Mooring Integrity for Floating Offshore Installations Joint Industry Project: Phase 2 summary

Prepared by the Joint Industry Project Steering Committee for the Health and Safety Executive
Mooring Integrity for floating offshore installations is an important safety issue for the offshore oil and gas industry. This report summarises the outcomes of Phase 2 of the Joint Industry Project on Mooring Integrity. This work ran from 2008 to 2012 and had 35 industry participants. It followed the Phase 1 work described in HSE Research Report RR444 'Floating Production System: JIP FPS mooring integrity' (2006). The Phase 2 work compiled research on good practice for mooring installations and dealt with topics recommended during Phase 1. The primary focus was on testing, data gathering and correlation of in-field behaviour of mooring systems. This summary report acts as a compendium for the 8 detailed reports produced during the Phase 2 Joint Industry Project, which are published as RR1091 to RR1098 and is intended to be read in conjunction with these detailed reports.

The Phase 2 Joint Industry Project has given the industry concise insight into the methods currently in place to identify, survey and monitor mooring integrity for offshore floating installations. It also highlights the challenges facing mooring integrity now and in the years to come.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.
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1 PREFACE

This report summaries the findings, conclusions and recommendations compiled during Phase 2 of the Mooring Integrity Joint Industry Project (JIP) which focused on testing, data gathering and correlation of in field behaviour of mooring systems.

The following companies sponsored Phase 2 of the Mooring Integrity JIP:-

- Maersk Oil
- Petrobras
- BP
- Chevron
- Statoil ASA
- Exxon Mobil
- A/S Norske Shell
- Conoco Philips
- Husky Energy
- 2H Offshore
- Wood Group Engineering
- Single Buoy Moorings Inc.
- SOFEC
- Bluewater Energy Services
- Health and Safety Executive (HSE)
- BG Plc
- Total
- Franklin Offshore
- Lloyds Register EMEA
- Det Norske Veritas (DNV)
- Bureau Veritas (BV)
- American Bureau of Shipping (ABS)
- Welaptega
- Vicinay Cadenas S.A.
- TSC Inspection Systems
- Hamanaka Chain Mfg Co Ltd
- Imes Group
- Sanmar Chain International Pte
- Viking Moorings
- Intermoor
- Ramnas Bruk AB
- Mooring Systems Limited
- Bruce Anchors Limited
- Inpex
- Delmar
- Film Ocean Limited
2 INTRODUCTION

This report acts as a compendium for the sub-reports issued during Phase 2 of the Mooring Integrity for Floating Offshore Installations JIP. It should be noted that this report should be read in conjunction with the original reports and is only intended to summarise some of salient information of each report. Phase 2 produced a total of 9 Reports/Papers and these are listed below.

The contents of the reports were varied and the information plentiful which has given the industry concise insight to the present methods in place to identify, survey and monitor mooring integrity as well as highlighting the problems facing mooring integrity now and in the years to come.

<table>
<thead>
<tr>
<th>REPORT NUMBER</th>
<th>ORIGINAL ISSUE NUMBER</th>
<th>TITLE</th>
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<tbody>
<tr>
<td>RR1091</td>
<td>A5704</td>
<td>Remote Operated Vehicle (ROV) Inspection of Long Term Mooring Systems for Floating Offshore Installations</td>
</tr>
<tr>
<td>RR1092</td>
<td>A5923</td>
<td>Practical Method for Calculating Mooring Chain Wear for Floating Offshore Installations</td>
</tr>
<tr>
<td>RR1093</td>
<td>A6287</td>
<td>An Assessment of Proof Load Effect on the Fatigue Life of Mooring Chain for Floating Offshore Installations</td>
</tr>
<tr>
<td>RR1094</td>
<td>A6743</td>
<td>Microbiologically Influenced Corrosion of Mooring Systems for Floating Offshore Installations</td>
</tr>
<tr>
<td>RR1095</td>
<td>A6767</td>
<td>Guidelines for Monitoring the Service and Behaviour of Mooring Systems for Floating Offshore Installations</td>
</tr>
<tr>
<td>RR1096</td>
<td>A7064</td>
<td>The Effect of Wear and Corrosion of Steel Components on the Integrity of Mooring Systems for Floating Offshore Installations</td>
</tr>
<tr>
<td>RR1097</td>
<td>A7134</td>
<td>Mooring Failure Detection Systems for Floating Offshore Installations</td>
</tr>
<tr>
<td>RR1098</td>
<td>A7629</td>
<td>Degradation of Mooring Chains of Floating Offshore Installations: Chain Measurement, Estimation of Wear, Corrosion Rates, and their Effect on Break Load</td>
</tr>
<tr>
<td>RR1090</td>
<td>OTC20613</td>
<td>Mooring Integrity for Floating Offshore Installations Joint Industry Project: Phase 2 Summary</td>
</tr>
</tbody>
</table>

Figure 2-1 - Phase 2 Mooring Integrity JIP Reports/Papers Issued
3 SUMMARY OF SUB-REPORTS

3.1 REMOTE OPERATED VEHICLES (ROV) INSPECTION OF LONG TERM MOORING SYSTEMS FOR FLOATING OFFSHORE INSTALLATIONS (RR1091/A5704)

3.1.1 Background

This report looked at the need to use Remotely Operated Vehicles (ROVs) to inspect a Floating Production System (FPS) which would remain in fixed positions for considerable period of time. Given the design of FPSs, it is essential to regularly inspect the mooring systems and the report provided guidelines for ROV inspections and what to survey/check and how to conduct the survey.

The value of these inspections is dependent on a number of factors that can be broken down into Hardware, Operational and Human Factors as outlined in Figure 3-1 below:-

<table>
<thead>
<tr>
<th>HARDWARE</th>
<th>OPERATIONAL</th>
<th>HUMAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>∙ Suitability/manoeuvrability of ROV(s) for specified survey</td>
<td>∙ Allocated Survey Time</td>
<td>∙ Depth of knowledge of mooring system integrity issues of person specifying survey and preparing survey pack</td>
</tr>
<tr>
<td>∙ Type of lights and cameras fitted to ROV(s)</td>
<td>∙ General Visibility</td>
<td>∙ Depth of knowledge of ROV(s) operational team of mooring system integrity issues. Both in terms of what to look for and the views that will be of greatest value to those reviewing the footage</td>
</tr>
<tr>
<td>∙ Dimension of ROV and any tooling compared to the size of the access to the inspection site</td>
<td>∙ Marine Growth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>∙ Elapsed time since significant weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td>∙ Width of any mooring line trench in relation to size of ROV(s)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3-1 - Inspection Values

It also gave general guidelines under the following topics:-

- Preparation.
- Gross Damage.
- Relative Pre-tension.
- Straightness.
- Trenching.
- Cathodic Potential Readings.
- Extent of Visible Corrosion.
The report goes on to give detailed descriptions and images of chain, wire and mooring jewellery in varying conditions which included:

- Buoys and Buoy Connections.
- H-Shackles.
- Kenters.
- Shackles.
- Swivels.
- Tri-Plates and other Connectors.
- Clumpweights.
There are four basic areas that can affect the strength of a wire rope by damage to the individual wires within the rope, and all of which to a greater or lesser extent can be detected by ROV survey, namely and each condition was discussed in depth in the report:-

- Wear.
- Corrosion.
- Strands opening up.
- Broken wires.

3.1.2 Conclusion

The original report contained a variety of pictorial examples of corrosion, broken strands, fatigue cracking, loose studs, kinks and twists. This should help Inspectors and ROV pilots gain a better understanding of the problems occurring to mooring lines in the field and during installation.

3.2 PRACTICAL METHOD FOR CALCULATING MOORING CHAIN WEAR FOR FLOATING OFFSHORE INSTALLATIONS (RR1092/A5923)

3.2.1 Background

This 98 page report looked at the mooring line shape, generalised wear, surface roughness and the overall problems in developing of a method/theory for the formulation of calculating the interlink wear for chains that form part of a mooring system. The report went on to give details of chain link movement, chain wear calculation development and calibration and, of course, validation.

Any variation in Top Tension or Depth or a horizontal translation will result in a change in the shape of the catenary and hence a change in the angle between adjacent chain links. If for the moment, a pair of adjacent idealised studless chain links is considered i.e. links of homogenous round cross-section throughout their torus shape, then the physical mechanism that allows the change in angle between the links to take place can be hypothesised.
First, consider the generalised condition, as shown in Figure 3-5 below, of a studless chain link under tension \('T'\) at an angle \('\beta'\), in relation to its adjacent link due to the shape of the catenary curve.

If the tension in the chain length is increased by an amount \('dT'\) then the catenary curve will tend to straighten as illustrated by Figure 3-6. This will cause the angle between the two links to start to decrease by an angular increment \('d\beta'\) (note \('d\beta'\) is taken as being in radians in the following equations), causing the link to rotate in a clockwise direction, in this case, as illustrated by the red link in.

Due to friction, the rotation of the link will cause it to initially ride up the other link by an amount \('dr'\), as shown in the figure above, until such time as the tangential force \('F_T'\) at the contact point, overcomes the friction force \('F_F'\), due to the normal force \('F_N'\) at the contact point, at which point the surfaces will then slide along each other. In order to calculate these forces, at the transition point between rolling and sliding, it is first necessary to determine the angle \('\delta'\) in Figure 3-7, which determines the relationship between the Tension on the link \('T+dT'\) and both the tangential and normal forces at the contact point.
Figure 3-7: Close up of Rolled Up Position

From Figure 3-7 it can be seen that:

\[ \beta + d\beta = \beta + \delta - d\beta \]

**Equation 3-1: Angle balance**

Where ‘\( \beta \)’ is the angle between the two contact points. Based on the fact that the circumferential distance rolled by the moving link, must be equal to the circumferential distance rolled along the non-moving link, then the angle ‘\( \beta \)’ is given by:

\[ \beta = d\beta \frac{r}{R} \]

**Equation 3-2: Angle between contact points due to rotation ‘\( d\beta \)’**

Thus reducing Equation 3-1 to:

\[ \delta = d\beta \left( 1 + \frac{r}{R} \right) \]

**Equation 3-3: Angle between Tension ‘\( T+dT \)’ and the normal force at the contact point due to rotation ‘\( d\beta \)’**

Given the definition of ‘\( \delta \)’ in Equation 3-3, the normal force ‘\( F_N \)’, the tangential force ‘\( F_T \)’, and the friction force ‘\( F_f \)’, at the contact point can be determined:
\[ F_x = (T + dT)\cos(\theta) = (T + dT)\cos\left(\frac{d\beta}{1 + \frac{r}{R}}\right) \]

**Equation 3-4: Contact Point Normal Force**

\[ F_z = (T + dT)\sin(\theta) = (T + dT)\sin\left(\frac{d\beta}{1 + \frac{r}{R}}\right) \]

**Equation 3-5: Contact Point Tangential Force**

\[ F_r = \mu F_x = \mu(T + dT)\cos\left(\frac{d\beta}{1 + \frac{r}{R}}\right) \]

**Equation 3-6: Contact Point Friction Force**

where \(\mu\) is the coefficient of friction.

In order for the link to roll up the other link, then the Friction Force must exceed the Tangential Force. Similarly, for the link to slip, the Tangential Force must exceed the Friction Force. Hence, the following expression can be developed for the point at which slippage occurs:

\[ F_r = F_z \Rightarrow F_r = \mu F_x \]

\[ (T + dT)\sin\left(d\beta_{\text{Critical}}\left(1 + \frac{r}{R}\right)\right) = \mu(T + dT)\cos\left(d\beta_{\text{Critical}}\left(1 + \frac{r}{R}\right)\right) \]

\[ \frac{1}{\mu} \tan\left(d\beta_{\text{Critical}}\left(1 + \frac{r}{R}\right)\right) = 1 \]

**Equation 3-7: Roll Up Limit for Studless Chain**

If the two radii and the coefficient of friction are taken as pseudo-static quantities, then the Roll Up Limit Angle, \(d\beta_{\text{Critical}}\), can be found by solving Equation 3-7 for \(d\beta_{\text{Critical}}\). This can then be related to a change in tension \(dT\) from a starting tension \(T\) via the Catenary Equation. If \(T + dT > T\), where \(T\) is the final tension for a given tension change, then no slippage will occur and the chain link will simply roll up the adjacent link. If, however, \(T' > T + dT\) then slippage will occur and the chain link will take up a new position as dictated by the Catenary Equation, with the link at an angle \(\Phi\) such that \(\Phi\) equals \(\beta - d\beta\), as shown by the green link in Figure 3-8 below.

![Figure 3-8: Final Position](image-url)
This means that if the change in angle \(d\beta\) is less than the **Roll Up Limit Angle** \(d\beta_{\text{Critical}}\), such that friction prevents the chain links from sliding over each other, then the total distance traversed by the chain links over each other will be given by:

\[
For \ d\beta < d\beta_{\text{Critical}} \ldots dr = 2\pi r \frac{d\beta}{2\pi} = r |d\beta| \ldots \text{Rolling only}
\]

Equation 3-8: Rolling only Distance for Studless Chain

Whereas if the change in angle \(d\beta\) is greater than the **Roll Up Limit Angle** \(d\beta_{\text{Critical}}\), then the chain links will roll-up before sliding to their final position. Therefore the total distance travelled of one link relative to the other will be the summation of the rolling \(dr\) and sliding \(ds\) distances given by:

\[
For \ d\beta > d\beta_{\text{Critical}} \ldots \left[ dr = r |d\beta_{\text{Critical}}| \ldots \text{Rolling} \right] + \left[ ds = r |d\beta_{\text{Critical}}| + R |d\beta| \ldots \text{Sliding} \right]
\]

Equation 3-9: Rolling and Sliding Distances for Studless Chain

The same process can also be used to find similar equations for studded chain, where it is assumed that the inside of a studded chain link can be represented by an ellipse with a semi-major axis length equal to half the inner length of the chain \(b\) and a semi-minor axis length equal to half the inner width of the chain at its widest point \(a\):

\[
\tan^{-1}\left( \frac{(a \times (a \times \tan (r \times d\beta_{\text{Critical}}) + b \times \tan (\beta)))}{b \times (a - b \times \tan (r \times d\beta_{\text{Critical}}) \times \tan (\beta))} \right) - \beta + d\beta_{\text{Critical}} = \mu
\]

Equation 3-10: Roll Up Limit for Studded Chain

\[
For \ d\beta < d\beta_{\text{Critical}} \ldots dr = r |d\beta| \ldots \text{Rolling only}
\]

Equation 3-11: Rolling only Distance for Studded Chain

\[
For \ d\beta > d\beta_{\text{Critical}} \ldots \left[ dr = r |d\beta_{\text{Critical}}| \ldots \text{Rolling} \right] + \left[ \tan^{-1}\left( \frac{(b \times \tan (\beta - d\beta))}{a} \right) - \tan^{-1}\left( \frac{(b \times \tan (\beta))}{a} \right) \right] \ldots \text{Sliding}
\]

Equation 3-12: Rolling and Sliding Distances for Studded Chain

If standard studded chain geometry is assumed then:

\[
\tan^{-1}\left( \frac{(0.32 \times \tan (r \times d\beta_{\text{Critical}}) + 0.8 \times \tan (\beta))}{(0.8 - 2 \times \tan (r \times d\beta_{\text{Critical}}) \times \tan (\beta))} \right) - \beta + d\beta_{\text{Critical}} = \mu
\]

Equation 3-13: Roll Up Limit for Standard Studded Chain

\[
For \ d\beta < d\beta_{\text{Critical}} \ldots dr = r |d\beta| \ldots \text{Rolling only}
\]

Equation 3-14: Rolling only Distance for Standard Studded Chain
The above idealised condition makes a number of assumptions, particularly as regards the shape of the bar and the shape of the link. In reality chain links are not of uniform cross-section due to a variety of reasons.

There is a well known formula for the minimum break load of chains, namely:

$$MBL = k d^2 (44 - 0.08d)$$

Equation 3-16: Chain Minimum Break Load Equation

Where:

\(d\) = nominal chain diameter

and \(K\) is proportional to the minimum ultimate strength of the grade of material

0.08d takes into account the effect of thickness of the material on its mechanical properties. With the use of defined constants \(K\), for each chain grade, this formula results in the following curves for the minimum break loads of various chain grades that appear in manufacturers’ and Class rules, and for which break tests are performed against.

**Minimum Break Load versus Chain Diameter**

![Minimum Break Load versus Chain Diameter](image)

**Figure 3-9: Minimum Break Loads curves for various grades of Offshore Mooring Chain**

The actual geometry of the links needs to be taken into account in the diameter loss versus volume loss relationship as well as the fundamental difference in geometry between a studded and studless link, as shown below:-
Figure 3-10: Chain Link Geometry
Figure 3-11 - Chain Wear Calculation Methodology

### 3.2.2 Conclusion

Extracted from original report:

“At first glance, this figure appears to show a significant over prediction of the double diameter loss over time. In reality though, the over prediction at the end of the period is only 1.7%, 3.5% and 4.5% respectively for inter-grip links 21/22, 22/23 and 23/24. This is an acceptable error rate for such a calculation. The predicted diameter loss rates in given in Table 6-2 are also an improvement on those typically stated in mooring codes of up to 0.6mm/year, as these links would appear to have been seeing between 2 and 5mm per year wear depending on how the measured data is interpreted.”
This error rate can be reduced to 0.001%, 1.405%, and 2.152% respectively for inter-grip links 21/22, 22/23 and 23/24 if the sliding wear coefficient \( K_s \) is reduced to 0.0139, without the model under-predicting the wear, as shown in the figure overleaf. Consequently, it is believed that there is a good basis for utilising the methodology when predicting the wear on mooring systems. Further application of this method to other mooring systems will also act as a useful cross-check and will allow the further validation of the methodology and in particular the wear coefficients.

![Figure 6-2 - Absolute Actual Double Diameter Wear versus Predicted Double Diameter Wear with \( K_s=0.0139'' \)](image)

<table>
<thead>
<tr>
<th>Inter-grip Links</th>
<th>Predicted Wear Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>21/22</td>
<td>1.91 mm/year</td>
</tr>
<tr>
<td>22/23</td>
<td>2.34 mm/year</td>
</tr>
<tr>
<td>23/24</td>
<td>2.81 mm/year</td>
</tr>
</tbody>
</table>

Table 3-1: Loss of Diameter Wear Rates
3.3 AN ASSESSMENT OF PROOF LOAD EFFECT ON THE FATIGUE LIFE OF MOORING CHAIN FOR FLOATING OFFSHORE INSTALLATIONS (RR1093/A6287)

3.3.1 Background

The report investigated the effect of the residual stresses from proof loading on the fatigue life for both Tension-Tension and Tension-Bending.

The topics covered, in some depth, under this report included:-

- Proof Testing.
- Fatigue Failures in Chain.
- Fatigue and Residual Stress.
- Tension Fatigue Proof Load Test Results.
- Bending, Torsion and Proof Load.

![Figure 3-12 - Stress Distribution in Chain Link during Tension](image)

![Figure 3-13 - Fatigue Cracks at the Crown](image)
3.3.2 Conclusion

The report identified the following issues:-

- Proof load has been found to be beneficial for the integrity of chain and enhances fatigue life under tensile loading.

- Even though proof loading is proven beneficial to tension fatigue, it may reduce out of plane bending fatigue life or detrimental to twisted chains. Formulae that estimate non-tensile chain fatigue life based on the chain tension fatigue design curves should account for the distribution and effect of residual stresses and should be investigated.

- Any beneficial effect of proof loading may be confined to the period until the residual stresses are relieved- cyclic loading/higher working loads. This requires further investigations.

- Crack initiation is influenced by the mean tensile stress. Hence compressive residual stress is beneficial. However, once a crack is formed, crack propagation may not be influenced by the mean stress in the chain, and hence residual stress.

- A difficulty for high strength (e.g. R4) chain is that proof stress is cited with reference to specified minimum Ultimate Tensile Strength (UTS)/Break Load, not batch tested break load. It is difficult to ensure that there has been small permanent set to induce the beneficial compressive stress (in tension fatigue).

- If a batch has significantly higher UTS (which in many aspects is desirable) the degree of plasticity at the proof load level may be significantly less than the assumed with minimum specification material. A better definition of proof loading with respect to the actual break strength is required to make best use of the beneficial effect of proof loading.

- It has been noted that the rate at which break load is applied influence the outcome. The influence of the rate of proof loading is not known and deserves further discussion.

- For stud link chain if the degree of plasticity under proof loading is less than anticipated, studs will be more likely to become loose in service.

- Plastic deformation at the contact zone due to proof loading has a detrimental effect due to a possible partial locking of the links, thereby increasing susceptibility to out of plane bending.

- Quick reversal of residual stress at the periphery of the interlink contact zone may initiate cracks. Assisted with sea-water and contact fatigue, the cracks may propagate faster.
3.4 MICROBIOLOGICALLY INFLUENCED CORROSION OF MOORING SYSTEMS FOR FLOATING OFFSHORE INSTALLATIONS (RR1094/A6743)

3.4.1 Background

This report provided an up-date of the views currently held in connection with Microbiologically Influenced Corrosion (MIC) and how it affects corrosion.

<table>
<thead>
<tr>
<th>CASE</th>
<th>CAUSE OF INVESTIGATION</th>
<th>POSITION ON MOORING SYSTEM</th>
<th>CORROSION PATTERN</th>
<th>EVIDENCE OF MIC</th>
<th>DEPTH OF ATTACK OR PITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Planned inspection</td>
<td>Bottom / touch down</td>
<td>Pitting and irregular corrosion</td>
<td>High sulphur, black patches and corrosion products $\rightarrow$ Fe, Add HCI $\rightarrow$ H2S</td>
<td>1-2mm</td>
</tr>
<tr>
<td>2</td>
<td>Failure</td>
<td>At FPSO</td>
<td>Pitting and weld corrosion</td>
<td>High sulphur in corrosion products</td>
<td>2.1mm</td>
</tr>
<tr>
<td>3</td>
<td>Failure</td>
<td>Above seabed - occasional seabed contact</td>
<td>Pitting small and large</td>
<td>Black patches on retrieval suggesting Fe high sulphur in corrosion pits</td>
<td>5-6mm</td>
</tr>
<tr>
<td>4</td>
<td>Planned inspection</td>
<td>Touch down &amp; above touch down</td>
<td>Severe material loss / pitting</td>
<td>Suggested based on severity of metal loss, pit topography, black patches and foul smell</td>
<td>14mm loss of segment; 2-4mm deep pits</td>
</tr>
<tr>
<td>5</td>
<td>Planned inspection</td>
<td>At FPSO</td>
<td>Pits</td>
<td>Suggested based on topography and black patches. Unique compared to neighbouring chains</td>
<td>3-4mm</td>
</tr>
</tbody>
</table>

Figure 3-14 - Summary of key information from field cases with suspected MIC

The study was compiled as a result of available information and helpful discussions with international experts.

3.4.2 Conclusion

Perhaps one of the significant observations in the study was that the fact that the most vulnerable parts of the mooring system seemed to be the touch down region and the area just below the splash zone.

It was discovered that most of the severe corrosion was found to be in the warm regions although, somewhat illogically, the majority of the cases reported were from the cold regions.

It was hoped that the study would encourage operators to inspect and test any MIC found and to report the findings so that the industry could utilise the data to bring about improvements in the future.
3.5 GUIDELINES FOR MONITORING THE SERVICE AND BEHAVIOUR OF MOORING SYSTEMS FOR FLOATING OFFSHORE INSTALLATIONS (RR1095/A6767)

3.5.1 Background

This report covered the reasons behind installing a monitoring system and the various types of systems available for use.

Reasons for carrying out a monitoring campaign or installing a permanent monitoring system are covered in Figure 3-15.

<table>
<thead>
<tr>
<th>PURPOSE</th>
<th>CAMPAIGN</th>
<th>PERMANENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verify Design Analysis and Assumptions</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Correlation of Fatigue Analyses</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Instantaneous Integrity Monitoring</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Continuous Integrity Monitoring</td>
<td>✗</td>
<td>✓</td>
</tr>
</tbody>
</table>

*Figure 3-15 - Possible Reasons for a Monitoring Campaign or Permanent System*

It would be necessary, as a minimum, to monitor and record:

- Vessel motions.
- Vessel position.
- Vessel Draft and Trim.
- Wind speed and direction.
- Wave height, period and direction.
- Current speed and direction.
Description of metocean conditions, structures and connected items were briefly detailed. The report proceeds to explain the best ways to monitor them and how to use the data gathered.

**Figure 3-16 - Items to be Monitored**

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>ITEM</th>
<th>MEASURE</th>
<th>VERIFY STRENGTH ANALYSIS</th>
<th>CORRELATE FATIGUE ANALYSIS</th>
<th>INSTANTANEOUS INTEGRITY MONITORING</th>
<th>CONTINUOUS INTEGRITY MONITORING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Time base line</td>
<td>Time</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Motions</td>
<td>Surge</td>
<td>Acceleration</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Position</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Sway</td>
<td>Acceleration</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td></td>
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<td>Yes</td>
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<tr>
<td></td>
<td>Heave</td>
<td>Acceleration</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td></td>
<td></td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Pitch</td>
<td>Acceleration</td>
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<td>Yes</td>
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<td></td>
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<td></td>
<td>Roll</td>
<td>Acceleration</td>
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<tr>
<td></td>
<td></td>
<td>Position</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Yaw</td>
<td>Acceleration</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td></td>
<td></td>
<td>Position</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Metocean Conditions</td>
<td>Wind</td>
<td>Speed</td>
<td>Yes</td>
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<td></td>
<td></td>
<td>Direction</td>
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<tr>
<td></td>
<td>Waves</td>
<td>Height</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td></td>
<td></td>
<td>Period</td>
<td>Yes</td>
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<td>Current</td>
<td>Speed</td>
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<td>Yes</td>
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<td></td>
<td>Direction</td>
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<td>Yes</td>
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<td>Water</td>
<td>Level</td>
<td>Consider</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Structure</td>
<td>Deck</td>
<td>Strain</td>
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<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N/A</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
</tr>
<tr>
<td></td>
<td>Columns&quot;</td>
<td>Strain</td>
<td>N/Ai</td>
<td>N/Ai</td>
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<td>Consideri</td>
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<tr>
<td></td>
<td>Mid-ship Section&quot;</td>
<td>Strain</td>
<td>N/Aii</td>
<td>N/Aii</td>
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<td>Considerii</td>
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<tr>
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<td>Strain</td>
<td>N/Aiii</td>
<td>N/Aiii</td>
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<td>Consideriii</td>
</tr>
<tr>
<td></td>
<td>Turret Spider / Spar Cantilevers&quot;</td>
<td>Strain</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
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<tr>
<td></td>
<td>Buoy Structure&quot;</td>
<td>Strain</td>
<td>Consider</td>
<td>Consider</td>
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<tr>
<td>Relative Motions</td>
<td>Turret to Hull&quot;</td>
<td>Rotational Motion</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
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<tr>
<td></td>
<td>Unit to Platform&quot;</td>
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<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
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<td>Tension</td>
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<td>Yes&quot;</td>
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<tr>
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<td>Angle</td>
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<td>Yes&quot;</td>
<td>Yes&quot;</td>
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<td>Mooring Tendons&quot;</td>
<td>Tension</td>
<td>Consider</td>
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<td>Yes&quot;</td>
<td>Yes&quot;</td>
</tr>
<tr>
<td></td>
<td>Angle</td>
<td>Consider</td>
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<td>Yes&quot;</td>
<td>Yes&quot;</td>
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<td>Consider&quot;</td>
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<tr>
<td></td>
<td>Angle</td>
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<td>Consider</td>
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<td>Yes&quot;</td>
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<td></td>
<td>Angle</td>
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<td>Yes&quot;</td>
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<td>Consider</td>
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<td>Top Tensioned Risers</td>
<td>Tension</td>
<td>Consider</td>
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<tr>
<td></td>
<td>Angle</td>
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<td>Yes&quot;</td>
<td>Yes&quot;</td>
<td>Yes&quot;</td>
<td>Yes&quot;</td>
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<td>FPS Weight</td>
<td>Displacement</td>
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<td>Yes</td>
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<tr>
<td></td>
<td>Trim / Heel</td>
<td>Consider</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Ballast / Cargo</td>
<td>Levels</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
</tr>
<tr>
<td></td>
<td>Position</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
<td>Consider</td>
</tr>
</tbody>
</table>
Data management can be reduced to the following simple questions:-

- What data and where from?
- What data analysis needs to be undertaken?
- Where does it need to be and when does it need to be there?
- How will this be achieved?

3.5.2 Conclusion

The report is of particular benefit to an Operator at the initial stages of a floating production project to identify how best to make use of full scale data.

3.6 THE EFFECT OF WEAR AND CORROSION OF STEEL COMPONENTS ON THE INTEGRITY OF MOORING SYSTEMS FOR FLOATING OFFSHORE INSTALLTIONS (RR1096/A7064)

3.6.1 Background

The purpose of this 42 page sub-report was to give insight into issues relating to wear and corrosion of mooring system components and provide guidelines to identify how the degradation modes are affected by material properties, design and operation.

Some of the topics covered included the following:-

- Basic Mechanisms and Reactions.
- Driving Forces for Corrosion.
- Corrosiveness and Natural Limitations.
- Galvanic Effects.
- Pitting or Localised Corrosion.
• Corrosion Vulnerability for Mooring System Components.
• The Sea Water Environment.

![Image](image1.png)

**Figure 3-21 - Example of “Black” Cracked Chain on the Back Deck of an Anchor Handling Tug**

![Image](image2.png)

**Figure 3-22 - Typical Corrosion Pattern on a Chain after a Long Deployment**

### 3.6.2 Conclusion

This JIP sub-report is the result of evaluation of material compatibility and degradation issues for steel parts of mooring systems on permanently moored floating installations. The assessment focussed on chain and connecting components such as shackle and tri-plates as well as vessel fixed equipments that are in metallic contact with mooring chain. The following is extracted from the original report:-

**“Material Properties**

*Steel components in a mooring system are made from low alloy steel with typically less than 5% alloying elements with a minimum yield strengths of 700 MPa and 760 MPa.”*
MPa for the R4 and R5 grades respectively. The primary requirements for the
different grades are defined in terms of mechanical properties and toughness.

Relevant industry standards for mooring chains specify requirements for acceptable
types of heat treatments and grain size. Certain alloying elements such as
Molybdenum should exceed defined minimum values. Apart from this the chemical
composition should be agreed between manufacturer and purchaser.

The main material compatibility and degradation issues considered are corrosion
and wear. The susceptibility to fatigue is not considered, but it is essential to be
aware that excessive corrosion or wear can lead to the initiation of fatigue cracks
under cyclic loading.

The corrosion and wear properties will be influenced by the chemical composition,
macrostructure, hardness and surface condition in terms of roughness and oxides.
For the relevant steel qualities hardness tend to be proportional to the strength of
the steel. The hardness of the R4 grade has a Vicker's hardness around 275 while
the equivalent for R5 is around 305.

**Corrosion**

Low alloy steels exposed to seawater environment will corrode through dissolution
(oxidation) of iron as the anodic reaction and reduction of oxygen as the cathodic
reaction. Models predict general corrosion where anodic and cathodic sites move
around on the surface while in reality there will be a combination of general and
pitting corrosion. A high degree of homogeneity of the steel (on the surface) will be
the best inherent material property to minimise corrosion. However, conditions on
the surface and close to the surface will strongly influence the corrosion behaviour.
Availability of oxygen (enhanced by flowing water) and temperature are important
factors. It has been reported in the literature that a 10 degrees increase in
temperature could increase the corrosion rate by a factor between 1.5 and 2.

**Formation of calcareous deposits** on the steel surface is considered to be one of the
strongest features to limit the corrosion rate. Deposits of corrosion products (such a
iron hydroxides) will also contribute to limiting corrosion rates. Bare steel surfaces
are more anodic (more prone to corrosion) than surfaces covered with deposits and
bio-films. Thus damages to surface deposits can lead to enhanced corrosion and
possibly tendencies to pitting corrosion.

Relative motion of contacting steel surfaces in the link to link inter-grip area in
chains will lead to damage of surface deposits and exposure of bare steel surfaces.
This will make the inter-grip areas more vulnerable to corrosion and the same also
apply in similar ways to other contact areas with relative motion. The location where
the chain is in contact with the hawse pipe is an example.

There are reported cases of excessive corrosion in the weld region (HAZ) on chain
links. One reported investigation has demonstrated that the likely cause was related
to the formation of a structural (micro-structural) steel phase that was more anodic
than the base material. This may have been caused by inadequate heat treatment
resulting in significant in-homogeneities in the steel. This points to the importance
of ensuring good material homogeneity.

Galvanic corrosion can take place when materials with different galvanic potentials
are electrically connected. Low alloy steels with similar composition and
macrostructure will exhibit similar galvanic potentials in the same environment
ensuring that galvanic corrosion is unlikely. If there is a need to combine
components with different galvanic potentials it is important that the smallest
component is made from a more noble material. If the smallest component is less
noble excessive corrosion can take place on the smallest component.
Non-intentional electrical current that pass through parts of a mooring line may causes stray current corrosion. Sources of current could be faulty electrical equipment or impressed current cathodic protection systems with poor design. In locations where the electrical currents leave a steel component excessive dissolution of metal ions will take place. Stray current corrosion should be avoided through appropriate design and adequate maintenance.

Cathodic protection (CP) is normally not implemented on mooring chains and connecting components. However cathodic protection systems on the floater will reach some way down the chain. The reach will depend on the electrical resistance between chain links and the level of protection will go down with distance from where the chain is electrically connected to the floater. It has been estimated that CP will lose any noticeable effect 20 – 40 links out from the floater the chain is connected to.

It is important to note that wire ropes that are protected through galvanisation should be electrically isolated from steel components they are connected to. This is to avoid that the galvanisation is consumed through cathodic protection of other steel components rather than protect the wire rope itself. This principle of electrical isolation must also be applied for components that are protected with attached anodes to avoid non-intentional anode consumption.

Wear

Mooring system components are susceptible to wear on contacting surfaces such as the inter grip between chain links, shackle bolt and at locations where chains are in contact with hawse pipes and fairleads. The degree of wear will depend on properties of the surfaces such as roughness and hardness, the environment, contact forces and the movement pattern.

The corrosive nature of seawater may lead to synergistic wear rates that are higher than the sum of wear and corrosion as independent processes. Wear can remove protective deposits enhancing the rate of corrosion and corrosion may increase surface roughness. There will be significant variability due to variations in contact forces, movement patterns and environmental conditions.

The first and simplest step to minimise wear is to reduce friction by ensuring that contacting surfaces are reasonably smooth without any sharp edges or proud weld deposits in contact locations.

Another solution to reduce wear is to increase the hardness on one of the contacting surfaces (for instance in shackle bolts). The increase should be significant (minimum 30%) and the hardest surface should have the lowest roughness. The differences in hardesses for standard steel grades for mooring system components are too small to achieve the required hardness differences. Special surface treatments or deposits should be considered such as Wolfram Carbide or ceramics but it is important that they do not peel off. The use of a different material than steel on the harder surface will also reduce the adhesive wear.

Development Needs

To enhance the design optimisation and service life prediction capabilities related to corrosion and wear of mooring components a range of experimental type investigations should be carried out. These should cover:

- The influence from surface conditions on the corrosion properties of chain links.
• Measure the variation in corrosion properties of materials from different batches and different manufacturers.

• Establish standardised methods for measuring galvanic properties of material samples taken from different location on chain links or other relevant components.

• Characterisation of combined wear and corrosion properties for a range of relevant configurations and conditions.

• Possible effects from stray current

• Solutions for cathodic protection

• Enhanced material selection and preparation to minimise wear.”

3.7 MOORING FAILURE DETECTION SYSTEMS FOR FLOATING OFFSHORE INSTALLATIONS (RR1097/A7134)

3.7.1 Background

The purpose of this report was to provide the industry with a summary of the state of the industry as regards mooring failure detection systems and covered the following questions:-

• What regulations exist?

• What guidance exists?

• What systems are being marketed?

• What systems are being considered as potential developments?

The report, aimed mainly at Operators, reviewed the industry available published guidance in order to provide a summary of the considerations for those seeking to install a mooring failure detection system and what they need to take into account and stated:-

“A Mooring Failure Detection system is one that is a safety system, one that provides important and immediate information to the personnel on board as regards the level of risk they are exposed to right now, including risk to the unit itself and potentially to the environment – from failed risers - and other installations in the vicinity from a drifting unit.”

A Mooring Failure Detection system fitted to a floating production unit is just one aspect of a larger and more inclusive mooring monitoring system that has additional purposes including:-

• Verifying design analyses and assumptions.

• Correlation of fatigue analyses.

• Continuous integrity monitoring.
The following list shows the currently available systems types, some of which are illustrated below:-

- Direct Tension Measurement.
- Tension / Angle Measurement.
- Tension / Stress Measurement.
- Sonar.
- Visual.

![Figure 3-23 - Example Sonar Graphical User Interface (Courtesy of Tritech)](image1)

![Figure 3-24 - Example of Deck Equipment for a Deployable Camera System (Courtesy of Ocean Tools)](image2)
Outlined in the report were systems under consideration to benefit monitoring failures and these are detailed below together with illustrations showing some these:-

- Hull Mounted Sonar.
- Seabed Sonar.
- Oscar.
- Depth Sensor.
- Multi-Sensor Unit.
Figure 3-27 - Seabed Mounted Sonar Arrangement

Figure 3-28 - Example of an Optical Fibre Strain Transducer embedded in a Polyester Rope (Courtesy of BPP-Tech)

Figure 3-29 - Depth Sensor Transponder Unit Arrangement (Courtesy of QinetiQ)
Typical initial arrangement

Line failure below unit

Line failure above unit

Figure 3-30 - Operation of Depth Sensor Arrangement (Courtesy of QinetiQ)
3.8 DEGRADATION OF MOORING CHAINS OF FLOATING OFFSHORE INSTALLATIONS: CHAIN MEASUREMENT, ESTIMATION OF WEAR, CORROSION RATES, AND THEIR EFFECT ON BREAK LOAD (RR1098/A7629)

3.8.1 Background

The above report was written to provide operators and those involved in the designing, verifying and integrity management of offshore floating production units with guidelines in respect of:-

- Above water / on shore chain measurement.
- Cross-sectional area estimation.
- Chain measurement analysis techniques.
- Typical wear and corrosion rates for offshore mooring chains.
- Break testing of aged mooring chains.
- Down rating of aged offshore mooring chains.

![Figure 3-31 - Chain Link Measurement Locations (Studded or Studless Chain)](image1)

![Figure 3-32: Standard Measurement Gauge over Worn Chain in an attempt to find the Diameter](image2)
<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Region</th>
<th>Years Service</th>
<th>Mean D&lt;sub&gt;in Line&lt;/sub&gt;</th>
<th>CoR D&lt;sub&gt;in Line&lt;/sub&gt;</th>
<th>Mean D&lt;sub&gt;out of Plane&lt;/sub&gt;</th>
<th>CoR D&lt;sub&gt;out of Plane&lt;/sub&gt;</th>
<th>Nominal Corrosion Rate</th>
<th>Nominal Wear &amp; Corrosion Rate</th>
<th>Nominal CSA Loss Rate</th>
<th>Sample Size</th>
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<td>102.5%</td>
<td>3.2%</td>
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<td>0.62% p.a.</td>
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<td>Semi-submersible FPU</td>
<td>North Sea</td>
<td>15</td>
<td>99.3%</td>
<td>7.1%</td>
<td>101.8%</td>
<td>4.51%</td>
<td>0.61% p.a.</td>
<td>0.13% p.a.</td>
<td>580</td>
<td></td>
</tr>
<tr>
<td>Semi-submersible FPU</td>
<td>North Sea</td>
<td>17</td>
<td>95.1%</td>
<td>9.2%</td>
<td>102.2%</td>
<td>3.2%</td>
<td>0.34% p.a.</td>
<td>1.39% p.a.</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Semi-submersible FPU</td>
<td>North Sea</td>
<td>16</td>
<td>90.5%</td>
<td>7.2%</td>
<td>98.2%</td>
<td>4.4%</td>
<td>0.3% p.a.</td>
<td>1.39% p.a.</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Semi-submersible FPU</td>
<td>North Sea</td>
<td>19</td>
<td>91.8%</td>
<td>13.0%</td>
<td>100.0%</td>
<td>7.4%</td>
<td>0.3% p.a.</td>
<td>0.39% p.a.</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Spread Moored FPSO</td>
<td>Africa</td>
<td>12</td>
<td>95.3%</td>
<td>5.6%</td>
<td>100.0%</td>
<td>7.4%</td>
<td>0.9% p.a.</td>
<td>0.39% p.a.</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Turret Moored FPSO</td>
<td>Africa</td>
<td>9</td>
<td>100.6%</td>
<td>3.2%</td>
<td>101.8%</td>
<td>4.51%</td>
<td>0.3% p.a.</td>
<td>0.9% p.a.</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>New Studded Chain</td>
<td></td>
<td>0</td>
<td>100.6%</td>
<td>3.2%</td>
<td>101.8%</td>
<td>4.51%</td>
<td>0.3% p.a.</td>
<td>0.9% p.a.</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3-33 - Normalised Indicative Wear and Corrosion Rates
3.8.2 Conclusion

Figure 3-34 below, contains the results of a number of break tests that have been carried out and made available in an anonymous manner. Gratitude is expressed to the companies and units that have made the data set available, which covers four different units, three grades of chain, and thirteen individual break tests.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Type</th>
<th>Service</th>
<th>BL/MBL Ratio</th>
<th>BL/MBL Ratio Loss Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>R4</td>
<td>Studless</td>
<td>10years</td>
<td>98.5%</td>
<td>0.15% per annum</td>
</tr>
<tr>
<td>R4</td>
<td>Studless</td>
<td>10years</td>
<td>100.0% ⁴</td>
<td>No Loss</td>
</tr>
<tr>
<td>R4</td>
<td>Studless</td>
<td>10years</td>
<td>98.8%</td>
<td>0.12% per annum</td>
</tr>
<tr>
<td>R4</td>
<td>Studless</td>
<td>10years</td>
<td>100.3% ⁴</td>
<td>No Loss</td>
</tr>
<tr>
<td>R4</td>
<td>Studless</td>
<td>10years</td>
<td>100.3% ⁴</td>
<td>No Loss</td>
</tr>
<tr>
<td>R3</td>
<td>Studless</td>
<td>12years</td>
<td>97.1%</td>
<td>0.24% per annum</td>
</tr>
<tr>
<td>R4</td>
<td>Studded</td>
<td>20years</td>
<td>83.5%</td>
<td>0.83% per annum</td>
</tr>
<tr>
<td>R4</td>
<td>Studded (stud removed)</td>
<td>20years</td>
<td>84.9%</td>
<td>0.76% per annum</td>
</tr>
<tr>
<td>R4</td>
<td>Studded (stud misplaced)</td>
<td>20years</td>
<td>88.1%</td>
<td>0.60% per annum</td>
</tr>
<tr>
<td>ORQ+20%</td>
<td>Studless</td>
<td>4years</td>
<td>97.4%</td>
<td>0.65% per annum</td>
</tr>
<tr>
<td>ORQ+20%</td>
<td>Studless ⁶</td>
<td>4years</td>
<td>90.7%</td>
<td>2.33% per annum</td>
</tr>
<tr>
<td>ORQ+20%</td>
<td>Studless ⁸</td>
<td>4years</td>
<td>94.7%</td>
<td>1.33% per annum</td>
</tr>
</tbody>
</table>

\textit{Notes}

\begin{enumerate}
\item \textit{Chain sustained this load for 30 seconds before test was curtailed without link actually failing.}
\item \textit{Notch with a length equivalent to 13\% of the nominal diameter was introduced on the shoulder of the link to investigate the effects of this.}
\item \textit{Notch with a length equivalent to 17\% of the nominal diameter was introduced on the shoulder of the link to investigate the effects of this.}
\end{enumerate}

3.9 MOORING INTEGRITY FOR FLOATING OFFSHORE INSTALLATIONS
JOINT INDUSTRY PROJECT: PHASE 2 SUMMARY (RR1090/OTC20613)

3.9.1 Background

This OTC paper was presented at the 2010 Offshore Technology Conference in Houston in May of 2010.

The paper essentially provided a useful and valuable summary of the findings of the JIP.

3.9.2 Conclusion

The paper highlighted the findings to-date of the second phase of the Mooring Integrity JIP and the objectivity needed to improve mooring durability whilst maintaining safety.

The paper emphasised that the information gathered throughout the JIP was not just of interest and benefit to the floating production industry but would also be apt for the offshore drilling industry as well as moored renewable energy systems.
4 EXECUTIVE CONCLUSION

During the lifetime of this JIP much data has been gathered, digested, discussed and distributed on mooring integrity and the issued reports have provided the industry with beneficial insight to the existing systems being used and the advantages of making improvements. Whilst the reports have been detailed on the subjects discussed it should be considered that as technology advances and more monitoring is conducted and results collated (and hopefully shared for the greater benefit of the industry) further reporting should be carried out under another JIP.

5 ACKNOWLEDGEMENTS

As previously documented, it goes without saying that the Phase 2 JIP would not have been as successful and productive without the support and information sharing of the Sponsors and contributing suppliers who provided data.
This report is intended for the sole use of the person or company to whom it is addressed and no liability of any nature whatsoever shall be assumed to any other party in respect of its contents.

GL NOBLE DENTON

Signed: ____________________________________________

Martin Brown CEng MRINA MSc MBA BSc (hons)

Countersigned: _______________________________________

Eur Ing Andrew Comley CEng MRINA BEng (hons)

Dated: Aberdeen, 4 May 2012
Mooring Integrity for floating offshore installations is an important safety issue for the offshore oil and gas industry. This report summarises the outcomes of Phase 2 of the Joint Industry Project on Mooring Integrity. This work ran from 2008 to 2012 and had 35 industry participants. It followed the Phase 1 work described in HSE Research Report RR444 ‘Floating Production System: JIP FPS mooring integrity’ (2006). The Phase 2 work compiled research on good practice for mooring installations and dealt with topics recommended during Phase 1. The primary focus was on testing, data gathering and correlation of in-field behaviour of mooring systems. This summary report acts as a compendium for the 8 detailed reports produced during the Phase 2 Joint Industry Project, which are published as RR1091 to RR1098 and is intended to be read in conjunction with these detailed reports.

The Phase 2 Joint Industry Project has given the industry concise insight into the methods currently in place to identify, survey and monitor mooring integrity for offshore floating installations. It also highlights the challenges facing mooring integrity now and in the years to come.

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