In-service Inspection of Mooring Hardware for Floating Structures

API RECOMMENDED PRACTICE 2I
THIRD EDITION, APRIL 2008

REAFFIRMED, JUNE 2015

AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, D.C. 20005, standards@api.org.

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Introduction

The third edition of API RP 2I is an extension of the second edition, which addresses in-service inspection of mooring components for MODUs only. Major changes of this edition include:

— inspection guidelines for steel permanent moorings on permanent floating installations are added;

— inspection guidelines for fiber ropes used for permanent and MODU moorings are included;

— special guidance for MODU mooring inspection in the areas of tropical cyclones is provided.

The third edition was developed in response to the need for inspection guidelines of permanent and fiber rope moorings in addition to MODU moorings. The additional guidelines are based on study results of joint industry projects (JIPs) and industry experience accumulated in the last 15 years operating a large number of MODUs and permanent floating installations. This document compiles factors that are best understood and can be quantified at this time. The information in this document will be updated after further experience and knowledge are gained. Accordingly, comments and suggestions toward broadening and refining these guidelines are encouraged.

In-service Inspection of Mooring Hardware for Floating Structures

1 Scope

1.1 General

This recommended practice provides guidelines for inspecting mooring components of mobile offshore drilling units (MODUs) and permanent floating installations. Although this document was primarily developed for the moorings of MODUs and permanent floating installations, some of the guidelines may be applicable to moorings of other floating vessels such as pipe-laying barges and construction vessels. Furthermore, some of the guidelines may be applicable to secondary or emergency moorings such as moorings for jack-up units, shuttle tanker moorings, and dynamic positioning (DP) vessel harbor mooring.

The applicability of this document to the moorings of other floating vessels is left to the discretion of the user.

1.2 Purpose

The need for rigorous, effective inspection of mooring hardware is apparent because most of the mooring failures involved faulty mooring components including corroded or physically damaged wire-rope or chain, defective connecting links, or mooring hardware of inferior quality. This document should be useful to engineers and operating personnel concerned with the following:

a) planning a mooring inspection;

b) conducting or supervising a mooring inspection;

c) deciding whether to reject, repair, or replace mooring hardware;

d) communicating with others concerning acceptable mooring hardware.

1.3 Inspection Philosophy and Exception to This Document

1.3.1 Inspection Philosophy

The inspection philosophy of this document is to remove a mooring component with excessive deterioration from service. Based on this philosophy, a criterion of limiting the strength reduction to 10 % minimum breaking strength (MBS) was established in the first edition of this document. This criterion has been used by the industry for more than 20 years with generally satisfactory results, and it has become a long standing and widely accepted criterion.

1.3.2 Inspection and Design Check

It should be emphasized that this document does not address the critical design issues such as tension factor of safety and fatigue, although some discussion is given to the design issue of corrosion allowance. Any attempt to link inspection with these critical design issues will make discard criteria a moving target, depending on design assumptions, analysis software used, margin of safety, and location of the operation, etc. Setting an industry inspection standard in this case is impossible. The design check should be conducted separately. If the design check indicates that the reliability of the mooring system can be overly compromised, the acceptance of a mooring component that passes the discard criteria should be carefully re-evaluated. On the other hand, if the design check indicates that the mooring component is significantly over-designed, and it can tolerate much more damage than allowed by this document, design calculations should be submitted to the appropriate authority asking for permission to take exception to API 2I. This process has been used by the industry under various conditions, and some examples are provided below.

— A MODU chain was found to have a large number of loose studs that exceeded the discard criteria and therefore should be replaced. However, the chain was accepted for continued service based on: 1) Break test of samples taken from the problem area indicated the chain retained more than 90 % MBS. 2) A fatigue analysis, taking into consideration the additional stress concentration at the stud footprint due to loose stud, indicated sufficient fatigue life for continuous operation.

— A mooring component was found to have lost 15 % of its strength, well exceeding the discard criteria of 10% MBS. A design check indicated the factors of safety were twice the required factors of safety for the operation. The component was accepted for continued service.

1.3.3 Safety of Inspection Personnel

Safety should be given high priority during mooring inspection. If a certain recommended inspection procedure poses a significant risk of jeopardizing the health and safety of the inspection personnel, the procedure should be modified to minimize the risk. However an effort should be made to ensure the inspection objectives are not compromised.

1.4 Mooring Component Traceability and Inspection Documentation

Since the inspection philosophy of this document is to remove a mooring component with excessive deterioration from service, it is important to keep a complete and auditable record of the component history. This component history shall be maintained in accordance with Annex A and shall include manufacturing, inspection, usage, and retirement records.

In cases where a complete component history for in-service mooring components is not available, decisions to keep a component in service should be based on its present condition and experience with components in similar services. Furthermore, a lack of historical documentation does not eliminate the need to maintain on-going documentation for future use.

2 Guidelines for In-service Inspection of MODU Mooring Chain and Anchor Jewelry

2.1 Common Problems with MODU Chain

The rough treatment to which mooring chain is exposed can lead to various chain problems. Eight such common problems for which inspectors should be aware of are described in 2.1.1 to 2.1.8.

2.1.1 Missing Studs

A studlink chain without a stud may significantly increase the possibility of link failure; high bending stresses and low fatigue life in links are predictable consequences of missing studs.

2.1.2 Bent Links

A bent link is the result of chain-handling abuse. The link may have been excessively torqued when traversing a sharp, curved surface; or the chain may have jumped over the wildcat, making point contacts between the link and the wildcat. Jumping of chain over the wildcat is usually caused by a worn wildcat, by chain dimensions out of tolerance, or by too abrupt braking of fast moving chain.

2.1.3 Corrosion

Excessive corrosion increases the possibility of chain failure from fatigue or overloading due to reduced cross-sectional area.

2.1.4 Sharp Gouges

Physical damage to the chain surface (such as cuts and gouges) raises stress and promotes fatigue failure.

2.1.5 Loose Studs

Loose studs caused by manufacturing defects, abusive handling, or excessive corrosion between the link and the stud, allowing excessive stretching of chain, causing higher bending stresses in the chain. A typical loose stud is shown in Figure 1a.

2.1.6 Cracks

Surface cracks, flash-weld cracks, and stud-weld cracks may propagate under cyclic loading, resulting in premature chain failure. A typical stud-weld crack is shown in Figure 1b.

2.1.7 Wear

Wear between links in the grip area and between links and the wildcat (see Figure 2b) reduces the chain diameter. The diameter reduction decreases the load-carrying capacity of the chain and invites failure.

2.1.8 Elongation

Excessive permanent elongation may cause the chain to function improperly in the wildcat, resulting in bending and wear of the links. Wear in the grip area of the chain and working loads in excess of the original proof load will result in a permanent elongation of the chain.

2.2 Recommended Inspection Method

2.2.1 General

Chain installed on MODUs can be inspected by the two methods discussed in 2.2.2 and 2.2.3.

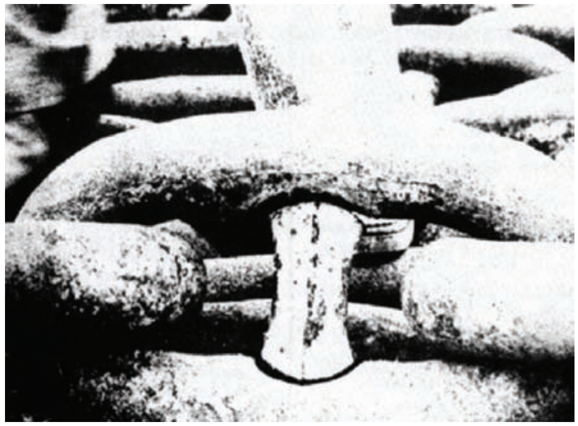
2.2.2 Dockside Inspection

As shown in Figure 3, the drilling vessel is taken into a dock, and the chain is laid out for inspection. Normally such chain inspection is carried out in conjunction with other work such as major structural repair or special survey.

In this manner the entire chain can be thoroughly cleaned and carefully inspected, and the connecting links and anchor shackles can be examined by magnetic particle inspection (MPI). Since the chain is not under tension, the chain diameter in the grip area can be readily measured. However, the measurement of a length of five links, in this case, which should be accomplished under tension, would be inaccurate.

2.2.3 Offshore Inspection

As shown in Figure 4, the drilling vessel stays offshore, and the chain is inspected with the assistance of a workboat. The chain in the chain locker should be paid out fully and then examined by an inspector standing close to the windlass while the chain is slowly taken back into the chain locker. At the same time, the workboat picks up the anchor and moves slowly toward the vessel.



a) Loose stud in 3-in. ORQ chain

b) Cracked stud weld in 3-in. ORQ chain

Figure 1—Typical Chain Stud Problems

The advantage of this method is that it requires no dock facilities. The inspection can be performed whenever a work boat is available or in conjunction with anchor retrieval. Two disadvantages of the offshore inspection method and their correction measures are discussed in the following.

— Inspecting the last approximate 200 ft of chain is difficult. However, if the chain can be reached by a crane, and deck space on the drilling vessel is available, the anchor and the last portion of chain can be picked up by the crane and laid on the deck for inspection. Otherwise, the anchor and the last portion of chain can be brought on board the work boat and inspected there.

— Inspection of connecting links by MPI is suggested in 2.3. However, MPI is difficult and time consuming with the offshore inspection method; it could substantially increase workboat waiting time and delay the MODU moving schedule. This problem can be alleviated by exchanging the connecting links in the chain with spare connecting links that have been examined by MPI prior to the chain inspection.

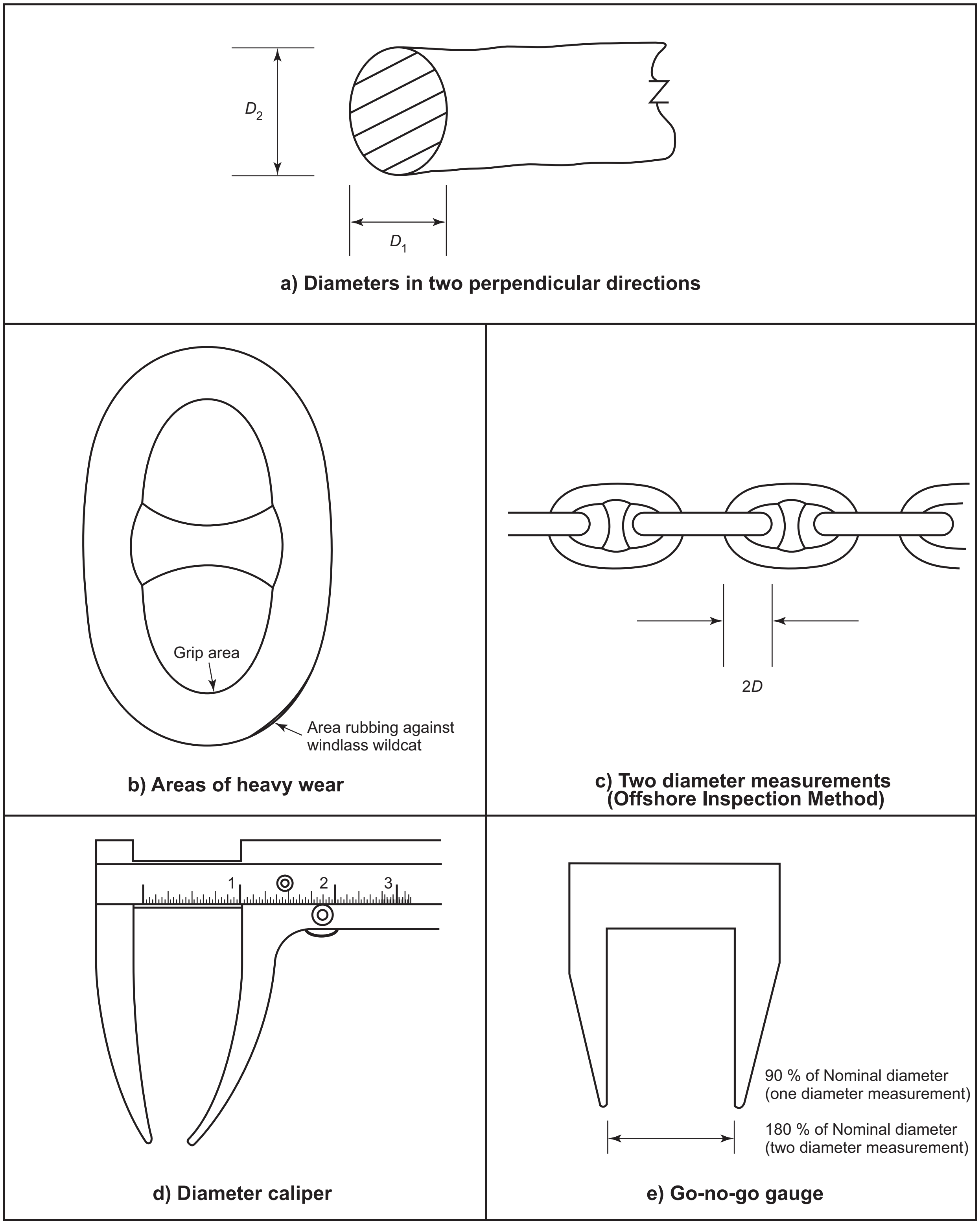


Figure 2—Chain Diameter Measurement

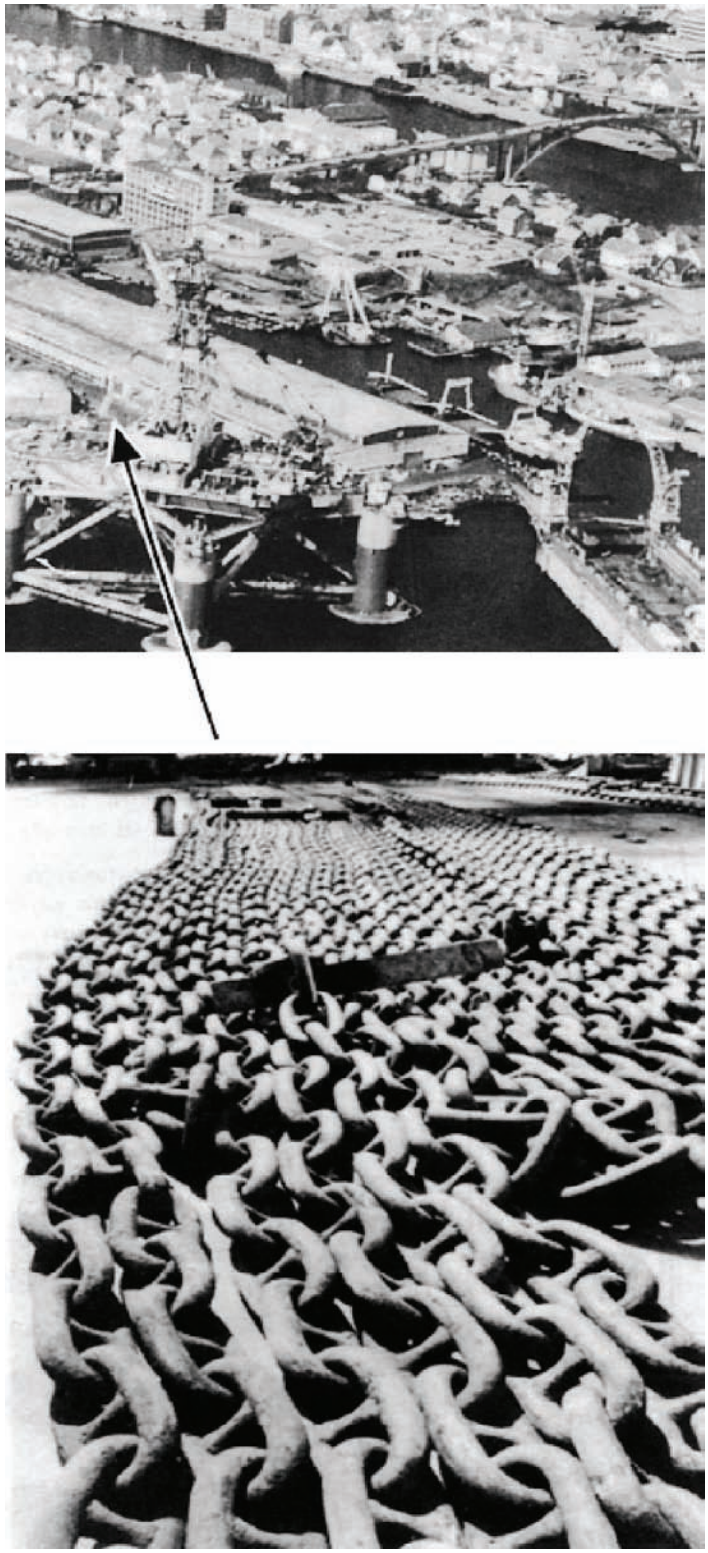


Figure 3—Dockside Inspection Method

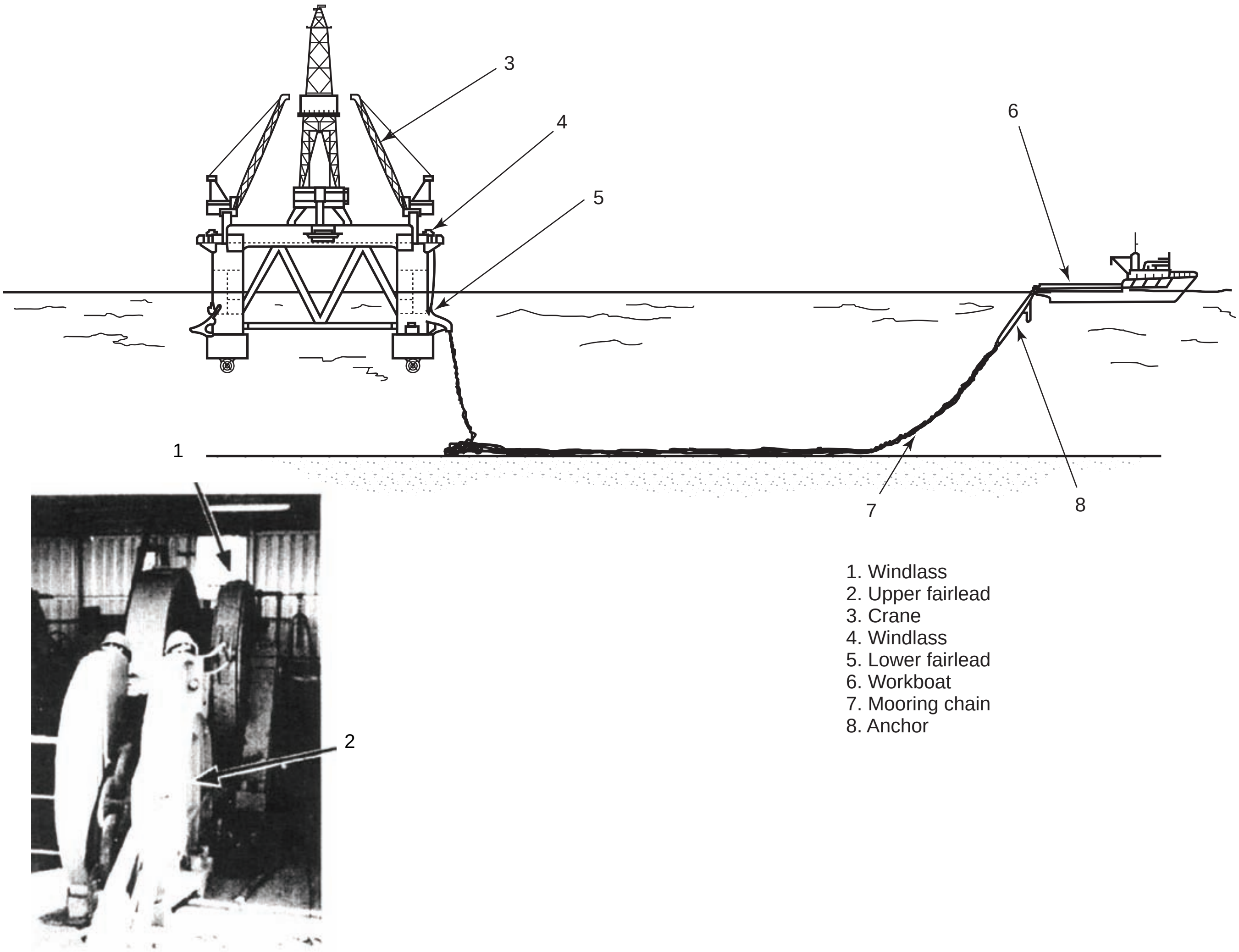


Figure 4—Offshore Inspection Method

2.3 Recommended Inspection Procedure

2.3.1 Personnel

2.3.1.1 Dockside Inspection Method

The following list describes personnel and duties for the dockside inspection method:

a) the chief inspector coordinates the work among inspection personnel, performs visual inspection, performs measurements, and rejects or accepts damaged links;

b) the assistant keeps inspection records and assists with measurements;

c) the MPI inspector performs MPI on connecting links and anchor jewelry;

d) roughnecks clean chain, grind out surface defects, dismantle/assemble connecting links, and assist in inspection of anchor jewelry.

2.3.1.2 Offshore Inspection Method

The following list describes personnel and duties for the offshore inspection methods:

a) the windlass operator runs and stops chain on the order of the chief inspector, stopping chain after every 100 ft of chain movement;

b) the chief inspector coordinates the work among the inspection personnel, gives orders to the windlass operator, rejects or accepts damaged links, and performs visual inspection and measurements;

c) the assistant inspector keeps inspection records, performs visual inspection, and assists with measurements;

d) the MPI inspector performs MPI on anchor jewelry and spare connecting links prior to inspection;

e) roughnecks clean chain, grind out surface defects, change connecting links, and assist with inspection of anchor jewelry.

2.3.2 Equipment

The following equipment is often needed for chain inspection. Its need and availability should be checked before the inspection is started:

a) workboat (offshore inspection method);

b) dockside crane or other suitable equipment to lay out chain (dockside inspection method);

c) high-pressure hose;

d) sandblasting equipment;

e) MPI equipment;

f) go-no-go gauge for chain diameter measurement (see Figure 2e);

g) go-no-go gauge for maximum allowable length over five links (see “Offshore Inspection Method,” in Figure 5a) or go-no-go gauge for maximum allowable length of individual link (see “Dockside Inspection Method,” Figure 5b);

h) steel wire brush;

i) hammer;

j) spare connecting links that have been inspected by MPI (a sufficient number of connecting links must be prepared for replacing existing connecting links and damaged common links);

k) grinder;

l) diameter caliper (see Figure 2d);

m) measuring tape;

n) tape recorder;

o) spray paint;

p) camera;

q) lighting equipment.

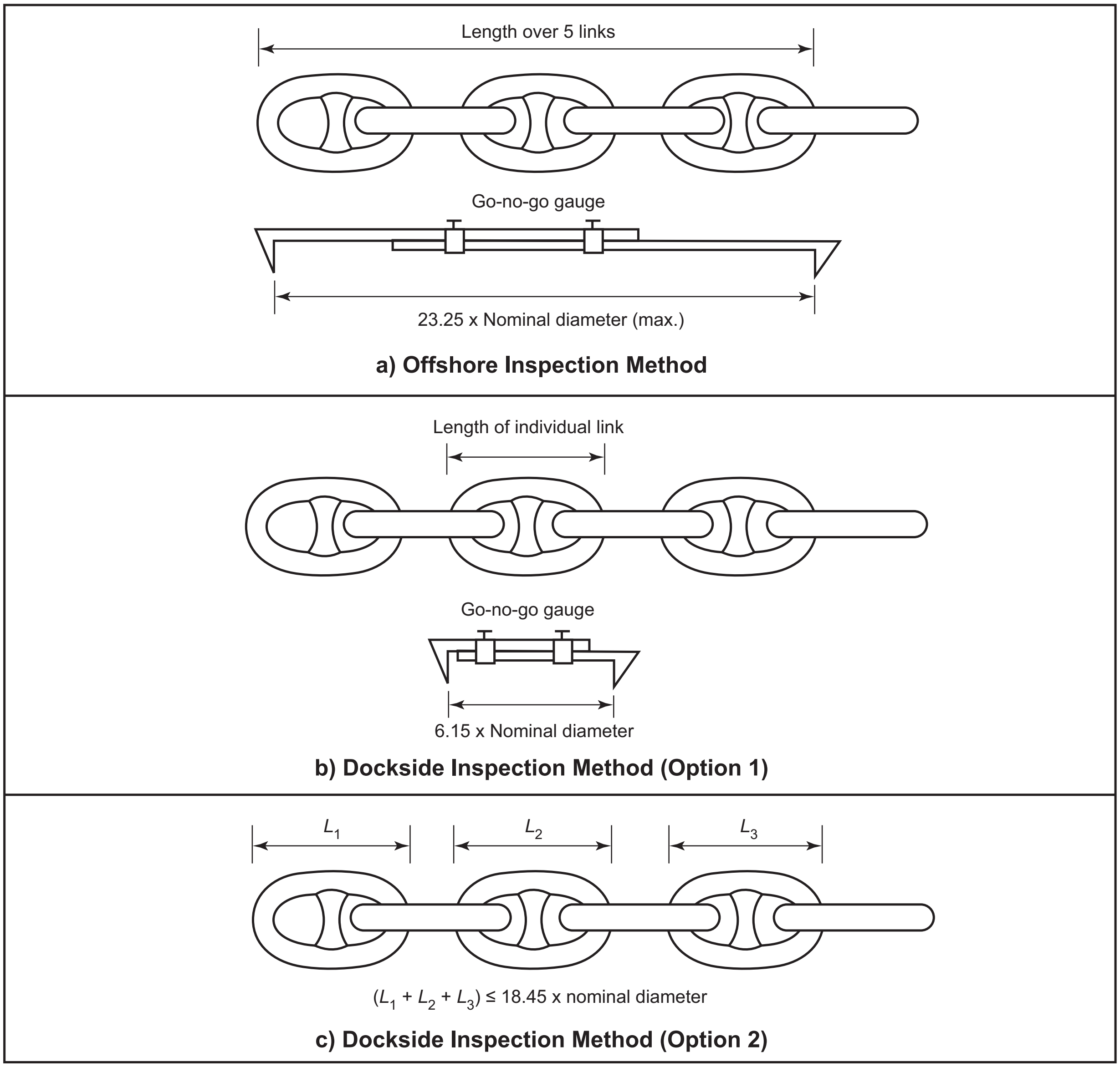


Figure 5—Chain Length Measurement

2.3.3 Arrangement

2.3.3.1 Dockside Inspection Method

For arrangement in the dockside inspection method, one should lay out the chain in rows approximately 100 ft long. If this arrangement is impractical, one should use spray paint to mark every 100 ft of chain.

2.3.3.2 Offshore Inspection Method

The inspector should stand close to the windlass or the upper fairlead. Chain inspections have been carried out on a specially built platform near the lower fairlead of a semi submersible, but this practice is discouraged because it can endanger the inspectors if the chain breaks at the windlass. For chain systems, inspection could be accomplished on the deck of a large anchor-handling boat that has adequate handling gear and chain lockers.

2.3.4 Cleaning

One should clean the chain with a high-pressure hose. Also marine growth and corrosion scale should be removed at every 100 ft of chain and at places where close examination is needed.

2.3.5 Inspection Steps

2.3.5.1 Visual Inspection

One hundred percent of the chain is visually inspected for missing studs, bent links, corrosion, sharp gouges, loose studs, cracks, and wear. When using the offshore inspection method, the line speed should be less than 30 ft per minute. When chain abnormalities are suspected, the chain movement should be stopped for close examination. The inspector should also watch the movement of the chain passing through the wildcat. Jumping of chain over the wildcat may indicate misfit between the chain and wildcat.

The inspector should tap each stud with a hammer to check for loose studs. An experienced inspector can detect loose studs by listening to the tone of the tapping.

The offshore inspection method is most effective where one inspector checks the links in a vertical plane while another inspector checks the links in a horizontal plane.

The last portion of chain should be brought on board the deck of the drilling vessel or the deck of the workboat for inspection.

2.3.5.2 Connecting-link Inspection

To perform a connecting-link inspection, the inspector should dismantle all connecting links and inspect by MPI or replace with links that have been examined by MPI.

2.3.5.3 Measurement

One should measure the following parameters once at every 100 ft of chain and on both sides of each connecting link. If chain problems are found, more measurements may be needed.

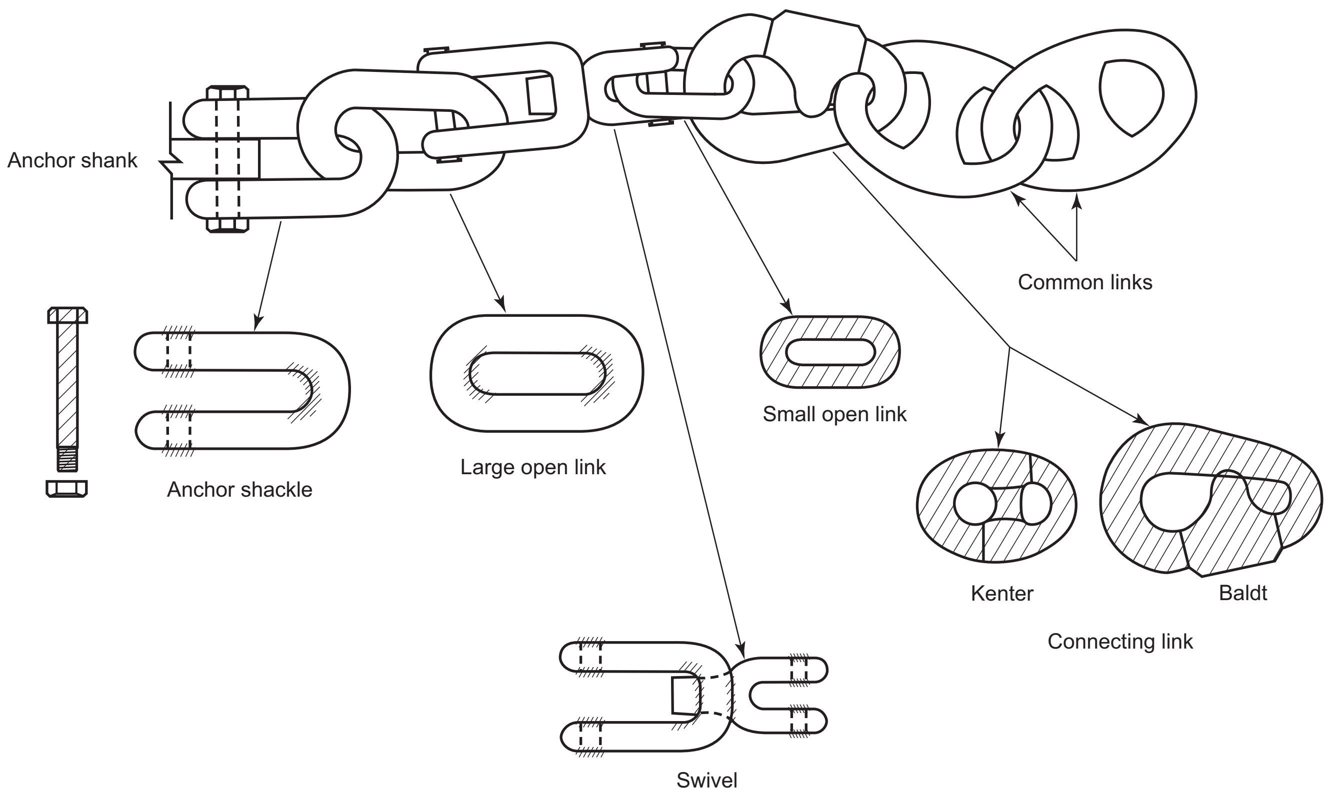
For chain diameters in two perpendicular directions as shown in Figure 2a, one should remove corrosion scale and marine growth before measuring diameters. The diameter measurement should be performed at the location with the worst reduction in cross-sectional area, which is normally the grip area or the area that rubs against the windlass wildcat (see Figure 2b). If the grip area has the worst reduction and the offshore inspection method is used, two diameters should be measured as shown in Figure 2c.

In the offshore inspection method, length over five links can be measured with a go-no-go gauge (see Figure 5a). For the dockside inspection method, length over five links cannot be measured accurately since the chain is not under tension. Therefore, the length of individual links should be measured by a go-no-go gauge as shown in Figure 5b. Another option of chain length measurement for dockside inspection is shown in Figure 5c.

If grinding is performed to remove surface defects, one should measure link diameter after grinding with a diameter caliper as shown in Figure 2d.

2.3.5.4 Anchor and Anchor Jewelry Inspection

The inspector should visually inspect all anchor jewelry such as anchor shackles, swivels, open links, and connecting links. In addition, certain areas as shown in Figure 6 should be inspected by MPI. MPI procedures should be based on ASTM E709 [13].



NOTE Shaded areas inspected by MPI, visual inspection for the rest.

Figure 6—Inspection of Anchor Jewelry

The inspector should visually inspect the anchors after cleaning, looking for structural cracks and noticeable deformations such as bending of the anchor shank or fluke. Attention should be given to welds, corners, and areas of high stress. If a crack is suspected in an area of high stress concentration, the area should be inspected by MPI.

MPI should be conducted under the supervision of an operator’s representative or a representative from a recognized classification society. The areas to be examined by MPI should be clearly marked on each item. One should dismantle all connecting links and other anchor jewelry as required.

2.3.5.5 Winching Equipment Inspection

The working conditions of the windlasses, fairleads, chain stoppers and chain chasers, and the like, should be checked.

2.3.5.6 Inspection Record

The following information should be included on the inspection record:

a) name of the chain manufacturer, size and grade of chain, and method of securing studs (unwelded, one side welded, or both sides welded);

b) operation history, including the age of the chain, inspection and failure history, and previous operating locations;

c) inspection date and names of inspectors;

d) locations and nature of all chain abnormalities, plus the corrective measures taken;

e) chain diameter and length over five links (or length of an individual link) and locations where measurements are taken;

f) locations and types of connecting links and anchor jewelries, abnormalities detected and corrective measures taken;

g) MPI results;

h) recommendations for further action to be taken.

2.4 Guidelines for Rejecting Chain Components

Chain components having any of the following problems should be removed.

a) A missing stud.

b) A noticeable out-of-plane bending (see Figure 7).

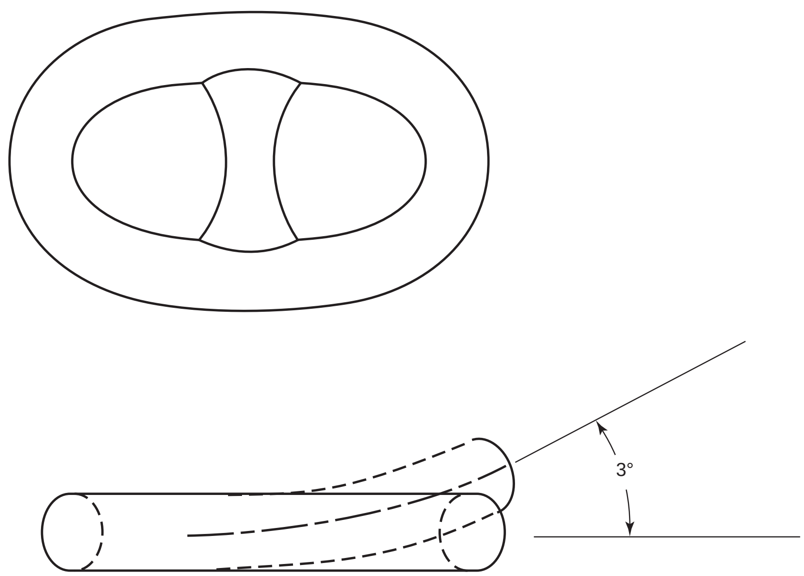


Figure 7—Discard Criterion for Bent Links

c) An average of two measured diameters less than 95 % of the nominal diameter (about a 10 % reduction of cross-sectional area) or a diameter in any direction less than 90 % of the nominal diameter.

d) A crack at the toe of the stud weld extending into the base material.

e) Surface cracks or sharp gouges that cannot be eliminated by light grinding. The link should be rejected if the chain diameter is reduced to less than 90 % of the nominal diameter after grinding.

f) Excessively loose stud. Since it is difficult to quantify excessive looseness of chain studs, the decision to reject or accept a link with a loose stud depends on the experience and judgment of the inspector. As a point of reference, if a stud can move more than $^1/_8$ in. (3 mm) axially or more than $^3/_{16}$ in. (5 mm) laterally in any direction (see Figure 8a), rejection of the link should be considered. Similarly, if a gap of more than $^1/_8$ in. (3 mm) exists between the stud end and the link in a link with a stud welded on one end, rejection of the link should also be considered (see Figure 8b).

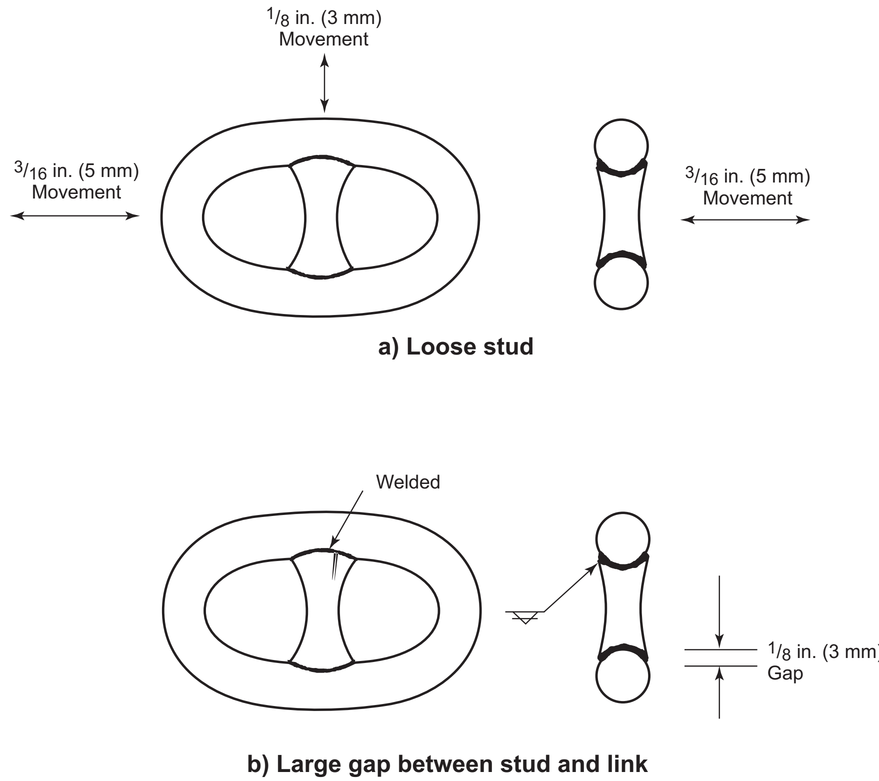


Figure 8—Examples of Severely Loose Studs

g) Cracks detected by MPI in the internal locking area of connecting links. External surface defects in connecting links are not cause for rejection if they can be eliminated by grinding to a depth of no more than 8 % of the nominal diameter of the chain.

h) Length over five links exceeding 23.25 times the nominal chain diameter (offshore inspection method) or the length of an individual link exceeding 6.15 times the nominal chain diameter (dockside inspection method). The upper limit values of length over five links and length of the individual link for different sizes of used chain can be found in Table 1.

i) Excessive wear or a deep surface crack on anchor shackles, open links, or swivels. Moderate wear and surface cracks that can be eliminated by light grinding are acceptable for the anchor jewelry. They should be rejected, however, under either of the following conditions.

— Reduction in cross-section area due to wear and grinding is more than 10 %. This is equivalent to a 5 % reduction in the average diameter for distributed wear or grinding.

— Reduction in diameter or critical thickness in any direction is more than 10 %.

j) Cracks in anchor or noticeable anchor deformation, which impact anchor performance, such as bending of anchor shank or fluke. Cracks are acceptable if they can be repaired by proper welding procedure.

Table 1—Upper Limit of Length Over Five Links and Length of Individual Link for Used Chain

Nominal Diameter (in.)	Length over 5 Links (23.25*D*, in.)	Length of Individual Link (6.15*D*, in.)
2	46.5	12.3
2 1/8	49.4	13.1
2 1/4	52.3	13.8
2 3/8	55.2	14.6
2 1/2	58.2	15.4
2 5/8	61.0	16.1
2 3/4	64.0	16.9
2 7/8	66.8	17.7
3	69.8	18.5
3 1/8	72.7	19.2
3 1/4	75.5	20.0
3 3/8	78.5	20.8
3 1/2	81.4	21.5
3 5/8	84.3	22.3
3 3/4	87.2	23.1
3 7/8	90.1	23.8
4	93.0	24.6
4 1/8	95.9	25.4
4 1/4	98.8	26.1
4 3/8	101.7	26.9
4 1/2	104.7	27.7
4 5/8	107.4	28.4
4 3/4	110.5	29.2
4 7/8	113.3	30.0
5	116.3	30.8
5 1/8	119.2	31.5
5 1/4	122.0	32.3
5 3/8	125.0	33.1
5 1/2	127.8	33.8
5 5/8	130.8	34.6
5 3/4	133.7	35.4
5 7/8	136.6	36.1

2.5 Guidelines for Chain Repair, Removal, and Replacement

2.5.1 Removal of Individual Links

Individual links that meet the discard criteria should be removed and replaced with connecting links that have been examined by MPI.

2.5.2 Removal of Chain Sections

If a substantial number of links in a chain section meet the discard criteria, the chain section should be removed, and the chain can be joined again by connecting links that have been examined by MPI.

2.5.3 Limit in Number of Connecting Links

The number of connecting links in a mooring line should not exceed an average of one per 400 ft of outboard line length. Furthermore, the total number of connecting links in a mooring line should be no more than ten, excluding the connecting links at the anchor end.

2.5.4 Removal of Whole Chain

If a large number of links meets the discard criteria and these links are distributed in the whole length, the chain should be replaced with a new chain.

2.5.5 Re-welding of Loose Stud

Rewelding of loose studs in the field is undesirable for the following reasons:

— welding in the field may produce hard heat-affected zones that are susceptible to cold cracking;

— hydrogen embrittlement may occur from absorption of moisture from the atmosphere or welding electrodes.

Weld repairs on loose studs should be delayed as long as possible. Where a few links are found with loose studs in a short section of a chain, it is recommended that this portion of the chain be cut out and a connecting link put in.

If the major portion of the chain has loose studs, the chain should be scrapped. In the case where the chain is not too old, but contains many loose studs, the chain may be reconditioned onshore at a qualified chain manufacturer where the loose studs are rewelded at one end and the chain is heat-treated again. However, this practice cannot be applied to Grade 4 chains, for which stud welding is normally prohibited.

Studs in chain links serve two purposes:

a) to avoid knots or twist problems during handling operations; and

b) to support the links and prevent the sides of the links from deflecting inward during tensile loading, thus preventing high bending stresses in the chain.

It is important to keep the stud in place to accomplish the purposes just discussed. Although weld repair of loose studs should be discouraged, excessive stud movement can be prevented by careful welding using the proper electrode, preheat, interpass temperature, and rate of cooling after welding. Some regulatory bodies permit field rewelding of studs in oil rig quality chains. However, they normally require the welding contractor to submit welding specifications for their approval prior to such weld repair.

2.5.6 Grinding

Any grinding to eliminate shallow surface defects should be done parallel to the longitudinal direction of the chain, and the groove should be well rounded and form a smooth transition to the surface. The ground surface should be examined by MPI.

2.5.7 Replacement of Mooring Jewelry

Replacements for mooring jewelry such as connecting links, anchor shackles, swivels, wire rope sockets, and pelican hooks should meet or exceed the original design and manufacture requirements.

2.6 Recommended Inspection Schedule

A chain inspection schedule should be based on the age, condition and operational history of the chain (ground chain versus rig chain over fairleader under high load) and type of operation.

The recommended major inspection intervals are given in Table 2 and may be modified based on the condition and previous inspection history of the chain. As a minimum, a full visual inspection of all mooring lines, including connectors and jewelry must be conducted as per the frequency in Table 2. If deterioration is found during inspection, defined as a difference between the as-built and current condition but within the tolerance prescribed by API 2I, then the inspection interval should be reduced to effectively monitor the condition of the components and ensure they are fit for intended service at all times. However, the major inspection interval shall never exceed five years.

Guidance for conducting a major inspection is defined in 2.3 and rejection criteria are defined in 2.4.

Table 2—Chain Inspection Intervals

Number of Years in Service	Recommended Intervals Between Major Inspections [a]
0 to 3	36 months
4 to 10	24 months
over 10	8 months

[a] With a grace period not to exceed 4 months.

In addition to the major inspections, chain and connecting hardware should be checked for visible defects frequently during anchor retrieval.

Special attention should be given to the long term operations where the inspection schedule is current at the start of the operation, but the inspection will expire during the operation. For example, a development drilling will take 18 months to complete, but the inspection will expire in 6 months after start of the operation. In this case, an inspection of the mooring system should be conducted before the MODU is moored on location or while the MODU is in operation.

2.7 Special Event Inspection

Rigorous mooring inspection is critical for operations in the areas of tropical cyclone where the probability of mooring failure can be much higher. Also guidance is needed to address the reuse of the components from a mooring damaged by a tropical cyclone. Additional guidance for MODU mooring inspection in these areas can be found in Annex B.

3 Guidelines for In-service Inspection of MODU Mooring-wire Rope and Anchor Handling Equipment

3.1 Common Problems with MODU Mooring-wire Rope

Mooring-wire ropes receive rough treatment in service, which may result in various types of damage. Inspectors should be particularly attentive to the common wire rope problems described in the following paragraphs.

3.1.1 Broken Wires

3.1.1.1 Broken Wires at the Termination

Broken wires at the termination, even if few in number, indicate high stresses at the termination and may be caused by incorrect fitting of the termination, fatigue, overloading, or mishandling during deployment or retrieval.

3.1.1.2 Distributed Broken Wires

The nature of the wire breaks is an important key to diagnosing wire rope problems. For example, a crown break on the top of the strand may indicate excessive tension, fatigue, wear, or corrosion. Necking down at the broken end of the wire indicates failure in tension. Broken faces perpendicular to the axis of the wire indicate fatigue. Reduced cross sections of the wire breaks may indicate corrosion and wear. An example of distributed crown breaks is given in Figure 9, and typical wire fractures are shown in Figure 10.

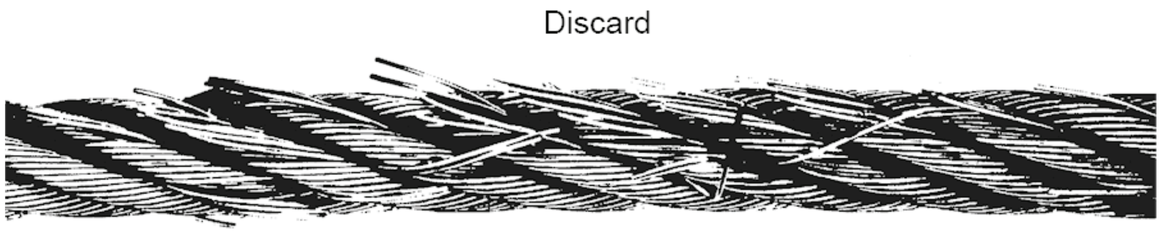
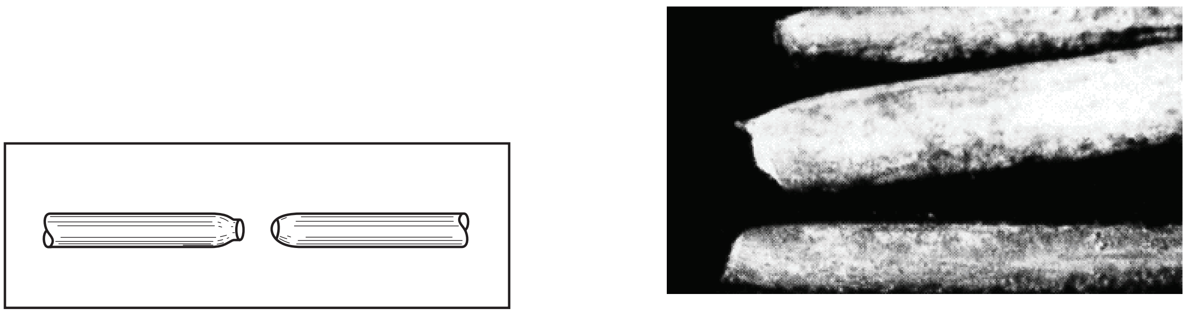
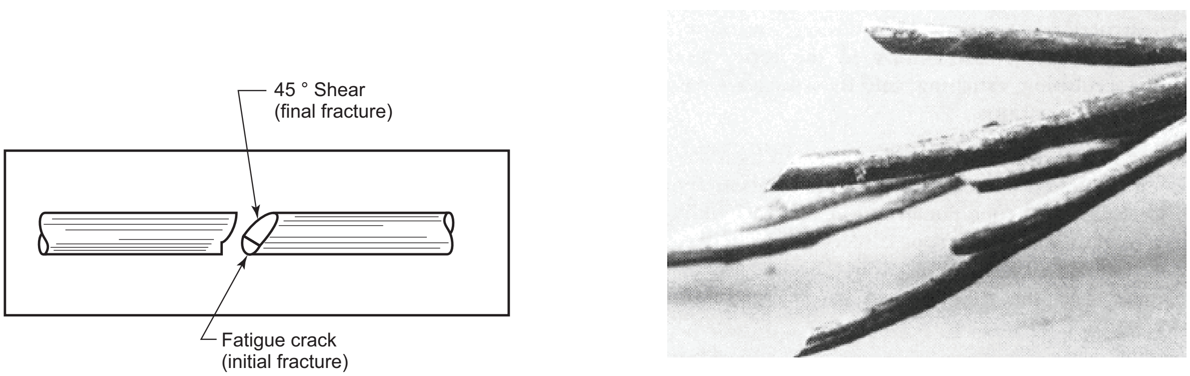


Figure 9—Examples of Distributed Crown Wire Breaks



a) Failure due to tensile overloading characterized by the cup cone



b) Fatigue failure-initial fracture from fatigue and final fracture by shear

c) Fatigue failure straight across

d) Fatigue failures characterized by no reduction in cross section area

Figure 10—Typical Wire Fractures

Valley breaks at the interface between two strands indicate tightening of strands. This is normally caused by internal corrosion reducing the area of the core or by a broken core. Valley breaks can also be caused by tight sheaves, extremely small sheave-to-rope diameter ratios, and high loads.

3.1.1.3 Locally Grouped Broken Wires

If broken wires are closely grouped in a single strand or adjacent strands, as shown in Figure 11, there may have been local damage at this point. When wire breakage of this type begins, it will usually worsen. Such concentrated wire breakage will upset the balance of loads carried by the strands.

Figure 11—Locally Grouped Broken Wires

3.1.2 Change in Rope Diameter

The rope diameter can be reduced by external wear, interwire and interstrand wear, stretching of the rope, and corrosion. Excessive reduction in diameter can substantially reduce the strength of the rope. Therefore, the diameter should be measured and recorded periodically throughout the life of the rope. The new rope diameter should also be measured and recorded.

An increase in the rate of change in diameter may indicate accelerated corrosion or stretching of the rope due to overload. A localized decrease in diameter at any point in the rope as shown in Figure 12 may indicate a break in the core. Any increase in wire rope diameter is also a cause for concern, since it may indicate swelling of the core due to internal corrosion.

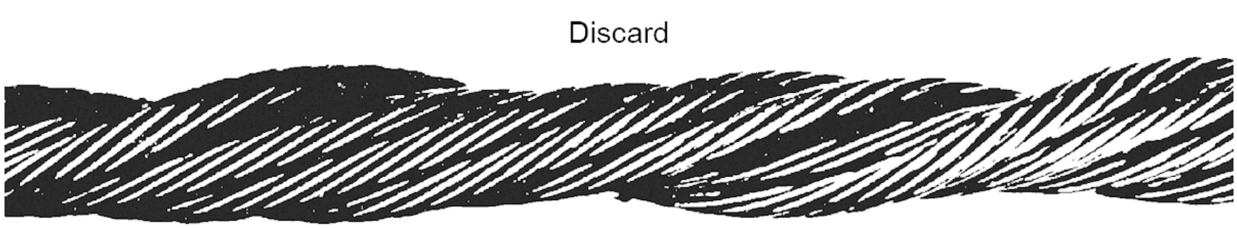


Figure 12—Local Decrease in Rope Diameter

3.1.3 Wear

Wear of the crown wires of outer strands in the rope can be caused by rubbing against the fairlead sheaves or hard seafloor. In particular, external wear of mooring-wire rope can be caused by dragging the wire rope on hard seafloor during anchor deployment or retrieval.

Internal wear is caused by friction between individual strands and between wires in the rope, particularly when it is subject to bending. Internal wear is usually promoted by lack of lubrication.

Wear reduces the strength of wire ropes by reducing the cross-sectional area of the steel. Progression of external wear is illustrated in Figure 13.

3.1.4 Corrosion

Corrosion in marine atmosphere not only decreases the breaking strength by reducing the metallic area of the rope, but also accelerates fatigue by causing an irregular surface that will invite stress cracking. Severe corrosion may reduce a rope's elasticity.

Corrosion of the outer wires as shown in Figure 14 may be detected visually. Progression of external corrosion is illustrated in Figure 15. Internal corrosion is more difficult to detect than external corrosion that frequently accompanies it, but the following indications may be recognized.

— In positions where the rope bends around fairlead sheaves, a reduction in diameter usually occurs. However, in stationary ropes, an increase in diameter could occur due to the buildup of rust under the outer layer of strands, although this condition is rare for mooring-wire ropes.

— Loss of gap between strands in the outer layer of the rope frequently combines with valley wire breaks and loss of flexibility.

3.1.5 Loss of Lubrication

Proper and thorough lubrication is important to permit the wires and strands to work without excessive internal wear and to inhibit corrosion. Operating a wire rope in frequent bending service without lubrication will reduce its life to only a fraction of normal life because of internal wear. Figure 16 shows a large reduction of cross-sectional area due to internal wear in the wires of a wire rope that has lost internal lubrication. A nongalvanized mooring-wire rope working in a marine environment without lubrication can rapidly develop severe corrosion and fail in corrosion fatigue in a few months.

Loss of internal lubrication is normally caused by a washing out of lubricant during service. A great variety of lubricants are used in wire rope manufacturing, and some of the lubricants can be easily leached out by wave actions. Figure 17a shows heavy internal corrosion in a mooring-wire rope caused by lack of internal lubrication. When an improper lubricant applied to the wire rope during manufacturing was rapidly lost in service, severe corrosion developed, leading to a mooring-line failure. On the other hand, as shown in Figure 17c, a dismantled strand with lubrication on the internal wires shows no evidence of internal corrosion. Figure 17b shows a dry rope with no internal lubrication. In this case, internal wear and corrosion are not obvious, but may soon develop.

External lubrication is difficult to maintain for mooring wire ropes. Some drilling contractors have a policy to relubricate wire ropes periodically. However, relubrication has not been proven to be effective in preventing internal corrosion, which is the main cause of many mooring-wire rope failures. In addition, relubrication may violate pollution control codes in many areas.

3.1.6 Deformation

Distortion of the rope from its normal construction is termed deformation and may result in an uneven stress distribution in the rope. Kinking, bending, scrubbing, crushing, and flattening are common wire rope deformations.

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Figure 13—Progression of Wear in Wire Rope

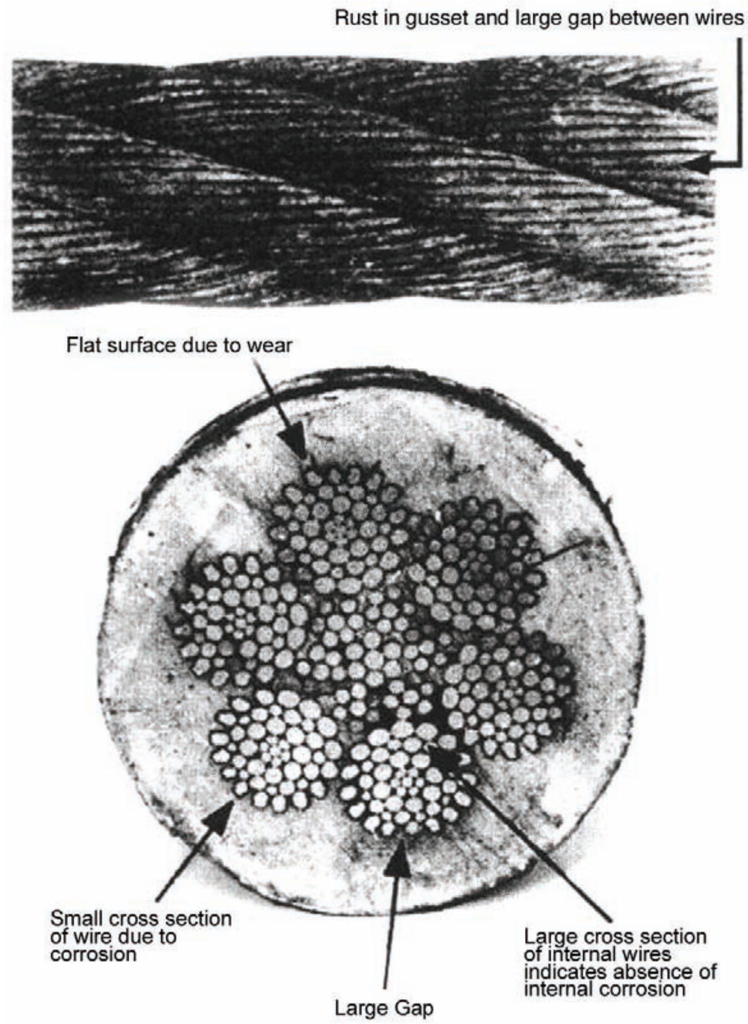

Figure 14—Wire Rope with Heavy External Corrosion

A kink is a deformation in the rope created by a loop that has been tightened without allowing for rotation about its axis. Unbalance of rope construction due to kinking will make a certain area of the rope disproportionately susceptible to excessive wear (see Figure 18a). Bends are angular deformations of the rope caused by external influence (see Figure 18b).

Scrubbing and crushing of wire rope as shown in Figure 19a, 19b and 19c can be caused by improperly winding the rope on the winch drum. Flattening of wire rope (see Figure 19d) may occur if the rope escapes from the winch drum and is pinched between the drum and another member. These problems are normally caused by a malfunction of the level wind or failure to maintain proper line tension while winching. Wire ropes with only slight deformations would lose no significant strength. Severe distortions, however, can accelerate wire rope deterioration and lead to premature rope failure.

3.1.7 Thermal Damage

Serious heat damage to a mooring wire rope is rare in normal service. Nevertheless, prompt attention should be given to any indication that excessively high or low temperature has caused damage to the rope.

a) Beginning of surface oxidation

b) Wires rough to touch. General surface oxidation

c) Oxidation now more marked

d) Surface wire now greatly affected by oxidation. Pitting obvious. Rust in gussets.

e) Surface heavily pitted and wire quite slack

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Figure 15—Progression of External Corrosion

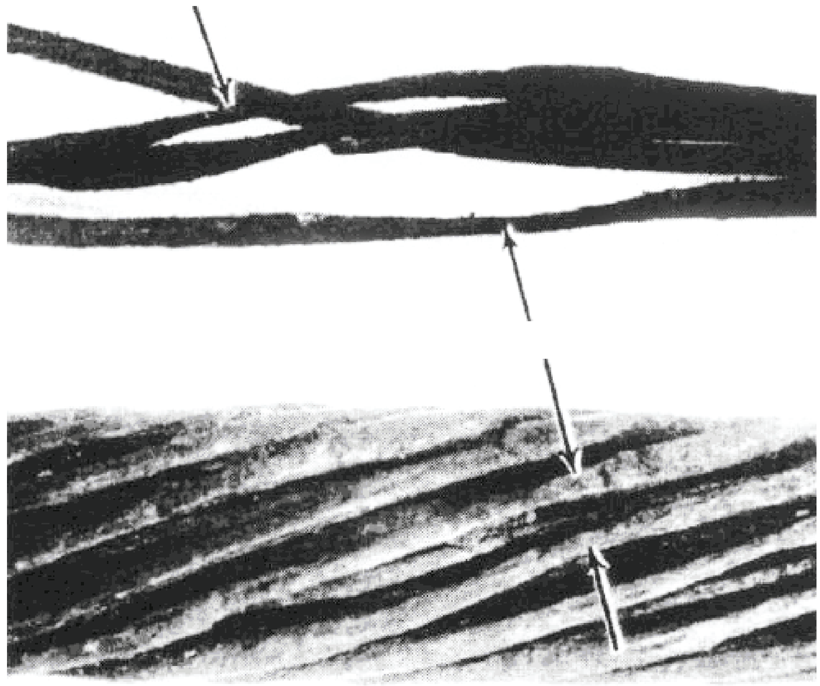


Figure 16—Wear of Internal Wires Caused by Lack of Lubrication Between Wires

Minor variations in temperature may affect the lubricant. When heated, some lubricants become thin and drip off; and when cooled, some oils and greases stiffen and lose ability to lubricate.

Sustained usage at temperatures in excess of 400 °F may cause metallurgical changes in a wire rope, with accompanying tensile and fatigue strength reductions. Such temperatures can occur in electrical arcing or exposure to fire, flame, or hot gases. Discoloration of the metal can indicate thermal damage.

The effect of temperatures below 0 °F on wire rope is unclear except for their known detrimental effect on lubricants. No published data on wire rope performance at low temperatures and under normal loads is known.

3.2 Recommended Inspection Method

3.2.1 General

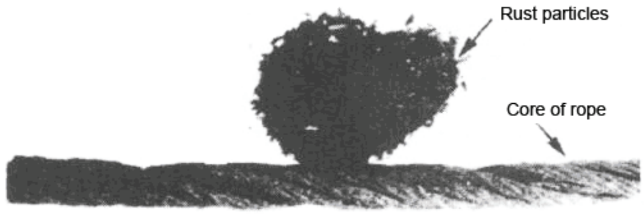
In-service wire rope for mobile offshore drilling units is usually inspected with the assistance of a workboat as shown in Figure 20. Two common methods for wire rope inspection are described in 3.2.2 and 3.2.3.

3.2.2 Inspection During Anchor Retrieval

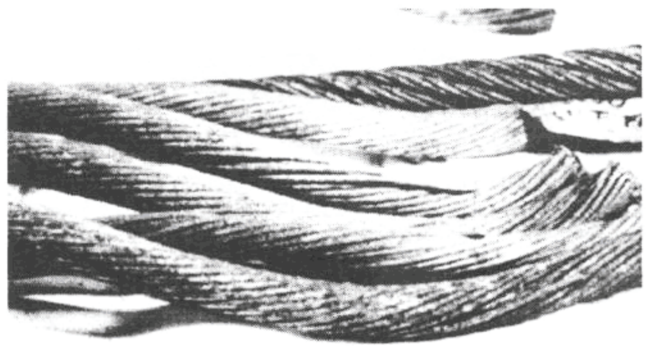
The wire rope is inspected in conjunction with anchor retrieval. Such inspection requires no additional equipment since a workboat is always available during anchor retrieval. However, the inspection can substantially slow down the anchor retrieval operation and delay a MODU move schedule.

3.2.3 Dockside Inspection

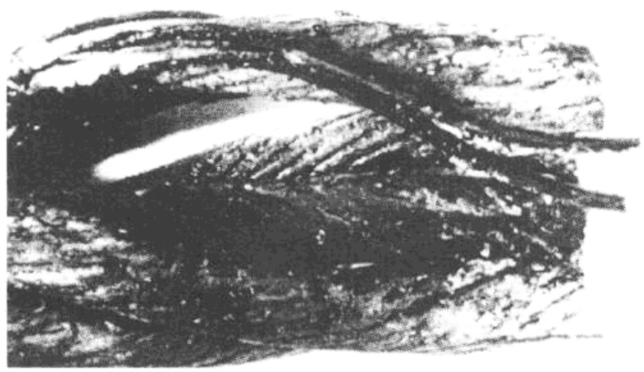
The drilling vessel stays in a dock or harbor for repair, special survey, and the like, and a workboat is contracted for the wire rope inspection. This method has two disadvantages. First, the inspection is economical only when it coincides with MODU repair or special survey. Second, because the MODU's location is close to land, the radius for



a) Heavy corrosion caused by lack of internal lubrication



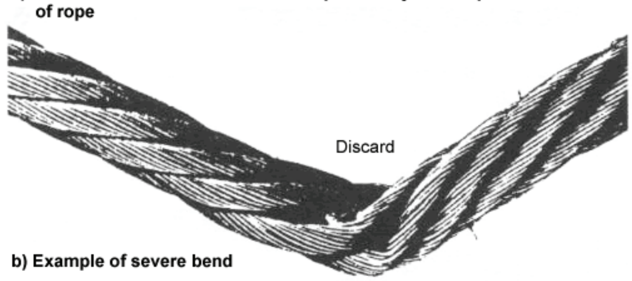
b) Dry rope with no internal lubrication. Internal wear and corrosion are not obvious but may soon develop.



c) Rope with proper internal lubrication. No internal wear and corrosion expected.

Figure 17—Effect of Internal Lubrication on Wire Rope

a) Wear and deformation created at a previously kinked portion of rope



b) Example of severe bend

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Figure 18—Kink and Bend of Wire Rope

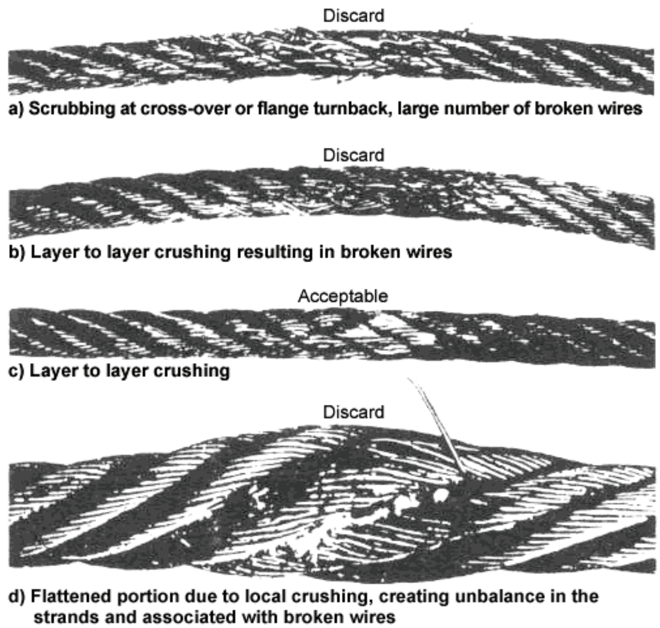

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Figure 19—Deformation Caused by Improper Drum Winding

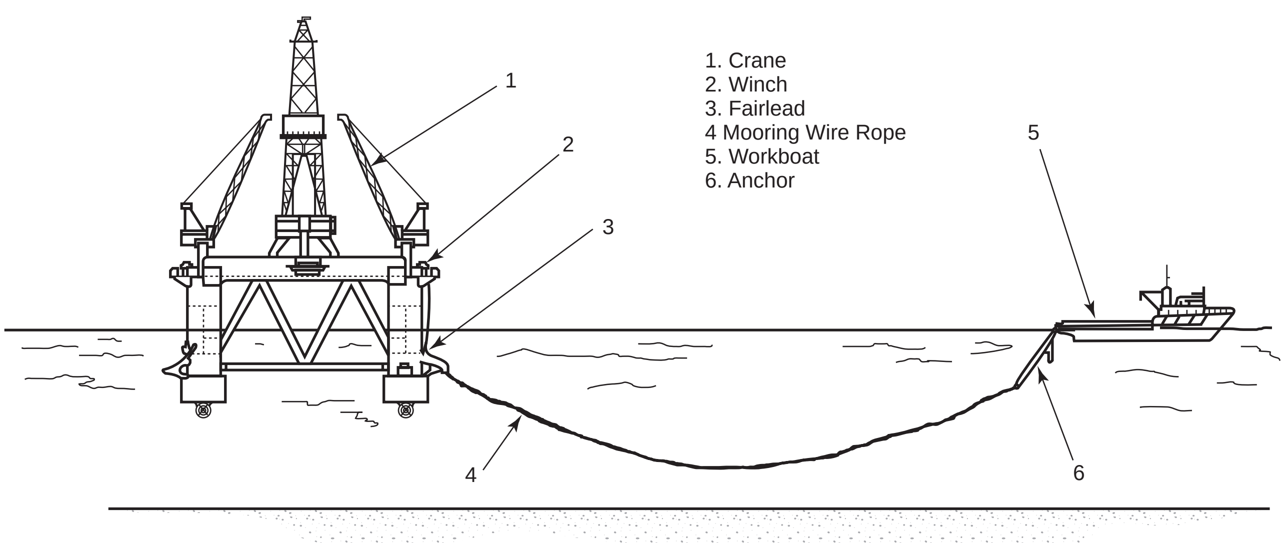


Figure 20—Wire Rope Inspection with Assistance of a Workboat

workboat operation can be limited on one side of the MODU. To inspect all mooring lines, rotating the MODU 180° would be necessary in some cases, and this would delay the inspection and increase operating costs. Therefore, inspection during anchor retrieval is preferred.

3.3 Recommended Inspection Procedure

3.3.1 Personnel

The recommended inspection procedure includes the following personnel and their duties:

a) the winch operator runs and stops the winch on the order of the chief inspector;

b) the chief inspector coordinates the work among inspection personnel, gives orders to the winch operator, performs visual inspections and measurements, and rejects or accepts wire rope;

c) the assistant inspector keeps inspection records, performs visual inspections, and assists with measurements;

d) roughnecks assist with inspections.

3.3.2 Equipment

The following equipment is often needed in wire rope inspection; its need and availability should be checked before the inspection is started:

a) workboat;

b) rope calipers (see Figure 21b);

c) high-pressure hose;

d) cutting torch;

e) wire rope sockets and filler;

f) lighting equipment;

g) parallel-jaw pliers;

h) camera;

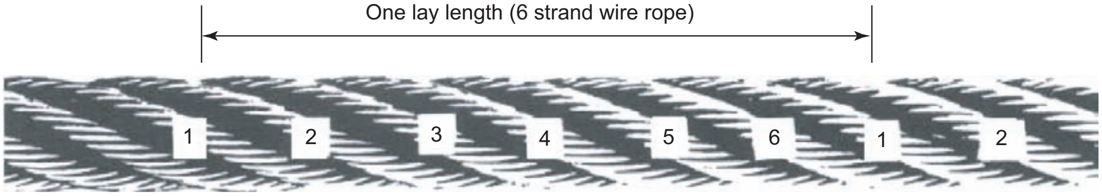
i) tape recorder;

j) measuring tape;

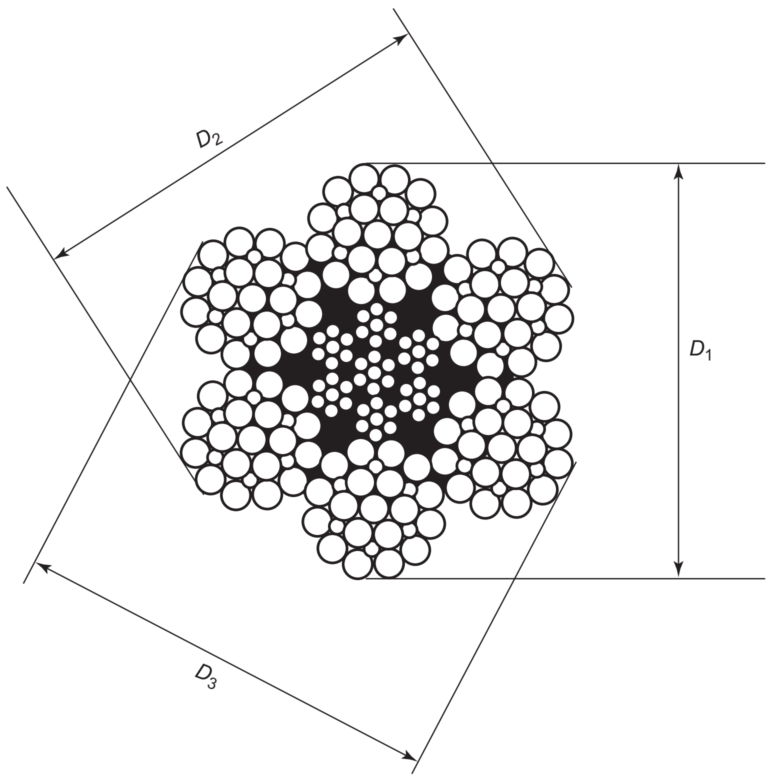
k) sheave gauge.

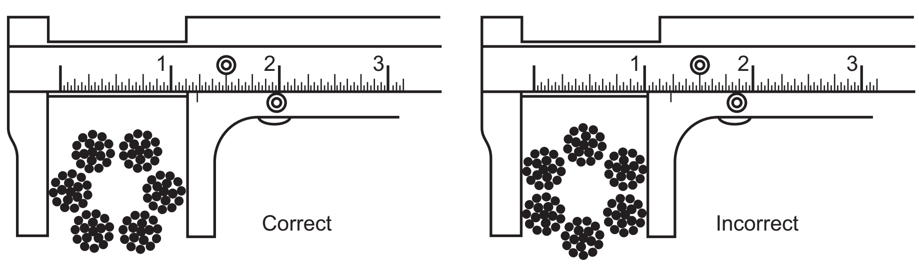
3.3.3 Length of Rope Covered by Inspection

Although it is desirable to inspect the whole mooring line, it may be impractical in many cases because of operational constraints. As a general rule, inspection should cover at least the maximum outboard line length that could be deployed. The inspector should determine the length of rope covered by inspection based on rope deployment history and future operations plan.



a) Definition of lay length





b) Diameter measurement

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Figure 21—Lay Length and Diameter Measurement

3.3.4 Arrangement

Wire rope inspection is carried out with the assistance of a workboat as shown in Figure 20. The workboat first picks up the anchor and then moves away from the drilling vessel. At the same time, the drilling vessel pays out the mooring line until the predetermined outboard line length is reached. Then the workboat moves back slowly toward the drilling vessel while the winch on the vessel takes in the mooring line at a rate of no more than 30 ft/min. For a more thorough inspection, a lower speed of 15 ft/min to 20 ft/min is recommended.

The inspectors should stand close to the winch or wherever lighting is adequate and communication with the winch operator is convenient.

3.3.5 Cleaning

The portion of rope covered by mud should be cleaned with a high-pressure fire hose. Marine growth should be removed where measurements and close examinations are to be performed.

3.3.6 Inspection Steps

3.3.6.1 Visual Inspection

While the line is slowly taken in, the inspectors should look carefully for signs of abnormalities such as broken wires, excessive wear, corrosion, or physical deformations. When abnormalties are observed, line movement shall be stopped and the abnormalties closely examined. The inspector should record the nature of each observed abnormality and make appropriate measurements and estimates to quantify the damage.

The termination should be closely examined, and the seizing at the termination should be removed to facilitate the detection of broken wires. Particular attention should also be given to the portion of rope against the fairlead, previous problem areas, and areas in the splash zone.

3.3.6.2 Measurement

The inspector should measure the distance of three lay lengths and wire rope diameters in three directions as shown in Figure 21 at the beginning, middle, and the end of the portion of the rope being inspected. If substantial diameter reduction or rope stretching is found, further measurements should be taken along the line. In addition to these measurements, the general condition of the rope, such as degree of wear and corrosion at the three places, should also be recorded.

3.3.6.3 Internal Inspection

Selection of rope for internal inspection should be made as follows: If all the wire ropes onboard the vessel are made by one manufacturer, at least one mooring line should be inspected for internal corrosion. Internal inspection should first be performed on the oldest rope or the rope with the most severe external corrosion if the ages of the ropes are not known. If internal corrosion is detected in the first rope internally inspected, internal inspection should be performed on the rest of the ropes.

If the ropes are made by more than one manufacturer, the preceding practice should be followed for the ropes made by each manufacturer.

The internal inspection procedure is as follows.

a) Cut a length of approximately 15 ft to 20 ft of rope at the end. Remove a 2-ft to 3-ft section from the cut end and dismantle it for inspection of internal wires (see Figure 22).

b) If internal corrosion is observed, repeat Step a) until a good internal condition is found. The lengths of rope to be removed in subsequent cuttings should be determined by the inspectors.

c) If no internal corrosion is found, reterminate the rope with a socket and put it in service again. An example of acceptable internal conditions is illustrated in Figure 17c. It may be advisable to remove a rope section of 30 ft from the cut end (see Figure 22). A break test performed on this rope section may provide useful information on the remaining strength of the rope.

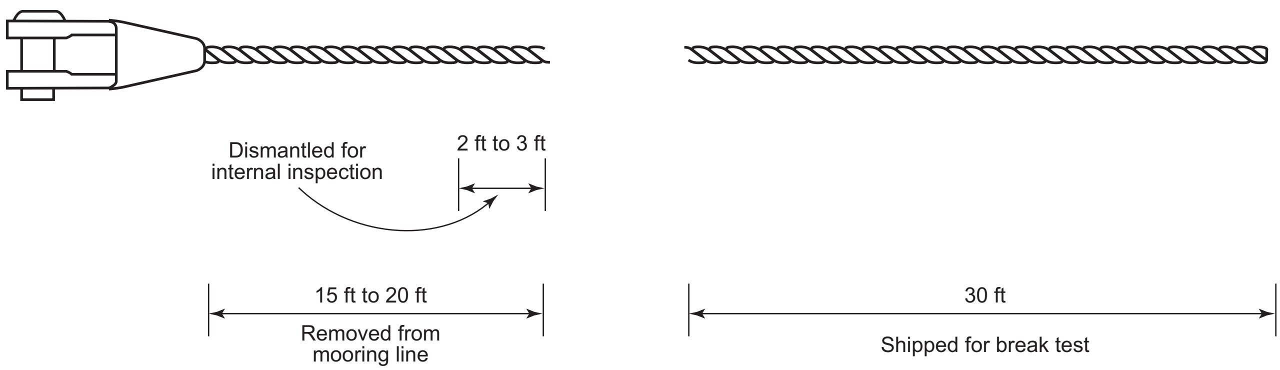


Figure 22—Internal Inspection of Wire Rope

3.3.6.4 Inspecting the Last Portion of Rope

Inspecting the last approximately 200 ft of wire rope is difficult for an all-wire-rope system. However, if the location of the wire rope can be reached by crane, and deck space on the vessel is available, the anchor and the last portion of the wire rope can be picked up and laid on deck by the crane for inspection. Otherwise, the anchor and the last portion of wire rope can be brought on board the workboat and inspected there.

3.3.6.5 Inspecting Anchor Jewelry and Miscellaneous Items

All anchor jewelry such as anchor shackles, swivels, open links, and connecting links should be inspected in the manner specified in Section 2. Sockets for reterminating wire rope should be visually inspected. In addition, the eyes of the sockets should be examined by MPI. Open links, connecting links, and shackles used to connect wire rope and chain should be inspected by the same method used for anchor jewelry inspection (see Figure 6).

3.3.6.6 Inspection Record

The following should be recorded on the inspection record:

a) the manufacturer, size, construction, grade of steel, coating (galvanized or not), and age of the wire ropes;

b) the operation history, including inspection and failure history and previous operating locations;

c) the inspection date and names of inspectors;

d) locations and nature of all wire rope abnormalities, and corrective measures taken;

e) wire rope diameter and lay length measurements, and general conditions where the measurements are taken;

f) recommendations for further action to be taken.

3.4 Guidelines for Rejecting Wire Rope

3.4.1 General

A wire rope should be rejected when any of the following conditions is found. In each case, the rope should be replaced or the damaged portion removed as prescribed.

3.4.2 Distributed Crown Broken Wires

The number of visible broken wires distributed within a lay length reaches or exceeds the limits presented in Table 3. These limits are equivalent to about an 8 % reduction in cross-sectional area of the rope or a 10 % reduction in strength when unbalance of load is taken into consideration. Rope constructions listed in Table 3 are commonly used in mooring wire ropes and are illustrated in Figure 23. (A lay length is the distance parallel to the axis of the rope in which a strand makes one complete helical convolution about the core. For a six-strand regular lay rope, a lay length is about 6 to 7 times the nominal diameter, as shown in Figure 21a.)

3.4.3 Grouped Crown Broken Wires

In this group, the number of adjacent broken wires in one strand reaches or exceeds the limits presented in Table 3. These limits are equivalent to about a 3 % reduction in the cross-sectional area of the rope or a 17 % reduction in the cross-sectional area of the strand. This criterion applies to damages concentrated in a small area of a strand as shown in Figure 11.

3.4.4 Valley Broken Wires

In this group, two adjacent wires are broken in the valley. A valley break is initiated at the interface between two strands. One should discern a valley break from a wire break that is initiated at the crown of a strand first, and broken off at the valley later.

3.4.5 Broken Wires at Termination

In this group, the number of broken wires within 12 in. of the termination reaches or exceeds the limits presented in Table 3. These limits are equivalent to about a 3 % reduction in cross-sectional area of the rope.

Rope replacement is normally not required for this condition, but a minimum of 15 ft of rope at the end should be removed and the rope reterminated. Both spelter (zinc) poured and resin sockets are acceptable. Recommended procedures for retermination of wire rope can be found in the *Wire Rope Users Manual* [12].

3.4.6 Wear and Stretch

In this group, the average of the three measured diameters is less than 94 % of the nominal diameter.

3.4.7 Internal Corrosion and Wear

In this group, internal corrosion and wear are observed. The wire rope shown in Figure 17a, is an example of extreme internal corrosion. However, a clear indication of internal corrosion and wear combined with a lack of lubrication is a justification for discard.

Where internal corrosion and wear are not obvious but internal lubrication is absent, as shown in Figure 17b, the rope is acceptable for use temporarily; however, internal inspection should be repeated within six months.

3.4.8 Deformations

Deformations include any of the conditions:

a) kinking;

b) severe bending;

c) severe scrubbing;

d) severe crushing;

e) severe flattening.

Table 3—Criteria for Crown Broken Wires

Rope Construction	Number of Outer Wires in a Strand	Number of Distributed Broken Wires in One Lay Length	Number of Adjacent Broken Wires in One Strand	Number of Broken Wires at Termination
6 × 26	10	8	3	3
6 × 25 or 6 × 31	12	10	4	4
6 × 36	14	13	5	5
6 × 41 or 6 × 49	16	17	6	6
6 × 46	18	21	8	8
Equivalent reduction in cross-sectional area [a]		8 %	3 %	3 %

[a] This information can be used to calculate the allowable number of broken wires for rope constructions not listed in this table.

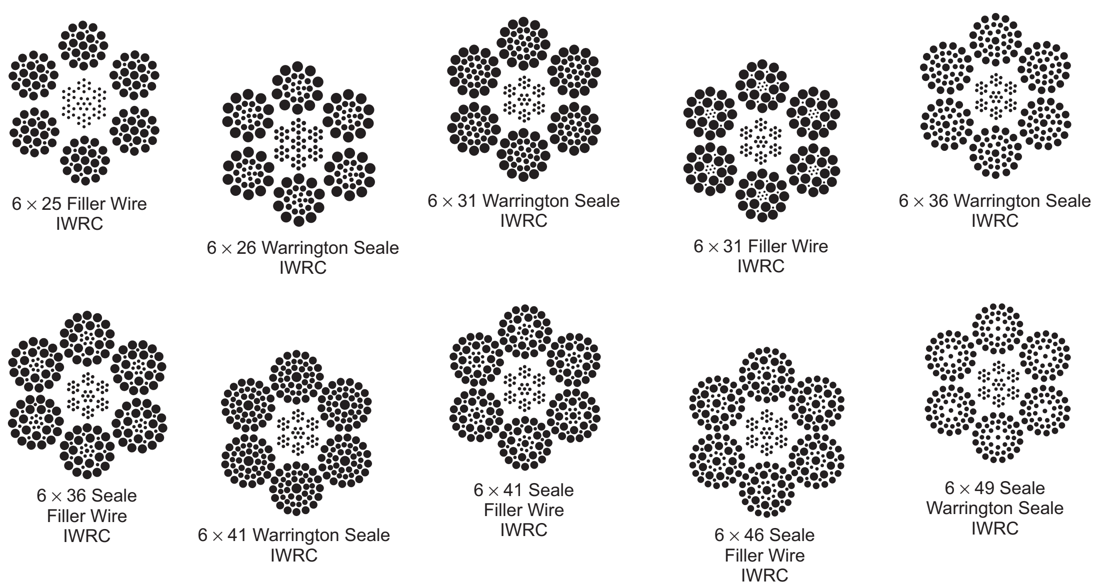


Figure 23—Common Rope Constructions for Mooring Applications

Since it is difficult to quantify wire rope deformations, the decision to accept or reject a deformed rope must depend on the experience and judgment of the inspector. As a point of reference, Figures 18 and 19 illustrate acceptable and unacceptable wire rope deformations.

3.4.9 Core Deterioration

In this group, there is an abrupt reduction in the diameter (see Figure 12), which is usually accompanied by an increase in lay length.

3.4.10 Summary

Each of the preceding guidelines deals with one type of wire rope damage, but sometimes several types of damage may occur in one area of a wire rope. Even though none of the guidelines is violated, the rope should be rejected when the combined effect of the damage jeopardizes the integrity of the rope. Consider a case, for example, where the number of distributed broken wires in one area of a rope is less than, but close to, the limit specified in Table 3, and in addition this area has considerable external corrosion and wear. In this case, the rope should be replaced as soon as possible.

3.5 Recommended Inspection Schedule

A wire rope inspection schedule should be based on the age, condition and operational history of the wire rope (ground wire rope versus rig wire rope over fairleader under high load) and type of operation.

The major inspection should be scheduled according to the conditions of the wire rope detected during the prior inspection. The recommended major inspection intervals are given in Table 4 and may be modified based on the condition and previous inspection history of the wire rope. As a minimum, a full visual inspection of all mooring lines, including connectors and jewelry must be conducted as per the frequency in Table 4. If deterioration is found during inspection, defined as a difference between the as-built and current condition but within the tolerance prescribed by API 2I, then the inspection interval should be reduced to effectively monitor the condition of the components and ensure they are fit for intended service at all times.

Guidance for conducting a major inspection is defined in 3.3 and rejection criteria are defined in 3.4.

Table 4—Wire Rope Inspection Intervals

Number of Years in Service	Recommended Intervals Between Major Inspections [a]
0 to 2	18 months
3 to 5	12 months
over 5	9 months

[a] With a grace period not to exceed 4 months.

In addition to the major inspections, wire rope and connecting hardware should be checked for visible defects frequently during anchor retrieval.

Special attention should be given to the long term operations where the inspection schedule is current at the start of the operation, but the inspection will expire during the operation. For example, a development drilling will take 18 months to complete, but the inspection will expire in six months after start of the operation. In this case, an inspection of the mooring system should be conducted before the MODU is moored on location or while the MODU is in operation.

3.6 Special Event Inspection

Rigorous mooring inspection is critical for operations in the areas of tropical cyclone where the probability of mooring failure can be much higher. Also guidance is needed to address the reuse of the components from a mooring damaged by a tropical cyclone. Additional guidance for MODU mooring inspection in these areas can be found in Annex B.

3.7 Recommendations for Proper Use and Maintenance of MODU Mooring-wire Rope

Recommendations for proper use and maintenance of mooring-wire rope are as follows.

a) Reterminate mooring wire rope on mobile offshore drilling units when necessary. A minimum of 15 ft of rope should be cut and the rope reterminated.

b) When deploying wire rope on hard seafloor, maintain proper tension in the rope by applying the dynamic brake to avoid dragging the wire rope on the seafloor.

c) Maintain a tension when winching in the mooring lines.

d) Avoid, if possible, test loading anchors when the wire rope is at the riser point where a new layer starts on the winch drum.

e) Gauge the fairlead sheave grooves at convenient times, such as during special survey or MODU repair. If the groove is substantially under gauge, replace or repair the fairlead sheave. The radius of the fairlead sheave groove should not be less than the minimum radius for worn groove specified in the *Wire Rope Users Manual* [12]. Fairlead sheaves should also be carefully evaluated for oversize grooves which can also cause damage to the wire rope.

f) Check the level wind of the winch periodically to ensure its proper function.

3.8 Inspection of Anchor-handling Equipment and Termination of Pendant Wire Rope

3.8.1 Inspection

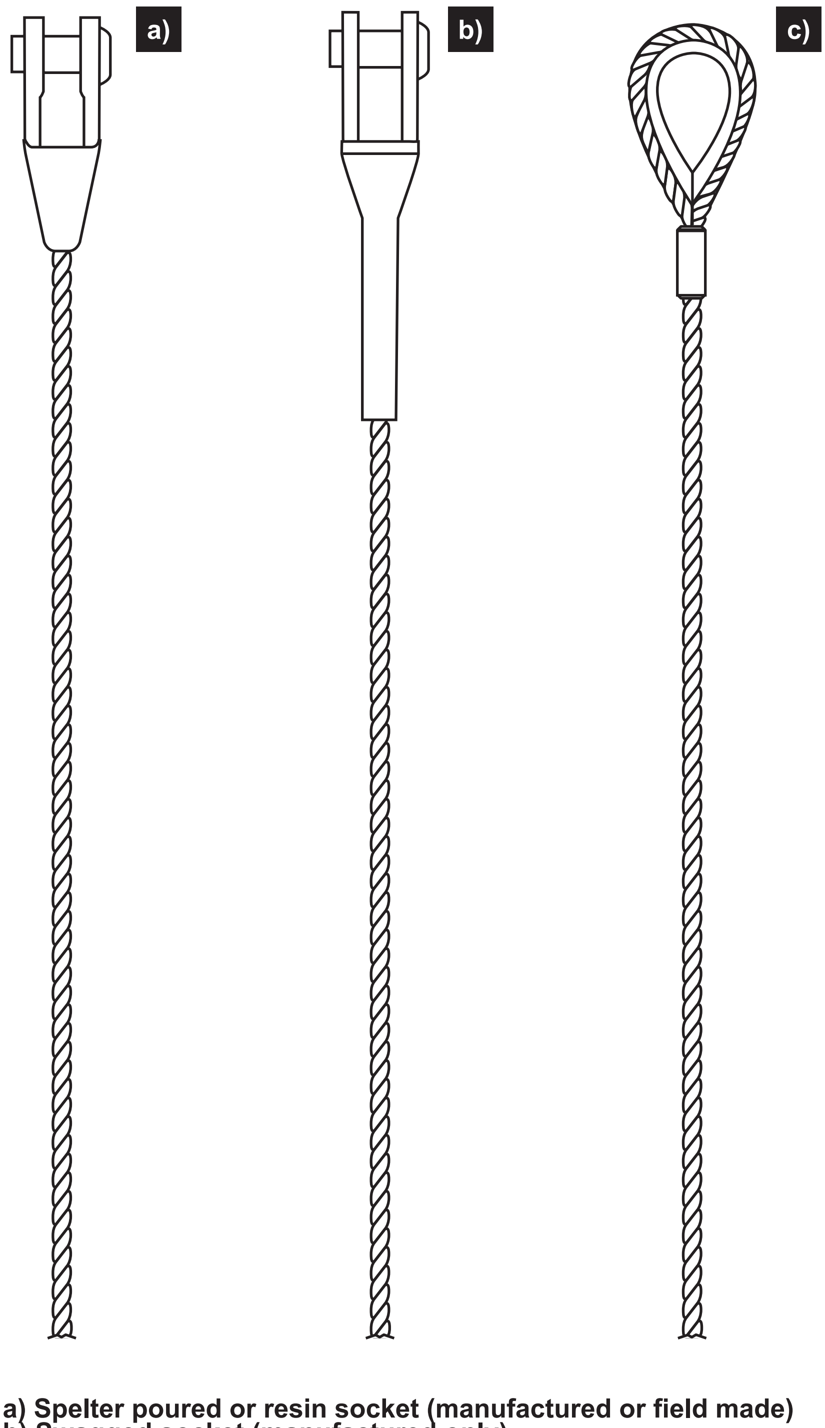
The anchor-handling equipment on the workboat should be inspected to ensure a safe operation. The discard criteria for mooring-wire rope would equally apply to wire ropes for pendant lines and work lines on a workboat. However, the inspection method, procedure, and schedule for pendant wire rope could be substantially different and should be determined by the operating personnel based on their experience, the pendant system, and the equipment on the workboat.

Miscellaneous connecting hardware, such as sockets, shackles, and connecting links for pendant lines and work lines, should be inspected in the same manner described in previous sections. Shark's jaw, pelican hook and similar stopping devices for temporarily securing a pendant line should be examined by MPI.

3.8.2 Termination

Three types of wire rope termination are acceptable for pendant lines: spelter-poured or resin socket, swaged socket, and thimbled mechanical splice, as shown in Figure 24. The swaged sockets and thimbled mechanical splices should be made at the manufacturers' facilities. Only the spelter-poured and resin sockets can be made in the field.

Recommended procedures for making spelter- (zinc-) poured socket and thermo-set resin socket can be found in the *Wire Rope Users Manual* [12].



a) Spelter poured or resin socket (manufactured or field made)
b) Swagged socket (manufactured only)
c) Thimbled mechanical splice (manufactured only)

Source: Reprinted with permission of American Iron and Steel Institute, from Wire Rope User's Manual. ©1981 American Iron and Steel Institute.

Figure 24—Acceptable Terminations for Pendant Wire Rope

4 Inspection of Steel Components for Permanent Moorings

4.1 General

Inspection of steel components for MODU moorings is addressed in Section 2 and Section 3. This section covers inspection of steel components for permanent moorings. The inspection requirement for permanent mooring systems is similar in many ways to those for MODUs, but the method of inspection is very different. Monitoring and inspection of permanent mooring systems thus require different techniques.

4.2 Difference Between MODU and Permanent Mooring Inspection

The differences between inspecting MODU and permanent moorings are described in the following.

— MODUs are typically moored temporarily on location, and the mooring system is retrieved periodically and therefore is available for direct inspection in a dry and accessible location. Permanent mooring systems are normally not retrieved during their service life so all inspections must be performed *in situ* and rely primarily on limited diver access and/or ROV inspection.

— Deterioration of permanent mooring components can be concentrated in a few locations such as wear at the fairlead/stopper and seafloor touchdown point and corrosion at the splash zone. Deterioration of MODU mooring components is normally more evenly distributed.

— The design of a permanent mooring system requires adequate fatigue life, wear and corrosion protection or allowance. These are normally not required for MODU moorings.

— For permanent moorings, connectors and other mooring jewelry need to be designed to ensure robustness over the life of the field. The connecting hardware for MODU moorings can be inspected or replaced periodically.

4.3 Typical Components in Permanent Moorings

4.3.1 Chain

The mooring chain can be either studless or studlink chain.

4.3.2 Wire Rope

The wire rope can be of either six-strand or spiral strand construction. Spiral strand can be sheathed with a polyurethane cover or unsheathed. The wire rope segments are typically terminated with a socket that allows connection to other segments or a triplate.

4.3.3 Connectors

Various permanent connectors are used to connect segments of chain and/or wire rope to one another, either directly or via a triplate. The connectors are typically ‘D’ type or ‘H’ shackles with a pin and nut used to complete the connection.

4.3.4 Subsea Connectors

These connectors are typically used to facilitate installation of deepwater anchor legs or to allow easy replacement of mooring components. Two example connectors are the ‘Delmar’ and the ‘Ballgrab’ connectors (see Figure 25). These connectors are often located near the anchors.

4.3.5 Catenary Weights (‘Clump Weights’) or Drape Chains

These are sometimes used to increase the weight per unit length of the anchor leg near the touchdown region. These ‘weights’ are connected to the anchor leg components using connectors like shackles or triplates.

a) Delmar connector b) Ballgrab connector

Figure 25—Examples of Subsea Connectors

4.3.6 Mid-water Support Buoys

These buoys can be of syntactic foam or steel construction and are used to help support the anchor leg system to reduce the load on the floating facility. These buoys are typically connected to triplate or other connection interface.

4.4 Mooring Component Information

Certain information should be collected and provided to the inspector before start of the inspection. Following are some examples, which may not represent a complete list.

— *Chain*. Type (studless or studlink), grade, diameter (nominal and bar) and other link dimensions, segment length, MBS, manufacturer and year made.

— *Wire rope*. Construction (six-strand or spiral strand), jacket (sheathed or unsheathed), corrosion protection (galvanized wires, zinc filler wires, anodes on socket, blocking compound), termination (socket type, tri-plate, etc.), diameter (bare, with jacket), segment length, MBS, manufacturer and year made, re-tension hardware.

— *Connectors*. Type ('D' or 'H' shackles, Kenter), size, MBS, and location.

— *Subsea connectors*. Type ('Delmar', 'Ballgrab', etc.), manufacturer and year made, size, inspection requirements by manufacturer, and location.

— *Catenary weights*. Type ('clump weights' or drape chain), weight, and location.

— *Mid-water support buoys*. Type (syntactic foam or steel), buoy dimensions, net buoyancy, location, and connecting hardware.

— *All components*. Previous inspection report(s), including details of past found anomalies, as available.

4.5 Inspection Objective, Type, and Schedule

4.5.1 Inspection Objective

Permanent mooring components are normally designed to allow for some wear and corrosion, so the inspection is usually to confirm that the wear and corrosion is within the design values over the life of the field. In addition, the inspection is performed to monitor the integrity of the connections of the individual components. As the majority of the mooring system is below the sea surface, the inspection is usually conducted by divers in shallow water and by ROV in deepwater. The inspection is mainly visual with photographs, video, and inspectors comments taken. The inspection can also include measurements of component diameter or depth based on the inspection plan. It is sometimes desirable to measure the potential across various mooring components to provide some insight into the possibility of corrosion occurring.

For permanent moorings, the component deployed lengths and weights are well documented and generally accurate, and the installation is also performed generally with high accuracy. This allows the use of measured catenary properties (length, depth at known reference, angle at the fairlead, tension, etc.) to help monitor and diagnose the mooring system. This information can be effectively used to estimate mooring system performance and to make a decision if any adjustments are warranted.

4.5.2 Inspection Type

Inspection and monitoring of a permanent mooring system occur in several stages over its lifecycle. The first occurs right after mooring installation and floater hook-up when an as-built survey is conducted. Mooring systems are also inspected periodically at various levels of detail based on Class or project/operating company requirements. In addition some operators may inspect the mooring system after large storms or other events that warrant inspection (dropped objects, phased installation of risers, etc.).

4.5.2.1 As-built Survey

An as-built survey should be performed for the permanent mooring system once it is hooked-up to the platform and tensioned to the design values. The survey is primarily conducted to confirm that the anchor legs are connected as designed, to check or monitor for damaged during installation, and to ensure that the permanent twist in the anchor legs is within the design/installation margins. The as-built survey also serves as the baseline for comparison for all subsequent scheduled inspections over the service life of the installation, and the inspection should be documented accurately and with sufficient detail.

Most as-built surveys are conducted from the anchor to the fairlead or as close to the surface as practical and are primarily visual inspection performed with an ROV. The visual inspection is usually recorded electronically (video) along with comments made by the inspector. In many cases the ROV position and depth can be recorded and if performed with high precision, the measurements can serve as a useful guide for monitoring mooring system performance. The following data are generally recorded when performing an ROV survey:

— environmental conditions at the site during the survey;

— floating facility position and heading (if applicable);

— floating facility draft and trim;

— twist in the anchor leg;

— condition of the spiral strand wire sheathing (if applicable);

— condition of all anodes on wire rope sockets, triplates and other connectors if applicable;

— condition of all connectors (inspect pin, nut, cotter pin, etc. if applicable);

— measure depth of connectors as a reference for the catenary of the anchor leg;

— estimate distance between anchor leg/seabed interface to anchor location (when applicable—can help identify if inverse catenary is changed during subsequent inspections); and

— monitor condition of anchor (if applicable)—hatches/valves on suction piles, scour around anchor, etc.

The as-built details of the mooring system should be well documented in order to facilitate full materials traceability and future inspections. The as-built documentation should include a detailed listing of all components in each mooring leg such as manufacturer, serial number or other identification. In addition, it should include any information available on mooring system modifications made during installation.

4.5.2.2 Periodic Survey

The periodic survey is very similar to the as-built survey with as many measurements as possible repeated to check against the original survey. The survey can be conducted by divers in shallow water or ROVs in deep water. In addition to addressing the overall mooring performance, the survey should perform a detailed inspection of the various mooring components as detailed in 4.6. The periodic survey should be planned in detail to ensure that quantitative information is obtained if required and that the inspectors are provided a list of items to be inspected. Equipment or a means of removing marine growth at the desired inspection locations should be provided. Direct measurement of component diameter, if possible, provides quantitative data for component assessment. Depth measurement of connectors or buoys can provide useful feedback in overall mooring system performance. If the anchor leg system is provided with a load monitoring system, fairlead angle indicator (mechanical or electronic), or similar device, quality data should be recorded along with floater position to enable accurate assessment of the mooring system.

4.5.2.3 Special Event Survey

The scope of special survey should be determined based on the purpose of the survey. For example, if the survey is needed because of a dropped object, the inspection may be limited to the area that can be damaged by the dropped object.

4.5.3 Inspection Schedule

Inspection schedule may vary from project to project, based on type of mooring, area and nature of operation, seafloor condition, water depth, and class requirements, etc. Following are minimum requirements.

4.5.3.1 As-built Survey

As-built survey should be conducted within three months or as soon as practical after completion of initial hookup of the mooring system with the floating vessel. Additional survey should be performed after subsequent installation activities (riser hookup, etc.) that may have significant impact on the mooring system.

4.5.3.2 Periodic Survey

Periodic surveys should be conducted no less than once every five years.

A visual inspection should be conducted annually for the above water mooring components, including chain or wire rope, winches or windlasses, deck sheaves, stoppers, and fairleads or bending shoes.

4.5.3.3 Special Event Survey

A special event survey should be considered after severe storms or other events that warrant inspection (dropped objects, collision, and contact with work wire, etc.).

4.5.4 Inspection Record

The following should be recorded on the inspection record:

a) the component information as listed in 4.4;

b) the operation history, including inspection and failure history and previous operating locations;

c) the inspection date and names of inspectors;

d) type of inspection (as-built, periodic, or special survey) and inspection method (in air, diver, or ROV);

e) locations and nature of all component abnormalities, and corrective measures taken;

f) recommendations for further action to be taken.

4.6 Detailed Component Inspection and Discard Criteria

4.6.1 General

A detailed mooring survey should inspect all components in the mooring system as practically possible, paying careful attention to the interface points such as fairlead/stopper on the floating facility, the anchor on the seabed, the splash zone, and the touchdown point of the mooring line.

4.6.2 Chain Inspection

Typically, chain is used at the fairlead, the touchdown point, and at the anchor, though in shallow water all-chain mooring systems are very common. Chain has the lowest fatigue life of most common mooring components, and therefore wear and corrosion of the chain can also result in accelerated fatigue damage and failure of the anchor leg. Chain segments are susceptible to wear at the fairlead and the touch down point, and also between ‘grips’ of the chain links. In addition, chains are susceptible to corrosion in the splash zone, and near other mooring components constructed with dissimilar metals. The studs in studlink chain can get loose or fall out resulting in higher stresses in the link and thus accelerate fatigue damage. Connectors can be subjected to wear, corrosion, and failure of the retaining hardware. Therefore, an inspection plan for mooring chain should focus on the following regions:

— fairlead region;

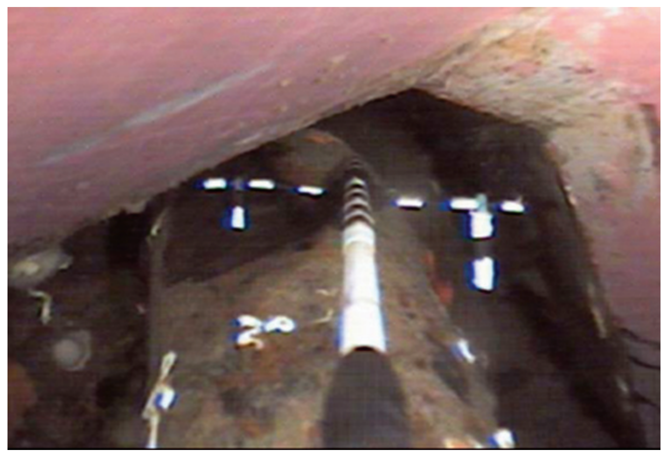
— splash zone;

— touch-down region;

— connectors.

Although MODU chain inspection is primarily based on direct measurement of the chain links at specified intervals, for permanent mooring systems all measurements have to be made *in situ* by ROV or by diver, and in many cases the only information available is video or photo. Figure 26 shows the level of details that can be recorded by different ROV inspection techniques.

a) Chain at trumpet recorded by typical work class



b) Chain at trumpet recorded by micro-ROV

Figure 26—Chain Details Recorded by Work Class and Micro-ROV

Figure 27—Example of Chain Wear from Sitting in a Fairlead Pocket

4.6.2.1 Areas of Inspection

4.6.2.1.1 General

Although the condition of the entire chain should be checked wherever possible, special attention should be paid to the areas described in 4.6.2.1.2 through 4.6.2.1.5.

4.6.2.1.2 Fairleads, Hawse Pipes, and Bending Shoes

Fairleads, hawse pipes, and bending shoes are critical areas that deserve maximum attention. Arrangement should be made to have some meaningful inspection of the chain in the fairlead, hawse pipe, or bending shoe. This may require, in some instances, paying out or hauling in the chain to gain access for inspection. The chain should be cleaned of all marine growth and scale, and inspected closely for wear, corrosion, loose stud, and out-of-plane bending. Figure 27 shows significant chain wear due to contact with the fairlead for a long period. If a hawse pipe or trumpet is used as part of the fairlead, the chain should be closely inspected at the end of the hawse pipe or trumpet to check for wear from abrasion between the hawse pipe or trumpet and the contact link. Figure 28 shows a notch on a chain link created by contact with the hawse pipe. If the fairlead is located above the waterline and the chain is readily accessible, direct measurements of the chain should be conducted. In regions of high stress or contact, particularly where fatigue damage is expected, inspection should include MPI or dye penetration and be performed at regular intervals. For segments below the waterline, divers or ROVs with calipers could be used to obtain $2 \times D$ (2 times diameter) measurements of the chain links in the grip area. The fairlead should also be inspected to ensure proper operation (rotation, etc.) as an inoperable fairlead can result in accelerated damage to the chain.

4.6.2.1.3 Splash Zone

The chain at the splash zone (or in the first 50 m of the water column) is susceptible to corrosion. This region is also prone to large amounts of marine growth making inspection very difficult. Figure 29 shows heavy marine growth and chain corrosion in this area. The marine growth should be cleaned in the regions where the inspection is performed using water jets or by scraping. Measurement of $2 \times D$ in the grip area is important as this region is prone to wear at the grips because of relatively high tension. Corrosion at the stud interface is also common in this region.

4.6.2.1.4 Touchdown

Chain in this region is susceptible to wear due to continuous contact with the seabed, and the wear is a function of soil conditions. Normally only visual inspections are possible in this region, although in shallow water divers may be able to perform some measurement on the chain. The touchdown region is also where clump weights or drape chains are attached to improve mooring system performance. The inspection needs to ensure that the integrity of the clump weights are maintained (connectors/bolts, etc.). Figure 30 shows clump weights detached from the chain. Note that in some soil conditions the mooring line can create a very deep trench at the touchdown point, and in extreme cases can radically change the performance of the mooring system or cause damage to the mooring component in the trench. The component in the trench should be monitored. Impact with the seabed can result in studs getting loose or falling out, and therefore special attention should be given to detecting loose studs.

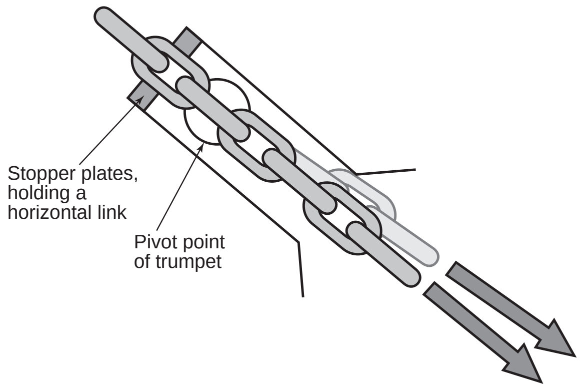
4.6.2.1.5 Anchor

The chain at the anchor is relatively static in shallow water though it could be suspended for deep water moorings. The monitoring of the position of the intersection of the soil and the chain segment can provide some insight if the inverse catenary of the chain to the anchor is modified due to high loading, leading to change in mooring line tension and mooring performance.

4.6.2.2 Discard Criteria for Chain

4.6.2.2.1 General

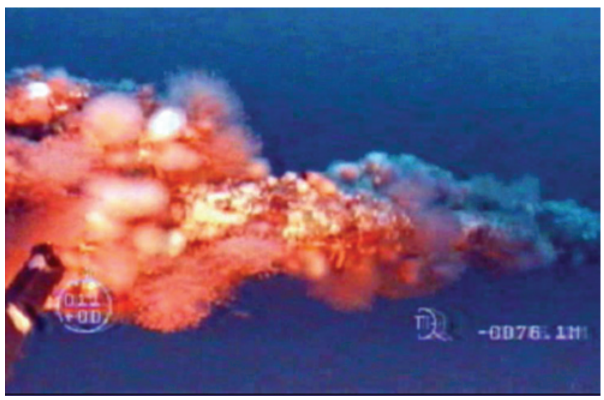
The discard criteria for MODU chain (see 2.4) are generally applicable although care should be taken when estimating the residual strength of the chain accounting for wear and corrosion. This is especially true for large chain



a) Typical FPSO chain stopper arrangement

b) Wear notch from contact with hawse

Figure 28—Example of Chain Wear at Hawse Pipe



a) Marine growth

b) Chain corrosion

Figure 29—Example of Heavy Marine Growth and Chain Corrosion at Splash Zone

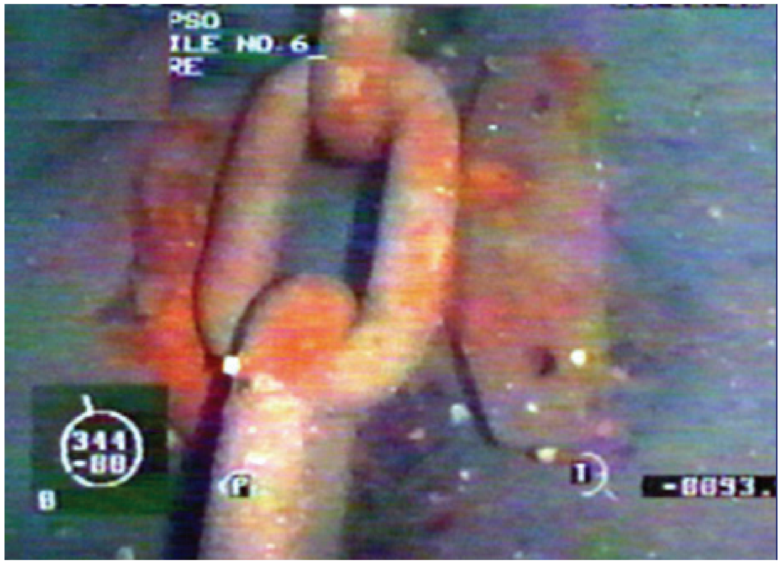


Figure 30—Example of Detached Clump Weight on the Seabed

Figure 31—Chain Diameter Reduction Due to Excessive Interlink Wear

Figure 32—Example of Chain Link Subjected to Out-of-Plane Bending

diameters commonly used for permanent mooring systems. The allowable strength reduction is 10 % based on end of life breaking strength.

4.6.2.2.2 Chain Diameter

Chain diameter is best measured at the grip area of the chain where interlink wear can significantly reduce the chain diameter (see Figure 31); however measurements can also be made along the body of the chain segment. Since the base bar stock of chain is always greater than the nominal diameter of the chain, it may be best to obtain a dataset of chain diameter at various locations along the links of the new chain to serve as a benchmark. For permanent mooring systems the first comparison should be to the design wear and corrosion allowance in the original design (typically 0.2 mm to 0.4 mm per year for the service life of the field). If this allowance is exceeded, the strength reduction of the chain should be estimated based on diameter reduction from the end of life diameter used in the original design. It should be noted that chain links are manufactured according to some dimension tolerances. For example, according to ISO 1704 [17], the allowable manufacturing tolerances on the nominal diameter *d* the common links measures at the crown are:

— 0/–1 mm for $d \leq 40$ mm;

— 0/–2 mm for 40 mm $\leq d$ 84 mm;

— 0/–3 mm for 84 mm $\leq d$ 122 mm;

— 0/–4 mm for $d > 122$ mm.

The cross-sectional area at the crown of the link shall be not less than the area of a circle of the nominal diameter. The allowable manufacturing tolerance on the nominal diameter measured elsewhere on the link is 0/–2.5 %.

4.6.2.2.3 Out-of-Plane Bending

See 2.4 for guidance on out-of-plane bending. If there is evidence of bending deformation at the fairlead or due to contact of the chain with the hawse pipe (see Figure 32), then the fatigue life of the system may be compromised unless it has been accounted for in the design. If practical, the links in contact with the fairlead should be shifted periodically to avoid excessive bending.

4.6.2.2.4 Loose or Missing Studs

Although the guidance for loose or missing studs in MODU chain (see 2.4 and 2.5) can be useful, special consideration should be given to chain in permanent moorings because replacement of links with loose or missing stud may not be justified in some cases. Loose or missing studs can result in a very different stress distribution in the links and thus negatively impact the fatigue life of the chain segments. If the original design is fatigue sensitive, this may warrant further monitoring of the chain link or replacement. The chain manufacturer should be contacted for feedback on chain performance, and evaluation of fatigue life reduction due to loose or missing stud can be carried out by comparing stress concentration factors before and after the stud becomes loose or missing.

4.6.2.2.5 Cracks and Grooves in Chain

Use guidance in 2.4 with chain diameter adjusted for wear and corrosion allowance as discussed in 4.6.2.2.2.

4.6.3 Wire Rope Inspection

Two wire rope constructions are commonly used in permanent moorings, six-strand and torque-balance spiral strand construction. All permanent mooring wire ropes are provided with cathodic protection, typically using an anti-corrosion coating or galvanized wires in the outer two layers of rope coupled with the use of a blocking compound to block the ingress of water. Additional cathodic protection can be achieved by incorporating zinc filler wires at the outer layer of a spiral strand. Spiral strand wire ropes can be sheathed with polyurethane to provide additional corrosion protection or unsheathed. Six-strand ropes are normally unsheathed. Wire rope is terminated with a socket that is often provided with anodes for corrosion protection. It is also typical to electrically isolate the wire rope segments from the other mooring components using isolation bushings at the socket/pin interface. Socket for spiral strands are often equipped with a bend stiffener to limit free bending.

4.6.3.1 Areas of Inspection

4.6.3.1.1 Broken Wires

Check for broken wires for unsheathed wire ropes, especially near the socket interface. For sheathed wire ropes, check for broken wires in the area where the sheath is damaged.

4.6.3.1.2 Corrosion

Check for external corrosion in unsheathed wire ropes. For sheathed wire ropes, check for corrosion in the area where the sheath is damaged.

4.6.3.1.3 Sheath Damage

Polyurethane sheathing is susceptible to damage when it comes in contact with hard objects such as installation wire ropes or dropped objects. Loss of the sheathing integrity can reduce service life of a rope.

4.6.3.1.4 Sockets

Check bend stiffener interface for integrity (bolts, etc.) and broken wires at socket interface. Also check anodes on the socket and clips and pins at the socket/mooring component interface.

4.6.3.2 Discard Criteria for Wire Rope

4.6.3.2.1 General

Section 3 provides guidance for inspection and discard criteria of MODU mooring wire ropes with emphasis on six-strand ropes and dry inspection. The guidance is generally applicable for permanent mooring ropes with some modifications as discussed below. Similar to the MODU wire rope, the allowable strength reduction is 10 %.

a) Kinking

b) Bird caging

Figure 33—Example of Bird Caging and Kinking of Spiral Strand During Installation

4.6.3.2.2 Bird Caging or Kinking

This could occur during installation or at the touch down point of the mooring system. This usually results in a loss of wire rope integrity and requires replacement or re-termination (see Figure 33).

4.6.3.2.3 Broken Wires

The wire rope strength has to be estimated based on the number of broken wires and their distribution. This can be carried out qualitatively by using the ratio of broken wires to total number of wires for a relatively small number of broken wires, or more accurately by the wire rope manufacturer using their in-house models and experience. This estimate can then be applied to ensure that loss of strength is within the allowable limit of 10 % (see 3.4 for more detailed discard criteria). If the number of broken wires extends beyond the number of wires in the outer layer of the wire rope, this may indicate that the corrosion protection of the wire rope is affected. In this case the wire rope manufacturer or consultant should be contacted for detailed evaluation and decision of discard. Missing or broken zinc filler wires in an unsheathed spiral strand may signal internal corrosion, and retirement or increased monitoring should be considered.

4.6.3.2.4 Missing Anodes on Socket or Wire Rope

Missing anodes, which can be caused by detachment (see Figure 34) or severe internal corrosion, should be replaced with new anodes. In addition, increased monitoring should be considered to assess the potential of internal corrosion and the need for rope retirement.

4.6.3.2.5 Damaged Sheathing

Damage to the wire rope sheathing does not immediately impact the break strength or fatigue life of the wire segment but can impact the overall service life of the rope as it reduces the corrosion protection of the rope. Typically, sheathed wire rope is of similar construction and corrosion protection to unsheathed wire rope and thus is usually protected also

Figure 34—Example of Disconnected Anodes for Spiral Strand

by the galvanized layers and blocking compounds (to be confirmed by specific wire rope manufacturer). Small tears to the sheathing can be repaired both in dry and wet conditions using kits and methods provided by the wire rope manufacturers and installation contractors. For large damage to the sheathing, the attachment of a properly designed anode system coupled with periodic monitoring and inspection may be utilized to provide the desired service life. However, the implementation of this measure should be performed under the guidance of the rope manufacturer.

4.6.4 Inspection of Connectors and Support Buoys

4.6.4.1 Connectors

A variety of connectors are used to join various mooring components. Most permanent moorings utilize connectors such as 'D' or 'H' shackles, triplates, etc. to connect various chain, wire rope and anchor components. In addition, special connectors such as the 'Delmar' and 'Ballgrab' connectors are often used to aid in the installation of moorings and to allow rapid change out of anchor legs.

Connectors are typically designed to meet the strength and fatigue life of the weakest components of the mooring system using similar design principles and wear and corrosion allowance. Some connectors, e.g. triplates, have anodes to provide corrosion protection.

One critical component of connecting shackles is the pin with nut and retaining hardware (e.g. cotter pin). It is important to ensure that the pin maintains its integrity as there are numerous cases where pins have come apart due to failure of the retaining mechanism (see Figure 35). The connectors should be inspected visually for wear and to ensure that all retaining hardware is intact. If possible, wear measurements should be taken to allow estimation of remaining strength. Corrosion can take place between the threads of the pin and the nut so this should also be inspected.

Special connectors like the 'Delmar' and 'Ballgrab' may have specific inspection requirements, and the inspection should be conducted according to the O&M manual provided by the manufacturers.

Figure 35—Wire Rope Socket Disconnected Due to Detachment of Retaining Pin

4.6.4.2 Support Buoys

Mooring support buoys are normally built of syntactic foam or steel with interface to the anchor leg via a triplate or other specially designed connector. The inspection of the mooring support buoys should focus on the connections to the mooring system (triplate, pins etc.) and the integrity of the support buoy. The integrity is best assessed by measuring the depth to a reference point on the buoy as any loss of buoyancy will result in change in depth of the buoy. Note that syntactic foam absorbs water over time and changes in net buoyancy of 5 % to 10 % are not uncommon over 20 years.

If a surface piercing buoy is used, then the area of the mooring line near the triplate connections should be carefully inspected for damage due to twisting or chafing. Some support buoys utilize in-line chain or chain buoy swivels, which should fall under chain inspection procedures.

5 Inspection of Fiber Ropes for MODU and Permanent Moorings

5.1 General

This section provides guidance for typical in-service inspection and maintenance of fiber rope moorings.

A plan for fiber rope inspection and condition assessment should be developed by the operator of the mooring system and the manufacturer of the rope in conjunction with the certifying authority on a case by case basis to provide consistency in the overall safety assessment for a given installation.

An individual log should be kept for each rope which clearly records the history of the rope usage including information such as rope tensions, relevant environmental conditions, and inspection/re-tensioning details on the rope.

As a minimum the following information should be collected and provided to the inspector before the start of inspection: rope construction (number of subropes in rope and number of strands in subrope), jacket (type, material), filter type and filtering capability, splicing method (individual or paired, etc.), diameter, segment length, MBS, manufacturer and year made.

5.2 Inspection and Testing Techniques

5.2.1 Visual Inspection

Visual inspection techniques are limited to external visual examination only. Inspection of mooring legs may be performed on deck or at dockside. Visual inspection of installed mooring legs can be performed using divers or a remotely operated vehicle (ROV). The ability of visual underwater inspections to identify damage to the exterior of the fiber rope depends upon underwater visibility and extent of marine growth.

During deployment or retrieval, the inspector looks for any external signs of rope damage. If the inspector sees any signs of, or suspects rope damage the movement of the rope is stopped to allow the inspector sufficient time to conduct a close visual inspection of the suspect portion of the rope.

5.2.2 Destructive Inspection and Testing

In general the use of fiber rope test inserts for subsequent rope inspection is not recommended. Industry's experience with fiber rope test inserts indicates the information gained from the testing of test inserts has been of limited benefit [14], [15].

Some permanent moorings contain fiber rope test inserts, which are short segments typically 10 m to 15 m long, placed at the top of the fiber mooring line just below the fairlead chain (see Figure 36). The test insert arrangement may vary from project to project, having one or two test inserts placed in all or selected mooring lines. A test insert can be taken out periodically for detailed inspection and testing. This inspection method may provide information on the in-service condition of the fiber rope such as present strength and fatigue life, ingress of soil particles or marine growth, changes in yarn or fiber properties, and loss of marine finish, etc., for the insert tested.

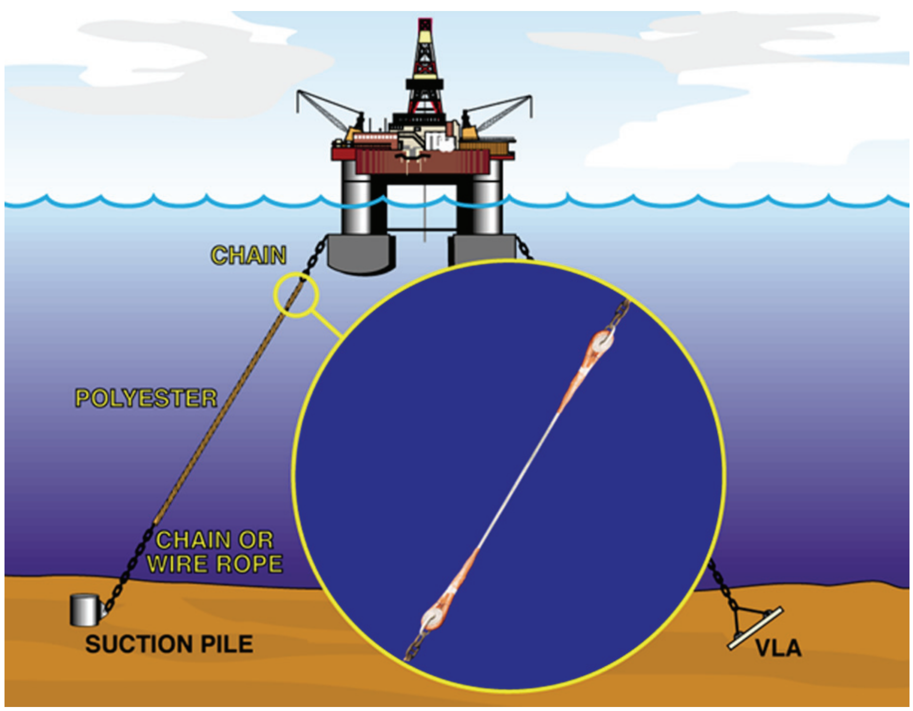


Figure 36—Fiber Rope Test Insert for Rope Inspection

There are concerns regarding the negative impact of this practice. Therefore the placement and inspection of test inserts need careful evaluation, which should consider the following factors.

a) The use of test inserts increases the number of terminations, which are potential weak points in the mooring.

b) Currently there is no standard methodology to apply the test insert data to the rest of the mooring line. The data gathered from a short segment placed at a particular location may not be representative of other rope segments.

c) There may be a considerable risk of damage to the mooring lines, risers, umbilicals or other infrastructure in the water column and on the seafloor during test insert retrieval or replacement operations, especially for operations that place test inserts several hundred ft below the water surface and adjacent to or between other mooring lines, risers, and umbilicals. Such operations require careful planning and execution in order to minimize the risk of damage to equipment and injury to personnel.

For these reasons, the potential benefits of test inserts should be carefully weighed against the potential adverse impact for each project before decisions of placing or retrieving test inserts are made.

Test inserts are not recommended for MODU mooring lines. The need for test inserts in this case is not apparent, since the entire rope is brought to the surface frequently and can be inspected or tested. If it is desired to test fiber rope, an end section may be cut from the fiber rope for testing.

5.3 Damage Assessment and Discard Criteria

5.3.1 General

Rope that has been damaged during installation or in service can be used provided certain criteria are met. If the rope is intended to remain in service, a damage assessment should be performed and recorded immediately after damage to the rope is detected. The assessment should include detailed description of the damage and causes. Measurements of the damage, such as length and depth of a cut and photographs of the damaged area should be included in the damage report. An evaluation of rope strength reduction due to the damage should be carried out. Guidelines for such an evaluation are provided in 5.3.2 through 5.3.8.

5.3.2 Concentrated Damage

Concentrated damage is a form of damage for fiber ropes. It is often caused by contact of the fiber rope with sharp edges during rope deployment or retrieval. For an installed fiber mooring line, concentrated damage can also be caused by a falling object or contact with a steel work line used for other installation activities. An example of concentrated damage is shown in Figure 37.

5.3.2.1 Factors Affecting Damaged Strength

5.3.2.1.1 Fiber Area Reduction

Fiber area reduction due to concentrated damage has a direct impact on the damaged strength of the rope. Test data indicates that fiber area reduction and strength reduction are not highly correlated.

5.3.2.1.2 Rope Construction

Rope construction affects the damaged strength of the rope. Therefore, applying test results from one type of construction to another type is not valid. Parameters representing rope construction include strand, subrope, and full rope construction type (parallel, braided, or wire rope), number of strands in a subrope, and number of subropes in a full rope, jacket tightness, use of strand jackets, and subrope pitch, etc.

Figure 37—Example of Concentrated Damage

5.3.2.1.3 Rope Splicing Method

There are two splicing methods commonly used by the rope manufacturers.

a) *Individual subrope splicing.* This is the most common method where a subrope is spliced back to itself.

b) *Paired subrope splicing*. In this splicing method, two subropes are spliced to each other at both ends. Ropes spliced in this manner may have a lower damage strength since failure of one subrope could result in the effective failure of two subropes.

5.3.2.2 Discard Criteria for Concentrated Damage

Similar to steel components, there are two types of discard criteria that can be used for fiber rope concentrated damage.

a) *Allowable strength reduction*. The allowable strength reduction is 10 % MBS, which is the same as that for chain and wire rope. To use this criterion, a procedure to assess strength reduction due to concentrated damage is required.

b) *Allowable fiber area reduction*. In this method, the percent load carrying fiber area reduction corresponding to 10 % MBS strength reduction is used as discard criterion. This criterion may be established by the following procedure.

   1) Conduct break tests for damaged rope samples with different degrees of simulated damage and undamaged samples, and use the method described in API 2SM to determine the undamaged and damaged break strength.

   2) Plot a curve of percent fiber area reduction versus damaged strength in terms of percent MBS.

   3) Determine the allowable fiber area reduction, which is the percent load carrying fiber area reduction corresponding to a damaged strength of 90 % of MBS.

It should be noted that the allowable fiber area reduction depends on rope construction, subrope splicing method, and other factors. Annex C, which discusses test results from two fiber rope damage assessment JIPs, suggests that allowable fiber area reduction could be small.

5.3.2.3 Guidelines for Damage Assessment, Rope Discard, Repair, and Replacement

5.3.2.3.1 Permanent Mooring

A more rigorous approach involving detailed damage assessment based on rope manufacturer test data is recommended for a permanent mooring because of its long service life and difficulty to monitor the damaged area. Consultation with the rope manufacturer is recommended. Most fiber ropes are equipped with a jacket and filter, and it is difficult, if not impossible, to perform a detailed damage assessment without opening up the jacket and filter. Consequently, the following procedures are recommended.

5.3.2.3.1.1 Damage During Installation

If a spare rope segment is available, the damaged rope segment should be replaced with the spare segment. A detailed damage assessment may then be performed on the damaged rope segment, which may be repaired and used as a spare or active rope segment.

If a spare rope segment is not available, a detailed damage assessment should be performed on the damaged rope. The jacket and filter should be opened up to allow a detailed inspection. If the damage is found to be acceptable, the rope may be placed in service after the jacket and filter are properly repaired. Otherwise the damaged rope segment should be retired or repaired.

5.3.2.3.1.2 Damage During Service

It is much more difficult to perform inspection and detailed damage assessment if the rope is damaged during service. The inspection is often performed by an ROV using a video camera, which is unlikely to provide an accurate damage assessment. If damage to the load bearing fiber is suspected, the rope segment should be removed for a detailed inspection.

5.3.2.3.2 MODU Mooring

If damage to the rope body, splice or termination is detected the rope manufacture should be contacted to assist in assessing the damaged rope break strength and repair procedures.

For MODU mooring operations where a detailed damage assessment is possible, the rigorous approach recommended for permanent moorings should be used. For MODUs a visual inspection is often conducted in conjunction with mooring deployment or retrieval. For a strength reduction of 10 % MBS, the allowable fiber area reduction is small. It is practically impossible to estimate this level of fiber area reduction by close visual inspection, which is without opening the jacket and conducting a detailed internal inspection of the rope. In the absence of a reliable estimate of the damaged fiber area, any damage extending to the load carrying fibers should be considered justification for removal or possibly repair.

For any damage detected and accepted, the location and degree of the damage should be recorded, and the damaged area should be monitored in subsequent mooring deployment or retrieval operations.

5.3.3 Distributed Damage

Distributed damage, which is more evenly distributed than concentrated damage, can be caused by external abrasion. Ropes that have worked against fixed objects or have been dragged on a hard seafloor may be subjected to distributed damage. For ropes protected by a jacket and filter, distributed damage to the load carrying fiber is unlikely without first destroying the jacket and filter. In this case assessment of distributed damage should be conducted in conjunction with the jacket and filter damage assessment. An example of distributed damage is shown in Figure 38.

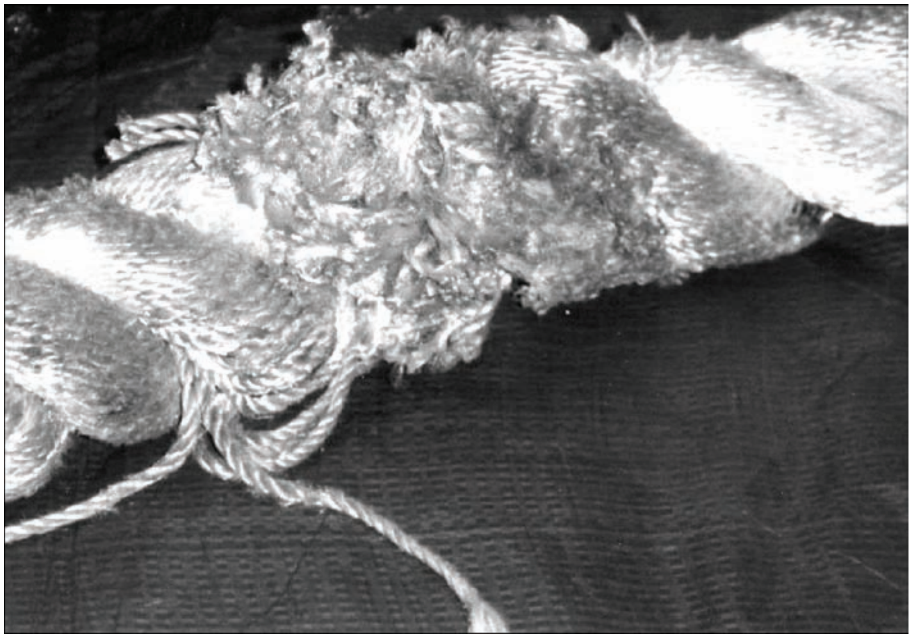


Figure 38—Example of Distributed Damage

The allowable strength reduction for distributed damage is 10 % of the MBS. The allowable load carrying fiber area reduction for distributed damage depends on a number of factors such as rope construction, rope splicing method, location and type of the distributed damage.

5.3.4 Damage to Splice

Damage to a splice is most likely to occur during installation when the splice comes in contact with installation equipment. An example of splice damage is shown in Figure 39. The allowable load carrying fiber area reduction for splice damage depends on a number of factors such as rope construction, rope splicing method (individual or paired), location and type of the splice damage. Since the splice is generally weaker than the main body of the rope, the allowable load carrying fiber area reduction for splice damage is lower than that for damage to the main body of the rope. If damage in or near to the splice or termination are detected the rope manufacture should be contacted to assist in assessing the damaged rope break strength and defining repair procedures.

5.3.5 Damage to Jacket

5.3.5.1 General

Since the jacket is not a load carrying element in a fiber rope, minor damage to jacket may be acceptable. However, severe jacket damage may affect the load sharing of strands and subropes. In this case jacket damage may justify discard or removal of the affected portion of the rope. The acceptability of jacket damage can be determined by the considerations described in 5.3.5.2 through 5.3.5.5.

5.3.5.2 Degree of Damage

Figure 40 shows an example of minor jacket damage, which may be acceptable without repair. Figure 41 shows examples of severe jacket damage, which may justify discard or removal of the affected portion of the rope.

5.3.5.3 Location of Damage

Jacket damage in the water column close to or on the seafloor or in the marine growth zone can be more detrimental than the jacket damage in other locations.

Figure 39—Example of Damage to Splice

Figure 40—Example of Minor Jacket Damage

Figure 41—Examples of Severe Jacket Damage

5.3.5.4 Filter

An undamaged filter under the jacket provides protection against particle ingress and therefore may make minor jacket damage more acceptable.

5.3.5.5 Type of Mooring

Jacket damage may be less acceptable for MODU moorings than for permanent moorings. The jacket integrity for MODU moorings is important because MODU mooring ropes are frequently deployed and retrieved. Thus, a MODU mooring rope can be more susceptible to damage throughout its service life. However, the damage for MODU mooring rope can be monitored and repaired if necessary prior to subsequent redeployment.

When jacket damage is detected, an evaluation based on the considerations above should be carried out to determine whether the damage is acceptable. Generally speaking, if the jacket damage is minor, it can be accepted without repair. If the jacket damage is significant, an inspection for core damage should be carried out. The rope will either be discarded or placed in service after repair, depending on the outcome of the investigation. A special consideration should be given to MODU moorings, where minor jacket damage may be acceptable without repair, however the damage should be monitored and documented in subsequent mooring deployments and repaired as soon as is practical.

5.3.6 Soil Ingress

Industry research indicates that ingress of soil particles into the load carrying polyester fibers can significantly reduce the rope's strength and fatigue resistance [9], [10]. However, limited industry experience indicates that high modulus fibers such as aramid and HMPE may have better resistance to the harmful effect of soil ingress, but they have not been rigorously studied. Ingress of soil particles may occur when the rope comes in contact with the seafloor during installation, e.g. a rope accidentally dropped to the seafloor. Also it may be possible for the fiber ropes of leeward mooring lines to touch the seafloor under extreme environmental conditions. To address this problem, many fiber mooring ropes are equipped with filters or soil blocking jackets that are effective in filtering soil particles [7].

Ingress of soil particles into the load carrying polyester fibers can be justification for discard for the affected portion of a rope. However, it is impossible to determine whether soil particles have penetrated into a dropped rope by visual inspection. In the past, if a rope segment for a permanent mooring was dropped to the seafloor during installation, field samples of the dropped rope were taken. Break test and an internal inspection for soil ingress were conducted to determine the acceptability of the rope segment for service. Similar procedures have been used for MODU mooring ropes with and without filters or soil blocking jackets. Inspection and testing of field samples may not be required for mooring ropes with effective filters or soil blocking jackets. As the industry gains more experience in the effectiveness of filtering methods, the current practice will be adjusted.

5.3.7 Marine Growth

Marine growth can be harmful to fiber ropes if it penetrates through the jacket into the load carrying fibers. This situation was detected in insert inspections for an early polyester rope mooring operating offshore Brazil (see Figure 42). Some of the marine growth, as shown in Figure 43, appears to have the potential of damaging the load carrying fibers. This problem was avoided offshore Brazil by placing the fiber rope below the marine growth zone, 100 m below the water surface. Note the marine growth zone depends on water temperature, etc. and is different from location to location.

The polyester ropes for the DeepStar TLM field test conducted in the late 1990s in GOM had some soft marine growth attached to the jacket after two and half years in place (see Figure 44). Similar marine growth was found recently in a GOM spar polyester mooring. Testing of the rope indicates that soft marine growth is not harmful to the integrity of the rope [11].

5.3.8 Twisting

Twisting of fiber ropes may occur during installation (see Figure 45). A fiber rope's tolerance to twisting depends on rope construction (parallel, braided, or wire rope construction, etc.) and fiber type (polyester, HMPE, or aramid, etc.). Industry studies indicate that parallel lay polyester rope, which is typically used in mooring applications, can tolerate significant twisting [7]. Therefore some temporary twisting during installation may be acceptable, and the rope manufacturer should be consulted for allowable twisting of a specific rope.

Figure 42—Marine Growth Detected Between the Jacket and Load Carrying Fiber

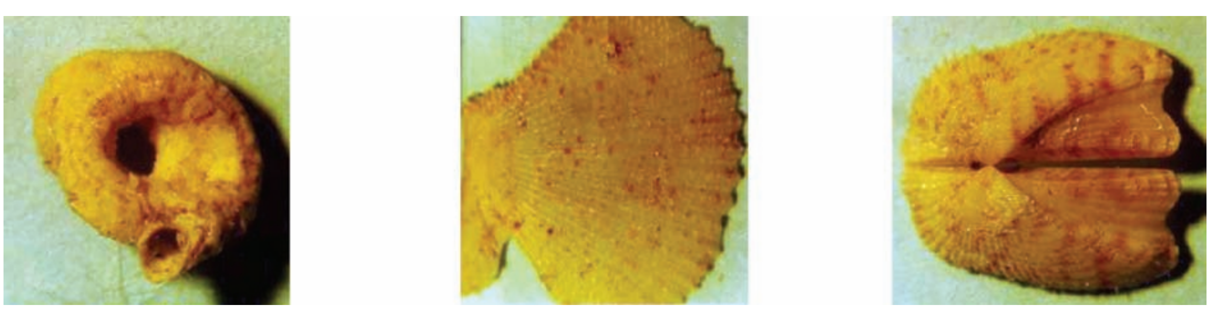


Figure 43—Examples of Potentially Harmful Marine Growths

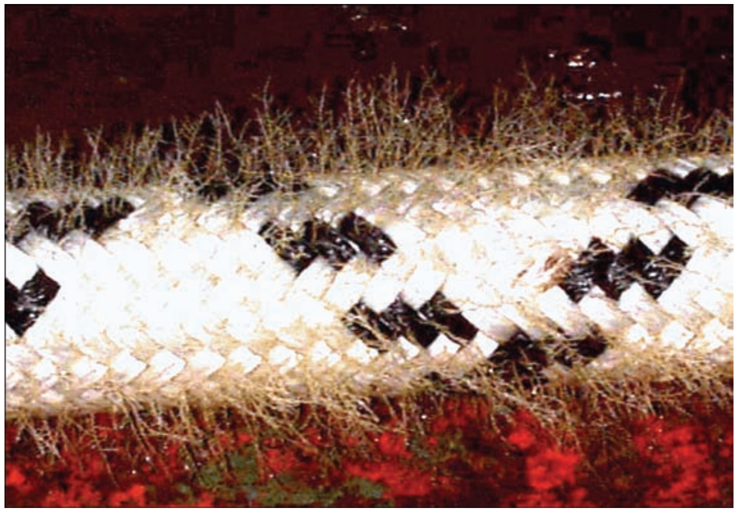


Figure 44—Marine Growths at 200 ft Below Water Surface in DeepStar TLM

Figure 45—Rope Twisting During Installation

However, twisting of polyester rope may cause twisting of chain or wire rope connected to the polyester rope. Chain and wire rope have limited tolerance to twisting, and the manufacturers of these components should be consulted for twisting limits during installation.

5.4 Repair Procedures

Rope repairs should be carried out by personnel trained and qualified to a standard approved by the rope manufacturer and the certifying authority. Repairs may be carried out offshore provided adequate facilities are available and detailed procedures for the operation have been documented and approved by the certifying authority.

Repair procedures should include:

— description of strand repairs, in-line splice or termination splicing techniques which may be employed to restore the rope strength;

— description of jacket and filter damage repair that can be performed, and type of facilities and equipment required to perform the repairs;

— log of details of the damaged area;

— removal of obvious abrasive particles from load bearing part of rope;

— prevention of further ingress of abrasive particles into the load bearing part of the rope;

— reinforcement to make rope suitable for subsequent redeployments without further damage.

All strand repairs, in-line splice and re-terminations should be based on the same quality control procedures used in making the new rope.

5.5 Inspection and Maintenance Procedures

5.5.1 Permanent Mooring

A typical permanent fiber rope mooring system consists of steel components at the floating vessel and anchor ends, and therefore inspection procedures for fiber rope moorings and steel moorings are closely related. The inspection objective, type, and schedule established for steel moorings in 4.5 are generally applicable to fiber rope moorings. This section addresses only additional issues unique to fiber ropes.

5.5.1.1 As-built Survey

After installation, the mooring line should be inspected for any external damage by ROV or diver. Twist can be verified at installation by ROV/diver monitoring of the marking that runs externally on the jacket. Particular attention should be made to the condition of fiber ropes terminations. Other design aspects which should be verified immediately following hook-up are the fiber rope near surface termination position and the installation tension. Estimated elongation should be recorded for all lines during the application of installation tension. The purpose of the inspection is to establish the initial condition, which will be compared with future inspection results.

5.5.1.2 Periodic Survey

Periodic inspection of the mooring lines should be performed over the service life of the mooring system. The inspection and/or maintenance scheme should include methods and techniques used to verify that the system is operating as designed. The following steps are recommended.

— Records of anchor leg retensioning caused by non-recoverable elongation should be reviewed, and confirmed with the designer that adequate lengths of chain/wire segments are available for further retensioning due to non-recoverable elongation such that the fiber rope does not come into contact with the fairlead and stays well below the water surface.

— The pretensions of mooring lines are within the designer's recommended limits. The measurement of catenary angles may not necessarily be very accurate for taut leg moorings. Thus, other means should be used to determine the mooring line tensions.

— Conditions of the terminations are checked regularly.

— Foreign particles in way of rope body and crevices are examined and removed if possible.

— Marine growth, if affecting the condition of the rope, should be removed on a regular basis, by a method which will not damage the rope.

5.5.1.3 Special Event Survey

See 4.5.2.

5.5.1.4 Inspection Schedule

See 4.5.3.

5.5.2 MODU Mooring

Regular inspection of fiber mooring ropes may be feasible, while the fiber rope moorings are recovered and before they are redeployed at a new location. In general before a fiber rope is reinstalled it should be carefully inspected for damage to the jacket, rope core, terminations, and termination hardware. Such inspection can be performed during recovery of the moorings on board the recovery vessel(s), or it can be performed at a base port facility.

5.5.3 Inspection Record

The following should be recorded on the inspection record:

a) mooring system record, including inspection and failure history and previous operating locations;

b) component record;

1) the manufacturer, size, construction (number of subropes in the rope and number of strands in each subrope), soil particle filtering method (filter or jacket), and age of the fiber ropes;

2) the inspection date and names of inspectors;

3) type of inspection (as-built, periodic, or special survey) and inspection method (in air, diver, or ROV);

4) locations and nature of all fiber rope abnormalities, and corrective measures taken;

5) location and number of test inserts, history of insert retrieval and test results;

6) recommendations for further action to be taken.

Annex A
(normative)

Mooring Component Traceability, Inspection, and Retirement Documentation

A.1 Basic Considerations

Mooring component traceability, inspection and retirement documentation is intended to provide a complete, auditable record of the component history. These records will serve to improve mooring system integrity by ensuring the use of fit-for-purpose components.

The history of any mooring component shall be fully logged. This history includes:

— manufacturing record;

— inspection record;

— usage record;

— retirement record.

A.2 Manufacturing Record

The manufacturing record serves as a reference baseline for future mooring component inspections. All mooring components shall be traceable back to the manufacturer. Each mooring component shall have a comprehensive manufacturing record. The information detailed in the manufacturing record will vary by component type, as described in A.2.1 to A.2.7. The manufacturer shall retain a copy of the manufacturing record.

A.2.1 Mooring Chain

For mooring chain, the manufacturing record shall include as a minimum the following items:

— drawings, calculations and other relevant component design information;

— manufacturing specification or equivalent;

— material certification records;

— classification society certificates or equivalent;

— proof loading certificates;

— break loading certificates for the batch;

— chain link measurement records and dimensional tolerances as shown in Figure A.1;

  — measurements of the chain bar diameter in the grip or crown area of the link (labeled Dg1 and Dg2);

  — measurements of the chain bar diameter in the main body of the link (labeled Db1 and Db2);

  - — 2D measurement in the grip or crown area of the link (equal to 2 Dg1).

- — manufacturing records for all components with serial numbers and other applicable identification information; and
- — measured and calculated unit weight.

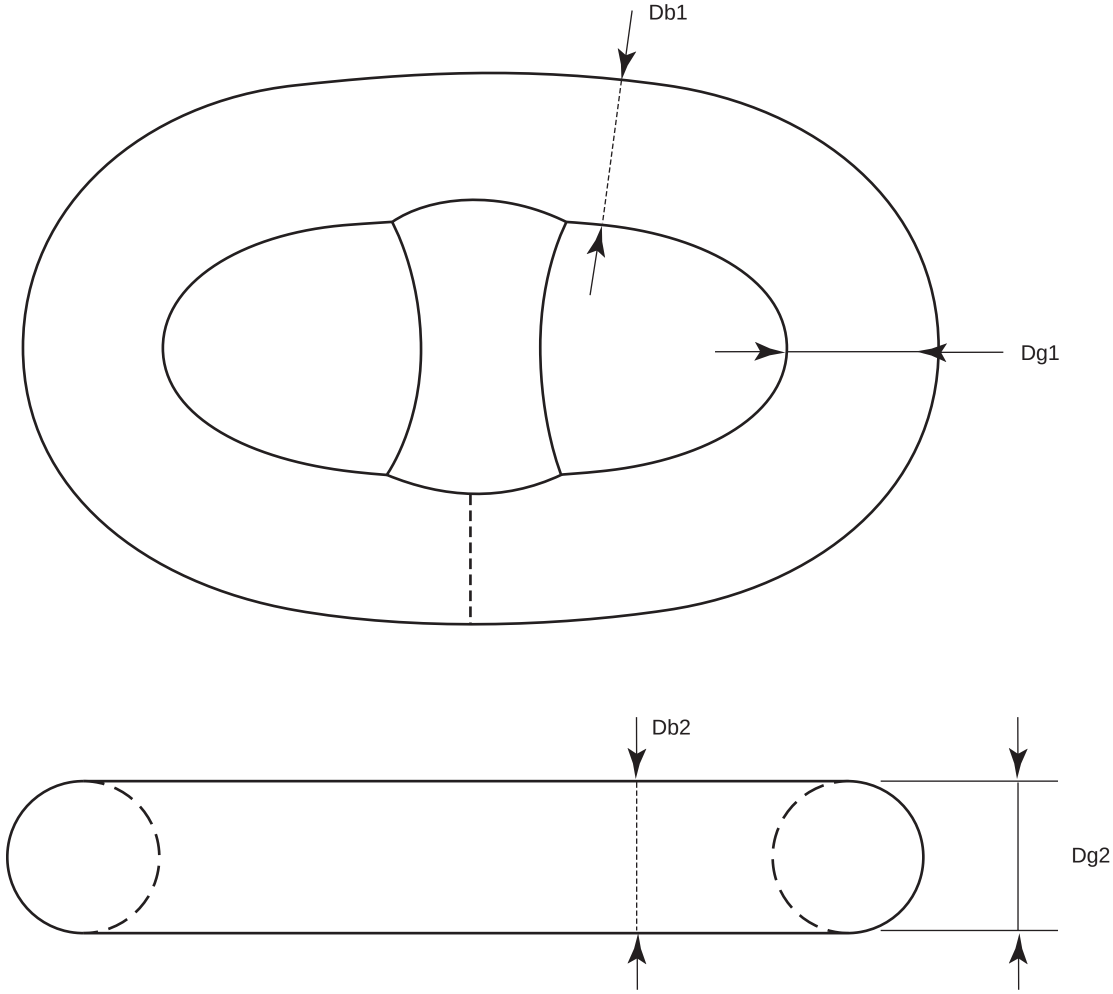


Figure A.1—Measurements for Chain Manufacturing Record

A.2.2 Mooring Wire Rope

For mooring wire rope, the manufacturing record shall include the following items:

— drawings, construction information (construction type, number of wires, wire sizes, sheathing thickness, etc.), calculations (including corrosion calculation as required) and other relevant component design information;

— manufacturing specification or equivalent;

— classification society certificates or equivalent;

— wire rope break loading certificates;

— manufacturing records for all components with serial numbers and other applicable identification information;

— measured and calculated unit weight of wire rope mass properties;

— torque properties and allowable twist (maximum number of turns per unit length); and

— overall wire rope section length measurement and/or calculation reports to demonstrate compliance with the length requirements.

A.2.3 Synthetic Fiber Rope

For synthetic fiber rope, the manufacturing record shall include the following items:

— drawings, construction information (construction type, number of subropes, splice details, particle filter, jacketing, etc.), calculations and other relevant component design information;

— manufacturing specification or equivalent;

— classification society certificates or equivalent;

— polyester rope break loading certificates;

— manufacturing records for all components with serial numbers and other applicable identification information;

— splicing record, inclusive of procedure and splice code documentation;

— manufacturing records for spool pieces and associated termination hardware;

— measured and calculated unit weight of polyester rope;

— measured weight of spool pieces and associated termination hardware;

— torque properties and allowable twist (maximum number of turns per unit length);

— overall polyester rope section length measurement and/or calculation reports to demonstrate compliance with the length requirements; and

— records of other tests required to show that the synthetic rope meets other design requirements, such as elongation, stiffness, particle filtration, and jacketing.

A.2.4 Submersible Buoy

For submersible buoys, the manufacturing record shall include the following items:

— drawings, depth rating, foam properties (as applicable), calculations (buoyancy vs. depth, etc.) and other relevant component design information;

— manufacturing specification or equivalent;

— classification society certificates or equivalent;

— complete material tracking records, etc., as required;

— coating specifications, as applicable;

— anode specification, as applicable; and

— as-built drawings.

A.2.5 Subsea Connector

For subsea connectors, the manufacturing record shall include the following items:

— drawings, calculations and other relevant component design information;

— manufacturing specification or equivalent;

— classification society certification or equivalent;

— inspection, maintenance and test procedures;

— subsea connector arrangement and shackle drawings;

— certification of materials;

— fabrication reports and records;

— proof and/or break loading records and certificates for ancillary connectors and shackles, as applicable;

— coating specifications, as applicable;

— anodes specifications, as applicable; and

— as-built drawings, including records of subsea connector dimensions and weight verification.

A.2.6 Anchor

For anchors, the manufacturing record shall include the following items:

— drawings, calculations and other relevant component design information;

— manufacturing specification or equivalent;

— classification society certification, or equivalent;

— anchor arrangement, shear pin, anchor shackle and/or padeye drawings, as applicable;

— certification of materials;

— fabrication reports and records;

— proof and/or break loading records and certificates for shackles and other hardware, as applicable;

— records of anchor dimensions and weight verification; and

— detailed instructions for anchor assembly and field adjustments (i.e. fluke angle adjustment) as required.

A.2.7 Connecting Hardware

For connecting links, shackles, triplates and other specialty connectors, the manufacturing record shall include the following items:

— drawings, calculations and other relevant component design information;

— manufacturing specification or equivalent;

— classification society certification or equivalent;

— inspection and test plans;

— certification of materials;

— fabrication reports and records;

— proof loading records and certificates, as applicable;

— break loading records and certificates, as applicable;

— coating specifications and/or anodes specifications, if required; and

— as-built drawings, including records of dimensions and mass verification.

A.2.8 Quality System Documentation

All mooring components shall be certified and manufactured with quality system documentation. A manufacturing record should be retained by the manufacturer, and be inclusive of the following:

— Quality Assurance and Quality Control Audits, both internal and external;

— procedures for handling of non-conformities;

— procedures for subcontractor follow-up;

— procedures for follow up of proposed corrective action;

— procedures for follow up of proposed preventative action; and

— final documentation.

A.3 Inspection Record

The inspection record traces changes in the mooring component throughout its service life. The mooring component owner shall keep an inspection record for each mooring component as described in 2.3.5.6 (MODU chain and connecting hardware), 3.3.6.6 (MODU wire rope), 4.5.4 (steel components for permanent moorings), and 5.5.3 (fiber rope).

A.4 Usage Record

The usage record traces the work history of the mooring component throughout its service life. The primary function of the usage record is to identify and track components that have been subject to extreme loads due to storms or other incidents.

A.5 Retirement Record

The retirement record shall include information on the final disposition of the mooring component.

Annex B
(informative)

MODU Mooring Inspection for Areas of Tropical Cyclone

B.1 Purpose

In the areas of tropical cyclone (hurricane, typhoon, etc.), MODUs may encounter environmental loads much higher than the design loads, and mooring failures are possible. For example, in 2004 and 2005, three severe GOM hurricanes caused a large number of MODU mooring failures. Rigorous mooring inspection is more critical for operations in these areas to ensure the integrity of the mooring system and minimize the probability of mooring failures. Also guidance is needed to address the reuse of the components from a mooring damaged by a tropical cyclone. This Annex is developed to provide additional guidance for MODU mooring inspection in these areas.

Although the guidance is based on experience dealing with GOM MODU mooring failures caused by hurricanes, it may be applicable to other operations where MODU mooring line breakage due to overloading may occur.

B.2 Preparation for Operations in the Tropical Cyclone Season

Before starting the operation in the tropical cyclone season, measures should be taken to ensure mooring inspection has been rigorously conducted according to the procedure, criteria, schedule, and documentation requirement specified in Section 2 and Section 3.

MODU mooring inspections are sometimes conducted by groups, e.g. two lines inspected after completion of a well. In this case the inspection schedule of individual mooring line, whether the MODU's own line or third party supply, should be no more than four months behind schedule. When additional mooring lines are added for an operation in the tropical cyclone season, the inspection of the additional mooring components should be current and not due to expire during the operation.

Special attention should be given to the situation where the inspection schedule is current at the start of the operation, but the inspection will expire during the operation. For example, a development drilling will take 18 months to complete, but the inspection will expire in six months after start of the operation. In this case, an inspection of the mooring system should be conducted before the MODU is moored on location or while the MODU is in operation.

B.3 Mooring Inspection After Failure Due to Overloading

After a mooring line failure due to overloading, a mooring inspection should be conducted to determine whether components from the damaged mooring can be reused for subsequent operations.

B.3.1 Total System Failure or Multiple Line Failure

B.3.1.1 Inspection During Mooring Recovery

After the passage of a tropical cyclone, the reuse of mooring components (chain, wire rope, polyester rope, or connecting hardware) from a mooring system damaged by the tropical cyclone requires inspection of as much of the mooring system as is practical. The inspection can be conducted in conjunction with the mooring recovery operation. In addition to visual inspection, a dimension check using go-no-go gauges should be conducted since some components may have been stretched out of tolerance. Attention should be paid to loose chain studs and "necking" between chain links. MPI or replacement of connecting hardware should be carried out if practical. The anchors should be inspected for potential structural cracks and noticeable deformations such as bending of the anchor shank or fluke. This inspection applies to all mooring components including the lines that did not fail. All mooring components that do not pass inspection (criteria defined by Section 2, Section 3, and Section 5) should be removed from service. The goal of this practice is to put the mooring in the best condition possible to complete the current operation. The mooring inspection results should be documented and the document should clearly indicate the portion of the mooring that has not been inspected due to practical constraints such as anchors which cannot be retrieved. After reconnection of inspected or modified damaged mooring lines, all mooring lines should be test loaded, and the test load should not be less than the original anchor test load.

B.3.1.2 Subsequent Inspection

During the subsequent MODU moves, a close visual inspection should be conducted for the reused components that have not been inspected during the recovery operation. This inspection may include measuring the chain, wire rope, and connecting hardware diameters using go-no-go gauges, MPI or replacement of the Kenter links and anchor jewelries, etc. It is recommended to complete an API 2I inspection for all reused components before the MODU is moored up at the next location if the next operation is a high consequence operation (e.g. close to pipelines or other installations, etc.) or has a high probability of mooring failure (e.g. during the tropical cyclone season). Otherwise inspection of all reused components should be completed before the next tropical cyclone season.

B.3.2 Single Line Failure

If a MODU experiences a single line failure due to overloading under a tropical cyclone, the reuse of mooring components requires similar inspection as outlined in B.3.1. The difference is that the inspection is required for the failed line only. After reconnection of inspected or modified failed mooring line, all mooring lines including the lines with no failure should be test loaded, and the test load should not be less than the original anchor test load.

If the inspection of the failed mooring line indicates significant component deterioration that could have occurred in other mooring lines, inspection of other mooring lines should be conducted. The inspection can start with minimum of two lines that are adjacent to the failed line, and the need to inspect additional lines may depend on the outcome of the initial inspection.

B.3.3 Reuse of Fiber Rope

B.3.3.1 Reuse of Fiber Ropes from Failed Mooring Lines

1) Failure occurs in the fiber rope section.

   When a failure occurs in the fiber rope section, the damaged portion should be removed and a test sample made. If the break test result of the test sample is greater than 90 % of original MBS, the remaining rope can be re-terminated and returned to service.

2) Failure occurs in the components other than the fiber rope section.

   — If the rope section passes a rigorous visual inspection and an assessment indicates that the rope should not have been exposed to greater than 80 % of original MBS, it can be returned to service.

   — If the rope section passes a rigorous visual inspection and an assessment indicates that the rope could have been exposed to greater than 80 % of original MBS, a test sample should be taken from one end of the rope. If the break test result of the test sample is greater than 90 % of original MBS, it can be returned to service.

   — If multiple sections of rope do not pass visual inspection (e.g. there are signs of surface abnormalities) or have been exposed to loads estimated to be greater than 80 % of MBS, a group approval procedure can be used. In this procedure a number of samples are taken from the most loaded sections for break testing. Based on the break test results and further investigation, a decision on acceptance or rejection of the group is made. Sometimes testing of additional samples is required for the decision making. The following example illustrates the principle of this procedure:

All 8 mooring lines of a MODU failed at the wire rope section close to the fairlead under a severe hurricane, and there are 3 fiber rope sections in each mooring line. An assessment indicates that all the 24 fiber rope sections could have been exposed to loadings more than 80 % MBS. In addition, a rope section is badly damaged, and surface damage is observed in a number of rope sections. The following procedure can be used to determine the acceptability of the ropes.

a) The badly damaged portion is removed and the rope section re-spliced.

b) A minimum of three samples are taken from the estimated most loaded fiber rope sections for break test. In a typical situation this means taking three samples from the top sections of the three most loaded lines, say, No. 1, 2, and 3.

c) Test break loads of sample No. 1 and 3 are greater than 90 % MBS, but test break load of sample No. 2 is 82 % MBS, less than 90 % MBS. This means that group approval cannot be granted at this point. It is decided to conduct further testing.

d) Two more samples are taken from the lower two sections of line No. 2, and they all have test break load greater than 90 % MBS. Further investigation of the top section of line No. 2 shows signs that this section may have come in contact with the fairlead. This condition is not observed in other sections.

e) The final decision is that the top section of line No. 2 should be retired, and all the other sections can be returned to service.

B.3.3.2 Reuse of Fiber Ropes in Contact with Seabed

Fiber rope sections from the non-failure lines can come in contact with the seabed due to failure of other lines or large anchor drag. The reuse of these fiber rope sections should be determined by the following guidelines.

— Fiber ropes with proven particle filters or suitable jacketing require inspection according to API 2SM, its 2007 Addendum [16], or other relevant guidelines prior to reuse.

— For fiber ropes without proven particle filters or suitable jacketing, a test sample should be taken and an internal inspection should be conducted. If the break test result of the test sample is greater than 90 % MBS, and the internal inspection discloses no soil ingress, the rope can be returned to service.

Annex C
(informative)

Summary of JIP Test Data and Fiber Area Reduction Criteria

Two JIPs have been conducted to assess the impact of damage to polyester fiber rope strength: DNV JIP [1], [2] and MMS JIP [3], [4]. In both studies, break tests of rope samples with different degrees of simulated damage were performed allowing damaged strength versus degree of damage to be plotted. The full rope tests included various rope constructions (number of subropes and strands), splicing methods, sample length to diameter ratios, damage infliction methods, jacket tightness, use of strand jackets, and subrope pitch, etc.

All of the 26 damaged full rope break test data from the two JIPs are plotted in Figure C.1. Comparisons of undamaged and damaged break loads should be based on statistical properties of the test data (see API 2SM for definition of MBS). However, the undamaged break strength of the test ropes is not known in many cases and the test data set is small. Consequently the y-value used to present the JIP test data on Figure C.1 is somewhat uncertain.

Only two of the 26 damaged full rope break tests were performed for simulated damaged area ratios of less than 5 %, the level of damage of interest in trying to evaluate damage associated with a 10 % reduction in rope break strength. Consequently, the damaged rope data set of interest is extremely limited and therefore it is not possible to arrive at any definitive conclusions regarding acceptable level of fiber rope damage based only on the results of these JIPs.

However, the results of these two JIPs appear to indicate the following.

1) There is significant scatter in the damaged rope test data.

2) For a strength reduction of 10 % MBS, the allowable fiber area reduction is small. It should be noted that it is impossible to estimate this level of fiber area reduction by visual inspection. In the absence of a reliable estimate of the damaged area, any damage extending to load carrying fiber should be considered justification for removal or possibly repair.

3) Based on the data for 5 % or greater fiber area reduction, the scatter in the available full rope test data indicates that the allowable fiber area reduction corresponding to 10 % strength reduction varies significantly from rope to rope. This highlights the importance of consulting the rope manufacturer when a discard criterion is determined.

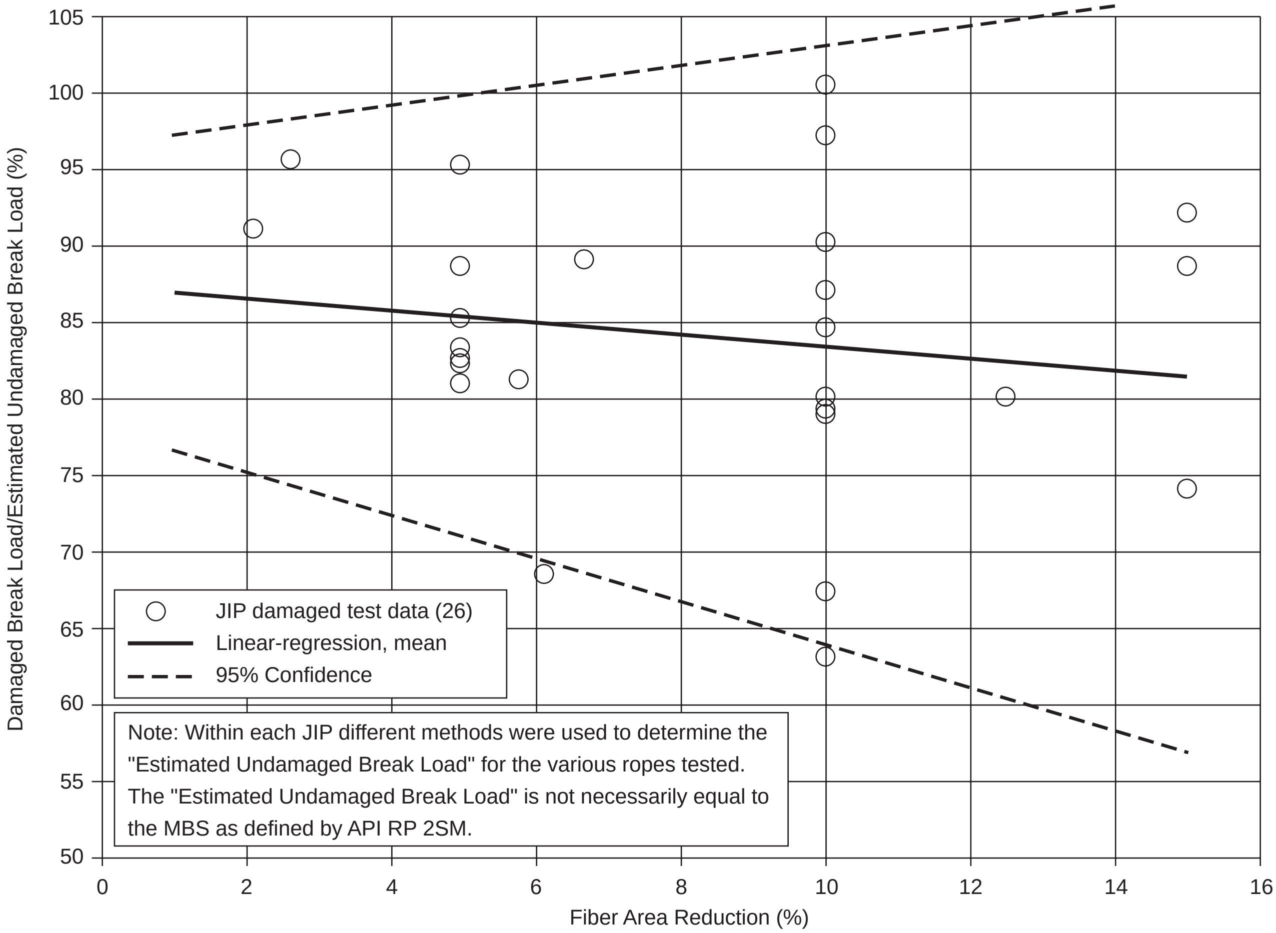


Figure C.1—JIP Full Rope Test Results

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