Summary of the Results of the MARIN Study to Validate the Adequacy of SPM Mooring Equipment Recommendations

Tandem Single Point Mooring Study 2005

May 2007

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1.0 Introduction

Shipboard equipment recommended in the 3rd Edition of OCIMF’s *Recommendations for Equipment Employed in the Mooring of Ships at Single Point Moorings* has been increasingly used for mooring conventional tankers in tandem to FPSOs and FSOs. Industry concerns regarding the suitability of such equipment for tandem mooring arrangements resulted in OCIMF members commissioning the Maritime Research Institute Netherlands (MARIN) to conduct a series of numeric modelling simulations. The study made use of the "Shuttle" numeric modelling application specifically designed for tandem mooring arrangements and was supervised by a small MARIN and OCIMF-member steering committee. The objective of the study was to "test" those concerns using the "Shuttle" application to simulate a range of tandem mooring configurations and environmental conditions.

The simulation scenarios were selected in order to isolate and identify the impact and magnitude of the main components affecting peak hawser loads in tandem mooring arrangements.

The results and conclusions derived from this study were considered informative and appropriate for summary in this information paper with reference in the renamed *Recommendations for Equipment Employed in the Bow Mooring of Conventional Tankers at Single Point Moorings* 4th Edition. They should be treated with caution as they represent simulations based only on pre-defined equipment in specific environmental conditions.

2.0 Study Assumptions

The study was subject to constraints. The following is a brief description of the main assumptions.

**Conventional Tankers**

Two typical conventional tanker models equipped with bow mooring equipment fitted as recommended in the 3rd Edition were used. Assumed deadweights were 150,000 and 300,000 tonnes.

**CALM Buoy**

Some simulations were conducted using conventional tankers moored to a typical deep water Cantenary Anchor Leg Mooring (CALM) buoy. This provided a useful comparison.

The CALM buoy mooring system selected represents a typical deep water mooring system (714 metres) consisting of 3 bundles of 3 mooring lines the angles between the bundles being 120 degrees. Each calm buoy mooring line consisted of a steel wire and chain combination 1070 metres in length.
A barge shaped FPSO of 300,000 tonnes DWT with typical deck equipment blocks was selected.

**FPSO Mooring Arrangements**

Two FPSO mooring arrangements were selected.

The turret mooring system selected represents a typical deep water mooring system (714 metres) consisting of an external turret moored by 12 lines in four bundles of three lines each.
The spread mooring system selected represents a typical deep water mooring system (714 metres) consisting of 12 lines in four bundles of three lines each.

Each mooring line (turret and spread) is made up of a combination of chain and wire of total length 1299 metres and anchor radius 1028 metres.

Some simulations were repeated with shallow water mooring systems (65 metres).

Hawser

A grommet nylon hawser with 5 metre length chafe chains at each end was assumed. During the simulations different total hawser lengths of 80, 110 and 160 metres were tested and in one simulation the hawser material was changed to a stiffer material (polyester). Several simulations were repeated utilising twin hawsers to separate chain stoppers.

Environmental Conditions

The FPSO, and/or tanker, was always heading north at the commencement of each simulation. For most of the simulations one of two extreme offloading conditions was assumed. It is important to understand that these extreme operating environmental conditions were selected in order to compare results and understand the effect of altering one component including environmental criteria. They were not intended to be reflective of maximum operating criteria for a particular mooring arrangement and the resultant hawser loadings should not be viewed out of context.

Environmental events of "wind squalls" and "internal waves, currents and solitons" were also simulated with a number of different sensitivities.

Condition E1 - (significant environmental criteria from same direction)

- Wind: 15 metres/second (m/s) from north
- Current: 1.5 m/s from north
- Waves: 3.5 m significant wave height (Hs)
- 10 s dominant wave period (Tp) from north
Condition E2 - (significant environmental criteria from different directions)

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<th>Value</th>
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<tr>
<td>Wind</td>
<td>15 m/s from west</td>
</tr>
<tr>
<td>Current</td>
<td>1.5 m/s from north</td>
</tr>
<tr>
<td>Waves</td>
<td>3.5 m Hs</td>
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<tr>
<td></td>
<td>10 s Tp from west</td>
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Variation on the above conditions were tested to simulate the hawser load sensitivity to:

- a) no current - to encourage fishtailing
- b) 150 and 120 degree angles between current and wind
- c) lower significant wave heights (2.5 m Hs)
- d) longer period waves (16 s Tp)

*Internal Waves, Currents and Solitons*

For tandem moored FPSO/tanker simulations it was assumed that the tanker would encounter a 3 knot current stern first and the FPSO would not react to the current (current forces set to zero). The velocity of the approaching current was varied as was the application of tug forces.

*Squalls*

The simulation used actual squall wind measurements both in terms of direction and speed provided by an OCIMF member company. A weak current was applied to some of the simulations and the sensitivity of using a single pull back tug was tested.

*Tugs*

The "shuttle" numeric modelling application has the ability to simulate the interactions of up to two tugs on the moored tanker by the following:

- a) constant pulling force in a constant direction
- b) vector tug(s) (either push or pull) in auto pilot mode which in the case of one vector tug controls the load on the hawser or, in the case of 2 or more vector tugs, controls the load on the hawser to minimise the heading difference between the FPSO and the tanker.

3.0 Study Sensitivity Results

*SPM Type*

In steady environmental conditions, the calculated and most probable maximum hawser loads were, as expected, significantly higher for the two FPSO mooring arrangements compared to the CALM buoy. The sensitivity simulations indicated the differences to range between 20 to 35%. The differences between the two FPSO mooring arrangements were more complex and are described separately.
Hawser Length

A standard nylon hawser length, excluding chafe chain(s), was selected at 100 metres. However several simulation runs were repeated with shorter (70 m) or longer (150 m) hawsers.

![Figure 4 - Loaded VLCC on CALM buoy](image)

The graph in Figure 4 represents the hawser loads predicted for a 110 metre hawser (blue) and a 70 metre hawser (red) for a loaded VLCC moored to a CALM buoy in steady severe environmental conditions from the same direction (E1). The same simulation comparison using environmental conditions E2 (different directions) produced similar results.

![Figure 5 - Loaded VLCC tandem moored to ballasted spread moored FPSO](image)

Figure 5 is a hawser length comparison graph representing the predicted hawser loads for 110 metre hawser (blue) and a 150 metre hawser (red) for a ballasted VLCC moored to a spread moored FPSO.
Figure 6 - Ballasted VLCC tandem moored to loaded turret moored FPSO

Figure 6 represents the same situation as Figure 5 except that the FPSO was turret moored and hence free to rotate. The differences between peak hawser loads are less pronounced than calculated for the spread moored FPSO configuration.

The main observation from these results is that increasing the length of the hawser and thus decreasing the stiffness of the mooring arrangement and can result in significantly lower peak hawser loads. Operators should be aware that increasing the hawser length can increase the tendency to fishtail.

Twin Hawsers

Several single hawser simulations were repeated using twin hawsers made secure to separate chain stoppers. The simulation assumes that the twin hawsers are evenly matched in terms of rope properties. The intention was to understand the value of twin hawsers in load sharing and the impact on individual peak hawser loads.

Figure 7 - Loaded VLCC tandem moored to a ballasted spread moored FPSO
Both Figures 7 and 8 represent different FPSO mooring configuration simulations under the same environmental conditions (E2) with the blue line indicating the hawser loads in a single hawser system and the red and black lines indicating the hawser load in each of a twin hawser system. It is of interest to note that the peak hawser loads for the Turret Moored FPSO (Figure 8) were, as would be expected, lower than those on the Spread Moored FPSO (Figure 7). The consistent observation from all twin hawser comparison simulations, including those with tug assistance, is that twin hawser systems reduce the peak load on an individual hawser.

**Tugs**

Simulations were repeated with combinations of tug assistance. The Shuttle tool is capable of simulating a constant force in a fixed direction or single or multiple vector tugs. Vector tugs can be simulated in auto pilot mode to attempt to maintain the hawser load below a specified peak load or if two or more vector tugs are used to maintain the hawser load and minimise the heading difference between the FPSO and the tandem moored tanker. For Turret Moored FPSO tandem simulations a single "pull back" 60-tonne bollard pull vector tug was made fast at the tanker stern. For Spread Moored FPSO tandem simulations combinations of 1 and 2 vector tugs (1 ASD tug acting as push/pull at the bow and the other pulling at the stern) were assumed.

The results of the simulations indicated that in most circumstances the use of 1 or more tugs resulted in a slight reduction of peak hawser loads however in some of the simulations higher peak hawser loads were experienced with tugs when compared to the equivalent simulation without tugs. Figure 9 is an example of the use of tugs actually increasing the peak hawser load.
Figure 9 - Loaded Suezmax tandem moored to a ballasted spread moored FPSO

Figure 10 - Loaded VLCC tandem moored to a ballasted spread moored FPSO

Figure 11 - Loaded VLCC tandem moored to a ballasted turret moored FPSO

Shallow Water

To compare the effect of the water depth (and hence stiffness of the FPSO mooring arrangement on mooring hawser loads) a number of simulations were repeated at a mooring depth of 65 metres utilising typical shallow water mooring systems.
In all cases the maximum hawser load increases due to the change from deep to shallow water mooring systems.

**Wind Squalls**

The effect of wind squalls was simulated using offshore wind squall data (West Africa) collected and provided by an OCIMF member.
For the purposes of the simulations the CALM Buoy and Turret Moored FPSO simulations assumed the use of a single "pull back" tug of 60-tonnes constant bollard pull. The Spread Moored FPSO simulation assumed two tugs.
Figure 17 - Wind squall simulation of a ballasted VLCC moored to a CALM Buoy

Figure 18 - Wind Squall simulation of a ballasted VLCC tandem moored to a spread moored FPSO

Figure 19 - Wind Squall simulation of a ballasted VLCC tandem moored to a turret moored FPSO

All three ballasted VLCC squall simulations predicted peak mooring hawser loads well below 200 tonnes. However, the main concern highlighted by wind squall simulations was the difficulty in controlling the position of the VLCC relative to a Spread Moored FPSO during the event. Figures 20 and 21 show the "birds eye" plot of the relative positions during the simulations. Figure 21 simulation with one tug in "pull back" mode results in a collision.
Internal Waves, Currents and Solitons

The effect of a moving current line on mooring configurations was modelled by assuming a current front approaches the stern of the moored tanker and imparts current forces increasing in magnitude depending on an assumed current front approach speed. The simulation confirmed the expectation that a tug assisted Spread Moored FPSO tandem operation could easily get into handling difficulties during severe events. However the simulation of a tug assisted tanker tandem moored to a Turret Moored FPSO demonstrated that severe moving current events could be handled safely with predicted peak hawser loads remaining less than 200 metric tonnes.
Waves

Some simulations were repeated with lower significant wave heights (2.5 m Hs as opposed to the simulation standard of 3.5 m Hs) and at a longer wave period (16 seconds as opposed to 10 seconds).

These simulations demonstrated a significant reduction in peak hawser loads with reduction of significant wave height and with increase in wave period. On average a reduction of 1 m Hs resulted in a reduction of 43% on peak hawser load. When combining increased wave period with a reduction in significant wave height a further reduction of 35% of average peak hawser load was recorded. Figures 23, 24 and 25 provide an example of the effects reducing significant wave height and wave period.

Figure 22 - Moving Current simulation - One tug attending a loaded VLCC tandem moored to a turret moored FPSO

Figure 23 - Tug assisted loaded VLCC tandem moored to a ballasted FPSO in E2 environment (Hs 3.5 metres and Tp of 10 seconds)
Angle between Wind and Current

The standard environment (E2) used in many of the simulations assumed a 90 degree angle between wind/waves and current. Some additional sensitivity runs were repeated assuming 120 and 150 degree angles. Increases in peak hawser loads up to 24% were noted. Because of these very high hawser loads further simulations were run reducing the current to 1.5 knots, reducing the wave height to 3 m Hs and using twin hawsers. From inspection of Figures 26 and 27, it can be seen that a combination of reduction of operating criteria and use of twin hawsers can significantly reduce peak hawser loads.
Figure 26 - Tug assisted loaded VLCC tandem moored to a ballasted turret moored FPSO in E2 environment with angle between wind/waves and current increased to 150 degrees. Note the very high peak hawser load of over 600 metric tonnes.

Figure 27 - Tug assisted loaded VLCC tandem moored to a ballasted FPSO in modified E2 environment with twin hawsers.

Note in Figure 27 the blue and red hawser loads represent twin hawser loads when the angle between the wind/waves and current increased to 150 degrees and the wave height reduced to 3.0 m Hs. The green and black hawser loads represent the same situation but with the current reduced to 1.5 knots (from 3 knots).

**Current**

Current obviously induces an additional component to the hawser load but it will also tend to damp the dynamic behaviour of the mooring system. Some simulations were repeated with zero current.
Figure 28 clearly demonstrates the fishtailing effect induced by wind when not dampened by current. The increase in peak hawser load was recorded at about 5% with no current.

Similar simulations were repeated for tankers tandem moored to both Spread Moored and Turret Moored FPSOs and similarly the increase in peak hawser load with no current was minimal and not exceeding 5%.

Fairleads

The simulations also provided calculated forces on the tanker fairleads. As expected the peak force imparted on the fairlead was normally less than that imparted on the hawser. However there were instances when the hawser angle to the fairlead approaches 90° that this was reversed and the peak force imparted on the fairlead was marginally greater than that imposed on the hawser. Forces on both bow chain stopper and fairlead should be equal when the hawser angle to the fairlead is 60°.

4.0 Summary

This study was undertaken to assist OCIMF members in developing revised recommendations for SPM mooring equipment in Recommendations for Equipment Employed in the Bow Mooring of Conventional Tankers at Single Point Moorings 4th Edition.

Based on the results of this study some of the most important conclusions are:

- Peak hawser loads in the same environmental conditions can be expected to be higher for FPSO/FSO tandem mooring systems than standard CALM buoy SPM systems. In some cases the increase is significant.

- Peak tandem hawser loads in the same environmental conditions with current and wind/wave forces from different directions were higher for Spread Moored FPSOs than for Turret Moored FPSOs.

- The use of twin hawsers can lead to a reduction in peak hawser loads.

- The applied wind squall and moving current results produced lower than expected peak loads (not exceeding 200 metric tonnes for a single hawser system), however for tankers tandem moored to a spread moored FPSO the
tendency for dangerous situations to develop (collision) was increased.

- The use of tugs in the simulations did improve the relative headings between the FPSO and the tanker and reduce fishtailing but did not consistently reduce peak hawser loads. In a minority of simulations peak hawser loads were higher using tugs.

- The wave conditions are the most significant single environmental criteria with regard to peak hawser loads. In a number of tandem situations, reducing the significant wave height by 1 metre resulted in peak hawser loads decreasing by 43%.

- Increasing the length of the hawser generally reduced peak hawser loads.

5.0 Study Conclusion

In preparing the 4th Edition of *Recommendations for Equipment Employed in the Bow Mooring of Conventional Tankers at Single Point Moorings*, OCIMF members faced some challenging decisions. The equipment guidance previously provided for conventional tankers (*Recommendations for Equipment Employed in the Mooring of Ships at Single Point Moorings* 3rd Edition 1993) recommended ship equipment levels which included twin chain stoppers and fairleads rated at 200 tonnes SWL for mooring VLCCs up to 350,000 DWT at SPMs. The 3rd Edition also recommended that terminal operators provide twin hawsers for mooring tankers over 150,000 DWT to SPMs. The increasing use of the same shipboard equipment to moor in tandem to FPSOs/FSOs, sometimes with a single hawser, posed some questions that required further investigation.

These simulations focused on the hawser loads in tandem mooring situations. The results are sufficiently conclusive for OCIMF members to state that the risk of imparting loads in excess of the recommended SWL on tanker chain stoppers and fairleads when moored in tandem to an FPSO/FSO is increased when compared to CALM buoy moorings. This risk is further compounded by the use of single hawser systems with some FPSO/FSO tandem mooring arrangements and the added station keeping difficulties associated with tandem mooring a tanker to a fixed azimuth spread moored FPSO/FSO.

In reviewing the results of this study, OCIMF members decided to retain existing recommendations for mooring equipment ratings on existing conventional tankers and to upgrade recommendations for new tankers delivered during or after 2009. The results of this study indicated to OCIMF members that there is sufficient margin for terminal operators to safely moor conventional tankers equipped in accordance with 3rd Edition recommendations in tandem to FPSOs/FSOs provided there is an awareness of the limitations of ship's equipment, the impact of the chosen terminal mooring system and limiting environmental operating criteria. The onus, therefore, for understanding terminal operating limitations and ensuring the safety of the complete mooring system, including ship's equipment fitted in compliance with the recommendations in the 4th Edition of *Recommendations for Equipment Employed in the Bow Mooring of Conventional Tankers at Single Point Moorings*, rests firmly with the terminal operator. Terminal operators, therefore, are strongly encouraged to understand and establish environmental limits and procedures that ensure that the SWL of the mooring equipment fitted to ships calling at these terminals is not exceeded.