to extreme loading conditions, as well as directly impacting on an operator's risk exposure.

Mooring lines have historically been considered a consumable product. If a crew is familiar with a particular rope construction, sourcing something similar may be the only selection criteria used, beyond strength and price, when searching for replacement lines. However, this approach neglects the positive impact that use of the four pillars of mooring line design can have on a mooring system's performance. As this is realised, the use of a focused review of the long-term consequences of a product choice is becoming more widespread.

It starts with product selection

Selection of the optimised mooring lines for a system starts with a holistic review of risks and performance requirements.

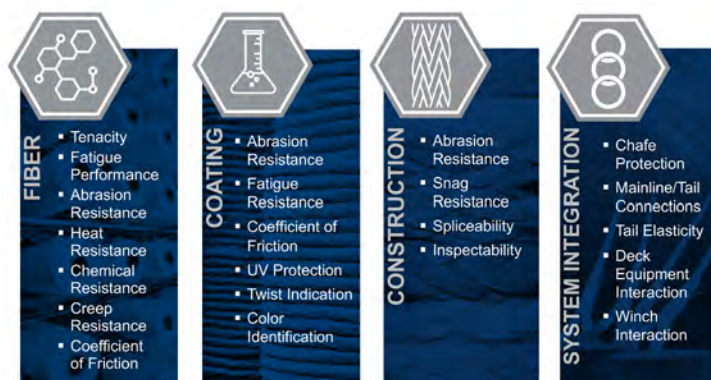


Figure 1. Rope design factors.

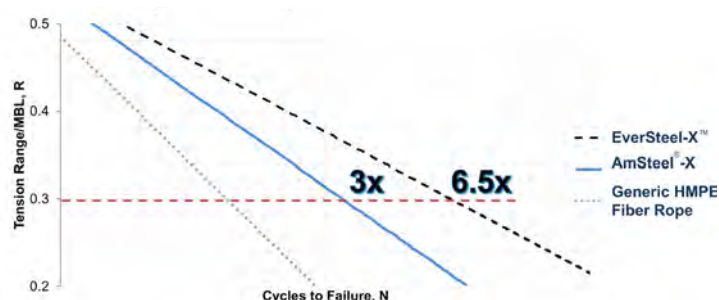


Figure 2. Rope design and creep resistance.

One common framework applied to this type of ground-up analysis is design failure mode and effects analysis (DFMEA). The ideal implementation of this process involves a cross-functional team performing a detailed review of the mooring system to rate potential concerns that could impact safe operation. Once all potential causes of failure are identified, a ranking of the most critical concerns can be established by considering the following: the likelihood of the event occurring, the severity of the event were it to occur, and the ability to detect the event before its occurrence. By undertaking this process, addressable issues with the mooring system can be identified and corrected prior to the installation of the lines. Examples of this include, but are not limited to: alteration of the mooring winch dimensions; adjustments to the fairlead design or location; inclusion of chafe protection elements in the system configuration; development of crew instructions to avoid specific line-damaging actions; introduction of protocols for the tending and tensioning of lines during operation.

Critical considerations for the selection of appropriate mooring lines can vary significantly between vessels, trade patterns, and operators. This operational variation is a key reason why formal DFMEA approaches are valuable tools to assess real risks and assure that lines are fit for purpose.

Some ships operate in predictable patterns where lines and their arrangements are consistent, thereby allowing for predictable wear generation. Others may have to adjust arrangements, lengths, and orientations to accommodate a range of berth designs and geometries. Variability requires mooring lines that can hold up to inconsistent patterns of applied stress. Conversely, in cases where the mooring lines

will be frequently deployed and recovered on short trade routes, the resistance of the rope to damage from low contact pressure with vessel surfaces will significantly impact the durability of the product.

The advantages of high-performance synthetic mooring lines have been embraced by operators, leading to an expansion of the technology in the LNG transport market as a preferred solution over steel wire or traditional fibre ropes. These benefits include everything from the obvious (e.g. reduced weight, faster operations, and easier completion of maintenance operations), to the more nuanced when fully incorporated into operating practices (e.g. line markings integrated into documentation of inspections, maintenance triggers identified, and status updates available at a glance).

Safety is job one

The safety of personnel working around any mooring system is of the utmost concern. It should be the primary factor taken into account when considering the demands of an operation and specific equipment choices and management. Whenever possible, line retirement cadence should be planned, along with a condition evaluation programme, during the design phase of the mooring system. By assessing the condition of retired lines in a consistent manner, operators can begin to make educated plans relating to their replacement cycle and identify system improvement opportunities. In order to be most effective, it is critical to keep accurate documentation

of a line's usage and movement during its operating life. Robust data collection facilitates the development of a better model, which can then be applied to vessel or fleet review of mooring line lifetimes. A comprehensive line management process is crucial.

Scenario comparison

In order to explore this further, two cases can be compared, each with a drastic difference in rope requirements: a permanently moored FSRU vs the system used for an LNG carrier undertaking varied terminal visits and mooring line utilisations.

When applying a DFMEA to the first case, the permanently moored FSRU, a few of the critical concerns identified would likely relate to the extended service conditions. The berthing conditions and configuration will be well known and consistent, allowing for predictable load amplitudes based on any given sea state. As the lines will be deployed constantly, in a relatively immobile environment, they will experience a consistent repetitive stress and relaxation cycle. This will require a product that has high tension fatigue resistance. Beyond the axial stress resistance requirement of the line, the vessel fairlead between the mooring winch and fixed dolphin will function continuously as a contact point for the same section of the line heaving back and forth with the swell. In addition, the section of line positioned between this fairlead and the dolphin will be exposed to unending sea spray and sunlight.

For the LNG carrier with a varied trade pattern, the concerns raised in the DFMEA will be quite different. By calling on different ports during each trip, the peak tensions are much less predictable due to the impact of currents, wind, mooring spread, and more. This requires a system capable of excelling in a wider variety of conditions than those experienced in the comparatively controlled setting of an FSRU mooring. On the other hand, the time spent with lines being active between all fast and all let go conditions will be much less on an LNG carrier that may spend fewer than three days per month in port. In this case, the lines have the advantage of being disconnected during travel, allowing for thorough inspection, maintenance, and protected storage on a covered winch. The line will not require the same level of tension fatigue resistance, but must be durable enough to hold up under the frequent handling required to moor and release the vessel.

Selecting the optimal mooring line assembly for these two systems requires

prioritisation of different characteristics (Figure 2). For the FSRU, a tension fatigue-resistant product such as Eversteel-X will be beneficial; with added components to provide tension reduction (i.e. elastic tails), abrasion resistance at contact points (i.e. chock protection), improved UV resistance, and policies around environmental protection (i.e. UV coverings). Alternatively, in the case of the LNG carrier, tension fatigue is not expected to be the primary driver towards retirement, and a product such as AmSteel-X, that is optimised for ease of maintenance (i.e. twist identification) and has high resistance to many forms of damage (i.e. abrasion-resistant construction), would be an ideal choice when paired with proper operation guidance. Either of these system designs can be impacted by the priority an operator places on minimising initial CAPEX, compared to the total cost of ownership over the entire lifecycle of the vessel's mooring system.

	ADVANTAGES	DISADVANTAGES
Jacketed	- High strength, low weight - Core is completely protected by outer jacket - Firm, round profile - Potential for higher heat resistance on the cover - Typically less expensive	- Impossible to inspect the core (strength member) - The cover will wear faster than the core - Doesn't float - Jacket can rupture - Difficult to repair or splice
Non-Jacketed	- Higher long-term residual strength because of 100% HMPE fiber - Easy to inspect, repair, and splice - Cut and abrasion resistant - Floats - No jacket ruptures - Chafe protection can be easily replaced	Higher content of HMPE fiber increases cost

Figure 3. Jacketed and non-jacketed rope comparison.

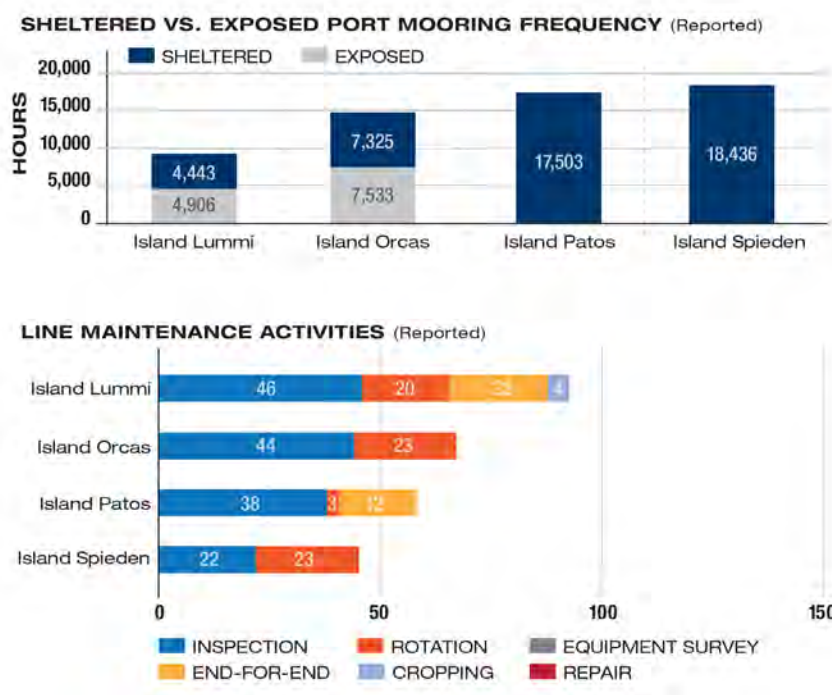


Figure 4. Sample fleetwide trend analysis.

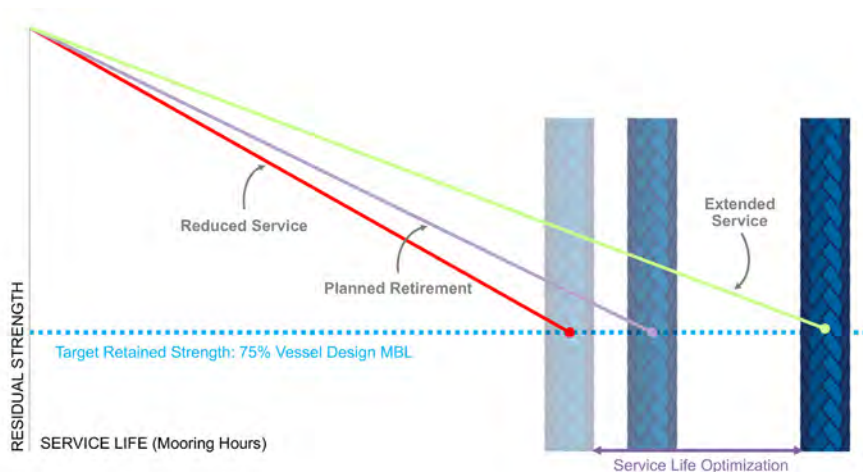


Figure 5. Service life management.

Understanding the trade-offs

Mooring configuration selection for any vessel should be determined by a comprehensive review of: the vessel's lifetime requirements, expected operating conditions, maintenance policies, and budget. As with any design, trade-offs exist when selecting solutions that address specific performance targets. For example, prioritising environmental resistance and resistance to external contact may lead a user towards a construction that includes an impervious jacket, which will have a critical impact on inspection methods, available maintenance actions, thermal energy build-up, and overall fatigue performance (Figure 3).

When elevated temperatures are a factor to be accounted for, an operator may elect to utilise an aramid rope, which has higher temperature resistance. However, this will have implications on the rope's resistance to abrasion, tension fatigue, and axial compression damage. These trade-offs are critical to understand before pursuing a solution to a single component of the risk – the optimal solution is often a balancing act between the critical needs of the application.

Mitigating risk over time

Rope health is a function of many variables, including: applied tensions due to arresting vessel motion (i.e. peak loads, tension range, cycle frequency, application rate); exposure to damage from other forms of external energy (i.e. incidental contact, UV exposure, thermal transfer); stress concentrations applied by the system (i.e. twisted lines, bending losses, abrasive surfaces); internal conditions (i.e. hysteretic heating, strand motion, yarn buckling, fibre creep). Different types of damage affect a mooring line in different ways, with varied combinations potentially providing synergistic or antagonistic results.

Evaluation methods for any given condition must vary drastically in order to form an accurate assessment of the current health and suitability of the ropes for continued use. While first principle theoretical models can correlate the remaining life of a mooring line with regards to a specific damage type, they often struggle when interacting combinations of factors apply, be they positive or negative interactions. Empirical models are the only way to address systems facing the potential of many different types of

damage. Similarly, some damage types may provide only an instantaneous impact (e.g. bending around a roller) and allow the line to return to the original condition when no longer present, while others leave lasting damage that persists even after the initial damaging event has occurred (e.g. abraded yarns from contact with rough surfaces). The intricacy of these interrelating scenarios presents constant challenges to comprehensive models based on a limited data input.

Condition assessment tools must be designed to capture a wide and varied set of data types. Visual condition assessments during line inspections, for instance, are critical

to identifying changes to the product as damage accumulates. Rope health assessments should be simplified for crew members, but require tools that are backed by sufficient data in order to provide statistical confidence. Combining this with tracking of line tension can further bolster an empirical model for mooring line life. Tension monitoring alone can only indicate whether/when a line has experienced a concerning peak load. Combining this line usage data with any wear characteristics identified during an inspection, allows a comprehensive fatigue model to correlate trends of each line's usage history, in order to produce a clear estimation of the potential line condition (Figure 4). Merging these measurements with current wind and temperature data further sharpens the comprehensive model.

The need for a complete system

The final critical piece to a holistic rope health management system is incorporation into a mooring equipment tracking system. By incorporating all of the measurements referenced earlier with maintenance operations, it is possible to create a digital representation of the functional history for all lines on a vessel, or even across an entire fleet. At any time, a particular section along a specific line can be singled out for review, based on the rope health assessment model and an estimate of its current condition. Continuous refinement of the operation-specific maintenance programmes can be further bolstered through post-retirement assessments. The data collected in this type of residual testing programme is reinforced by the expansive data collected throughout a mooring line's service life.

Conclusion

A wide variety of synthetic ropes are available for implementation in a vessel mooring system. Optimal decision-making demands a thorough understanding of safety concerns and the conditions that a vessel will endure. Beyond the selection of suitable mooring lines, the inclusion of a rope health management system can further elevate the performance of existing solutions and ensure the longevity of any mooring system. **LNG**