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VERIFICATION OF SPREAD MOORING SYSTEMS FOR FLOATING DRILLING PLATFORMS

VOLUME II: METHODS FOR MOORING INSPECTION

by

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PREFACE

As offshore oil exploration moves into ever deeper waters, greater demands are placed on mooring systems. Safety of the crew, preservation of the environment, and protection of the rig itself demand that mooring systems perform reliably during operations and storms. It is the responsibility of the Minerals Management Service (MMS) of the U.S. Department of the Interior to inspect the mooring equipment aboard exploratory oil rigs in service in United States offshore oil fields and evaluate the ability of the mooring equipment to perform safely in service.

This volume is part of a four-volume set. The purpose of these manuals is to provide a procedural structure to support the responsibilities mentioned above. It does not purport to be a textbook of mooring analysis or design, nor a compendium of mooring design data. That ground has been well plowed by others. Rather, a procedure for evaluating the mooring gear for a drilling rig is described.

Volume I	Methods for Spread Mooring Review
Volume II	Methods for Spread Mooring Inspection
Volume III	Dynamic Modeling in Spread Mooring Review
Volume IV	A Static Model for Spread Mooring Review

Volume I describes five steps for evaluating a mooring design and illustrates the procedures by evaluating a sample semisubmersible mooring. Volume II - this volume - is a review of mooring evaluation from the standpoint of the hardware itself: the components of a typical mooring, their inspection and testing. Volume III illustrates how to model the dynamic response of a floating drilling platform moored in a seaway using a large commercial computer model. Volume IV documents RIGMOOR, a computer program written to simplify estimating the static holding power of spread moorings.

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INTRODUCTION

Semi-submersible offshore exploratory drilling platforms are anchored where water depth does not exceed 15000 ft. Dynamic positioning is commonly used in greater depths. When anchored, the semi-submersible uses a spread mooring system consisting of eight or more anchors.

Each anchor line consists of chain, or a combination of wire rope and chain (See Figure 1). All chain is generally used in water depths less than 600 ft. A wire rope pennant is attached to the anchor crown for lowering and retrieving the anchor. This line is buoyed off after the anchor is in place.

Each anchor weights 20,000 to 30,000 pounds. Additional piggy-back anchors are used if additional holding power is required. The length of the mooring line is usually five or more times the water depth. The anchor chain leads to a fairlead at the rig which is underwater when the hulls are submerged for drilling. The chain then passes over a wildcat and thence into the chain locker. A separate drum holds the wire rope.

This volume discusses the types of mooring materials used in spread moorings, their mechanical properties and criteria to judge their condition and remaining strength.

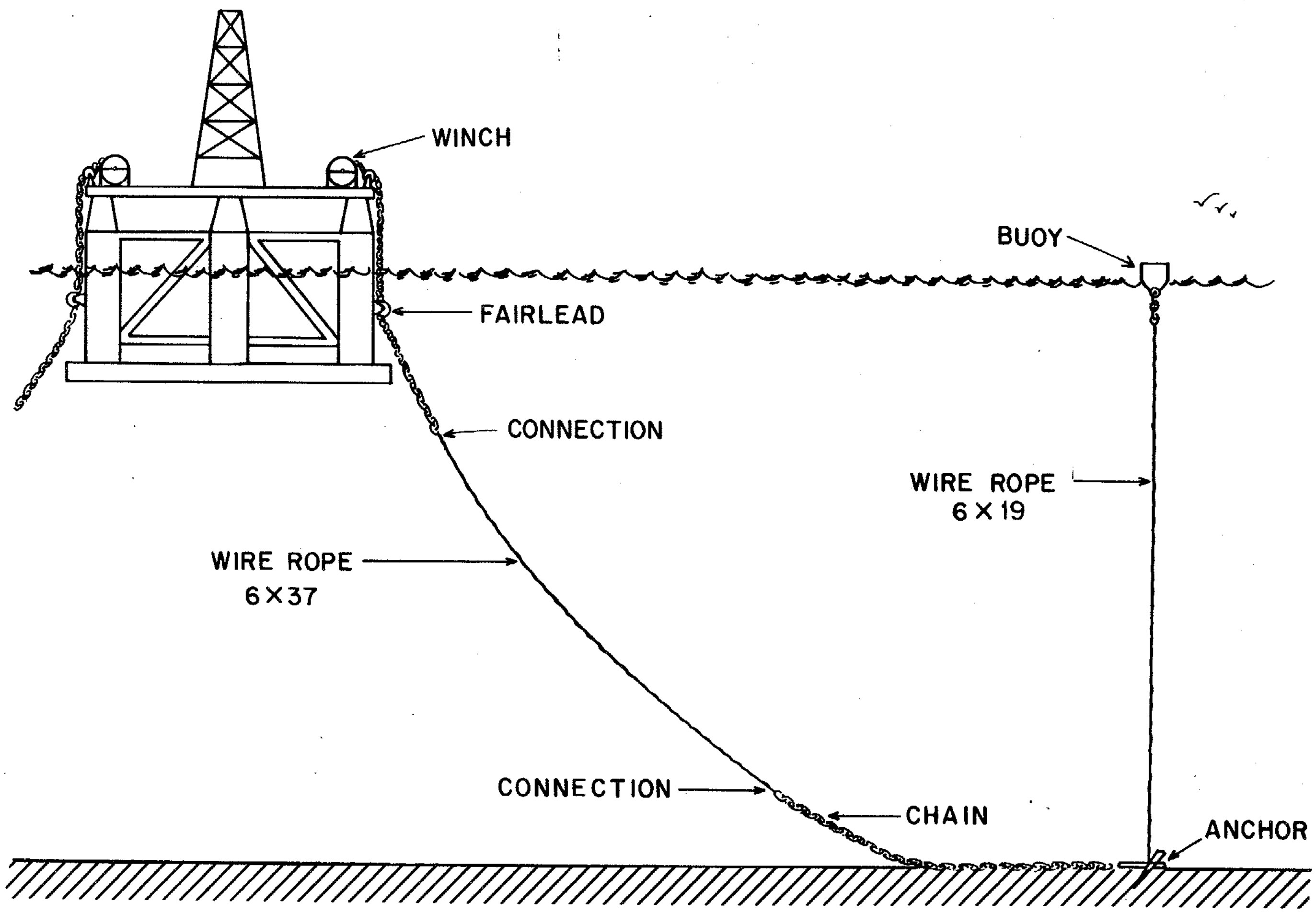

Figure 1. Typical Spread Mooring

SECTION 1

CHAIN AND CONNECTING HARDWARE

1.1 CHAIN

1.1.1 General. Moored drilling platforms generally use all chain mooring legs in water depths up to 500-600 ft. A combination chain and wire rope mooring is frequently used in greater depths. Two types of chain are used: flash butt welded stud link and Di-Lok stud link in sizes varying from two to four inches and are shown in Figure 1-1. Ship Grade II chain is gradually being replaced by extra high strength (Grade III ABS) having an ultimate tensile strength of 100, psi. A super strength chain is finding increased use in the industry as Grade IV. Table 1-1 shows the ABS proof and breaking loads for chain sizes between two and four inches. A three inch super oil rig quality chain with a breaking strength of 1.3 x 10^6 pounds in frequently used in the North Sea.

The maximum tension in a mooring chain should not exceed approximately 35% of its breaking strength or 50% of its proof load. 50% of breaking strength may be tolerated on a limited basis under conditions of maximum survival. Continuous operating loads between 15 and 20 percent of the breaking load will result in longer-life performance.

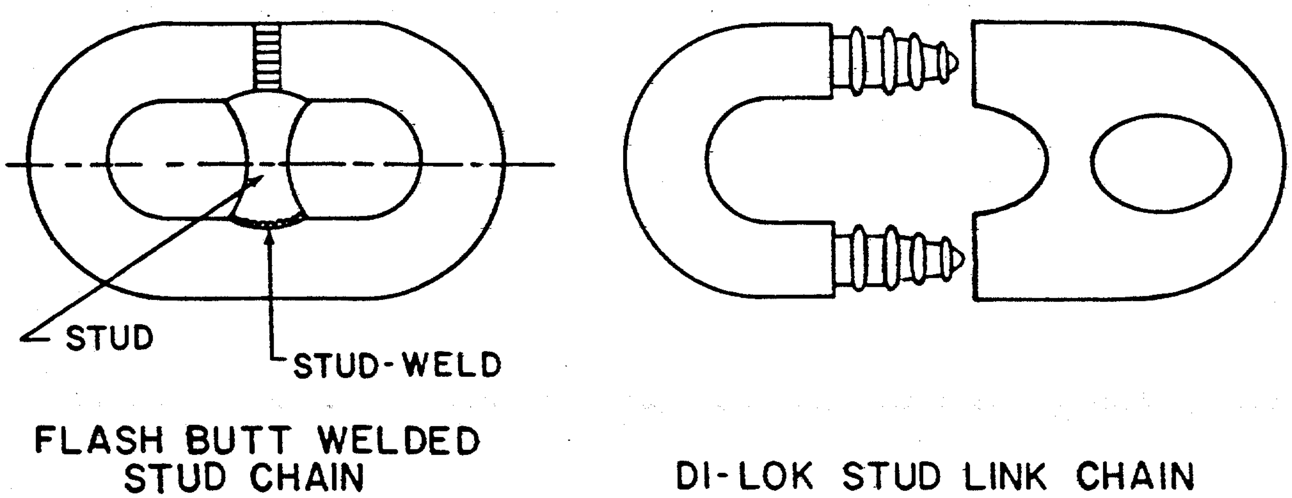

Figure 1-1. Stud-Link Chain Types

Table 1-1
Mooring Chain Proof and Break Tests

CHAIN SIZE	GRADE 2		GRADE 3		SUPER HIGH STRENGTH		DI - LOK	
	PROOF LOAD (x1K lbs)	BREAK LOAD (x1K lbs)	PROOF LOAD (x1K lbs)	BREAK LOAD (x1K lbs)	PROOF LOAD (x1K lbs)	BREAK LOAD (x1K lbs)	PROOF LOAD (x1K lbs)	BREAK LOAD (x1K lbs)
2	227	318	318	454	324	489	322	488
2 1/16	241	337	337	482			342	518
2 1/8	255	357	357	510	364	548	362	548
2 3/16	269	377	377	538			382	579
2 1/4	284	396	396	570	405	611	403	610
2 5/16	299	418	418	598			425	642
2 3/8	314	440	440	628	449	676	447	675
2 7/16	330	462	462	660			469.5	709.5
2 1/2	346	484	484	692	494	744	492	744
2 9/16	363	507	507	726			516	778
2 5/8	379	530	530	758	541	815	540	813
2 11/16	396	554	554	792			565	849
2 3/4	413	578	578	862	590	889	590	885
2 13/16	431	603	603	861			615	925
2 7/8	449	628	628	897	640	965	640	965
2 15/16	467	654	654	934			666.5	1005
3	485	679	679	970	693	1044	693	1045
3 1/16	504	705	705	1008			720.5	1086.5
3 1/8	523	732	732	1046	747	1125	748	1128
3 3/16	542	759	759	1084			776.05	1169
3 1/4	562	787	787	1124	802	1209	804.1	1210
3 5/16	582	814	814	1163			833.15	1253
3 3/8	602	843	843	1204	859	1295	862.2	1296
3 7/16	622	871	871	1244			892.1	1339.55
3 1/2	643	900	900	1285	918	1383	922	1383
3 5/8	685	958	958	1369	977	1473	1021	1566
3 3/4	728	1019	1019	1455	1039	1566	1120	1750
3 7/8	772	1080	1080	1543	1101	1660		
4					1165	1756		

1.1.2 Causes of Damage. It has been estimated that chain failures occur as often as one per month on North Sea mobile offshore units (Ref. 1). These failures often lead to disruption of the drilling operating resulting in costly delays.

Failures originate from two principal causes, 1) production defects and irregularities and 2) mechanical damage through use. In one study (Ref. 1) laboratory examinations of both failed and neighbor links (links adjacent to those which failed) resulted in the observation of a number of different causes for the failures, the majority originating from defective chain production. The most commonly observed defects and irregularities were:

Poor heat treatment	Surface carburization
Weld defects	Loose studs
Burn marks	Poor stud welds
Hydrogen cracks	Weld repairs
Longitudinal cracks	Poor trimming

Another source (Ref. 2) mentions the following causes for some failures in common links as:

- Internal unsoundness
  - Casting blowholes
- Weld unsoundness
  - Lack of fusion
- Heat affected zone (HAZ)
  - Microcracking
- Brittle failure
  - Improper heat treatment
- Manufacturing variables
- Improper operation
  - Overloading
  - Incorrect lead angles
  - Fatigue

1.1.3 Quality Control, Testing and Inspection. Offshore mooring chain must be regarded as complex structures dependent upon proper design, technological know-how and reliable manufacturing processes as well as implemented QA/QC routines.

Manufacturing. The manufacturing process requires a series of controlled operations including inspection and testing of the finished product. American Petroleum Institute specifications (Ref. 3) lists the tests which are performed at each step of the manufacturing process. The publication lists the bar stock chemical composition and mechanical properties required for chain material. A detailed set of requirements and tests are then listed. Included are tensile and impact specifications, dimensional tolerances, identification procedures, heat treating, cleaning, and test inspection. Details of proof and break tests are given with sample lengths.

Design Strength and Recommended Testing. It is recommended that all components of the system have a safety factor of three based on the strength of new components. The chain size and type should be selected on this criterion of three times the tension experiences under the most severe loading anticipated. Shop testing to loads of 150% of the maximum anticipated loads should then be made. The frequency of the shop test depends on the age and service of the chain. In general, new chain should be tested every four to five years initially and as frequently as every two years when it reaches 20 years of age (Ref. 4).

When installing the drilling rig, the initial tensioning of each anchor provides a most important test for the entire system. Initial tensioning with values of tension equal to the calculated highest storm load provide an in site test of the chain and other mooring components.

Inspection. All chain should be periodically inspected and test loaded to insure reliability. Inspection of the condition of rig mooring chain can best be done when the rig is being moved or in drydock. When retrieving the anchor, the chain will be hauled aboard providing an opportunity for visual inspection of the links. The same opportunity exists during anchor deployment. A better opportunity exists during periods of rig overhaul and drydocking. At this time the chain can be removed from the chain locker and be laid out on a dock for a more thorough inspection. Links may also be removed for laboratory tests.

American Bureau of Shipping inspections of chain and chain lockers while the rig is in drydock are recommended every three years.

Visual Inspection. At each opportunity a visual detailed inspection of the common links should be make. Of particular interest are sections of the chain which have resided in the fairlead, have been in the splash zone or have been tangential to the ocean floor.

The surface of the links should be examined for fatigue cracks, gouges and other surface defects. Deep pitting is indicative of heavy corrosion. All welds should be checked. Loose studs can be detected by hitting them with a hammer. Links should be inspected for abrasion and wear. Elongation of a link can be due to overload or wire diameter decrease due to corrosion or abrasion. No criteria are available for chain removal when damage is primarily be fatigue. When fatigue is a problem, usual field practice keeps a chain in service until breakage or general deterioration begin to show (Ref. 5). Any cracks observed should be carefully examined both visually and by other fault testing methods. Di-Lok chain should be checked for separation between the male and female sections and longitudinal cracks in the female section.

Dimension Checks. Measurements of wire size and link length can reveal corrosion and abrasion damage and/or overload history. The grip area should be closely scrutinized for wear. Table 1-2 shows wire diameter reductions justifying replacement. Maximum elongation permitted over five links is 55% of the wire diameter. Table 1-3 shows the length and allowable tolerance over five links for chain sizes between two and four inches. The weight per foot is also shown.

Table 1-2. Chain Diameter Reduction
(from Reference 4)

Chain Diameter (Inches)	Diameter Reduction (Inches)
1.75 - 2.00	0.25
2.00 - 2.50	0.31
2.50 - 3.00	0.38
3.00 - 3.50	0.44

Table 1-3 (from ABSS)
Mooring Chain Length Over Five Links
and Approximate Weight

NOMINAL DIAMETER (inches)	CHAIN LENGTH OVER 5 LINKS		APPROXIMATE WEIGHT (lbs/ft.)
	Minimum (inches)	Maximum (inches)	
2	44.00	45.10	39.7
2 1/8	46.75	47.95	44.8
2 1/4	49.50	50.75	50.2
2 3/8	52.25	53.55	56.0
2 1/12	55.00	56.40	62.0
2 5/8	57.75	59.20	68.4
2 3/4	60.50	62.00	75.0
2 7/8	63.25	64.85	82.0
3	66.00	67.65	89.3
3 1/8	68.75	70.75	96.9
3 1/4	71.50	73.25	104.8
3 3/8	74.25	76.10	113.0
3 1/2	77.00	78.95	121.5
3 5/8	79.75	81.75	130.4
3 3/4	82.50	84.55	139.5
3 7/8	85.25	87.40	149.0
4	88.00	90.20	158.7

Locating Faults. Links may be further examined by non-destructive methods to locate faults. Fatigue cracks can be more readily observed by first cleaning the link and applying a dye penetrant or by magnetic particle inspection (Magnaflux).

1.2 CONNECTING HARDWARE

1.2.1 General. Connecting elements are used to join the various sections of the mooring together. A typical anchor connecting arrangement is shown in Figure 1-2. Common types of connecting hardware, detachable links, and swivels are shown in Figure 1-3.

Historically, connecting elements represent weak points in a mooring system accounting for most failures. This especially true with fatigue failures, where life expectancies of connecting elements may be only 30% to 50% of the chain itself.

Connecting elements should be inspected often and replaced after ten years of service or when the mooring chain is renewed.

1.2.2 Causes of Damage. Wear, corrosion and fatigue are the principal sources of damage to connecting links. However mechanical damage may occur from improper handling, windlass malfunction or fairlead problems.

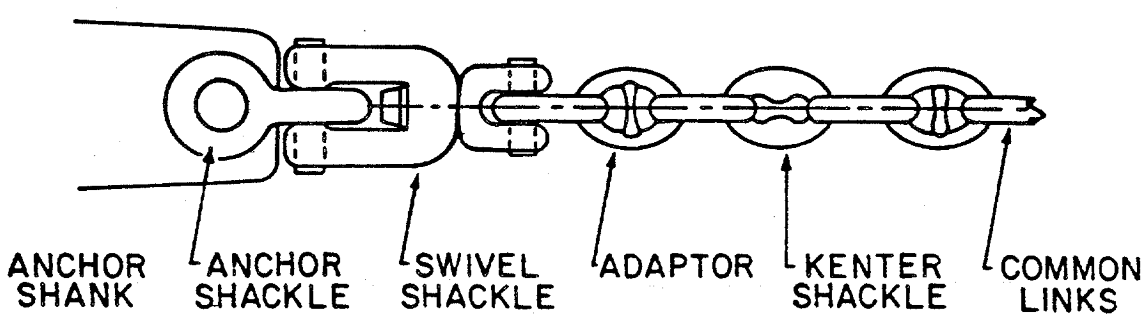

Figure 1-2. Anchor End Construction

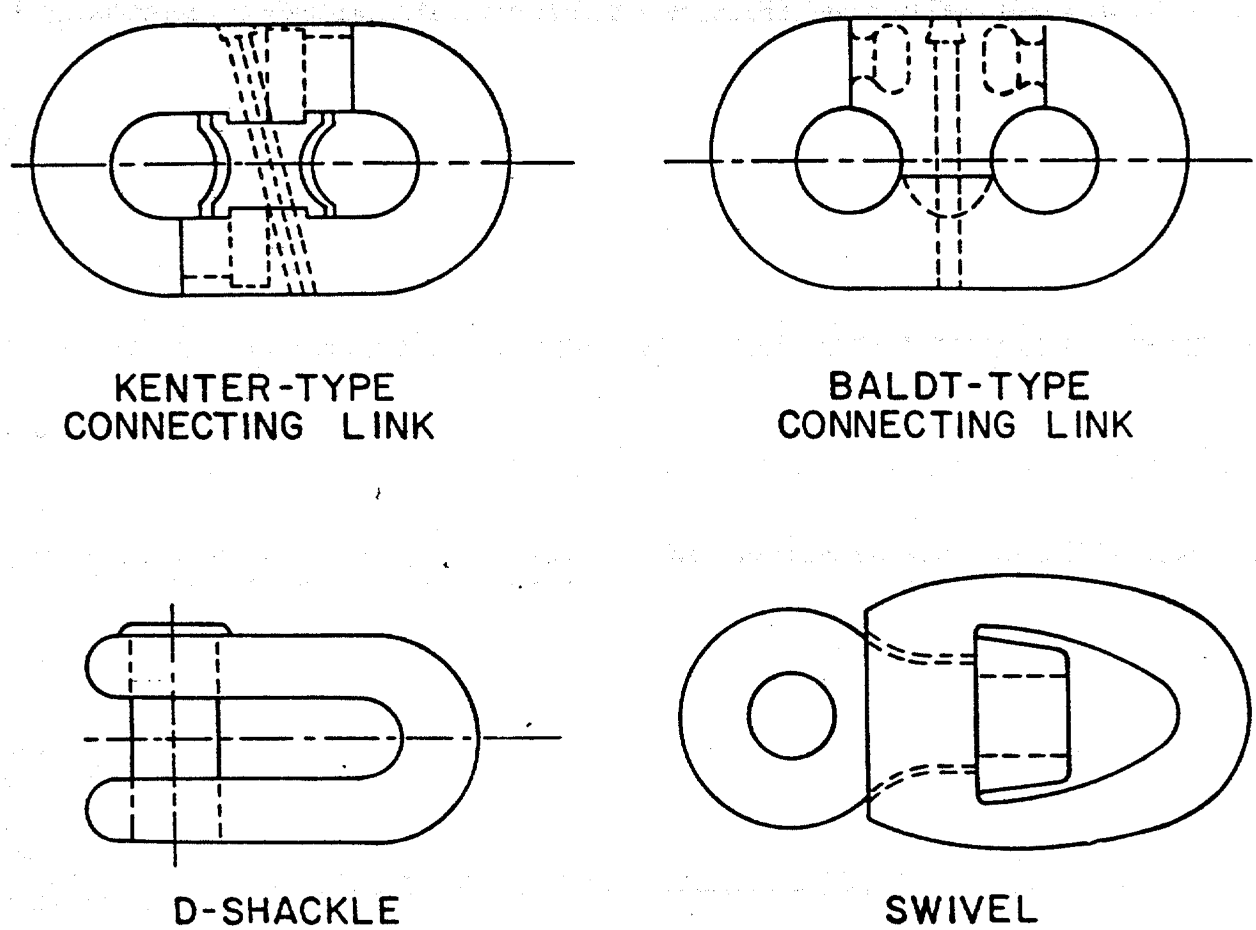

Figure 1-3. Common Auxiliary Chain Mooring Elements

1.2.3 Inspection and Testing

D-Anchor Shackles. The D-shackle as used at the anchor and in the chain locker has a fatigue life equal to or greater than common chain links. They should be inspected yearly by thoroughly cleaning and magnetic particle inspection. They should be discarded if cracks or wear reduction of 10% or more of its diameter is noted (Ref. 4).

Swivels. Some mooring arrangements use swivel shackles at the anchor. This element has a short fatigue life and is subject to internal wear. One set of fatigue tests found that swivels failed at about 3% of the life of the chain. For this reason many operators do not use swivels. They should be inspected yearly and discarded if worn more than 10%. They should be cleaned and subjected to magnetic particle inspection.

Kenter Detachable Links. Experience has shown that the failure frequency of detachable links is significantly higher than common stud links. The Kenter link fatigue characteristics are primarily controlled by the distribution of stresses within the link locking mechanism. One test showed that all fatigue failures had been initiated at the sharp corners of the locking chambers of the links.

The test results indicated that the mean fatigue life of the link was approximately 1/5 of the mean fatigue life of the common three inch stud link chain (Ref. 6). It was found in the above fatigue test that crack growth in the Kenter-type was rather slow and that cracks could easily be detected by means of a dye penetrant or a magnetic particle test on the flanges of the locking mechanism.

The links should be replaced if cracks are visible or if they show more than 10% wear reduction in diameter (Ref. 4).

Baldt Detachable Links. Another type of detachable link, the Baldt link is also frequently used. This link is subject to the same inspection steps as the Kenter link with replacement recommended where fatigue cracks occur or abnormal wear is evident.

Fairleads, Wildcats. An examination of the fairleads and wildcats should be an essential part of the overall mooring inspection. If the pockets are worn or gouged, excessive wear or bending of the chain may take place. Fairleads should be regularly lubricated and inspected whenever the rig is up on its hulls, such as in a shipyard or during a move.

1.3 FIELD INSPECTION TOOLS

Calipers should be available for determining wear or loss of metal through corrosion or wear. A steel tape should be available for link length measurements. Hardware elements can be cleaned with a wire brush and solvents prior to inspection. A dye penetrant kit and/or a magnetic particle tester will facilitate the locating of cracks from stress fatigue.

1.4 TESTING FACILITIES

New or used chain can be examined and tested at most chain manufacturers and at some commercial testing laboratories. A full facility for testing used chain is equipped to clean the sample specimen (5-7 links) and to perform mechanical property tests. These tests consist of impact tests of both the barstock and the welded area, a breaking test, and elongation and reduction in area measurements. Magnetic particle and utltrasonic inspection is generally available.

Some testing laboratories/facilities and their capabilities are:

(1) Baldt, Inc.
P.O. Box 350
Chester, PA 19016 215-447-5231

Baldt has full facilities for testing new and used chain in connecting hardware. They typically will clean, visually inspect (dimension and weight), and use magnetic particle and ultrasonic testing. A minimum of five links are required for proof and break tests. The cut link is used for mechanical property tests

(2) Washington Chain (Division of Baldt)
P.O. Box 3645
Seattle, WA 98124 206-623-8500

Capable of proof and break testing up to two million pounds. They clean, visually inspect, dimension and weigh and use dye penetrant for the detection of fatigue cracks.

They have magnafluxing done outside. Need at least three links for proof and break test.

(3) Battelle Petroleum Technology Center
1100 Rankin Road
Houston, TX 77073 713-821-9331

Battelle can proof and break test presently to a maximum capacity of 1.2 million pounds. The facility eventually will be capable of higher loadings. They provide cleaning, visual inspection, dimension and weight observations, dye penetrant and ultrasonic testing. An outside lab is used for magnaflux tests.

Typical non-laboratory services provided to the industry are:

(1) Vicinay International Chain
2226 S Loop West 255
Houston, TX 77054 713-664-6997

Vicinay has factories and complete test facilities in Spain, England and Brazil. While they have no factory in the U.S. they do have a team of inspectors available to assist in chain inspection and tests at other facilities. These inspectors are available for field inspections and can perform tests including ultrasonics.

(2) Hamanaka International, Inc.
1980 Post Oak Blvd., Suite 1000
Houston, TX 77056 713-627-7201

Hamanaka does not have a factory and test facilities in the U.S. but will assist in field inspections and tests at other facilities.

(3) Global Divers and Contractors, Inc.
P.O. 68
Maurice, LA 70555 318-894-6500

Global can supply diving services for the underwater inspection of chain, anchors, connecting hardware and pennant lines.

SECTION 2

WIRE ROPE TERMINATIONS

2.1 Wire Rope

2.1.1 General. As water depth increases the weight of the chain required to moor a drilling platform becomes prohibitive. Wire rope of equal strength but lesser weight is then used to connect the ground tackle to the platform. Wire rope pendants are also used to connect the anchor buoys to the anchor crown (see Figure 1).

The elementary unit of any wire rope is the wire. Wires are obtained by drawing through reducing dies to the desired size, rods of the metal selected for the rope. The specified strength and ductility of the wires is obtained by a combination of drawing and annealing operations. Wires are then spooled on bobbins which fit into stranding machines. Wire ropes are manufactured by first winding individual wires into strands and then winding the strands together around a core (Figure 2-1). When the strands are laid in a clockwise direction around the core, the wire rope construction is called a right lay. If the wires in the strand are laid in the opposite direction the resulting wire rope construction is a right lay, regular lay. Almost all wire rope used in offshore mooring systems is of the right lay, regular lay configuration and is of either the 6x19 or the 6x37 class. The number 6 referes to the number of strands twisted around the rope core, and the numbers 19 or 37 refer to the average number of individual wires per strand. The core of these ropes is almost exclusively made of a smaller wire rope, named independent wire rope core (IWRC).

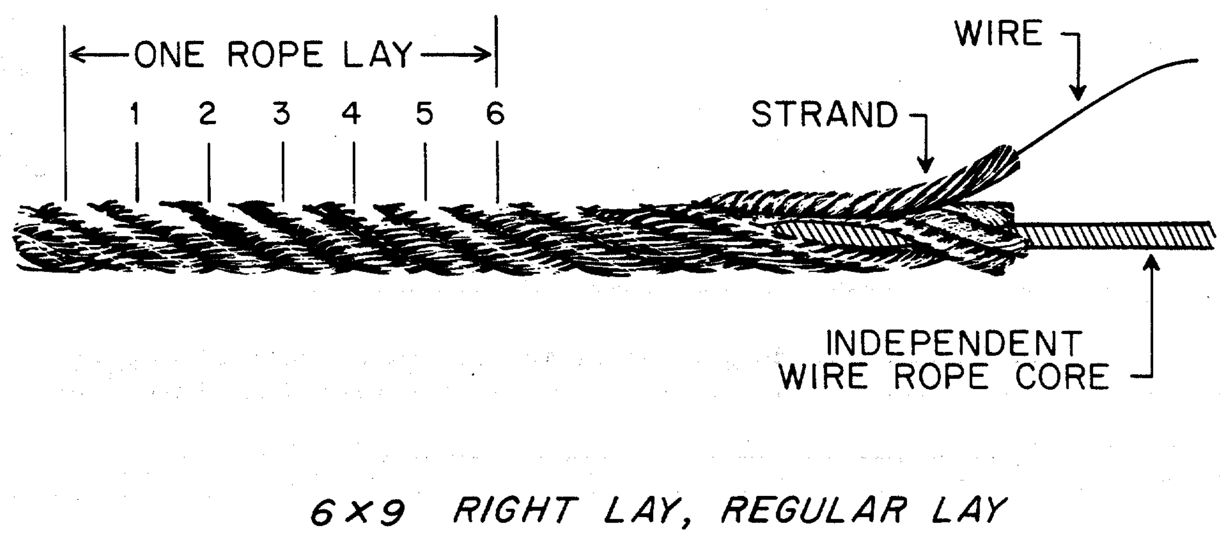

Figure 2-1. Components of a Typical Wire Rope

6x19 wire ropes have larger wires than 6x37 ropes of equal strength, and therefore have better resistance to corrosion and axial fatigue. However they have become increasingly stiffer as their size increases. When higher strength is required, more flexible 6x37 wire ropes must be used. All cables used in a seawater should be zinc coated or galvanized. There is a definite advantage in using galvanized wires for zinc in anodic to steel, and therefore, the zinc coating will act as a sacrificial anode at the points where the coating may break and the steel becomes exposed to seawater.

A jacket of extruded plastic - such as high density polyethylene - placed over wire ropes constitutes an additional barrier between the wires and the corrosive environment. Years of experience have shown a sustained tendency for plastic jacketed ropes to have a far better endurance and much longer service life than bare wire ropes (Ref. 7).

The grades of carbon steel commonly used to manufacture wire ropes are Improved Plow steel (IPS) and Extra-Improved Plow steel (XIPS).

The nominal strength of galvanized and non-galvanized (bright) wire ropes used as anchor lines in spread mooring systems, as specified by the American Petroleum Institute (Ref. 8) is shown in Table 2-1. As with anchor chain, wire rope diameters should be selected to provide three times the strength required under the most severe loading conditions.

2.1.2 Causes of Damage. During their service life mooring lines are constantly subjected to the combined detrimental effects of corrosion and fatigue. Vessel motion due to wave and wind action impart cyclic loads to the mooring lines. Steel wires when submitted to repeated stress cycles of sufficient amplitude will develop minute cracks that tend to grow and propagate across the metal until the whole wire breaks. Sea water corrosion accelerates the process. Large tension means combined with large deviations from the mean - as the case would be in stormy seas - will result in the greatest fatigue damage.

In addition to corrosion and fatigue wire ropes used in spread moorings can be damaged by abrasion, crushing, and kinking. Abrasion can and will occur if the rope is let free to contact the bottom, as often the case is with the anchor buoy pendants. Crushing happens when the wire rope is hauled through sheaves of incorrect diameter and/or groove for the particular rope size.

Kinks are the mortal enemy of wire ropes They start as a loop of the rope winding on itself and when the loop is pulled tight, wires and strands are permanently bent, ruining the rope at the point of kink. There are two kinds of kinks - tightening kinks and loosening links. The first tightens the lay of the wire rope, while the second tends to open the rope. Loosening kinks are more damaging and easier to form. Most of the kinks originate the torisonal energy stored in the rope followed by slack conditions. Proper handling techniques can minimize the danger of kinks. In particular, in free handing operations such as lowering of mooring anchors, ropes should not be allowed to twist or become slack.

For a more detailed description of wire rope field problems and field care the reader is referred to the API publication RP9B (Ref. 9).

Table 2-1
Strength of 6x19, 6x37 and 6x61 Construction Mooring Wire Rope, Independent Wire Rope Core

NOMINAL DIAMETER (inches)	APPROXIMATE WEIGHT (lbs./ft.)	NOMINAL STRENGTH Galvinized (lbs.)	Bright (lbs.)
1	1.85	93,060	95,800
1 1/8	2.34	117,000	119,000
1/4	2.89	143,800	145,000
1 3/8	3.50	172,800	174,000
1 1/2	4.16	205,200	205,000
1 5/8	4.88	237,600	250,000
1 3/4	5.67	275,400	287,000
1 7/8	6.50	313,200	327,000
2	7.39	356,400	369,000
2 1/8	8.35	397,800	413,000
2 1/4	9.36	444,600	461,000
2 3/8	10.40	493,200	528,000
2 1/2	11.60	543,600	604,000
2 5/8	12.80	593,800	658,000
2 3/4	14.00	649,800	736,000
2 7/8	15.30	705,600	796,000
3	16.60	765,000	856,000
3 1/8	18.00	824,400	920,000
3 1/4	19.50	885,600	984,000
3 3/8	21.00	952,200	1,074,000
3 1/2	22.70	1,015,000	1,144,000
3 3/4	26.00	1,138,000	1,290,000
4	29.60	1,283,000	1,466,000
4 1/4	33.30	1,438,000	1,606,000
4 1/2	37.40	1,598,000	1,774,000
4 3/4	41.70	1,766,000	1,976,000

2.1.3 Inspection and Testing

New Wire Rope. Because most wire ropes are manufactured and tested according to strict manufacturing and testing specifications (see Ref. 8), it is not usually necessary to test new ropes in the field. Manufacturers test certification for the particular reel should be available on request from the vendor. Sometimes it is good practice to pull test representative samples of new wire rope assemblies to ascertain the holding power of wire rope terminations applied in the field (see Section 2.2). Uncertified wire rope should be tested following the procedure outlines in Ref. 8. A list of wire rope testing facilities is given in Section 2.4.

Used Wire Rope. Ropes should be regularly inspected to ascertain their present condition as compared to their new condition. The inspector, either by judgement based on experience or by some prescribed procedure, estimates the remaining strength of the rope and thus determine the degree of operational safety at the time.

The best time to inspect mooring wire ropes is when the drilling rig is shut down and relocated. On every rig move the wire ropes should be carefully inspected for broken wires, wear, corrosion, reduced rope diameter, kinks and crushing. Magnetic and electronic devices may be used to assist inspection procedure. Visual inspection is still the best method for assessing a rope condition and for determining the proper time for its removal.

Significant modes of rope deterioration are hereafter discussed in further detail.

Broken Wires. Broken wires are often difficult to detect. It is important to clean the rope surface so that broken wires become visible. Holding a cotton rag around the rope as it is slowly hoisted will not only clean the rope but will enable small pieces of cotton to be caught by protruding wires, thus pinpointing their location (Ref. 10).

The broken wires should be carefully inspected so as to identify the mode and causes of deterioration. A magnifying glass can be used to advantage for this purpose. If the wires are badly flattened then wear due to abrasion certainly was a factor of failure. If the breaks are square across, the probable cause of failure is fatigue. Corrosion breaks are recognizable by a severly pitted wire surface and a needle point at the break. Cups and cones are typical of tension - overloading-breaks. Typical wire fracture modes are shown in Figure 2-2 (Ref. 11).

Wear. Wear can be exterior or interior. Exterior wear is detected by worn spots on the outer wires. It is caused by abrasion of the rope dragging on the bottom or being pulled through sheaves of the wrong size or in poor condition. Interior wear can be detected by prying the rope open with the help of a screwdriver or marlin spike. It is caused by excessive internal friction, usually due to a lack or a loss of rope lubricant.

Corrosion. A rusty wire rope should be carefully inspected to assess the extent of the corrosion process. Particles or flakes of rust which fall out when the rope is pried open indicate that the protective zinc coating has been lost and that the size of the wires in the rope have been reduced through oxidization.

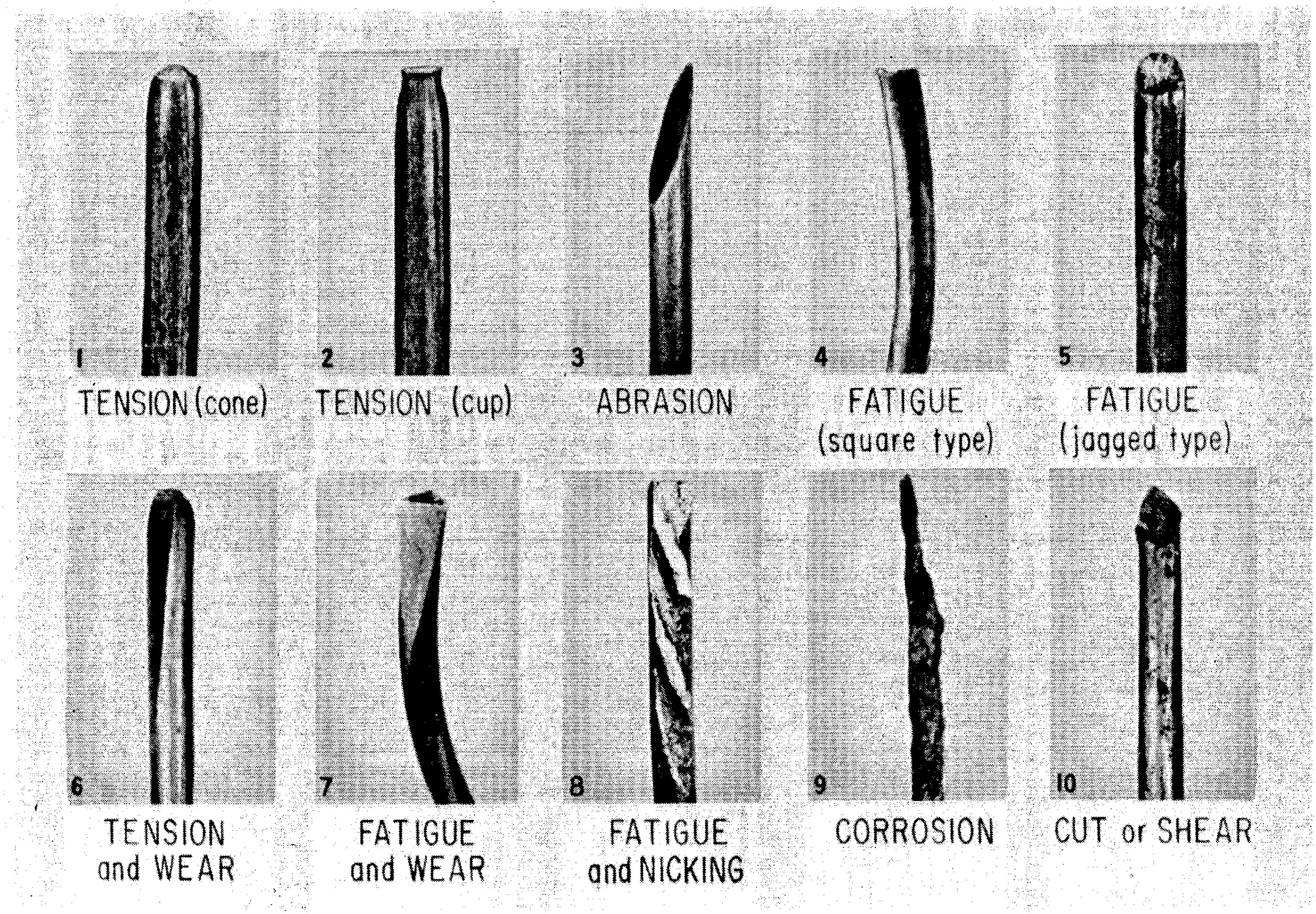

Figure 2-2. Typical Wire Rope Fracture Faces

Corrosion should be controlled not only because of the additional rope service, but because corrosion control makes it easier to judge the rope condition by visual inspection.

Often ropes will corrode at a faster rate in air - when stored on the winch drum, for example - than when immersed in sea water. Thus it is imperative that ropes be fresh water rinsed and properly lubricated every time the rig is moved.

It is extremely difficult to assess the remaining strength of a corroded rope solely by inspection. When in doubt, representative sections, preferably close to the socketed ends, should be cut off and tensile tested. Even then, a good remaining strength is no insurance against accelerated fatigue failure of a dried and internally abrasive rope.

Reduced Rope Diameter. The diameter of a new rope is the diameter of the smallest circle which fully contains the rope. A significant reduction of rope diameter can be the result of loss of metallic area due to corrosion and war of the wires or from excessive stretching due to broken wires. Rope diameters should preferably be measured with a three point micrometer.

Mechanical Damage. Rope structural damage includes: Kinks, dog-legs, birdcages, and crushed strands. These cause permanent rope deformations which are easy to spot.

2.1.4 Wire Rope Retirement Criteria

The decision for the removal and replacement of a used wire rope is a difficult one. Officials must make a decision, keeping in mind that for economic reasons all possible service must be obtained from the rope before its retirement while maintaining the necessary degree of safety.

Retirement criteria found in the literature vary from different wire rope types and applications. Based on common sense and experience, the following guidelines for the retirement of ropes used in spread mooring applications are proposed (see Ref. 4):

- The condition of the worst rope lay is a safe guide for rope removal. In other words, the worst rope lay dictates if a rope (or rope section) should be removed. A rope lay is that length of rope in which one strand makes one complete revolution about the core (Figure 2-1).

- A rope should be replaced whenever the number of outside and inside broken wires per rope lay equal 10% or more of the wires in the rope (excluding those of the core). For example a 6x19 rope, which has 114 wires, should be replaced if the number of broken wires found in a rope lay is 11 or more.

- In general, a rope should be replaced if the diameter is reduced by as much as 6%. For example a two inch rope reduced to 1 7/8 inches (a 1/8 inch diameter loss) has its diameter reduced by 6.25% and should be replaced.

- A badly corroded and dry rope, exhibiting flaking rust and markings of internal wear over a major portion of its length should be retired from service.

- Kinked, crushed, bird-caged ropes should always be replaced, or cut off if the damage is near one end.

2.2 Termination

2.2.1 General. Wire ropes used in spread moorings must be terminated at their points of attachment to each other or to other components of the mooring legs. Standard wire terminations include swaged sockets, zinc or resin poured sockets and eyes. Typical terminations are shown in Figure 2-3.

To resist shock loads and deterioration due to fatigue, corrosion and bottom chafing, good practice recommends to use mooring wire rope fittings of a higher strength and quality than the fittings used in many land applications. In particular, all sockets should be made from forged steel rather than cast steel to provide the extra strength needed in offshore service.

Swaged sockets are attached to the rope by inserting the rope in the shank of the fitting and then pressing or swaging the shank on to the rope with the help of an hydraulic press.

Zinc poured or thermoset resin poured sockets are attached by first inserting the wire rope end into the socket. The end is then splayed or "broomed out", properly cleaned, and pulled back in the socket. The filling material is then poured into the socket.

An eye termination is obtained by placing the wire rope in the groove of a drop forged steel thimble, and then attach the short end to the long end with wire clips as required.

Swaged sockets must be applied by wire rope manufacturers or riggers who have the heavy equipment required to swage wire ropes of large diameters. Poured sockets can be applied in the field, but their holding power is much more susceptible to quality control. Eye terminations, using wire rope clips, are the least reliable of the three. Specified materials and procedures to properly terminate wire ropes for offshore applications are fully reviewed in API RP9B "Application, Care and Use of Wire Rope for Oil Field Service" (Ref. 9).

2.2.2 Inspection and Testing. Much like chain and ground tackle fittings previously reviewed wire rope sockets should be carefully inspected for signs of deterioration due to wear, corrosion and fatigue. Often cracks can be seen in the shanks of swaged fittings.

The best way to ascertain the maximum holding power of new wire rope assemblies is to pull test lengths of the same wire rope terminated at both ends with fittings similar in all respects (material and method of application) to those to be used in the field. Correctly applied swaged or poured terminations should develop the full strength of the rope.

Used wire rope assemblies, like other components of the mooring legs, should be pull tested to 1.5 times the maximum load expected in service.

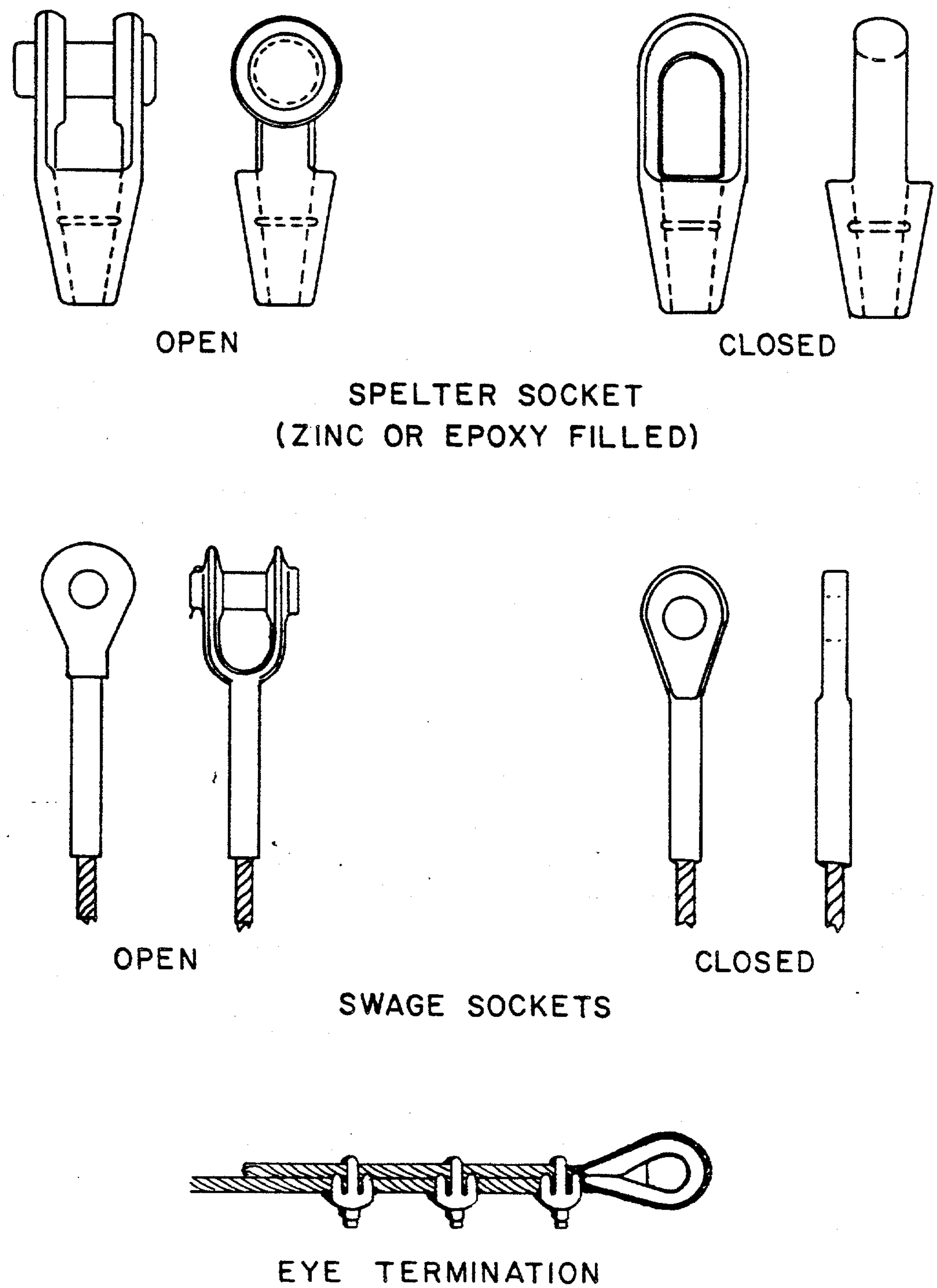

Figure 2-3. Typical Wire Rope Terminations

2.3 Field Inspection Tools

The following is a list of hand tools normally used to perform field inspections of wire ropes:

- Gloves. Work gloves should be worn to protect the hands from sharp broken wires (fish hooks).
- Cleaning fluids and rags should be in the field testing box. They will help clean the rope of grease and rust at points of inspection, and they may help find outside broken wires as previously explained.
- Marlin spike or large screwdriver, to pry the rope open and help inspecting the rope inside and the core.
- Magnifying glass to look at fracture faces of broken wires.
- Carpenter measuring tape, 10 to 12 ft., flexible, to measure length of rope lay, or strand lay, or rope circumference, or length of rope as required.
- Micrometers. A three point micrometer (see Figure 2-4) is preferred to measure the diameter of wire ropes.
- Calipers. Calipers can also be used to measure wire rope diameters. The proper use of calipers is shown in Figure 2-5.
- Groove Gages. This set of gages is used to check the diameter of sheave grooves, thus assessing that the sheave used has the proper groove for the wire rope passing through (see Figure 2-6).
- Electromagnetic Cable Testers. Inspection of wire ropes can also be performed automatically with the help of electromagnetic nondestructive test equipment. Normally such inspections are carried out by agencies whose trained personnel are expert in interpreting the signals resulting from broken wires or reduced rope diameter. Operators and/or vendors of such equipment are listed on Section 2.4. As excellent introduction to the working principles of electromagnetic wire rope testing is presented in Ref. 10, Chapter 1.

2.4 Wire Rope Testing Facilities

Table 2-2 is a partial list of U.S. based laboratories and facilities who can pull test wire rope assemblies and perform other mechanical and nondestructive tests of new and used wire rope. An extensive list of worldwide testing laboratories can be found in Ref. 8.

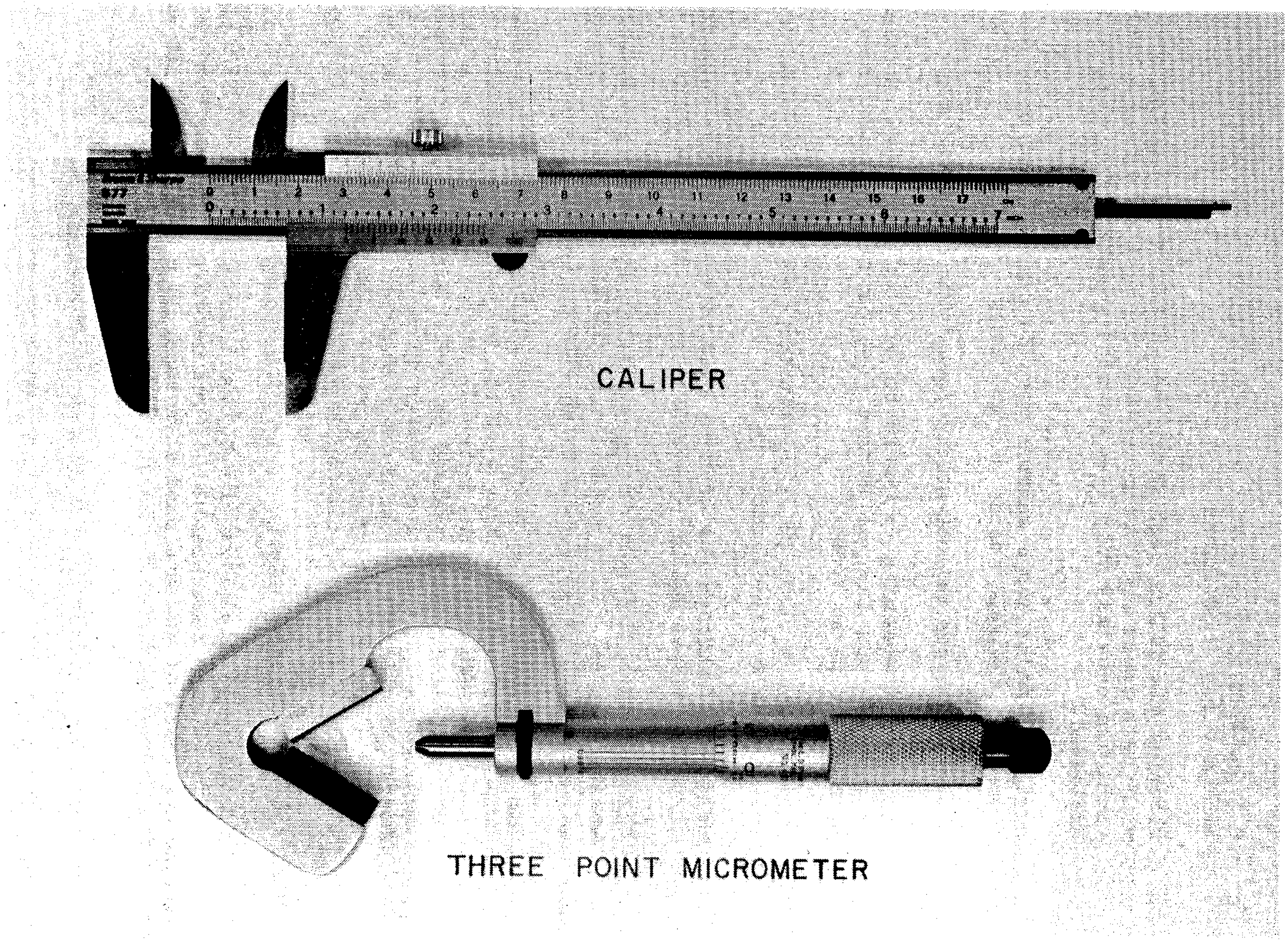

Figure 2-4. Tools for Sizing Wire Rope

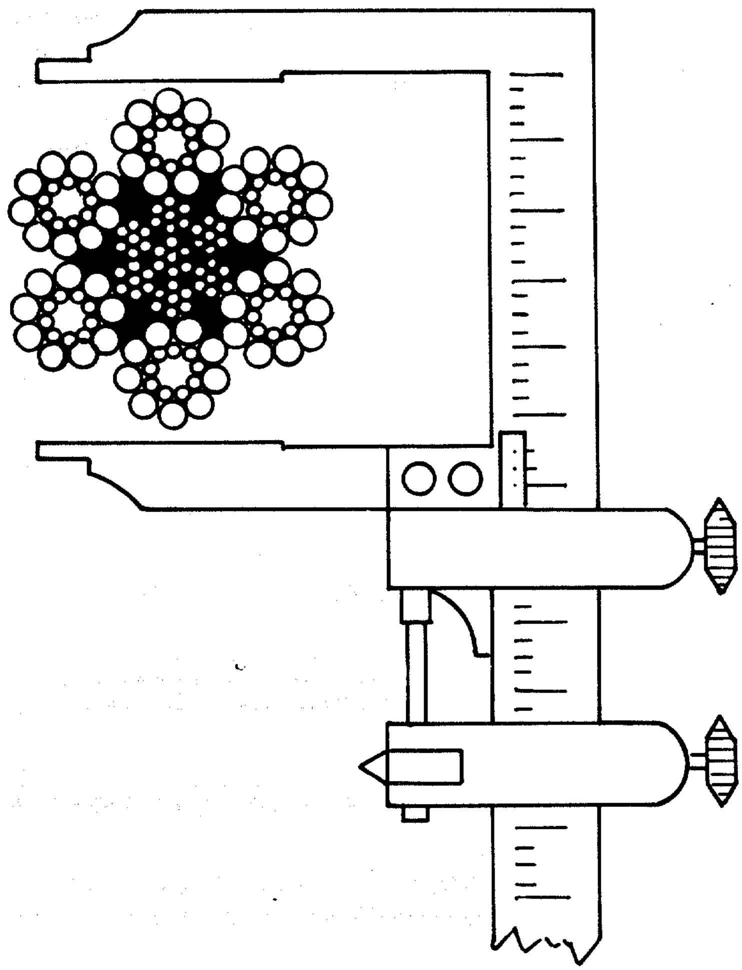

Figure 2-5. Correct Way to Measure the Diameter of Wire Rope

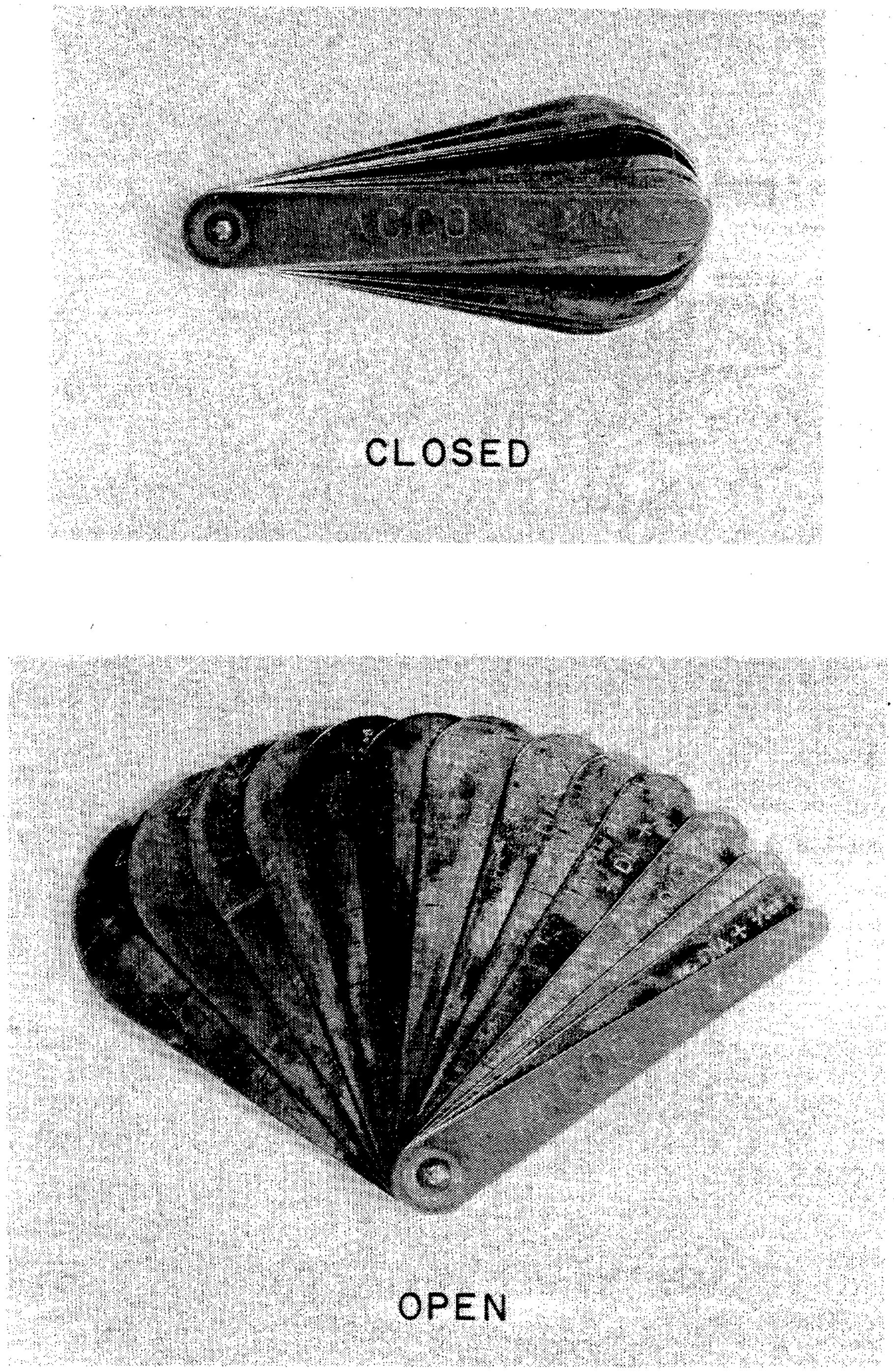

Figure 2-6. Groove Gages for Wire Rope Sheaves

Table 2-2. Wire Rope Testing Facilities in the United States

American Standards Testing Bureau, Inc.	New York, NY
Battelle Petroleum Technology Center	Houston, TX
Bethlehem Wire Rope Division, Bethlehem Steel	Williamsport, PA
Bridon-American Corporation	West Pittston, PA
Haller Testing Laboratories, Inc.	New York, NY
Hanks, Abbot A., Inc.	San Francisco, CA
Hurst Metallurgical Research Lab, Inc.	Euless, TX
Leschen Wire Rope Co.	St. Joseph, MO
Preformed Line Products	Cleveland, OH
Rochester Corporation	Culpepper, VA
Shilstone Testing Laboratory	Houston, TX
Southwestern Laboratories	Houston, TX
United States Steel Corporation	Trenton, NJ
Wire Rope Corporation of American	St. Joseph, MO
Magnetic Analysis Corporation*	Mt. Vernon, NY

* Magnetic inspection of wire rope

SECTION 3

ANCHORS

The type of anchor used on offshore rigs varies with the operator and bottom sediment conditions. Most rigs use anchors weighing between 20,000 and 30,000 lbs. Figure 3-1 shows types frequently used. The Light Weight Navy, Moorfast, Offdrill and Stato anchors are most frequently used in the gulf of Mexico, Stevin anchors in the North Sea and anchors such as the Bruce in the Beaufort Sea. Anchors should be cleaned and visually inspected at each hauling. The use of dye penetrant or magnetic particle inspection techniques will facilitate the discovery of stress fatigue cracks or other imperfections.

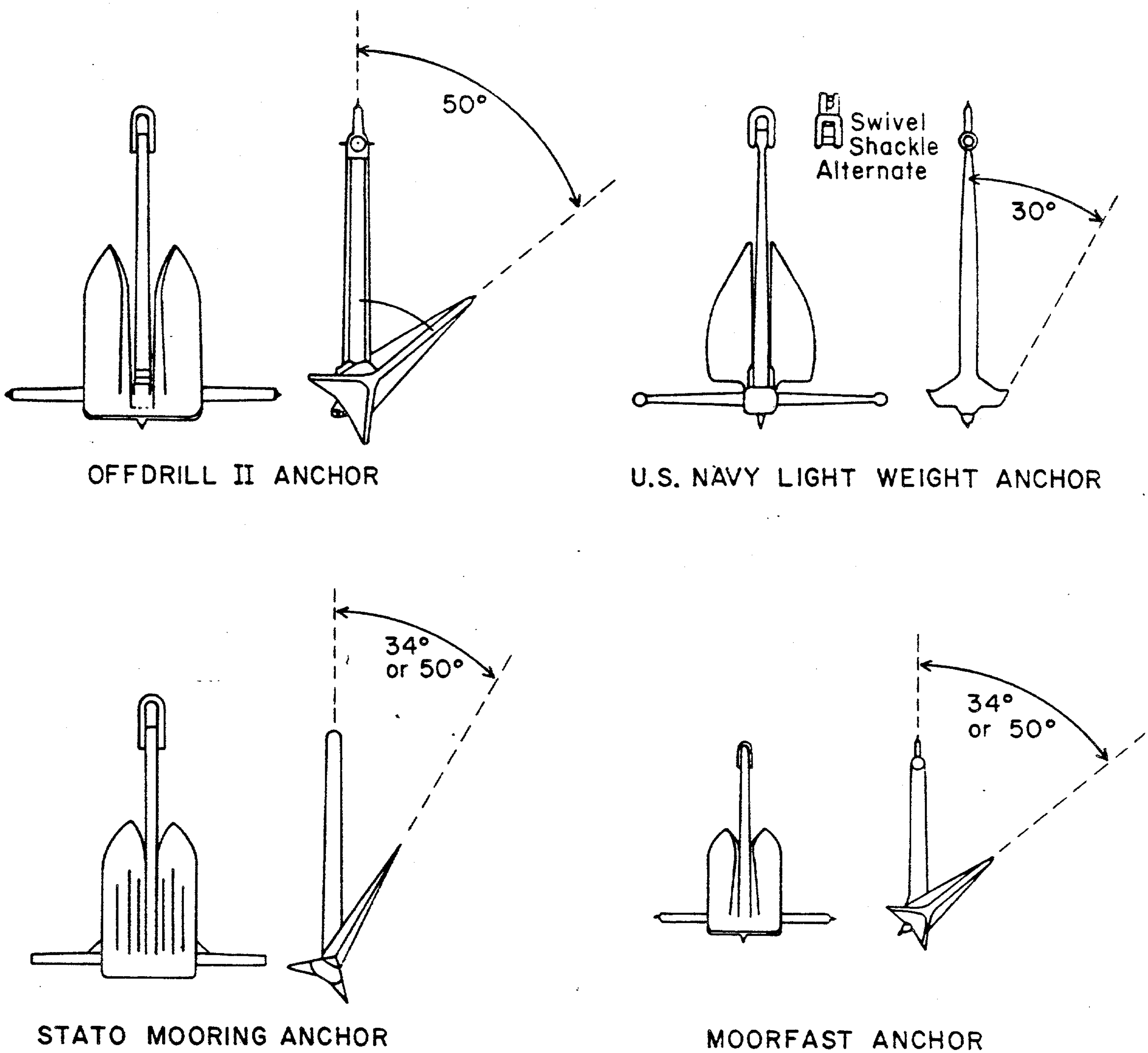

Figure 3-1. Common Anchor Types for Offshore Rigs

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