CHALLENGES AND CONSIDERATIONS IN SELECTION, ANCHORAGE DESIGN, AND INSTALLATION OF QUICK-RELEASE MOORING HOOKS ON EXISTING STRUCTURES

by

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ABSTRACT

Quick-release mooring hooks have become increasingly popular for use in design of new mooring systems, especially for larger vessels. Hooks offer several operational and safety benefits over the standard bollards or cleats. Such benefits include the abilities to release mooring lines without de-tensioning the lines, release mooring lines remotely from a distant control location in possible emergency situations, as well as monitoring of tension in the mooring lines while a vessel is at berth. In addition, mooring hooks are increasingly being required for new installations by local rules or regulations. This paper discusses the challenges and solutions for designing and installing quick-release mooring hook at existing marine facilities. Examples of successful installations and typical technical challenges are presented.

1. INTRODUCTION

Selection, design, and installation of quick release mooring hooks follow a relatively straight forward path when applied in design of new mooring structures. Several institutions and authorities offer standards or guidelines to aid in this process, such as Unified Facilities Criteria (UFC 2017), British Standards in the UK (BS 2014), the Marine Oil Terminals Engineering and Maintenance Standards – MOTEMS (CBC 2016) in California, as well as the recently released PIANC Working Group MarCom 153 "Recommendations for the Design of Marine Oil Terminals" (PIANC 2017).

Quick-release mooring hook installations for new designs in a best practice scenario adhere to a hierarchy of failure modes that attempt to maximize safety and minimize economic impact if the mooring system is accidentally overloaded (See **Figure 1**). PIANC Working Group MarCom 153 has identified that the successive modes of failure should be as follows: winch brake tending, mooring line failure, mooring hook failure, and finally, mooring structure failure. While the concept is simple for new designs, ensuring that the progression of failure adheres to this hierarchy can be difficult to accomplish when any changes are made to an existing mooring system. These changes can occur at different levels, including change in mooring line strengths or types that are carried by vessels calling at a terminal, upgrades of mooring hardware at a terminal due to regulatory requirements, or upgrades of mooring hardware due to changes of service at a terminal. The question will then arise as to how a possible break in the hierarchy of failure modes can best be handled and at what point in the chain the break should be implemented. In addition, existing marine terminals may have mooring systems and structures that were not designed to these standards, making possible upgrades of the mooring system even more challenging.

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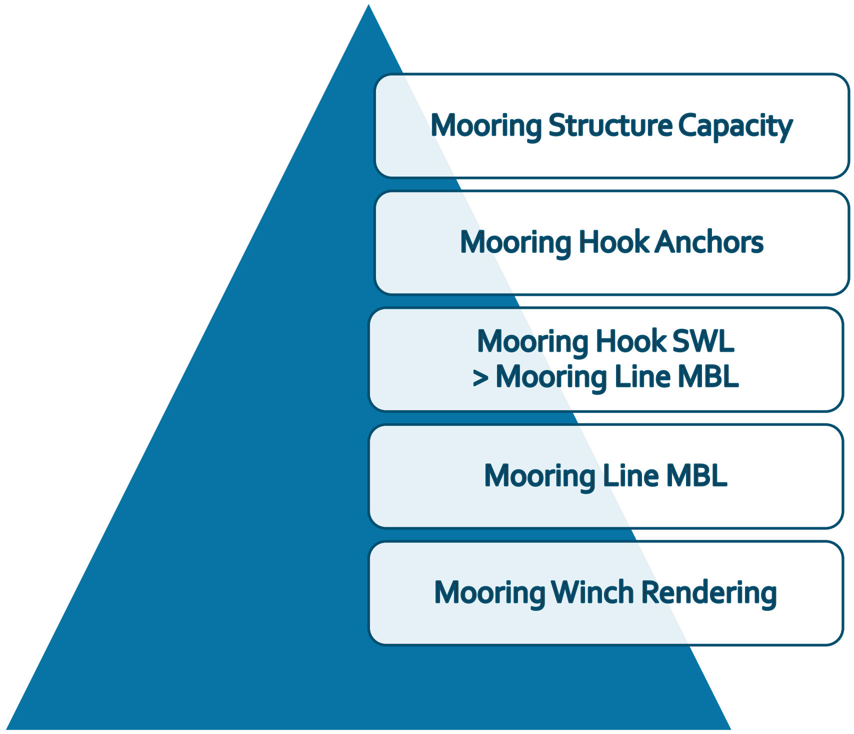

Figure 1: PIANC Working Group MarCom 153 Hierarchy of Failure for Mooring System Design (PIANC 2017)

2. DESIGN CHALLENGES

Installation of new quick-release mooring hooks at an existing terminal as either a replacement or upgrade require careful thought and attention by the design profession. The design professional must review the entire mooring system, not just the specific hook assembly, to ensure a design that is appropriate for the site, safe, and not overly conservative in terms of capacity (Iversen 2014). Blindly following the available design standards geared for new terminal installations may lead to impractical, unsuitable, and/or unnecessarily expensive designs.

For new installations at existing terminals, the design professional must consider the location of the mooring points, the number of mooring hooks at each mooring point, the appropriate Safe Working Load (SWL) for the individual hooks and the hook assembly, the type and design of the anchorage system, as well as the available structural capacity of the existing mooring structure. All these factors can greatly influence the size and scope of the design. Further challenges faced by the designer include developing a design that will work with operational expectations that the terminal will remain open or minimally impacted by installation of the new work. A successful design needs not only to consider the structural aspects of the installation, but also the order of installation as well as methodologies to speed up installation. A discussion of these common challenges and some successfully implemented solutions is presented below.

2.1 Selection of Mooring Line Strength for Design

Most mooring hook design guidelines state that for new construction, mooring hooks should be selected based on the anticipated maximum mooring line strength for vessels calling at the terminal. At first, this seems to be a reasonable approach to ensure that the mooring lines are the weakest link in the hierarchy of failure chain for the mooring system, but there are several pitfalls associated with this approach for installing new hooks on existing structures.

Firstly, the design professional may find it difficult to anticipate what this mooring line strength would be. Some of the references noted above provide good estimates for typical mooring line strengths for various vessel sizes and types. However, there will always be vessels carrying stronger lines than the normal range. A common observation is that many vessel owners tend to increase line strengths of their vessel during refitting or to accommodate a specific terminal with higher environmental loads. The motto of “stronger is better” often prevails in these situations. If a vessel with unusually strong lines be considered to size the new mooring hooks, the hooks are likely to be unnecessarily oversized compared to actual mooring loads and the corresponding demands on the supporting structures will be even larger, possibly exceeding available capacity, without a real increase in safety.

Overly conservative designs may be avoided by sizing the mooring hooks using a more reasonable line strength that is selected after careful review of all vessel types and sizes expected to call. The designer should carefully review the vessel inventory to understand actual line sizes and types calling at the terminal for the entire fleet, with the intend to identify vessels with unusually high line strengths. Line strength outliers may be considered an exception and ignored for the purposes of mooring hook sizing.

2.2 Selection of Number of Mooring Hooks

Selection of the number of mooring hooks should be done to provide the terminal operator with the maximum possible flexibility of vessels they can accept. For new terminals, the mooring analysis strives to establish the minimum mooring line strength needed to provide for safe mooring arrangements for the selected vessel types and environmental conditions. For existing terminals, the mooring analysis may focus on ways to limit hook or hook assembly loads by considering additional hooks or even additional mooring points. Overly conservative designs may be avoided by introducing more hooks or mooring points to the facility to spread mooring loads or reducing the load experienced by a single mooring structure. Introducing additional hooks is likely to be significantly cheaper than strengthening or rebuilding existing marine structures.

2.3 Selection of Hook Safe Working Load (SWL)

Following the hierarchy of failure, the hooks themselves are the next link in the hierarchy of failure chain. The Maximum Breaking Load (MBL) of the mooring lines is usually compared to the Safe Working Load (SWL) of the hooks for size selection. Mooring hooks are manufactured with a stated SWL from the manufacturer. The SWL is typically the capacity referenced by guidelines when recommendations are made for sizing of mooring hooks. However, the SWL is usually well below any real failure limits of the hook. The proof, yield, and ultimate loads of the hook are generally at least 1.5, 2, and 3 times the SWL of the hook, respectively. By inspection, the designer can see that the proof load of the hooks will be close in value to the anticipated MBL of the mooring lines if the SWL of the hooks are selected to match the MBL of the mooring lines. Based on this observation, there remains a significant margin of safety built into the design of the hooks themselves when hooks with lower SWLs are considered.

2.4 Hook Assembly Anchorage Design

In general, anchor bolt capacities are rarely a limiting factor in the capacity of new mooring hook assemblies on new structures. This is not the case for new installations on existing structures. Existing anchor bolts are frequently too corroded, too small, or an insufficient number for reuse. New bolts of larger size and number are almost always required. Installing new large diameter, embedded anchors into concrete structures can be a challenge. There are very post-installed anchorage systems (adhesive or mechanical) rated for bolt diameters between 46 and 90 mm, typical for most hook assemblies. Most manufacturers simply do not test anchors at these sizes because of their infrequent use. Allowable design capacities, when provided, tend to be very conservative as they are not supported by large test data sets. In addition, for concrete installations, the situation is made even more challenging by common design guidelines for post-installed anchorages, such as Appendix D of the American Concrete Institute (ACI) Standard 318, which heavily penalize mechanical anchorage installations in existing concrete. Existing reinforcing details, often non-conforming to modern code requirements, tend to be conservatively treated as being unreinforced for concrete pullout failure modes, potentially underestimating available capacity.

One successful solution for avoiding the concrete failure penalties is to install new anchor bolts that pass completely through the concrete deck of the supporting structure. In this case, the capacity of the anchors in uplift will be determined by the bearing capacity of washers and bearing plates in the deck soffit in conjunction with global bending of the deck. This approach can be an efficient design where the full tension capacity of the bolt can be more easily developed. Coring anchorage holes up to 155 mm in diameter through 2 m of reinforced is not an especially difficult practice. Issues such as conflicting deck reinforcement, interfering piles, as well as other obstructions can often be addressed by ordering custom hook assembly bases that allow placing the anchor bolts in desirable locations. Specifying custom bases will impact hook procurement times, but typically do not significantly increase the cost.

Another advantage of the through bolt design is that a hole pattern can be selected that is outside the footprint of the existing mooring hook as shown in **Figure 2**. This placement can allow coring work to be done before the old hook is pulled from service, greatly reducing the time to swap out an old hook for new during a terminal shutdown.

Figure 2: New mooring hook installations showing preinstalled coring for anchor bolts (left, arrows) and new bolt pattern prior to setting the new hook assembly (right).

2.5 Supporting Structure Capacity

Generally, the mooring structure has sufficient capacity to support an in-kind hook replacement. When the hook is upgraded with a larger SWL or additional hooks, the supporting structure might not have sufficient local or global capacity to support the new larger hook demands. In this case, a decision will need to be made to determine the proper path forward. While local strengthening is often feasible, global strengthening of the mooring structure can often prove to be too costly. In addition to local or global strengthening, it might be an option to reduce the potential loads on the structure. This can be done by limiting the size of the vessels that call at the terminal or limiting acceptable operating wind conditions.

2.6 Operational Considerations

Replacing mooring hooks often occurs at one time and may require weeks of terminal shutdown to install. For multi-berth facilities, this is not a big concern. However, for smaller, highly used terminals, this can be a significant disruption to service with business losses far exceeding project costs. In these cases, the hook installations can be timed to fit around vessel schedules, can be split up to install one hook at the time, and careful planning of the installation can minimize downtime. If the vessel schedules are known, mooring locations that will not be used during the upcoming arrivals can also be scheduled for replacement with no impact on operations.

2.7 Global Mooring System Considerations

Hook replacement projects are always at risk of ignoring overall mooring system performance with respect to the new work. The design professional can easily overlook the global aspects of the system and just jump into hook design, which is often the task assigned. This limited approach, when narrowly following the hierarchy of failure, may result in inefficient designs with an uneven distribution of the safety margin in the system. This uneven distribution is a characteristic often associated with over conservative and unnecessarily costly designs.

To avoid these situations, a detailed mooring analysis of the entire mooring system with the actual vessel fleet calling on the terminal and real environmental loads should be done by the design professional to understand the real demands in the system. Only by comparing these demands with actual capacities of the various components of the mooring system can the designer comprehend the force flow and margin of safety in the system. Careful evaluation of the results of this system analysis will make apparent if there is an unreasonable margin of safety for any individual component. Ultimate capacities of each component should be compared in this analysis with actual working loads to determine the relative safety margin. For cases where mooring structures are require strengthening or replacement, alternative mooring arrangements should also be considered, including the addition of new mooring points.

3. DESIGN EXAMPLES

A few design examples highlighting the lessons learned from successful mooring hook unit installations at existing terminals are provided in this section.

3.1 Selecting the Best Mooring Line Strength for Design

A California marine oil terminal serving vessels up to 188,000 DWT was in the process of replacing some of their mooring hooks to mitigate mooring arrangements that utilize two lines per hook, as well as to install tension monitoring at all mooring points. At this terminal, the existing mooring dolphins support double hook mooring assemblies, with each hook having a SWL of 45 MT. While this size of mooring hook can appear to be undersized for the size of vessels calling at this terminal, a comprehensive mooring analysis confirmed that operations were safe even under the combined loads of maximum currents and survival level wind speeds.

By using the available guidelines for mooring hook design, the size of the hooks would have to increase considerably as would the supporting mooring dolphins at significant cost beyond that of new hooks. In this case, it was therefore decided to not use the vessel MBL as a guideline for selecting hooks and new hooks were installed with a SWL that matched the original installation.

3.2 Selecting the Right Number of Mooring Hooks

In the example above, before the installation of the new hooks, the terminal would commonly tie up vessels with three lines to one double hook assembly, thereby often driving two thirds of the load to the assembly into just one hook. To improve operations, the terminal owner decided to go with triple hooks instead of the existing double hook arrangement. By installing just one additional hook, selecting a triple hook assembly instead of a double hook assembly, the actual maximum load seen by one hook was reduced by 50%. The load on the total assembly did not change.

3.3 Anchorage Design

In the example above where double hooks were replaced by triple hooks, the selected hook SWL was much lower than what would have typically been selected for a new terminal design. As mentioned, comprehensive mooring calculations were performed to ensure that this approach was feasible. As the ultimate capacity of the hooks are so much higher than the SWL, there were concerns that the anchorage to the mooring dolphin might not be strong enough. The anchorage itself was therefore designed based on the MBL of the strongest line. Anchor bolts were installed as through-bolts to ensure that full tension capacity of the bolts could be developed.

3.4 Selecting the Best Hook Safe Working Load (SWL)

For the example, while the existing mooring arrangements worked safely, with additional safety factors on both the SWL of the mooring hooks as well as the capacity of the supporting marine structures, the goal of the upgrade was not to increase the mooring capacity of the berth, but to improve operations by avoiding the need for two lines per hook mooring arrangements as well as to install tension monitoring. The operator decided that it was important to not install mooring hooks with more capacity than the existing ones to avoid driving more loads into the supporting structures and requiring significant strengthening.

The decision was made to install mooring hooks with the same SWL as the existing ones, but to replace the double hook units with triple hook units. This way the mooring dolphins would see the load from the same number of lines, but with similar safety factors in place when tying up the lines. While the new mooring hooks will not have a SWL larger than the MBL of the anticipated strongest mooring line, their proof load is larger than the MBL, as are both the yield and ultimate loads. The mooring hardware was also checked against actual loads, with proper load factors applied, with resulting acceptable factors of safety. This rational approach avoided unnecessary upgrades to the terminal that would not necessarily increase terminal safety.

3.5 Supporting Structure Capacity

Through the process described above, no strengthening of the existing supporting structure was needed. The selection of mooring hooks with the same SWL as the existing hooks in combination with the increase form double to triple hooks ensured safer operations, but with no increased chance of overloading the structure.

At another terminal site, local strengthening of the deck was required to provide sufficient capacity for support of the hooks. In this case, the deck was strengthened locally by thickening the section immediately around the hook anchorage from above or below to achieve the requisite bending capacity. This is shown in **Figure 3**. Although much easier to install from above, deck thickening also needed to consider hook access and use. It was needed to provide sufficient space around the hook for an operator to work without falling off the transition and to not elevate the integrated capstan too by the thickening, potentially making use difficult.

Figure 3: An example of localized deck strengthening in preparation to support a new quick-release mooring hook on an existing wharf deck.

3.6 Rapid Installation Considerations

For one California terminal replacing old mooring hardware, the installation time to install eight new quick-release hook units at once was determined to be too disruptive to terminal operations and would possibly conflict with a berth availability agreement with a major client. The terminal was too small and located in a relatively exposed site to allow multiple construction barges to operate to speed installation and reduce terminal downtime. To reduce the impact of the project, a piecemeal installation scheme was developed in cooperation with the owner and construction contractors, requiring only three days of berth shutdown to replace the mooring hook units at each mooring point. With only three days of closure, the operator felt confident the work could proceed within the normal gaps in the berth schedule.

To allow for this rapid installation, the anchorage at each mooring point would have to be installed with the existing hook assembly in service. The mooring structures at this terminal were too small to accommodate a parallel installation where a new hook assembly could be installed adjacent to the in-service hook. Rather, a new anchorage had to be installed around the existing, requiring the specification of custom bases for the new hooks with a bolting pattern outside the footprint of the existing.

By ordering the custom base, the contractor could core the marine structure deck and install the anchor bolts prior to new hook placement. A three-day window was left the pull the old hook, cut the old anchor bolts flush with the existing deck, place the new hook, and grout the new base. By the time the 6th hook was installed, only a two-day window was required. Most new hook units are immediately operable without installation of tension monitoring instrumentation and power. These systems were added later with the new hooks in service, greatly reducing berth downtime.

4. CONCLUSIONS

Unlike new installations, design new mooring hooks require more attention by the design professional to prevent overly conservative and costly installation schemes. Blindly following new design guidelines for retrofit or replacement project may result in impractical designs. Care must be used to carefully consider whether maintaining the hierarchy of failure is necessary or appropriate to maintain a sufficient margin of failure.

5. REFERENCES

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