APPENDIX VII

CONDUCTING CABLE WORKSHOP NOTES

For more information see Gibson, P.T. Operational characteristics of electromechanical cables. Journal of Energy Resources Technology. 1984, Vol.106, pp. 356-361.

CABLE WORKSHOP NOTES

Prepared for

Research Vessel Technical Enhancement Committee

1996 Annual Meeting

November 11 - 13, 1996

at

Harbor Branch Oceanographic Institution, Inc.
J. Seward Johnson Marine Education & Conference Center
Ft. Pierce, Florida

by

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SECTION 2

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    b. Stroke < sheave contact arc

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    c. Use of a swivel with a nontorque-balanced cable

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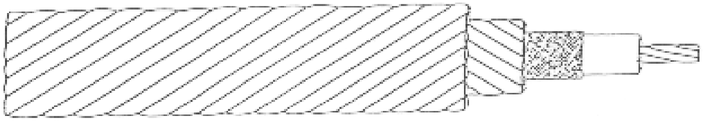
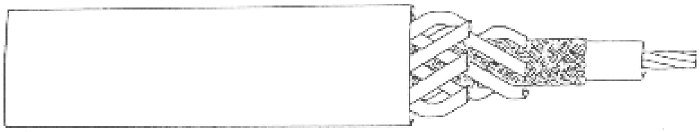
A



Double Steel Wire Armor

B

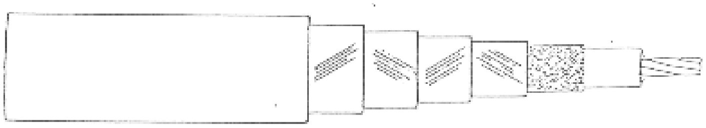


Spaced Armor and Integral Extruded Jacket

C

Braided Kevlar and Overall Jacket

D



Served Kevlar and Overall Jacket

TYPICAL CONFIGURATIONS OF CABLES HAVING
EXTERNAL STRENGTH MEMBERS

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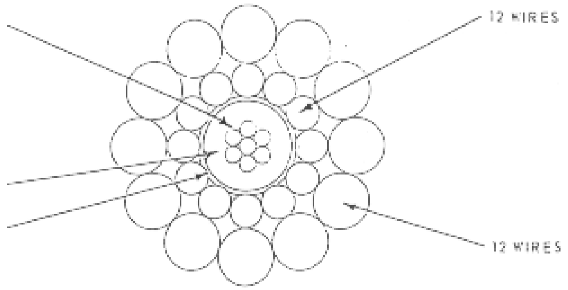

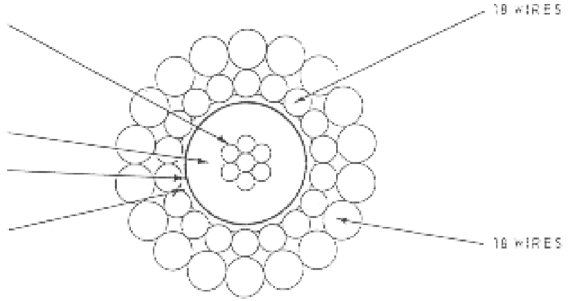

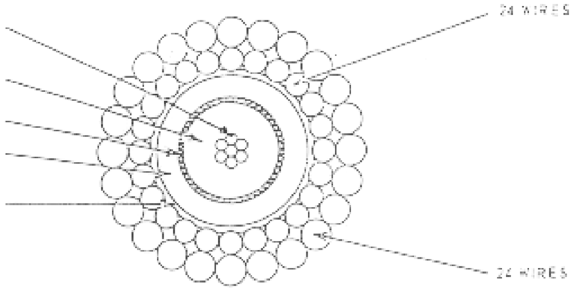

CABLES WITH EQUAL NUMBERS OF WIRES IN BOTH LAYERS

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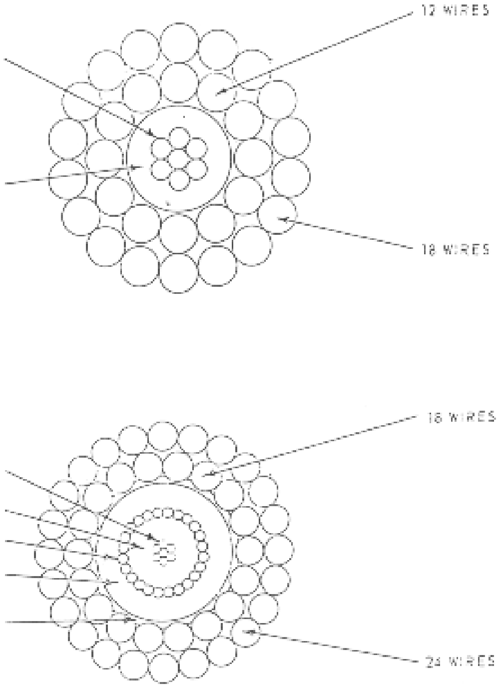

CABLES WITH EQUAL SIZE WIRES IN BOTH LAYERS

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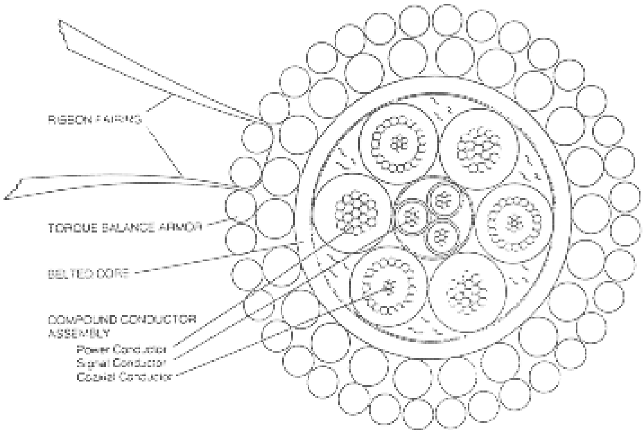

A Typical Compound Cable

(TORQUE BALANCED)

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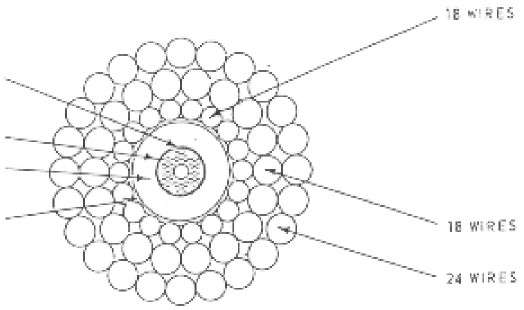
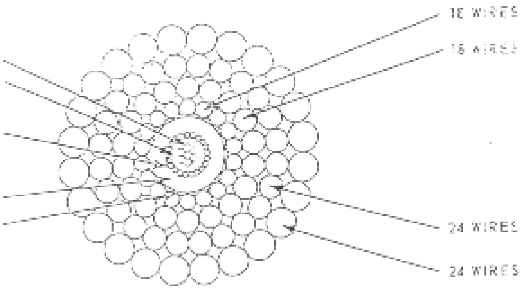


THREE LAYERS OF ARMOR



FOUR LAYERS OF ARMOR

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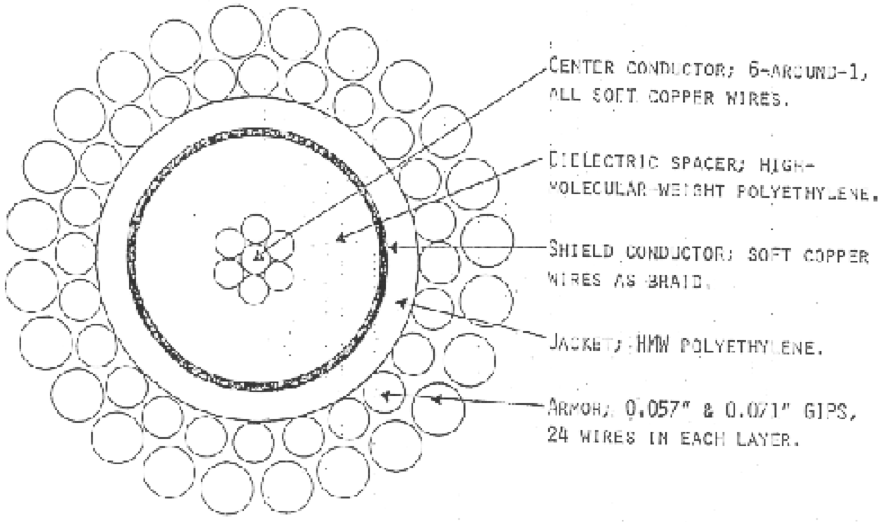
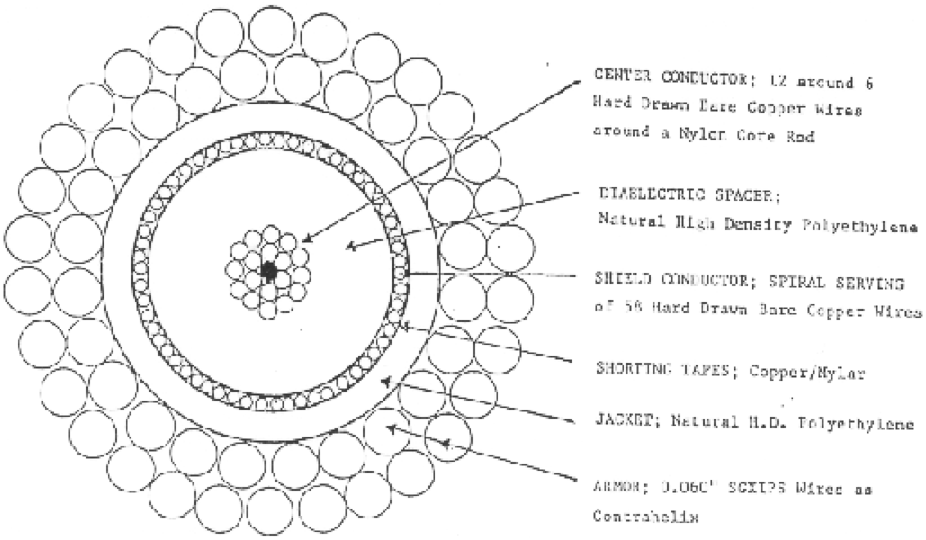
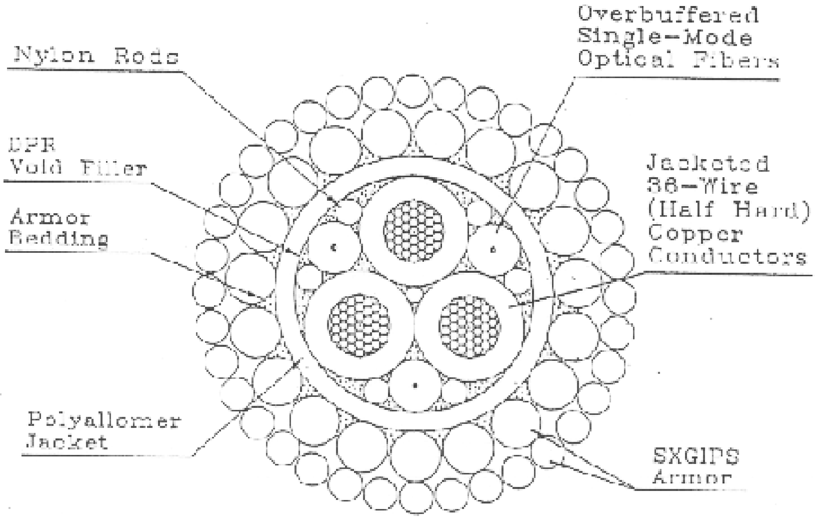


EARLY (CA 1972) NAVY VERSION OF MPL/WHOI CABLE.



CROSS SECTION OF SPECIFICATION ARMORED COAXIAL CABLE.
(ALL VOIDS IN THE CABLE CORE ARE FILLED.)



Prototype Deepsea E-O Tether Cable

TENSION

BENDING

TORSION

SHEAR

UNIFORM COMPRESSION

LOCALIZED COMPRESSION

FIBER ABRASION
DUE TO
ROPE BENDING

FIBER ABRASION
DUE TO
ROPE ELONGATION

FORCES AND MOTIONS AFFECTING INDIVIDUAL
ELEMENTS WITHIN A ROPE OR CABLE

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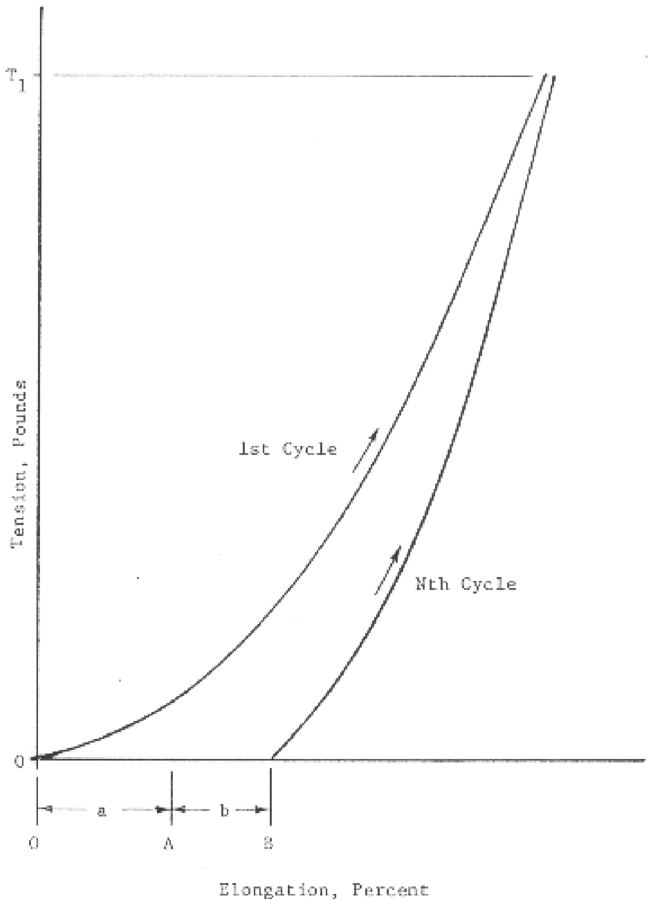
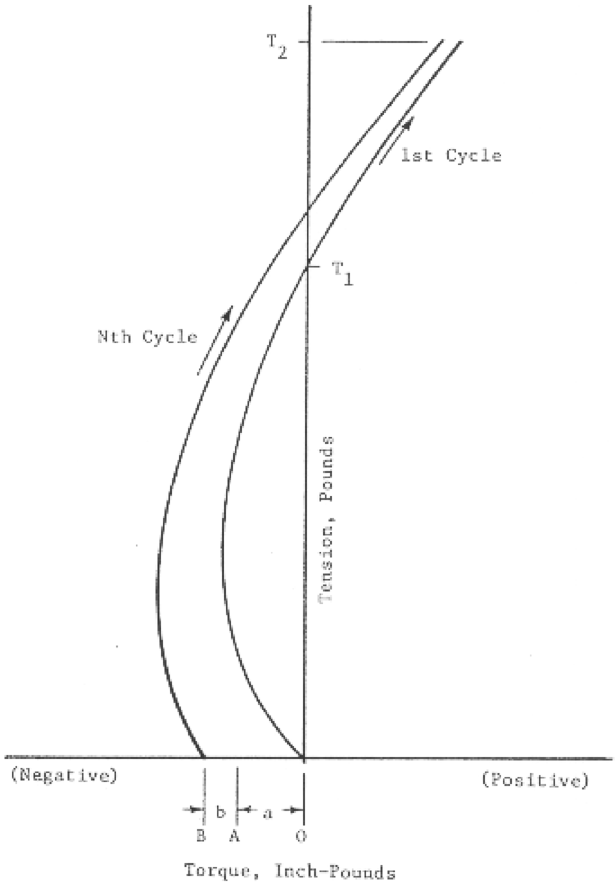
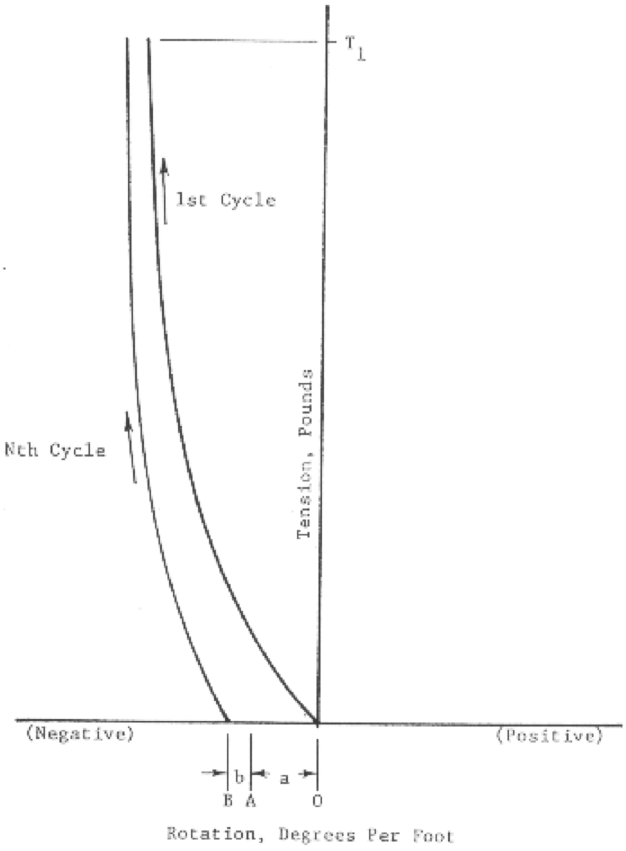


TYPICAL ELONGATION VERSUS TENSION CURVES FOR
FOR A DOUBLE STEEL-WIRE ARMORED ELECTRO-
MECHNICAL CABLE



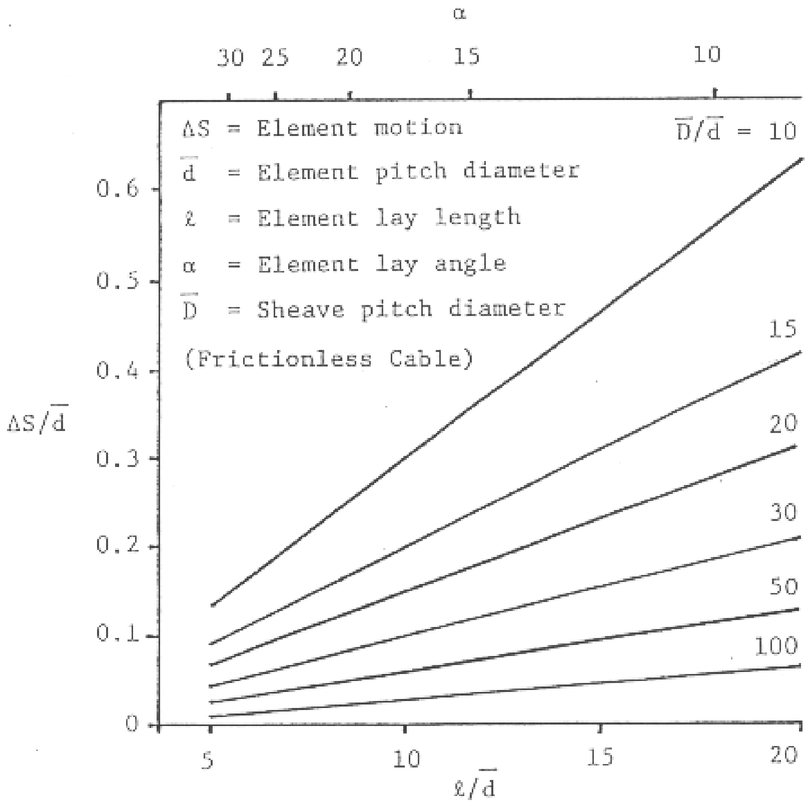
TYPICAL TORQUE VERSUS TENSION CURVES FOR
A 'TORQUE-BALANCED' DOUBLE STEEL-WIRE
ARMORED ELECTROMECHANICAL CABLE

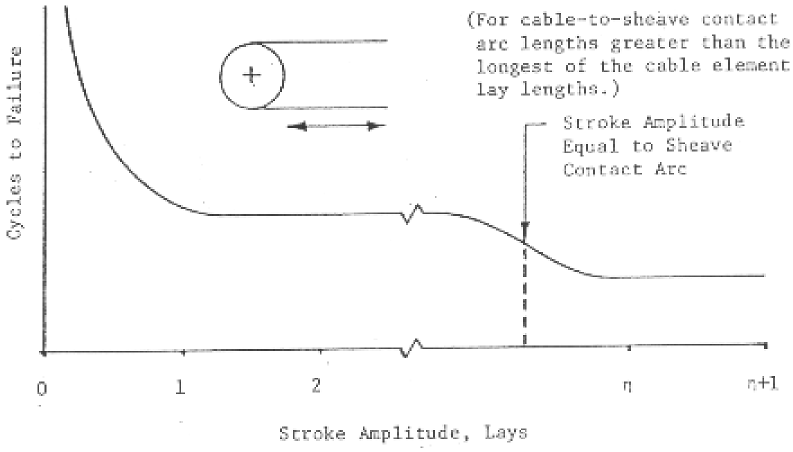


TYPICAL ROTATION VERSUS TENSION CURVES FOR
A 'TORQUE-BALANCED' DOUBLE STEEL-WIRE
ARMORED ELECTROMECHANICAL CABLE

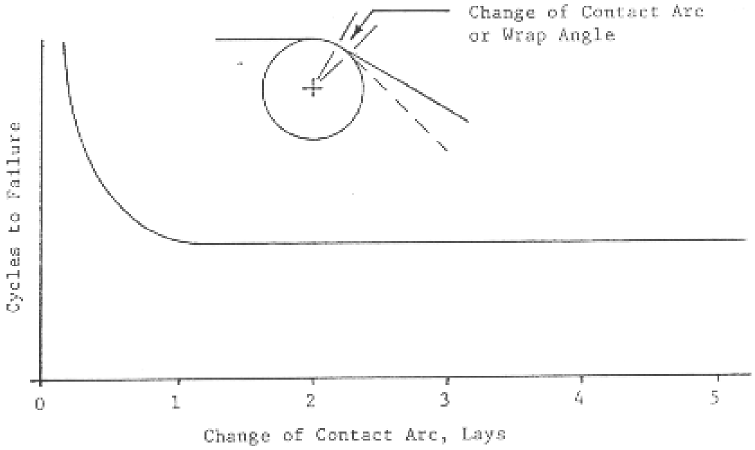
COMPONENT MOTIONS DURING CABLE BENDING

$\bar{d}$ = dia from center of cable to center of component
$\bar{D}$ = dia from center of sheave to center of cable





EFFECT OF CYCLING STROKE AMPLITUDE ON
CABLE BENDING FATIGUE LIFE



EFFECT OF BENDING AMPLITUDE AT OUTBOARD SHEAVE ON
CABLE BENDING FATIGUE LIFE

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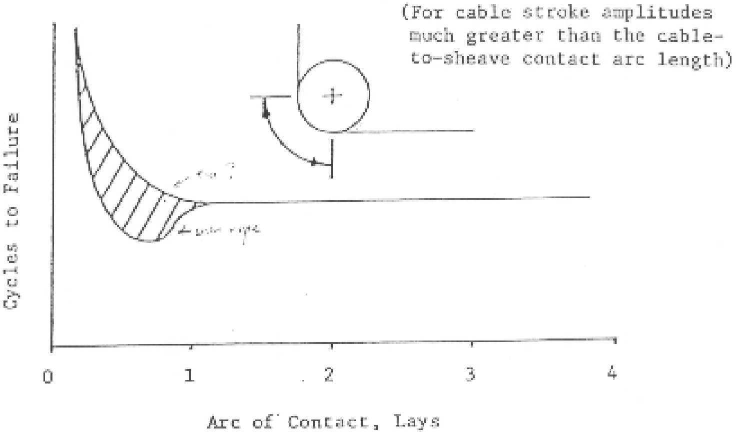
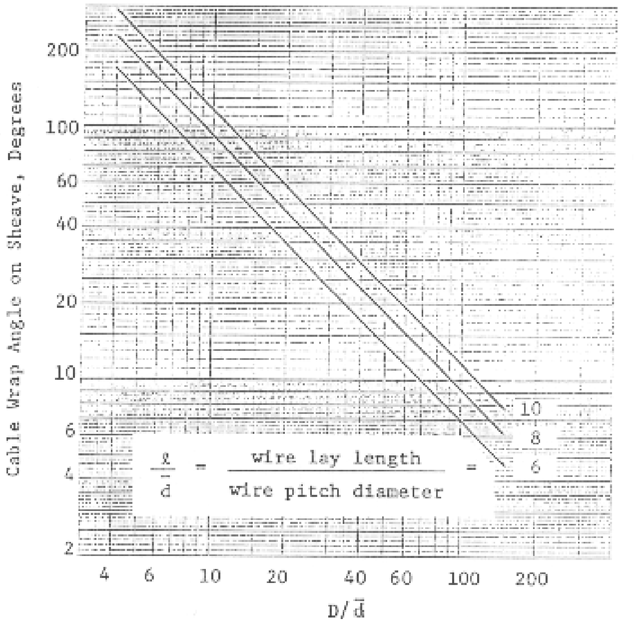


EFFECT OF SHEAVE CONTACT ARC ON CABLE
BENDING FATIGUE LIFE



WRAP ANGLE OF A CABLE ON A SHEAVE CORRESPONDING
TO A CONTACT ARC OF ONE LAY LENGTH OF THE OUTER
LAYER OF STRENGTH MEMBERS

SECTION 3

HANDLING SYSTEM CONSIDERATIONS

A. Single-drum winches

  1. Potential sources of cable damage

    a. Crushing due to winding many layers at high tension

    b. Crushing due to uneven winding

    c. Pinching at drum flange

    d. Cutting in

    e. Electrical resistive heating

  2. Drum configurations

    a. Flat faced

    b. Spiral grooved

    c. Lebus grooved

  3. Spooling aids

    a. Fillers

    b. Risers

    c. False flanges

  4. Level wind systems

B. Traction winches

  1. Single-drum capstan (not recommended)

  2. Double-drum capstan

  3. Linear puller

C. Sheave design considerations

1. Tread diameter

2. Groove diameter, depth, and flange angle

3. Groove material, hardness, and surface finish

4. Type of bearings

D. Reeving configurations

1. Safety considerations

2. Number of sheaves (minimize)

3. Reverse bends (avoid)

4. Fleet angles (minimize)

5. Sheave spacing (maximize for systems with motion compensation)

6. Cable wrap angles on sheaves (maximize for systems with motion compensation)

7. Use of guide rollers (avoid)

> Caution: never use a series of small rollers to replace a sheave!!

8. Use of swivels (to facilitate vehicle docking)

9. Special fairleads (wide-flange sheaves, rollers, chutes, bellmouths)

E. Motion compensation systems

1. Active drum

2. Active traction winch

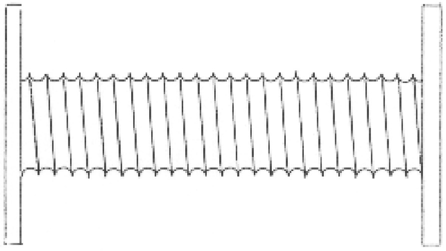
3. Ram tensioner system

4. Nodding (or bobbing) boom system
    a. Inflicts minimal cable flexure damage
    b. Can be used with a "stopper" to reduce cable flexure damage
5. Cable temperature rise
    a. Effects of sheave size, cable tension, and stroke amplitude
    b. Effects of cable jackets and sheave liners

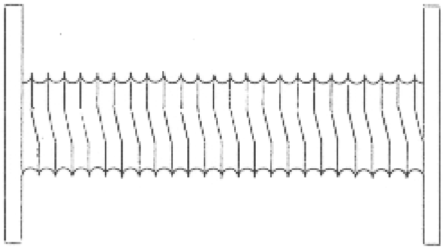
F. Use of operating logs to extend cable life by distributing wear
    1. Length of cable deployed
    2. Cable tension amplitude and frequency
    3. Cable motion amplitude and frequency
    4. Elapsed time

G. Tension measuring devices
    1. Load cell at termination
    2. Sheave axle or suspension system
    3. Winch suspension system
    4. Three-sheave device
    5. Vibration monitor

H. Cable storage
    1. Drum (low tension versus high tension)
    2. Basket or cage (with induced twist)
    3. On deck (figure eight)



SPIRALLY-GROOVED DRUM



LEBUS-GROOVED DRUM

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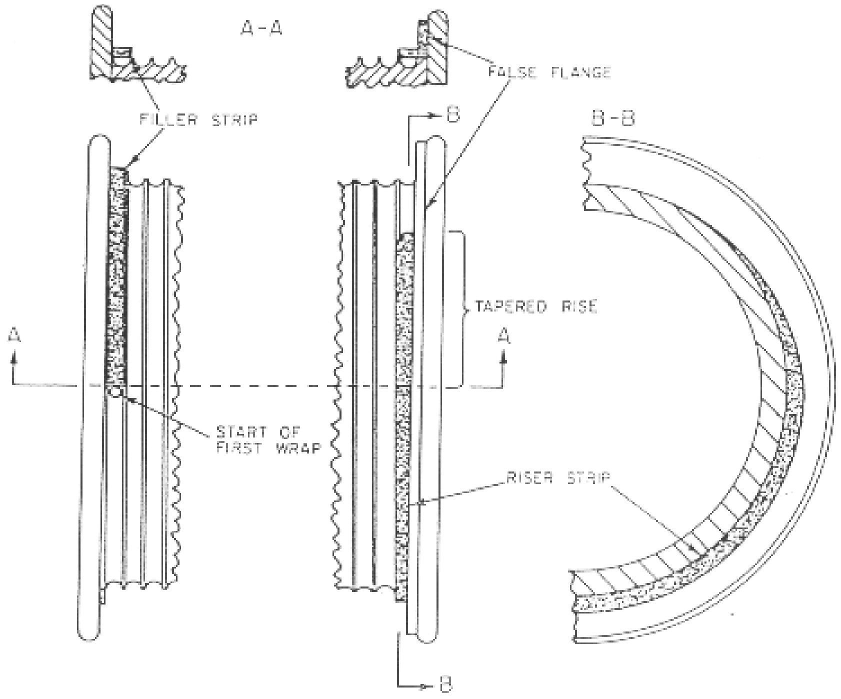

SPOOLING AIDS

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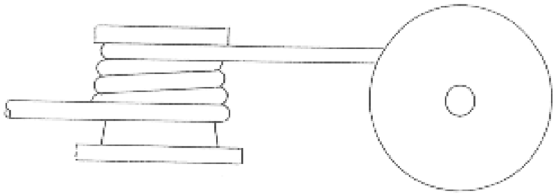
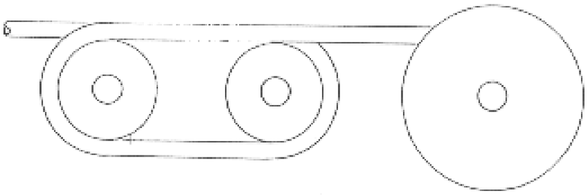
DRUM GROOVING CONSIDERATIONS

The following combinations are generally most effective:

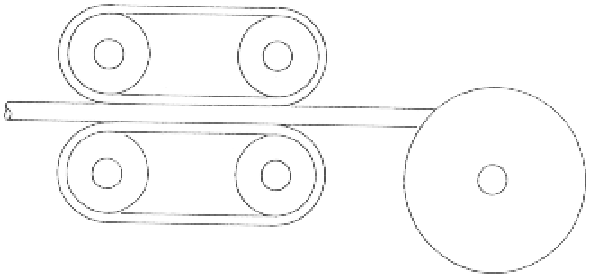
- For single layer winding, helical grooving is best.
- For two layer winding, either helical grooving with a riser or LEBUS grooving with a riser is satisfactory.
- For three layer winding, LEBUS grooving is preferred over helical grooving, but in either case riser and filler strips are needed.
- For more than three layer winding, LEBUS grooving should be used with riser and filler strips; helical grooving is not recommended.



SINGLE-DRUM CAPSTAN



DOUBLE-DRUM CAPSTAN



LINEAR TRACTION UNIT

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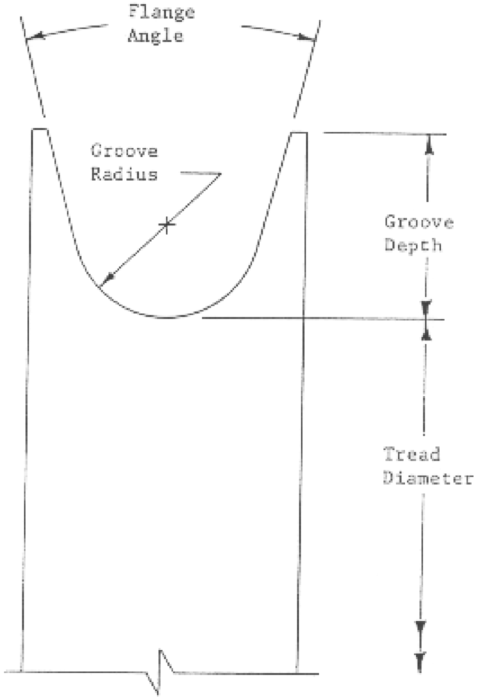

Material: ___________

Hardness: ___________

Surface Finish: _____

SHEAVE DESIGN PARAMETERS

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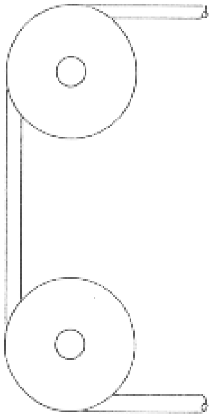
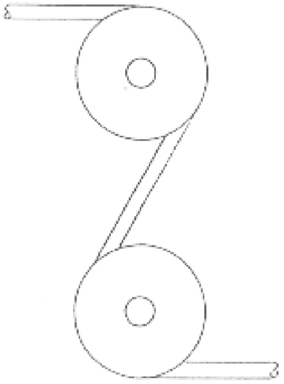


BENDING IN THE SAME DIRECTION
OVER TWO SHEAVES



REVERSE BENDING OVER TWO SHEAVES

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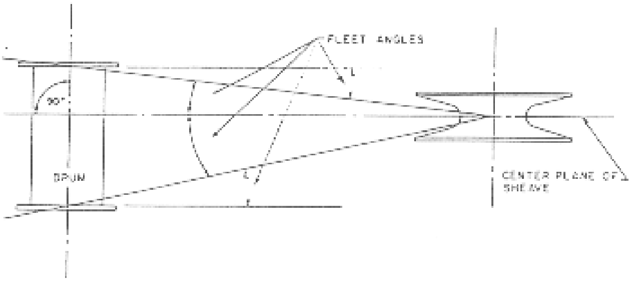

FLEET ANGLES

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SECTION 4

TERMINATIONS

A. Considerations in termination selection

  1. Size and weight limitations

  2. Compatibility with the cable design details

    a. Central versus external strength member

    b. Metallic versus nonmetallic strength member

    c. Potential impact on cable design

  3. Required strength and fatigue performance

  4. Requirement for field installation

  5. Load transfer mechanism

B. Externally applied cable terminations

  1. Capstans, bollards, and drum grips

  2. Twisted wire rod grips

    a. Single layer versus double layer

    b. Cable diameter sensitivity

    c. Bending strain relief

  3. Flexible mesh grips

  4. Split pipe grips

  5. Stoppers

C. Terminations integrated with strength members

  1. Resin sockets

  2. Mechanical compression fittings with conical wedge inserts

  3. braid-splice terminations

D. Bending strain relief considerations

E. Specifics of resin terminations

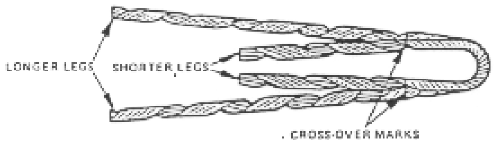
  1. Load transfer mechanism

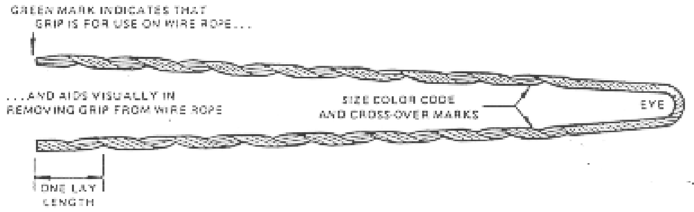
  2. Cavity shape and surface finish

  3. Resin matrix material

  4. Suitability for steel versus nonmetallic cable strength members

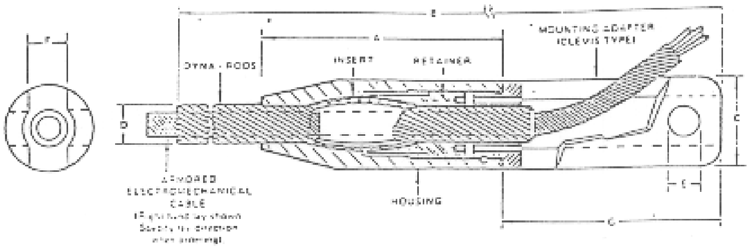
  5. Installation procedures





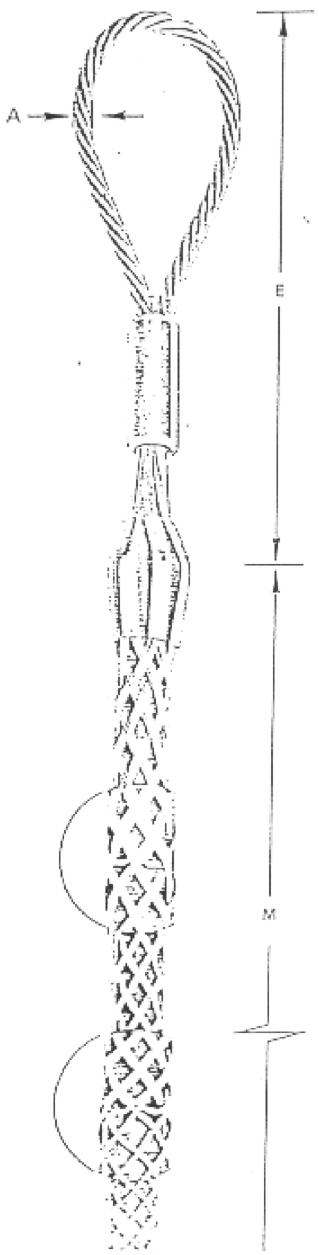
* Courtesy of Preformed Marine Cleveland, Ohio.

TWISTED WIRE ROD GRIPS



DYNA-GRIP TWISTED WIRE ROD TERMINATION

(Courtesy of Preformed Marine, Cleveland, Ohio)



WOVEN WIRE MESH GRIPS

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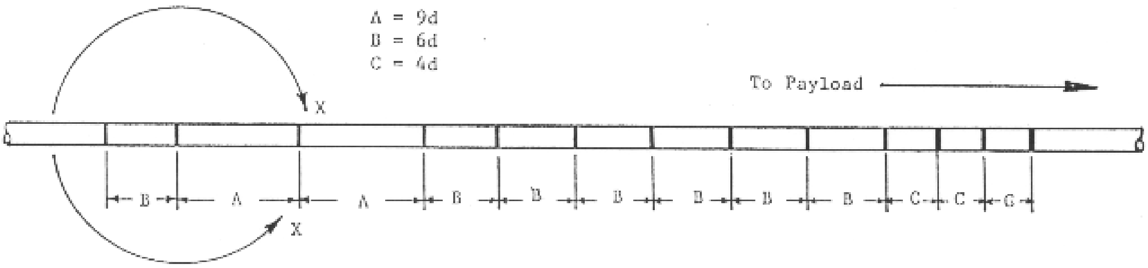
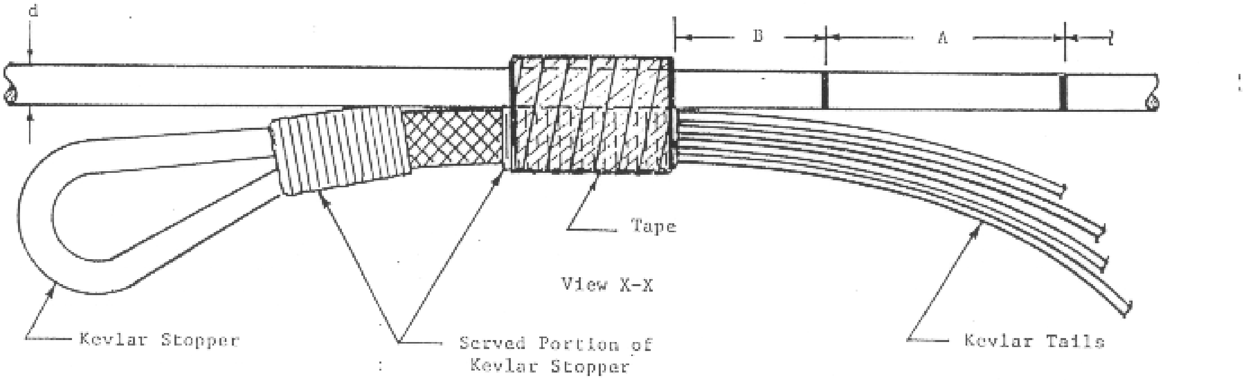


Premarking of Cable for Stopper Tail Crossover Points



ONE POSSIBLE CONFIGURATION FOR A CABLE STOPPER

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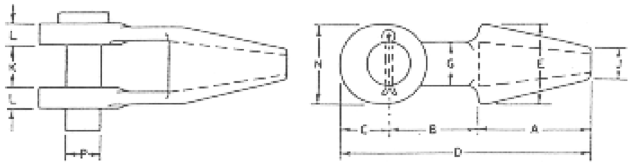
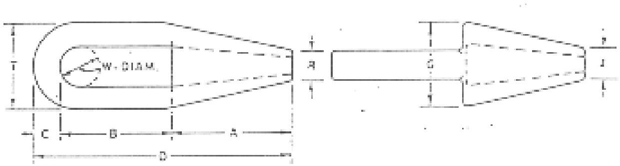


Rope Diam.	A	B	C	D	E	G	J	K	L	N	P	Approx. Wt Lb
3/16 & 1/4	2	1 9/16	3/4	4 5/16	13/16	3/4	11/32	11/16	7/32	1 3/16	11/16	0.9
5/16 & 3/8	2	1 3/4	7/8	4 5/8	1 5/16	13/16	3/4	13/16	15/32	1 1/2	13/16	1.1
7/16 & 1/2	2 1/2	2	1 1/16	5 9/16	1 7/8	1	13/16	1	1/2	1 7/8	1	2.3
9/16 & 5/8	3	2 1/2	1 1/4	6 3/4	2 1/4	1 1/4	1 1/8	1 1/4	9/16	2 1/4	1 5/16	3.8
3/4	3 1/2	3	1 5/16	7 13/16	2 5/8	1 1/2	1 1/4	1 1/2	5/8	2 5/8	1 3/8	6.0
7/8	4	3 1/2	1 3/4	9 1/4	3 1/8	1 3/4	1 1/2	1 3/4	3/4	3 1/8	1 5/8	10.0
	4 1/2	4	2 1/16	10 9/16	3 5/8	2	1 3/4	2	7/8	3 3/4	2	15.0
1/8	5	4 1/2	2 5/16	11 13/16	4	2 3/8	2	2 1/4	1	4 1/8	2 1/4	23.0

OPEN SOCKETS FOR USE WITH POURED RESIN



Rope Diam.	A	B	C	D	G	J	R	T	W	Approx. Wt Lb
3/16 & 1/4	2	1 3/4	9/16	4 5/16	1 3/16	9/16	1/2	1 5/16	11/16	0.5
5/16 & 3/8	2	2	9/16	4 9/16	1 5/16	3/4	5/8	1 11/16	13/16	0.9
7/16 & 1/2	2 1/2	2 1/4	11/16	5 7/16	1 3/8	13/16	7/8	2	1 1/8	1.5
9/16 & 5/8	3	2 1/2	13/16	6 5/16	2 3/8	1 1/8	1	2 5/8	1 3/8	3.0
3/4	3 1/2	3	1 1/16	7 5/8	2 3/4	1 1/4	1 3/4	3	1 5/8	4.5
7/8	4	3 1/2	1 1/4	8 7/8	3 1/4	1 1/2	1 1/2	3 5/8	1 7/8	7.0
	4 1/2	4	1 3/8	9 7/8	3 3/4	1 3/4	1 3/4	4 1/8	2 1/4	11.0
1/8	5	4 1/2	1 1/2	11	4 1/8	2	2	4 1/2	2 1/2	16.0

CLOSED SOCKETS FOR USE WITH POURED RESIN

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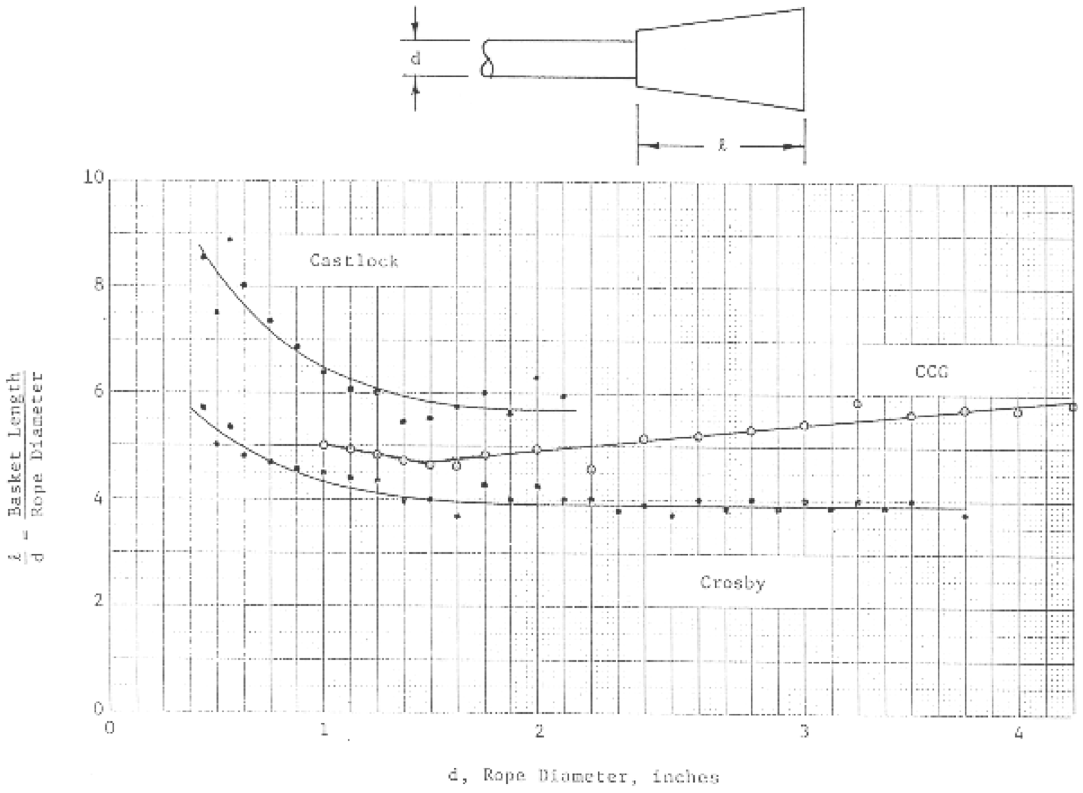

TYPICAL ROPE SOCKET BASKET CONFIGURATIONS

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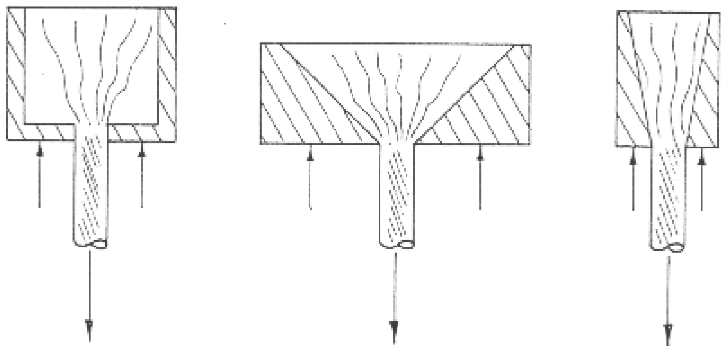
Huntington Beach, Ca 92649



VARIATIONS OF SOCKET BASKET GEOMETRY

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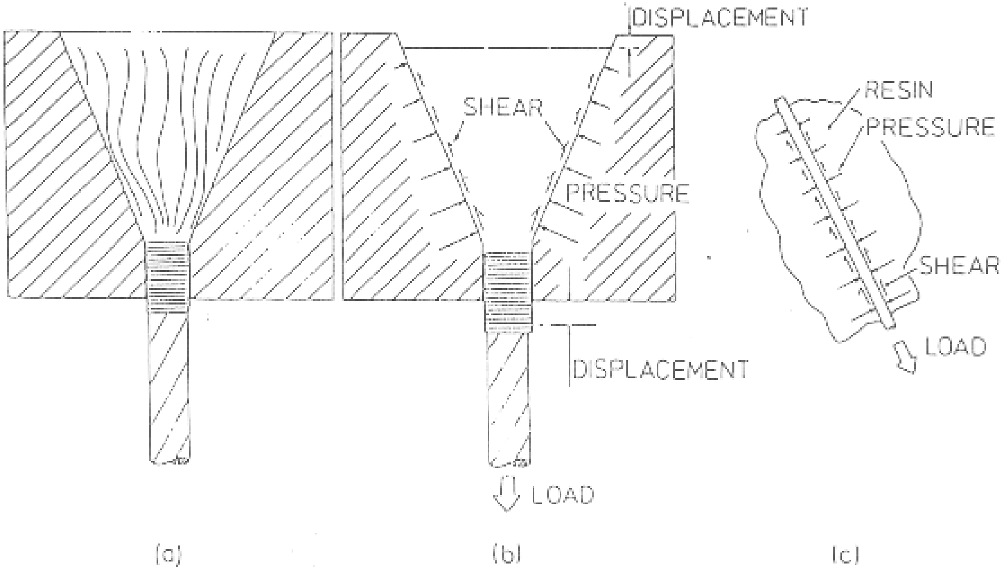

Schematic cross-section of termination showing:
(a) unloaded termination, (b) the effect of a load to produce an axial displacement of the rope relative to the socket generating transverse pressure and surface friction, (c) a similar situation at the wire/resin interface.

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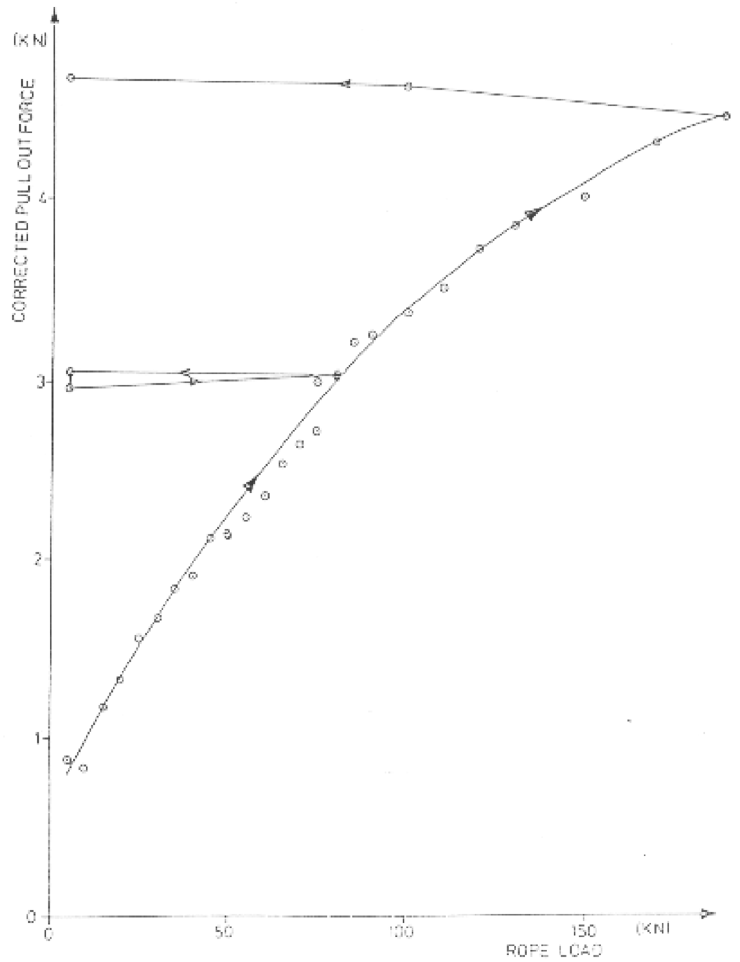

Pull-out force as a function of axial tensile load in the rope.

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PERFORMANCE CHARACTERISTICS OF ROV TETHER CABLES

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ABSTRACT

This paper describes some of the general operational characteristics of ROV tether cables which must be taken into consideration to achieve good cable service life. The reaction of a cable to tensile loading is discussed with regard to the component stresses and changes in cable elongation and diameter. Cable torque and twist characteristics are described, including design considerations for achieving torque and twist balance, the effect of twist on cable performance, and causes of cable hockling and kinking. The reaction of a tether cable to bending is discussed, including comments on how cable performance is affected by the details of the cable design and by the geometry of the components within the cable handling system.

Cable terminations are discussed with reference to the ease of installation and the strength efficiency achievable. Finally, typical cable failure mechanisms are reviewd and suggestions are included on ways to improve the mechanical and electrical performance of ROV tether cables.

CABLE REACTION TO TENSILE LOADING

The initial application of a tensile load to a new tether cable produces cable elongation which consists of a constructional stretch component and an elastic stretch component. The constructional stretch of the cable, a more or less permanent cable elongation (a portion of this elongation may dissipate if the cable is allowed to remain at zero tension for a period of time), is most evident in cables having external strength members and is primarily the result of core compression and strength member compaction.

External cable strength members, either steel or Kevlar, are wrapped helically around the cable core in either a braided construction or in one or more separate layers. As a tensile load is applied to the cable, the strength members exert a radial pressure on the cable core. In response to this pressure, the cable elements and filler materials experience deformations due to their own compressibility and due to material displacements associated with the elimination of voids within the cable structure. The result of this process is a reduction in cable diameter and a corresponding increase in cable length. Cables having Kevlar strength members typically exhibit a greater amount of strength member compaction than do cables having steel strength members. When the tensile load is removed from the cable, there is some recovery of cable diameter and a corresponding reduction in cable length. However, a significant portion of the core compression and strength member compaction may be relatively permanent, and, as a result, there will be some permanent increase in cable length.

This permanent change in cable length must not be overlooked, because its magnitude may actually be greater than the elastic stretch the cable exhibits under normal operating tensions. Obviously, the total strain experienced by the cable conductors (copper wires or optical fibers) will be a function of both the constructional and elastic cable elongation. Cables which experience a large amount of constructional stretch may impose strains on optical fibers which may, in the long term, contribute to fiber failures under quite moderate cable operating tensions or even during storage of the cable between missions.

CABLE TORQUE AND TWIST CHARACTERISTICS

Another consequence of changes in cable diameter with applied tension load relates to the cable torque characteristics. Any change in diameter of a cable having an external strength member (with the exception of a braided strength member) alters the load sharing among the strength member layers. As the stress balance among strength member layers changes, so does the torque contribution of each layer. Typically, reductions in diameter of double armored cables cause a small shift in tensile stresses from the inner to the outer layer of wires. As a result, the outer wires experience a proportionally higher tensile stress and, thus, produce a portionally higher torque component. In fact, most of the so-called torque-balanced double-armored cables which have been tested in the Tension Member Technology laboratory have exhibited a small amount of torque and rotation in a direction to unlay the outer wires due to an excessive torque component in that layer. On the other hand, cables which have two or more layers of served Kevlar strength members may experience a reduction in the tensile load and torque contribution of the outer layers.

Another consequence of cable constructional stretch is an increased torque contribution of the cable core due to an increase in the tensile strain on the core elements. This torque can be quite large in cables which incorporate one or more layers of large power conductors located just beneath the insulated jacket of the core assembly. To quantify the torque contribution of the cable core as well as the contribution of each layer of strength member elements, it has become common practice in the Tension Member Technology laboratory to conduct torque/dissection tests. During this test, a cable specimen is repeatedly loaded to the same total strain while continuous traces of cable torque versus tension are recorded after the removal of successive layers of cable elements. (A precision friction-compensated swivel is required to obtain accurate cable torque data.) The results of this test indicate how much tension load and how much torque is produced by each layer of elements within the cable. These data can then be used to determine how the cable geometry may be altered to achieve a design having better torque and twist balance.

The torsional stiffness of a cable (the amount of cable rotation which will be produced by a given amount of internal or external torque) is highly directional, especially for double-armored cables. A cable will typically rotate much more easily in the direction to loosen the outer layer of wires. Thus, to produce a cable with a minimum amount of rotation, it is desirable for any amount of torque imbalance to be in the direction which causes a tightening of the outer layer of wires.

It is usually desirable for a tether cable to have good torque and twist balance to minimize the possibility of cable hockling and kinking in service. A hockle is a loop which forms in a cable and then becomes twisted so that the portions of the cable on either side of the loop become helically wrapped around each other. The hockle itself may not seriously damage the cable, but it renders the cable useless where a tension load must be transmitted to a tethered vehicle. Any application of tension to a hockled cable may cause the hockle to tighten, thereby producing permanent cable deformation and kinking. In a double steel wire armored cable, the outer armor wires may become badly displaced or birdcaged as a result of this hockling and kinking.

The generation of a hockle in a cable requires only that a slack loop of sufficient size be allowed to form in a cable which contains a sufficient amount of stored torsional energy. If a cable contains no torsional energy, then the formation of a slack loop is not likely to produce a hockle. Similarly, if even a small amount of tension is maintained on the cable so that a slack loop cannot form, then no hockling will occur even if the cable contains a rather large amount of torsional energy.

If a cable is not of a torque-balanced design and if it is negatively buoyant and is suspended in long lengths in the ocean, then the cable may develop a significant amount of internal torque due to the tension produced by cable self weight. Should a slack loop be allowed to form at the lower end of the cable, then hockling is likely to occur.

Even if a cable has been designed to have good torque balance, the cable may still exhibit some torsional energy if any twisting has been induced in the cable. Such twisting can occur during the lowering or raising of a nonsymmetrical vehicle, by maneuvering of a vehicle so as to accumulate turns in the cable, or by the cable handling techniques. For example, if a tether cable which is deployed manually is allowed to pull out of a coil which is lying on the deck, the cable will develop one turn of twist for each wrap in the coil. Similarly, a cable handling system which does not incorporate a drum, but which allows the cable to lie in a cage or basket, will produce one complete twist of the cable for each loop of cable in the basket. Depending on the diameter of the tether cable and on its inherent torsional stiffness, the resulting twisting of the cable may be sufficient to produce hockling if a slack loop should be allowed to form.

The twisting of a cable has a number of adverse effects other than the potential formation of hockles. One of the major consequences of twisting is a reduction in cable breaking strength. This effect is most significant in cables having external contrahelical strength members arranged in either a braid or in multiple layers. When a cable is twisted, the strength members which are wrapped in one helical direction are tightened, while the strength members which are wrapped in the opposite helical direction are loosened. The resulting stress imbalance not only reduces the cable breaking strength but also reduces the cable fatigue performance. Kevlar strengthened cables, in particular, exhibit a dramatic reduction in breaking strength as a result of small amounts of induced twist.

Another potential consequence of cable twisting is the rapid failure of conductors within the cable core. Most cables having a complex core design incorporate several layers of conductors which are typically assembled with alternately right and left lay helical directions. With this type of core design, no matter which way the cable is twisted some of the conductors will tend to tighten while the others tend to loosen. Since cables having external strength members tend to become shorter no matter in which direction they are twisted (assuming that the strength members are either braided or are assembled in two or more contrahelical layers), then the conductors which tend to tighten will experience some strain relief due to shortening of the cable. However, those conductors which tend to loosen as a result of cable twisting experience even more loosening due to shortening of the cable, and they rapidly develop z-kinks which lead to conductor or insulation failure.

If it is known that a cable will be twisted in service due to the characteristics of the cable handling system, it is possible to design the cable to be twist tolerant. Such a cable must have all conductor layers arranged in the same helical direction so that they will all tighten and loosen together in response to cable twisting. Furthermore, the helical direction of the conductors should be such that the cable twisting induced by the handling system tends to tighten the conductors. Finally, the lay angle of each layer of conductors should be carefully chosen to minimize the additional conductor strain induced by cable twisting. Extensive cable twist tests have revealed that properly designed tether cables can survive many thousands of cycles of severe cable twisting without electrical or mechanical failure. Conversely, tether cables which have not been designed for twist tolerance may survive only a few cycles of moderate twisting.

Of course, whenever possible, cable twisting should be avoided so as to achieve maximum cable breaking strength and fatigue performance. In some systems, it may be necessary to employ a swivel to decouple a torque-balanced cable from a twisting payload. Conversely, it may be equally important to eliminate a swivel in a system which uses a nontorque-balanced cable with a stable and nonrotating payload. Regardless of the details of the service conditions for a specific cable,it is usually quite helpful for the cable to be manufactured with an obvious and permanent stripe positioned longitudinally along the cable jacket. This stripe will allow any cable twisting to be identified and quantified so that measures can be taken to minimize the number of accumulated twists.

CABLE REACTION TO BENDING

The bending of the cable around a sheave or other curved surface obviously produces a change in the radius of curvature of each cable element and a corresponding change in the bending stress in each element. In addition, cable bending produces relative motions among the various cable components.

Consider for example, the path followed by a single outer armor wire on a cable which is wrapped around a sheave. (See Figure 1.) Assume that the 12 o'clock position corresponds to the location on the cable furthest from the sheave centerline. It is apparent, then, that the path length of the wire as it moves from the three o'clock to the nine o'clock position is shorter than the path length of the wire as it moves from the nine o'clock past the 12 o'clock and back to the three o'clock position. If all of the wires within the cable were locked together so that no relative motion could occur, then the individual wires would experience high tensile strains on the side of the cable away from the sheave throat and compressive buckling strains on the side of the cable adjacent to the sheave throat. However, the mobility of the individual wires within the cable structure allows the excess wire length on the side of the cable toward the sheave throat to make up for the deficiency in wire length on the side of the cable away from the sheave throat. As a result, the tensile stress remains much more uniform along the length of each wire than would be the case if all wires were locked up so that no relative motions could occur.

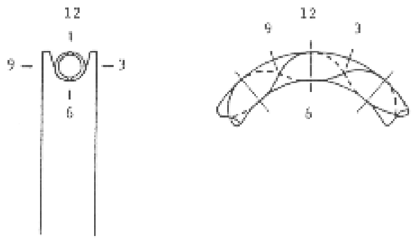


FIGURE 1. ARMOR WIRE GEOMETRY

As a cable is repeatedly flexed over a sheave, the largest magnitudes of relative motion among the cable elements occur at the three o'clock and nine o'clock positions. For example, when a cable having a braided Kevlar strength member is moved back-and-forth over a sheave during a laboratory fatigue test, the Kevlar strands within the braid become most severely worn at the three and nine o'clock positions, with very little Kevlar wear occurring at the six and twelve o'clock positions.

All of the bending-induced changes in bending stress and in the relative motions among the cable components as described above take place in the vicinity of the cable-to-sheave tangent point. Because of the internal friction within the cable structure, the affected portion of the cable is approximately one lay length either side of the tangent point. In other words, portions of the cable which are more than approximately one lay length away from a sheave, or portions of a cable which are on a sheave but are more than approximately one lay length away from a sheave tangent point, experience no changes in internal stresses or motions and thus are not influenced by the bending of other portions of the cable. If the arc of contact between the cable and sheave exceeds approximately one lay length, then there will be a certain portion of cable in contact with the sheave which, having undergone stress changes in the vicinity of one sheave tangent point, will experience no further changes in its state of stress until it approaches a second tangent point.

The conclusion which can be drawn from the previous discussion is that for typical deployment and retrieval operations, the bending fatigue life of a cable is not influenced by the wrap angle on a sheave as long as at least one lay length of the cable is in contact with the sheave. Tether cables which experience many deployment and retrieval cycles through a series of fairlead sheaves will provide a certain bending fatigue life which will be the same regardless of whether the cable wrap angles on the sheaves are 180 degrees or 90 degrees or any other angle which produces a cable contact from slipping longitudinally inside the cable and allows the core to extend through the strength member termination without affecting the stress distribution in the strength members.

Four basic types of cable terminations are in common use on ROV tether cables. The drum-grip termination is simplest in concept. It consists of a wide sheave having either a flat face or a helical, conformal groove upon which are wrapped several turns of cable. The friction between the cable strength member and the drum face provides a means for transferring the stress in the cable strength member to the drum grip. A portion of the cable tension is transferred to the drum for each wrap of cable, and the low tension end of the cable is anchored with a suitable secondary termination which can accommodate the lower tension level. The drum grip is particularly effective for steel wire armored cables, it works well with certain Kevlar-strengthened cables, and it may be easily installed in the field.

To maintain the greatest termination strength efficiency, the same geometry requirements as mentioned for sheaves must be met: i.e. a large drum-to-cable diameter ratio, a groove diameter equal to the cable diameter at zero tension, and a small fleet angle. (Termination efficiency is defined as the ratio of terminated cable breaking strength to unterminated breaking strength expressed as a percent.) Drum-grip terminations are usually large in diameter and are relatively heavy. Termination efficiencies of near 100 percent are achievable on steel wire armored cables without external jackets. However, jacketed tether cables having steel or Kevlar strength members can encounter problems when terminated with drum grips. If the coefficient of friction between the cable strength member and the jacket is less than the coefficient of friction between the jacket and the face of the drum grip, the strength members will slip inside the jacket, and upon repeated load cycling the entire load will eventually appear at the secondary termination resulting in cable failure. (If the secondary termination is capable of handling the entire load, then the drum grip is superfluous.) This same internal slippage problem can occur in systems utilizing traction sheaves, and total jacket delamination is the final result.

The resin-filled socket termination is a proven technology used successfully with steel wire armored cables. The large diameters of the individual tensile elements in steel wire cables (approximately one millimeter diameter) as compared to those in Kevlar-strengthened cables (0.012 millimeter diameter) has a great bearing on the strength efficiencies achievable with resin terminations. In Kevlar-strengthened cables, good wetting of the individual Kevlar strands by the potting compound is essential for high strength efficiency. Termination efficiencies of 100 percent are commonly achieved on steel wire armored cables, but efficiencies of as little as 60 percent are often encountered for Kevlar-strengthened cables.

A factor contributing to the low strength efficiency of resin terminations when used on Kevlar is the fact that, unlike steel wires which can yield under tension and allow all wires to share the load, Kevlar fibers fail without yielding. Thus, careful preparation of the Kevlar before pouring the resin in the socket is essential for good fiber load sharing and a high strength efficiency.

External compression-type terminations apply radial compression over some length of the cable and transfer the stress in the cable tension elements to some type of external tension elements. Woven wire mesh "Chinese finger" grips, single-layer and double-layer helical wire grips, and split-pipe grips fall into this termination category. They are quite effective on steel strength member cables and may work well on externally jacketed cables if the coefficient of friction between the jacket and the strength members is high enough. If this is not the case, the termination and a section of the jacket will pull off of the cable at a rather low tension. In cables which have multiple layers of Kevlar strength members (double-layer Kevlar braids and multiple layers of contrahelically served Kevlar), the friction between layers must be sufficient to allow the load transfer to take place from the inner to the outer layers to provide uniform loading of the cable strength members by the termination. Isolation tapes, if used between Kevlar layers to prevent layer-to-layer abrasion during cable flexing, must be specially selected to isolate while still providing adequate friction between layers if terminations of this type are to be utilized successfully.

Spliced eye terminations made of Kevlar fiber which is braided back into the end of Kevlar-strengthened cables are being used quite successfully. They circumvent the jacket-to-strength-member and layer-to-layer coefficient of friction problems by terminating all Kevlar fibers directly. The elasticity of the braided section provides some load sharing among the fibers so that good stress distribution is maintained. Spliced eye terminations are readily applied to braided Kevlar strength members and, with some judicious rearrangement of the geometry of the fibers in the cable strength member, they may also be applied to cables having multiple layers of braided or served Kevlar. Although somewhat time consuming to apply, they are light in weight and give strength efficiencies approaching 100 percent. The lay lengths of the braid tucks must be carefully engineered for each specific cable to provide uniform core compression over the length of the splice to avoid damage to the cable core. Premade splice eyes can be applied in the field and are also effective on cables having optical fibers in the cable core.

FAILURE MECHANISMS AND RETIREMENT CRITERIA

ROV tether cables seldom "wear out" in the same sense that, for example, elevator cables do. Elevator cables are used under a set of conditions which vary little from day to day. The environment is clean and dry, and the handling system is optimized to provide a long cable life. The cables wear out as a result of bending fatigue and are retired prior to failure by means of some experience-based retirement criteria. Catastrophic failure due to cable damage or fatigue is a rare exception to normal elevator operating procedures.

ROV tether cables have several modes of failure which may occur if the tether does not encounter accidental damage such as entanglement with propellers or slipping off of the handling system sheaves. One common operational mode of failure is tensile overload due to a snap load induced during docking of the vehicle with a surface ship or underwater garage. If the two masses involved have different motions, the snap loads induced in a short deployed length of tether cable can be large enough to produce a tensile failure.

Internal failure mechanisms are present in the tether cable itself and can be the cause of cable failure if the tether receives enough use. In tether cable designs which utilize several layers of contrahelically served Kevlar for the strength member, circumferential migration of the Kevlar may occur. The cable corkscrewing which results can cause internal damage to the cable core. This type of failure occurs most commonly at sheave and drum tangent points where the cable stops repeatedly, such as when the vehicle is secured in its cage or on deck.

If the tether cable receives sufficient use, the internal wear on the cable elements will be the ultimate cause of failure. Either the strength members will wear and degrade in strength allowing a tensile failure to occur at some lower tension, or the core elements will break or short out causing a failure in the power, communications, or control systems.

Another factor contributing to cable failure is heating of the cable power conductors due to IR losses. The conflicting requirements of neutral buoyancy, small diameter, high strength, and high power capability result in cables which operate at elevated temperatures. Usually, once the cable is underwater, the heat dissipation into the water column is sufficient to keep the internal cable temperatures within acceptable limits. When the tether is in air or rolled up on a drum, severe heating problems often exist.

Increasing the thermal conductivity of the Kevlar strength member by impregnating it with thermally conductive grease can be an effective means of lowering cable core temperatures, but the lubrication effect of the grease on the Kevlar has been shown to increase the probability of Kevlar migration and corkscrewing of contrahelically served strength members.

Since ROV tethers are usually retired from service following, rather than prior to, some cable failure, it is desirable to limit the damage to a localized area of the cable. The failure of communication or control system elements in the cable may scrub the mission, but will allow the vehicle to be retrieved by means of the tether cable strength member. If the failure occurs near one end of the tether cable, and particularly if it is due to an external cause rather than general internal wear. cutting off the damaged section and retermination of the cable is a reasonable approach. This technique also applies when opens in the power conductors cause loss of power to the vehicle.

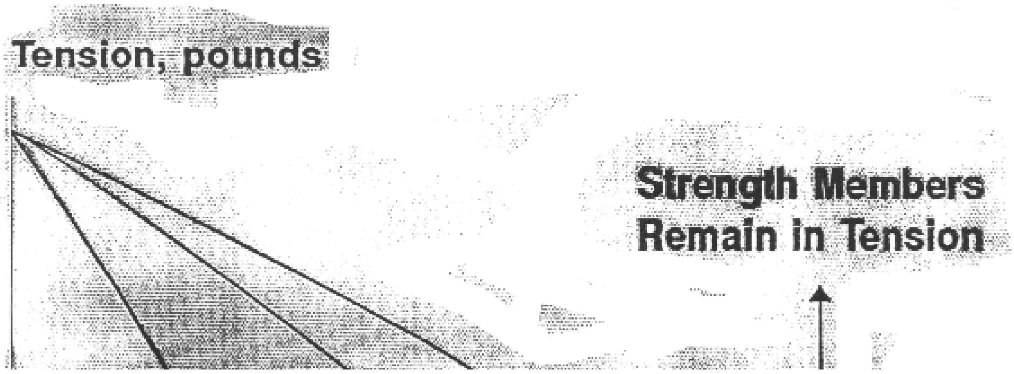
Perhaps the worst type of cable failure is a shorting of the power conductors where the system does not have adequate safeguards to prevent additional cable damage. Cables particularly susceptible to thermal heating damage during short circuits are those which use several power conductors in parallel to achieve the required conductor cross-sectional area. If, for example, three power conductors are used in parallel to carry 15 amperes and are protected by a single 15 ampere circuit breaker, shorting of one of the three conductors to a return conductor at a damage site in the cable can cause that conductor to carry the full 15 amperes with virtually no current being carried by the two remaining power conductors. Since the 15 amperes is the design current, this situation can exist without blowing any circuit breakers and can allow the insulation on one conductor to be thermally damaged along the entire length of the cable between the power source and the short circuit, forcing early retirement of the cable.

ROV power systems should be designed to accommodate shorts and opens in tether power conductors without causing any additional local damage such as arcing at the location of the cable short circuit. This approach will prevent additional damage from occurring along the length of the cable and will allow a failure analysis to be performed on the damaged section. The addition of conductive blocking compounds and drain wires to the cable core allows the use of ground-fault detector circuits at the power source. These circuits disconnect the power to the cable upon detection of electrical leakage above a predetermined level to either seawater or the cable drain wires. This system prevents power surges from passing through a shorted section of cable and heating the entire length of the power conductors sufficiently to thermally damage the conductor insulation.

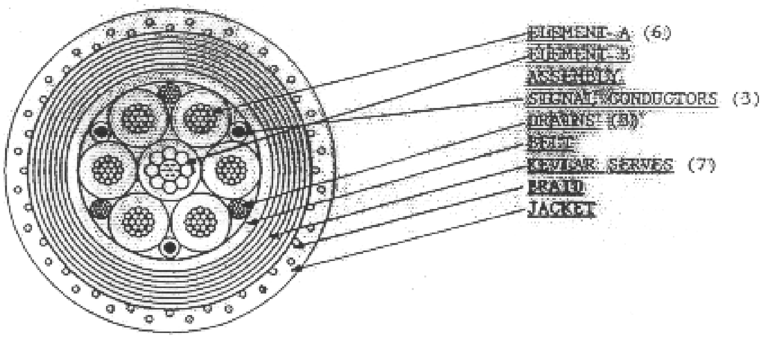
The importance of failure analysis cannot be over emphasized. In any tether failure, a 10-meter section of cable including the failure location should be saved for analysis. The end toward the vehicle should be marked, and a cable map prepared showing the location of the failed section in relationship to the handling system sheaves. The cause of failure, if known, the sea state, and other operating conditions should be recorded.

It is important to determine whether the failure is due to externally or internally induced cable damage. If externally induced, then an examination of the operational procedures is in order. If internally induced, the cable may be worn out or have design deficiencies which make it unsuitable for use under existing conditions. A change in operational procedure may reduce the cable stresses to a level which will allow the tether to perform satisfactorily.

Typical Bending Fatigue Performance of Cables Having High-Modulus-Fiber Served Strength Members



Typical Bending Fatigue Performance



OPTICAL MATRIX ROV CABLE

FIGURE 2