USE OF WIRE ROPE ON WEST COAST DRAGGERS

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I. INTRODUCTION

A. The Scope of this Report

This report's primary objective is to report the results of tests on the effects of various cathodic protection measures on the life of galvanized wire rope hooked directly to uncoated steel trawl doors.

The report will examine results of OSU experiments with wire rope in a series of controlled dock-side experiments and in a series of experiments of cathodic protection measures applied at sea. The report also examines documented corrosion experience (much of which was done in U.S. Navy-funded tests over the last 15 or 20 years) and engineering recommendations for cathodic protection.

A secondary objective is to examine and summarize documented engineering recommendations on the use, rigging, and construction of wire rope used for the purposes of trawl cables.

The discussion in the report is limited to commonly used materials and constructions. More exotic materials such as corrosion resistant steels, Kevlar non-metallics, and others, have not been included. Such expensive, more exotic materials would generally be disregarded because of the high risk of losing wire due to hangups.

A third objective is to make general recommendations based upon a synthesis of the preceding material. Recommendations will concern control of those factors tending to prolong the life of wire rope used as drag cable (or warp) on West Coast fishing vessels.

The report does not go into a detailed discussion of nomenclature, manufacturing practices, construction, and other details of wire rope. For these discussions the reader is referred to other references (for example, Meals, 1969; Malloch and Kolbe, 1978; Broderick and Bascom, 1980; Rochester Corp., 1975; SFE, 1973; British Ropes, undated c, d; Dardel, 1981; USN Spec., 1968.)

B. Present Practice

Slightly more than a hundred questionnaires were mailed to trawl fishermen based primarily in Oregon. Of these, 21 responded with data concerning present practice. Table 1, modified from Dardel (1981) summarizes some of the information contained in the questionnaires. This section is based on these responses as well as on information gained through discussions. Emphasis is placed upon bottom trawl fishing versus midwater fishing or shrimping.

Depth and Scope

fishing takes place in depths of water ranging from as little as 15 or 20 fathoms out to perhaps 300 or 400 fathoms, depending upon the size of the vessel, the species sought, and the amount of wire rope carried by the vessel. In general, the shallower the water, the larger the scope ratio (where "scope ratio" is the ratio of wire out, to depth of water). Scope ratios vary approximately as follows:

Depth of Water Fished	Typical Scope Ratio Used
D < 50 ftm	5:1
50 < D < 150 ftm	3:1
D > 150 ftm	2:1

Trawl Doors

Most area draggers use the steel "China Vee door" (FAO, 1974) which is almost always uncoated. The trawl warp is fastened directly to this door. A few fishermen have noted that the galvanized coating on new wire rope quickly disappears over a length of approximately 25-30 fathoms from the door -- thus the hypothesis that one of the greatest influences on wire rope deterioration at the lower end is the door/wire galvanic interaction.

Wire Rope Used

The wire rope used almost exclusively, has fiber core (hemp or some synthetic material), is galvanized, foreign-made, improved plow steel (IPS), and either 6x7 or 6x19 construction. Improved plow steel refers to the grade of metal used in the wires and depends primarily on the amount of carbon. (IPS carbon content is in the range .65 - .80). "Plow steel" and "extra improved plow steel" are lesser and higher grades of steel, respectively. Breaking loads vary with the steel grade as shown in Table 2 for both 6x7 and 6x19 constructions.

Of the 6x19, at least some appears to be "Seale" construction, implying layers of two different size wires within each strand.

Fishermen and wire rope suppliers feel that 6x19 is more flexible thus more suited to small sheave diameters found on trawlers. However, manufacturers indicate that 6x7 supplies better abrasion resistence because of the larger wire size in each strand. It is also cheaper than 6x19. Fishermen and suppliers also feel that a fiber core (vs IWRC or independent wire core) is best for

TABLE 1: WIRE ROPE USE QUESTIONAIRE SUMMARY.

Boat #	Length	Engine Power	Door Size (ftxft)	Door Material	Painted? Unpainted?	Warp Diam. (inch)	Warp Const.	Warp Galvanized?
1	90	425	6 x 9	steel	painted	5/8	6 x 7	yes
2	76	450	6 x 9	steel	painted	5/8	6 x 7	yes
3	90	675	---	Alu	---	3/4	6 x 19	yes
4	63	550	5 x 7	steel	painted	9/16	---	yes
5	75	360	5 x 7	steel	none	5/8	6 x 19	yes
6	72	250	5 x 7	steel	none	9/16	6 x 7	yes
7	57	250	5 x 7	steel	galv.	1/2	6 x 19	yes
8	60	300	5 x 8	steel	½ galv.	7/16	6 x 7	yes
9	52	165	3 x 6	wood	---	6/16	---	yes
10	73	310	7 x 10	wood & steel	---	7/16	---	yes
11	72	340	5½ x 7½	steel	none	9/16	6 x 7	yes
12	56	150	4 x 6	steel	galv. & painted	1/2	---	yes
13	56	290	4 x 7	steel	none	9/16	6 x 7	tar
14	60	300	5 x 7	steel	---	1/2	6 x 7	yes
15	67	250	4.6 x 6.6	steel	none	9/16	6 x 19	heavy tube
16	75	365	5 x 7	steel	none	9/16	6 x 7	galv. & lube
17	58	325	4 x 6	steel	none	1/2	6 x 19	yes
18	56	350	4½ x 6½	steel	none	1/2	6 x 7	yes
19	74	600	6 x 9	steel	painted	5/8	6 x 9	yes
20	65	200	4 x 7	steel	painted	9/16	6 x 9	yes
21	59	318	4 x 6	steel	none	1/2	---	yes

Thimble Used	WR on drums (fm)	Net used	Range of Depth Fishing (fathoms)	Scope ratio	Fishing day/yr	%of Trip Net is Immersed	WR dragging on bottom?
yes	525	--	60-150	2:1, 2½:1	130	50	no
no	500	Atlantic Western IIA	25-400	5:1 (D <50ftm) 3:1 (50<D<150) 2:1 (D>250)	--	--	yes
yes	500	Gourock #6 Polish rope (midwater)	30-200	3:1	180	30	yes
no	1000	--	15-380	3:1,2:1	120	65	no
--	--	--	--	--	--	--	--
yes	350	360 Modified Eastern	50-150	2½:1	120	60	no
--	--	300,400 Western	--	--	--	--	--
no	600	Atlantic Western IV A	40-370	--	120	60	--
yes	250	--	110	--	20	50	--
no	300	--	40-120	--	120	50	yes
yes	1000	400 Eastern 3 Bride Northeastern	30-700	--	--	--	no
no	600	--	220	2:1, 3:1	100	66	yes
no	500	360 Eastern	2-80	3:1	150	50	no
--	--	360 Eastern	--	--	--	--	--
yes	525	300 Eastern	20-200	3:1 (D<100 ftm) 2½:1 (D>100)	140	70	no
yes	--	Atlantic Western IIA 360 Eastern	20-300	1½:1 - 5:1	160	90	yes
no	345	--	less than 150	--	200	50	--
yes	1000	370 Dundee	100-500	3:1-1½:1	200	75	no
yes	500	--	less than 270	3:1 (shallow) 2:1 (deep)	120	--	yes
--	--	--	--	--	--	--	--
no	--	Atlantic Western IVA;400, 360,340 Eastern	20-400	2:1, 3:1	360	50	no

Frequency of Greasing	End Discarded? How Often?	How Much (fm)	Ever Parted?
8 months	one year	--	yes
3 months	3 months	25	no
never	one year	--	no
6 months	one year	25	no
--	--	--	--
no	6 months	3	no
every day	--	--	no
no	as needed	18	yes
one year	as needed	3	no
no	6 months	3	yes
6 months	as needed	--	no
no	6 months	--	yes
--	as needed	--	yes
--	--	--	--
3 months	6 months	5	no
no	3 months	2	no
one year	one year	17	no
no	never	--	no
no	3 months	1	--
--	--	--	--
no	as needed	25	yes

Table 2: BREAKING STRENGTH OF FIBER CORE WIRE ROPE (TONS)

Diameter (in)	Improved Plow Steel				Extra Improved Plow Steel			
	Galvanized		Bright		Galvanized		Bright	
	6x7[a]	6x19[b]	6x7[a]	6x19[a]	6x7	6x19	6x7[b]	6x19[b]
1/2	9.3	9.6	10.3	10.7			11.3	11.8
9/16	11.7	12.1	13.0	13.5			14.3	14.9
5/8	14.3	15.0	15.9	16.7			17.5	18.3
3/4	20.4	21.4	22.7	23.8			25.0	26.2

[a] Westco Wire Rope Company data

[b] Rochester Wire Rope Company data

shock loads experienced in fishing. It also absorbs and retains lubrication, of value in saltwater environment.

Foreign made wire seems to be purchased almost exclusively, primarily because of price. Some feel that foreign wire (here on the West Coast, primarily Korean) is inferior. Complaints heard concerning Korean wire included "torqued badly" and "bad galvanize." Others feel that it is of equal quality to that of US or European wire in addition to being almost half the price. Table 3 indicates comparative prices for several different constructions.

Drag Forces

Loads on wire rope are obviously both static and dynamic. Dynamic forces are caused by uneven loads at the net as well as the movement of the vessel on the open sea. We did not collect information on the dynamic nature of the loads but can indicate static loads based upon the horsepower of the vessel and the type of gear towed.

Dickson (1964) has indicated the following distribution of load in a trawl/cable system:

trawl:	58%
ground cable:	3%
doors:	29%
warps:	10%

Thus the load on the lower wire is approximately equal to the total drag on the trawl gear. This has been measured in a series of tests by Carrothers and others (Carrothers, et al., 1969, 1972a, b). By comparing net designs used in the present west coast practice

TABLE 3: PRICE OF WIRE ROPE (PER FOOT) (November, 1981)
IMPROVED PLOW STEEL* FIBER CORE

SIZE	U. S. Mfg.				Korean Mfg.			
	Galvanized[a]		Bright[b]		Galvanized[c]		Bright[b]	
	6 x 7	6 x 19	6 x 7	6 x 19	6 x 7	6 x 19	6 x 7	6 x 19
1/2	.69	.84	.54	.66	.32	.36	.25	.28
9/16	.82	.93	.64	.73	.36	.45	.28	.35
5/8	.97	1.12	.76	.88	.41	.59	.32	.46
3/4	1.35	1.61	1.05	1.26	.55	.84	.43	.66

a. Broderick & Bascom. Assumes 20% dealer discount

b. Assumes "galvanizing adds another 25-30%" as reported by Loggers Supply (Coos Bay, OR)

c. Loggers Supply

* Add 10% for Extra Improved Plow Steel (Westco Wire Rope Data)

and in the tests conducted by Carrothers, et al., one can ratio the anticipated loads under various conditions.

One calculation scheme is based on the assumption that total drag in a net is roughly proportional to the total number meshes and to the relative twine size. One can count the number of meshes and ratio the drag force proportionally (J. Jurkovich, personal communication). (Note that this scheme disregards the intermediate and cod end sections of the net while making the calculation.)

A second procedure used to compare nets of similar design is to ratio the drag by the square of the number of meshes around the thoat of the net (T. Croker, G. Loverich, personal communication). This gives roughly the same value, (i.e., as ratioing the total number of meshes in the net).

A third method of determining anticipated load on cables is to calculate the maximum bollard pull of which the vessel is capable. A rule of thumb used is to anticipate one long ton per 100 hp per warp, where "horsepower" used is something on the order of three quarters of the rated power of the vessel's engine (Dennis Lodge, personal communication). The value resulting from this calculation comes out close to that given by a method of Guillory (1981).

Using the technique of Lodge, anticipated cable loads for various horsepower ranges are:

Rated Vessel HP	Drag Load Per Warp at Vessel (lb)
100	1680
200	3360
300	5040
400	6720
500	8400
600	10,080

(Note that more specific calculations will be used in a latter section on wire rope configuration underway.)

Rigging

Rope terminations consist frequently of spliced eyes although many are formed by a swaged fitting. These are advertised as giving "100%" of wire strength, but some have given problems due to the inflexible nature of the wire at the swage. Drawing it over a sheave creates a bending 0tress failure. Thimbles, especially in spliced eyes, are rarely used.

Towing blocks vary in sizes. Many have a flat sheave surface, a type not recommended by wire rope manufacturers. (Recommendations will be covered in a later section.)

Winches on the newer vessels have level wind mechanisms with rollers to feed the wire onto the drum. Older vessels however do not have level winds--the wire is directed to the proper location on the drum by a crewman pushing against it with various forms of bars and rollers which are frequently unable to roll (the rope is abraided as it is wound on the drum).

Practice

Fishing time on west coast draggers might vary between 120 and 160 days per year, with some dragging operations going almost 'round the clock. The wire is infrequently greased, if at all. (The practice of greasing wires is dying for several reasons, to be discussed later.) It is periodically reduced in length by anywhere from a few fathoms up to 25 fathoms (the usual length between marks) it might be end-for-ended after a year and a half or two; the rope is usually discarded after two to three years. The ends nearest the doors always wear out first. The criteria for cutting back and replacing the eye might be: excessive rust, flattening of the rope, rotting of the core, reduction in diameter, broken wires, decreased springiness.

Thimbles are infrequently used. This practice creates a very sharp bend and rapid deterioration at the point at which the wire attaches to the shackle on the door.

Several have argued that one reason the lower wire deteriorates fast is because it occasionally strikes the ground, although several fishermen have argued against this possibility. The subject is covered in a later section. Another suggestion has been made that as the vessel is hauling back and doors are lifted from the seabed a virtual straight line exists between doors and vessel; the snap or shock loading of the vessel bouncing on the sea creates a higher strain than normal on that lower portion of the wire still in the water. Under normal conditions of tow, the catenary from the wire would tend to absorb such loadings from surface motion.

Recommendations on Longer Wire Life

In fact, opinions differ as to what factors might be most important in prolonging the life of wire rope. The major suggestions include the following:

(a) greasing/lubrication. A regular application of grease or lubrication will inhibit corrosion and lubricate the individual wires which are constantly moving in any working cable. The difficulty with greasing wires onboard the vessel includes messiness, oil dripping on deck creating a sliding hazard, oil getting into fish, oil spilling from the drum or cable into the water which is in violation of Coast Guard pollution regulations. Thus to be adequately greased or lubricated, the wire must be removed to land, a time-consuming and expensive operation.

(b) Proper zinc anodes or galvanized protection. This is one of the major suggestions to combat the interaction between the galvanized wire and the trawl door. It has also been suggested that "bright wire" (uncoated wire) with proper lubrication might be adequate, especially if a few zinc anodes were used in strategic locations.

(c) Proper rigging. Many feel that the most significant factors affecting the deterioration of wire rope relate to poorly designed or poorly selected terminations, sheaves, level winds, fleet angles, and other practices used in the rigging of trawl cables and trawl cable systems.

(d) Nothing. Several industry representatives felt that no efforts would be worthwhile, given the small gain that one could accomplish.

II. Corrosion of Wire Rope

A. General Principles

A number of corrosion mechanisms are at work on wire rope used as drag cable. A detailed discussion of these mechanisms and their relation to performance on wire rope is covered in several references and won't be covered in detail here (Dardel, 1981; Mahmood, 1981; Malloch and Kolbe, 1978; Wood, 1971; LaQue, 1975; and others).

A summary description of these mechanisms appears below (from Meredith et al., 1980).

Uniform Corrosion

Iron and mild steel are not thermodynamically stable in seawater in a metallic form. These metals are also not capable of retaining any degree of passivation in the presence of chloride ions and are thus ultimately destroyed by the process of uniform corrosion. In this type of reaction, iron forms +2 and +3 ions which in turn combine with water or oxygen to form common rust.

Galvanic Corrosion

When two metals of different chemical composition are electrically connected and immersed in an electrolyte, electrochemical reactions occur which can destroy at least one of the metals. This type of corrosion forms the foundation for cathodic protection and galvanization of metal whereby one surface or metals corrodes and protects another metal from the corrosion process.

Stress Corrosion

If a piece of steel is under sufficient stress and is immersed in a corrosive medium, we can observe one of two events:

(a) If the boundaries of the metallic grains are anodic, the boundaries will corrode, inducing hydrogen evolution on the grains.

(b) If the boundaries are cathodic then the nearby grains will corrode and hydrogen will be evolved at the junction of the grains. Such a phenomenon can lead to hydrogen embrittlement and stress corrosion cracking.

Occluded Cell Corrosion (Also referred to as Crevice Corrosion)

In some cases the prevalent ions in an electrolyte cannot be evenly distributed over the surface of a metal. A good example of this situation is found in wire rope where strands of wire may be imbedded and are thus not in contact with the bulk electrolyte. Such geometry gives rise to cavities which tend to become anodic with respect to outside surfaces. The anodic reaction creates ferrous ions and such ions in turn react with water to create ferric oxide and an acidic solution.

Erosion-Corrosion

Mechanical friction on a corroded metallic surface can cause the removal of surface oxide. This action reduces polarization and leads to additional corrosion of freshly exposed metal. This combination of erosion and corrosion can lead to extremely high metallic deterioration.

Wood (1971) and Kirby (1979) give some details of crevice corrosion and pitting, both examples of occluded cell corrosion. In the crevice areas having low oxygen concentrations, hydrogen alternatively combines with chloride ions present in seawater forming hydrochloric acid which is particularly hard on metal in the crevice area and the hemp used frequently in fiber cores. Lennox et al. (1973) found some very detrimental effects of this type of corrosion on the quality of the hemp core after a period of time. They also found that a galvanized wire with hemp core was in worse shape than a similar wire having as its only difference, an independent wire rope core (IWRC) instead of hemp. Wood (1971) further describes pitting corrosion, prevalent in wire rope in most seawater applications, and shows how it at least chemically fits into the category of occluded cell corrosion.

It is of value to examine a series of parameters that can influence corrosion rate. These parameters have differing influence on wire rope used as drag cable in the ocean. A summary based upon findings of Dardel (1981) and others follows.

Oxygen

All things being equal, the rate of corrosion has an almost linear dependence upon the concentration of oxygen in the water, in oxygen concentration ranges of interest. This is of possible significance in ocean fishing when one considers the oxygen profile in the deep ocean reported by Reinhart (1976). From the surface to a depth of about 1500 feet (250 fathoms) the oxygen concentration in the water varies by a factor of of approximately six. Levels approach a minimum at a depth of around 2300 feet.

Salinity

Although corrosion rate does vary with salinity, the variation of salinity within the depth ranges experienced in fishing is not a significant factor.

Temperature

At elevated water temperatures, the corrosion rate is said to double with every increase of 30° C. However once again, the variation of seawater temperature within the range of fishing depth and seasons is sufficiently minor to rule out temperature as a factor influencing corrosion rate, at least in the Pacific Northwest. (Reports from the Gulf of Mexico and the temperate areas of Australia however, indicate that the warm water in those areas does in fact seem to make corrosion a much more damaging phenomenon.)

Pressure

Although pressure is not in itself a factor in corrosion rates, Dardel (1981) showed how pressure which would affect an increased concentration of hydrogen in occluded cells, might lead to some hydrogen embrittlement once pressure in that cell is lowered. This happens when the cable is brought to the surface under various conditions of axial stress or shock loading.

Stress

Wire rope under most engineering designs is loaded with a factor of safety on the order of five, i.e. the rope is not subject to loads greater than about 20 percent of the ultimate breaking strength. This is approximately true in fishing, as seen when comparing anticipated drag loads (previous section), wire rope sizes used (Table 1), and breaking strengths of commercial wire rope (Table 2). In corrosion tests on wire rope in the deep ocean, Reinhart (1976) found no increase of corrosion due to stress for those samples stressed to 20 percent of their breaking strength. Heller and Metcalf (1974) on the other hand concluded that "mean load is a significant variable in the study of axial fatigue strength of corroded wire rope specimens." But more importantly, they found that "load range is the most significant variable in the study of axial fatigue strength of corroded wire rope specimens." As reported earlier we did not document the dynamic axial load range experienced by trawl cables in common use.

Wire rope used on draggers is exposed to essentially two environments. One is the sea in which the rope is completely immersed. The other is the on-deck environment as the rope is wound onto the winch and exposed to varying degrees of seawater spray and salty air environment. Kirby (1979) reporting the results of others, found that uniform corrosion in the "splash zone" above seawater is two to three times the rate of that found in quiet seawater. However, Dardel (1981) found lower corrosion rates in the intertidal zone, as reported in the following section. And Lennox et al. (1973) found that partially immersed galvanized samples corroded at about the same rate as those fully immersed. It is difficult to conclude much from this because of the conditions on the sea floor of high velocity, various degrees of corrosion due to turbidity or ground contact and perhaps the potential role of galvanic corrosion due to the influence on the wire rope (usually galvanized) of the bare steel trawl door almost universally attached directly.

B. Corrosion Due to Door/Wire Interaction

Lengthening the life of wire rope on draggers, investigation of interaction between trawl doors and wire used at sea, and check-out of various cathodic protection devices were all objectives of the reported study and would all normally be best conducted at sea. However, we decided to undertake a series of corrosion tests both at the Marine Science Center dock and within the laboratory for two reasons:

(a) We felt it was desirable and necessary to conduct experiments where all factors can be controlled; and
(b) We felt that basing total experiment success on the voluntary contribution of samples and test situations by fishermen having many higher priorities, would be a mistake.

Sections 1 and 2 below summarize the results of these relatively controlled experiments at the dock and in the laboratory respectively. Additional detail is presented in Dardel (1981) and Meredith et al. (1980).

1. Dockside Test Evidence

A series of experiments were set up with ½ inch diameter, galvanized, 6x19 wire rope having fibre (nylon) core, 26 wires in each strand; the manufacturer was a company (unidentified) in Korea. We conducted four experiments:

(a) several 15 ft samples, fastened to wooden frames, were completely immersed in seawater.

(b) several 15 ft samples affixed to wooden frames were suspended under the dock in the inter-tidal zone. These samples were immersed at high tide and exposed to air at low tide.

(c) three 5 ft samples were bolted to a 3 ft^2 uncoated mild steel sheet metal plate and totally immersed at the dock.

(d) two 25 ft (approximately) samples were totally immersed and continually "working" through a series of sheaves under some tension. One of these samples was directly connected to approximately 3 ft^2 uncoated mild steel plate.

It was determined that weight of zinc coating on wire samples was .333 grams per linear centimeter; total weight was 5.59 grams per centimeter.

In tests (a) - (c), weight loss for a period of three months was measured using a procedure described in Appendix A-1. For the same period, breaking strength tests were performed in a manner described by Dardel (1981).

Seawater conditions were approximately as follows:

-- Salinity varied approximately between 25 and 33, depending upon rainfall and tidal cycle.

-- Temperature was approximately 10° C.

-- Oxygen content varied around 6.4 mg/l.

-- Velocity varied around 2 knots depending upon tidal cycle.

Voltage of samples in test (d) was in reference to a $Cu\text{-}CuSo_4$ cell, for a period of three months.

The weight loss results for tests (a) through (c) are shown in Table 4 and Figure 1. The voltage measurements for the samples of test (d) are shown in Figure 2. Breaking strength tests for all samples were on the order of 22,000 lbs and indicated that:

(a) little if any decrease in strength took place in three months regardless of the conditions and appearance.

(b) Conducting a useful breaking strength test requires an element of skill and art. It is also very difficult to do on a wire that is already corroded. The variation is such that a substantial number of samples would have to be broken to note a statistical difference. The preparation of samples (fastening terminations) prior to exposure to corrosive conditions might be a better approach, as done in Heller and Metcalf (1974) and in Gibson, et al. (1972).

As indicated in Table 4, the most substantial loss in weight occurred with the wire rope sample directly attached to the simulated "trawl door." Note that zinc was measured to be only

TABLE 4: AT-DOCK WEIGHT-LOSS TEST ON WIRE ROPE:
WEIGHT-LOSS (%) VERSUS TIME (MONTH) *

New Sample: 5.592 g/cm

Zinc Coating: .333 g/cm 6% by weight

	Completely Immersed	Tidal Zone	Completely Immersed and Attached To Door
1 month	2.81%	1.4%	7.1%
2 months	3.8%	2.4%	9.6%
3 months	9.9%	6.8%	14.3%

ACCURACY: ± 1%

* % of Total Weight

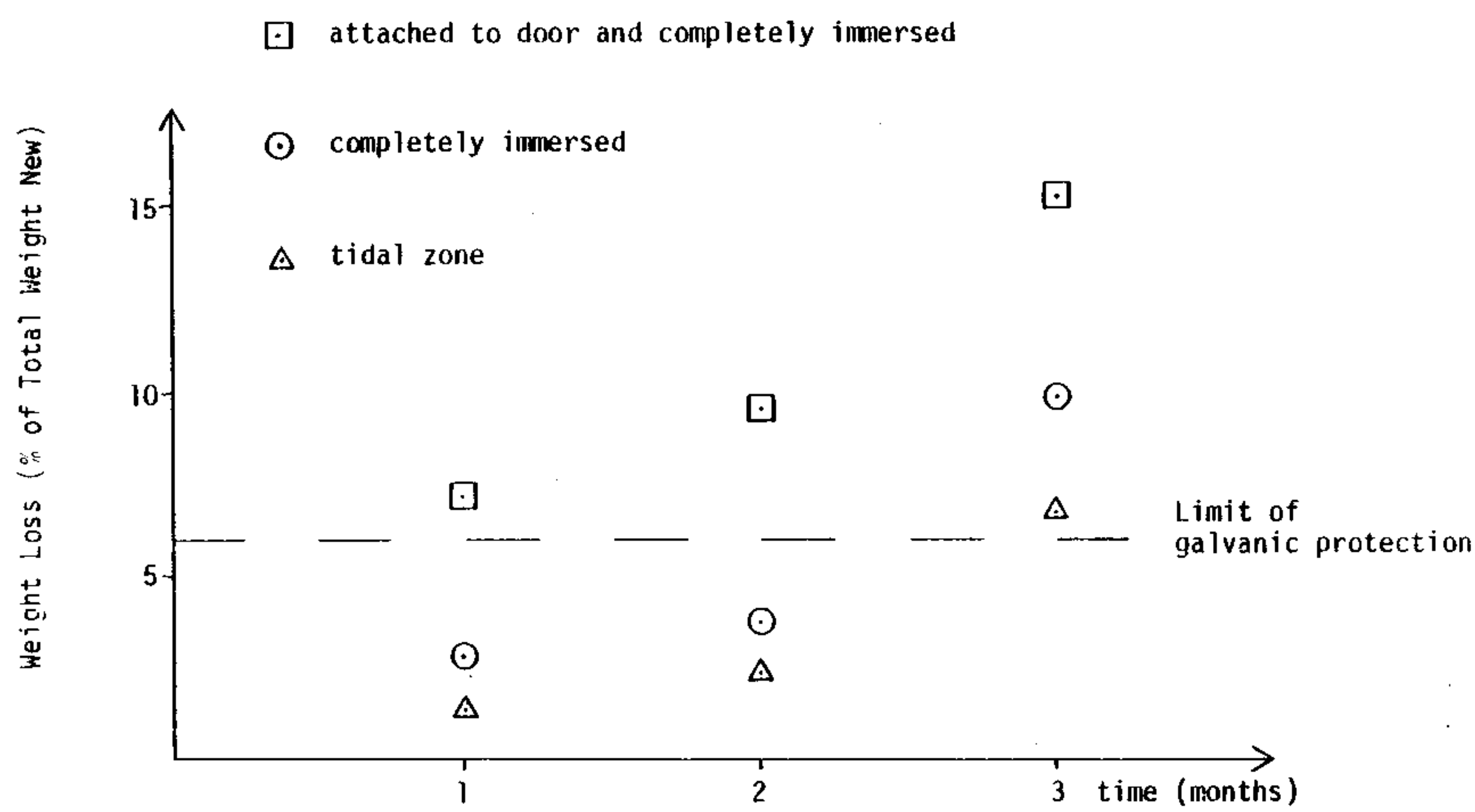
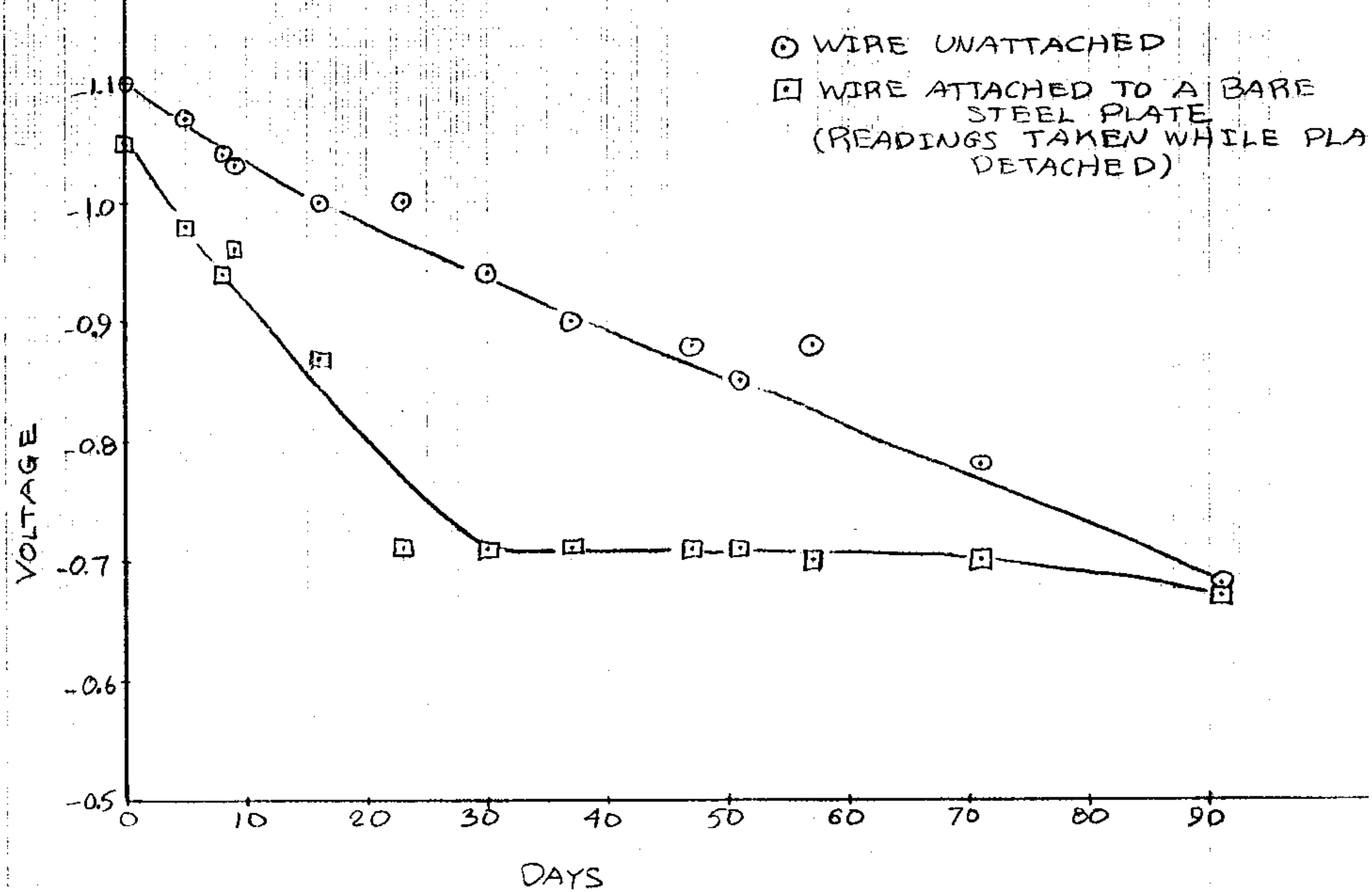


FIGURE 1 AT-DOCK WEIGHT LOSS TESTS ON WIRE ROPE
(FROM DARDEL, 1981)

FIGURE 2

VOLTAGE OF AT-DOCK WIRE ROPE SAMPLES, VS TIME
(VOLTAGE REFERENCED TO A Cu-$CuSO_4$ CELL)



approximately six percent of the total weight of the wire. Tests show that six percent weight was gone within one month and that perhaps due to remaining zinc on the inner surfaces, rapid additiona weight loss continued to occur. Because the percentage greatly exceeds the six percent attributed to the zinc, there is apparently a condition where the metal of the cable corrodes perferentially to that of the steel "door."

Note also that completely immersed cable corroded at a higher rate than that in the intertidal zone.

Voltage for wire rope samples in test (d) (one of which was connected to the bare steel plate) started at zero time at a voltage of around 1.05, the standard voltage of pure zinc, (relative to a $Cu-CuSo_4$ cell. The data show that within a month, the reading of the wire/plate couple falls to approximately the voltage of bare carbon steel, i.e. around 0.6. The voltage of the unconnected wire falls more slowly to the same value. This indicates that the bare steel plate is in fact accelerating by a factor of three, the deterioration of the wires galvanized coating.

These results roughly parallel those of Lennox et al. (1973), which indicated that galvanized rope immersed in seawater would lose galvanizing within a period of approximately 30 days, as shown here. The connection to the bare steel plate in our tests increased that rate by a factor of three.

These tests would suggest the following:

(a) Connection of a galvanized wire rope to a bare steel plate such as a trawl door would in fact increase the rate of deterioration of galvanized coating by a factor of approximately three.

(b) Presence of zinc in the crevices with partial contact with seawater may in fact cause an increased corrosion rate of the bare wire exposed to the outside.

(c) Galvanizing appears to "buy" only about three more months of life for the wire rope giving rise to the possible economic benefits of using ungalvanized, "bright" wire which may be properly or regularly lubricated.

2. Laboratory evidence

Some correlations exist between test results on individual wires and those on wire rope systems in full scale situations. (For example, Gambrell (1970) investigated fatigue life of wire rope in this manner.) Thus a series of laboratory tests were set up using individual wires in relatively warm (20° C) oxygen-saturated water to observe the effects of cathodic protection in accelerated corrosion conditions. The 0.61 millimeter wires selected for the tests were taken from the ½ inch 6x19 wires used in dock tests. It was measured that approximately 0.13 grams per meter of zinc coating was on each wire. This was removed to fabricate the "ungalvanized wire" samples used in the test.

These tests, reported by Dardel (1981) used weight loss measurement, breaking tests and voltage measurements to observe a number of configurations and conditions. Two indications of these tests are particularly noteworthy.

(a) The rate of weight loss of independent galvanized and ungalvanized wire was approximately equal. But in 540 hours of testing, much of the weight loss for the galvanized sample was the zinc coating, which contributes nothing to its strength. For the ungalvanized wire, the weight loss was naturally the base metal which does affect the strength.

(b) The corrosion rate of a single ungalvanized wire attached to a bare steel plate (simulating a trawl door) actually corroded slower than a galvanized wire which was unattached. It was felt that the reason for this was that the metal plate was actually anodic to the bare steel wire due to the metallurgies of the two materials.

3. At-Sea Evidence

In response to fishermen's suggestions, Malloch and Kolbe (1978) performed a series of tests on discarded wire which indicated that the steel door was in fact influencing corrosion rate of the wire. In one test, wire from a dragger using bare steel trawl doors showed a distribution of weight loss varying with distance from the door. The length observed was 10 fathoms. In the second series of tests, wire rope taken from a shrimper using wooden doors indicated no such variation in weight loss over the length of the cable.

Our at-sea test objectives were to set up a series of tests comparing one side of the gear to the other, under a series of conditions--different types of wire rope, fishing conditions, cathodic protection schemes. While trying for ten different tests, we were only able to get four tests involving three boats underway. Quantitative measurements on the samples collected from these tests were difficult. As reported earlier, breaking strength tests on previously corroded rope became difficult and was not pursued because of the lack of accuracy and sufficient numbers of samples, among other things.

Some attempt was made to ascertain the remaining thickness of the zinc on the samples collected. Mahmood (1981) attempted to measure zinc coating thickness by connecting the wire rope sample directly to a standard carbon steel electrode using a constant electrical resistor. Electrical discharge times were recorded and compared with probable zinc thickness. These tests were inconclusive and in hindsight the method outlined in U.S. specifications RR-W-410C (1968) or in ASTM Methods A90 (ASTM, 1978) would have been a better procedure to follow.

Because samples are unlikely to change in storage, weight loss and zinc coating thickness measurement are still future possibilities. Thus results of the at-sea tests are presently in a qualitative form with evidence being colored slides and samples available for inspection.

The experimental description and results of each are outlined below:

(a) Boat

TREGO, Newport, Oregon dragger

Length: 59 feet

Power: 318 horsepower

Winches, towing block

Towing block profile had a rounded groove, as recommended by literature.

Winch diameters: 16 inch ID; 42 inch OD

Winch level wind "by hand" (steel bar or pipe is used to pry and guide the wire onto the proper drum location)

Doors

Size: 4 ft x 6 ft steel Vee doors

"Protected side" characteristics: the door was sandblasted, given one coat of epoxy primer, one coat of "coal tar" epoxy antifouling paint, and fixed with two FMD (Federated Metals Div.) anodes as indicated in Figure 3.

Wire rope

Manufacturer: Korean company (unidentified)

diameter: ½ inch

construction: 6x7, hemp core, improved plow steel (IPS)

zinc coating thickness: unknown

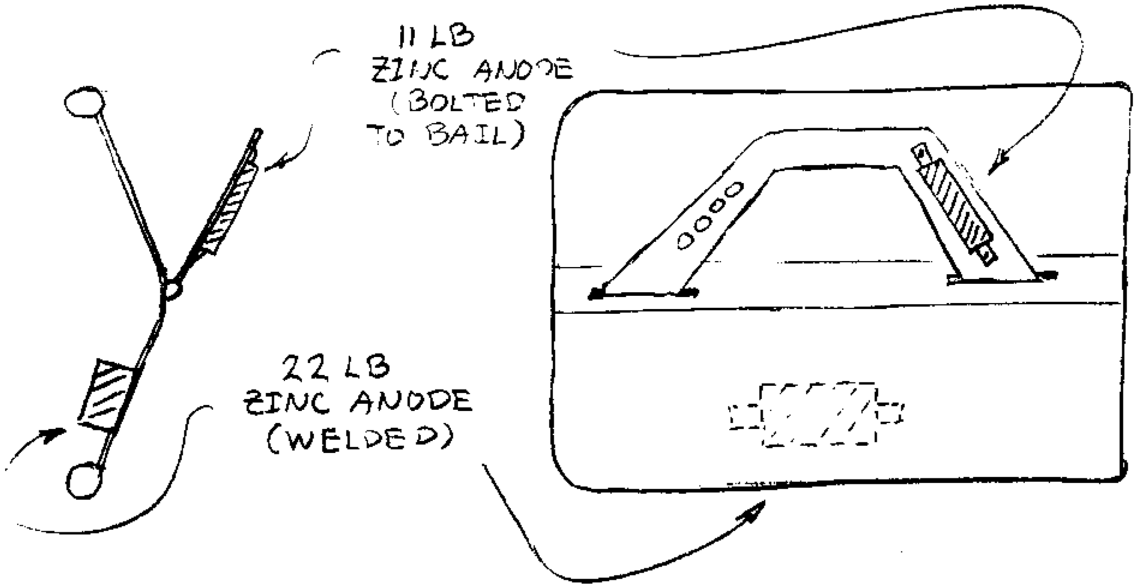
terminations: spliced eyes, no thimbles

approximately 175 fathoms were added to the end of older wire on each winch

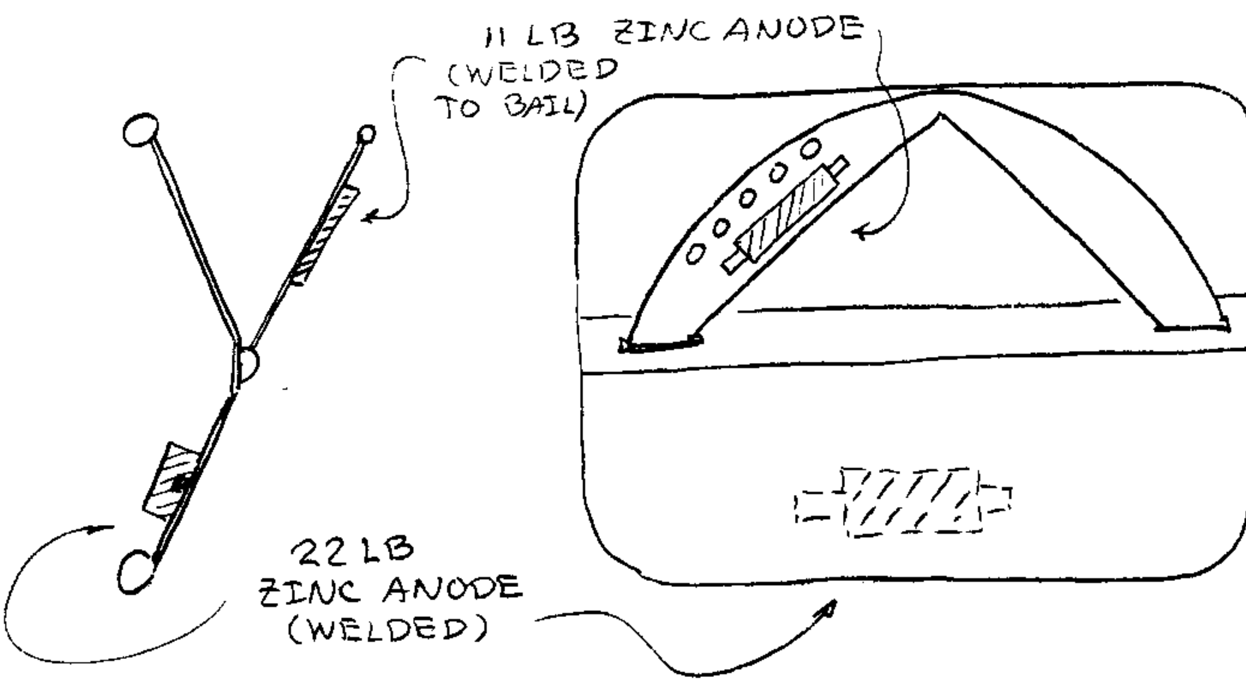
fishing practice

depth fished: 20-400 fathoms

scope: 2:1, 3:1



TREGO DOOR



OLETA DOOR

FIGURE 3

ZINC ANODE LOCATIONS ON TWO MODIFIED TRAWL DOORS

Good results were not obtained from the series of tests on this boat. During the 14 month period that the wire was observed, three different captains operated the boat which was idle for part of the time. Test conditions were modified. Information was lost.

The new wire was installed in February. After two months we noted that one bolt holding the 11 pound anode to the bail had worked loose, causing a poor electrical connection. This was then tightened. (Note: the captain had requested that the anode be bolted rather than welded to the bail to allow him the option to easily remove the anode in the event he felt it was interfering with fishing.)

After six months, the owner reported that the original eye plus 12 feet of wire had been cut back and discarded. After eight months we noticed that the 11 lb. bail zinc anode had disappeared and the mounting studs had been ground off. (There was no indication when this had happened.)

After 14 months the wire eyes were again cut back and we obtained these as the samples presently displayed. Some log books for the 14 month operating period were missing. After some interviews, we estimated that the wire had been in the water for a period of approximately 1200 hours. Both colored slide photos and the collected samples indicate some minor corrosion difference between the two sides.

(b) Boat

Oleta, Newport, Oregon dragger

Length: 63 feet

power: 550 horsepower

Towing block

The sheave has a flat surface; grooves are worn into each outside edge.

Doors

size: 5 ft x 7½ ft, steel, Vee doors

"protected side" characteristics: the protected door was newly constructed. We applied one coat of Ospho (a phosphoric acid rust converter), one coat of Rustoleum heavy duty primer, one coat of Rustoleum top coat. Two FMD anodes were fastened to the door as indicated in Figure 3.

Wire rope

Manufacturer: Korean company (unidentified)

Diameter: 9/16 inch

construction: 6x7, hemp core

zinc coating thickness: unknown (the distributor, referring to a specification sheet for a larger diameter wire, indicated zinc thickness to be .62 ounce per square foot)

terminations: spliced eyes, no thimbles

Fishing practice

Depth: 15-380 fathoms

scope: 2:1, 3:1

The fisherman installed new wire rope in April. The door was painted and zinc-protected at the same time. After 3½ months one end was reported to be "shot" and in fact one strand had parted at the eye when the net hung up on an underwater obstruction. Five feet on each end was cut off and given to us for inspection and display. Log books indicated that the wire had been in the water for 260 hours during that period. Both photos and the mounted sample indicated a fairly dramatic difference between the two sides. Zinc coating still remained on the "protected" side.

(c) Boat

Miss Mary, Ilwaco, Washington shrimper
length: 75 feet
power: 360 horsepower

Winch: 8 inches ID, 40 inches OD

Doors

size: 5 ft by 7 feet, steel, Vee doors
"protected side" characteristics: the protected side doors were sand-blasted then hot-dipped galvanized. (Note: the boat was a double-rigged shrimper having a pair of doors--one galvanized and one ungalvanized--on each side.

Wire rope

Manufacturer: Young Heung Iron and Steel; Korea
Diameter: 9/16 inch for the 50 fathom bridles
5/8 inch for main towing cables
Construction: 6x7, hemp core, improved plow steel (IPS)
Zinc coating: said to be minimum of .636 ounces per square foot taken from a specification sheet for a similar wire -- personal

communication, Ken Long of Loggers Supply, Inc.)

Terminations: eyes made with swaged (pressed) collars thimbles were used.

New wire and doors were installed in March. There was a protected and an unprotected door on each side of the vessel.

After 14 months and 1700 hours in the water (as estimated by the fisherman), 12 feet on each end of each bridle was removed at our request. No greasing of the wires occurred in the 14 month period. The outer zinc coating on each wire rope connected to the uncoated, bare steel door was completely gone and rust covered the wire. Zinc coating for those wire ropes attached directly to the galvanized doors was essentially intact. The fisherman noted that the most dramatic difference extended for a distance of approximately 20 fathoms from the door although some difference could be noted as far as 35 fathoms from the door.

Photos and samples of the wires from this vessel are available for inspection.

III. CATHODIC PROTECTION OPTIONS

The evidence clearly indicates some strong influence of bare steel doors on corrosion rate of galvanized wires. This section discusses several options which might serve to reduce corrosion rates under these circumstances. Most would extend wire rope life under many circumstances i.e., not only for the situation of direct contact with a bare steel plate.

A. Galvanizing

Galvanizing means coating with zinc to galvanically protect the base metal. This section considers coating of both wires and doors as cathodic protection options to protect wire life.

(1) Wires

Two terms are used to describe the galvanized coating on wires used in the construction of wire rope. The first is "drawn galvanized," also referred to as "finally drawn galvanized wire." In this procedure, individual wires are first coated with zinc (either by a hot-dipped process or by electroplating or "electrodeposition"), then drawn through dies, a process which stress hardens the material, smooths and ultimately reduces the zinc coating (van de Moortel, 1960).

The second type of galvanizing is referred to as "galvanized" also "hot-dipped galvanized." In this process the base wires are first drawn through dies then hot-dipped galvanized with a range of thickness depending upon the amount of protection or "class" of galvanized coating desired.

The "galvanized" wire generally has on the order of twice the thickness of zinc coating than does the "drawn galvanized" (British Ropes, undated, a). In the hot-dipped galvanized process, the heated base metal loses some of its stiffness and tensile strength, so galvanized wire rope is generally of lower strength than drawn galvanized or bright wire of the same overall wire rope diameter. Another reason for this is that with similar wire diameter but double zinc coating thickness, galvanized wire has less base metal and so less strength.

Wire rope manufactured by British Ropes Ltd. come with these same two galvanizing procedures, with fishing ropes receiving the higher coating thickness. According to Mr. Jack Stewart, a senior technical engineer, the British Standard 443 "Class A galvanizing" gives a coating of 135 gm/m^2 (0.44 oz/ft^2) for wire diameters to 0.77 mm (0.030 in), up to 230 gm/m^2 (0.75 oz/ft^2) for wire diameters of 2.4 mm (0.094 in) (Stewart, 1977).

Specification sheets for locally distributed Korean manufactured wire indicates galvanized thickness in this same order of magnitude. Table 5 gives information from three specification sheets obtained in private communication with Coos Bay Logger Supply and Newport Supply.

U.S. specifications for galvanized thickness on wire rope are given in at least two documents. The first (United States Federal Specification RR-W-410C), specifies zinc coating thickness for both galvanized wire and drawn galvanized

TABLE 5: ZINC COATING ON LOCALLY DISTRIBUTED WIRE ROPE

Spec. Sheet	Wire Dia. (in)		Break. Str. (lb)		Outer Wire Diam. (in)		Wt. of Zinc (oz/ft^2)	
	Spec.	Actual	Spec.	Actual	Spec.	Actual	Spec.	Actual
1[a]	.625	.64	23,180	34,090	.0701	.0700-.0707	.60	.824-.843
2[a]	.4375	.461	14,280	16,000	.0488	.0436-.0493	.20	.636-.651
3[b]	.625	.650	28,620	30,800	.0689	.0689-.0694	.60	.620-.642

a) Personal Communication, Coos Bay Loggers Supply Co.

b) Personal Communication, Newport Supply wire. An example appears in Table 6. The American Society for Testing and Materials (ASTM specification A475-78) gives further recommendations and identifies "types and classes" of galvanized coating for various size base wire diameters. These are shown in Table 7, with class A, B and C referring to increases in coating thickness. Note that Class A, also termed "extra galvanized" and "double galvanized," corresponds approximately to coating specified in Table 6. The examples of locally distributed wire ropes shown in Table 5 generally conform to class A galvanized coating.

As indicated earlier by van de Moortel (1960), the process of galvanizing causes a reduction in tensile strength. According to U.S. Spec. RR-W-410C, "galvanized rope wire has 10 percent less tensile strength than uncoated rope wire; drawn galvanized rope wire has the same strength as uncoated rope wire." Examples of this are shown in Table 2.

(2) Doors

Based upon at-sea experience with galvanized doors on the *Miss Mary*, galvanized coating appears to be a very good way to effect cathodic protection of directly connected galvanized wire. The following describes procedures we followed to have two doors hot-dipped galvanized at a commercial galvanizer.

Preparation

Under usual circumstances rust need not be removed by a sand blast operation unless there is very heavy scale

TABLE 6: WEIGHT OF ZINC COATING IN ROPE AND STRAND WIRES *

Galvanize at finish sizes		Drawn galvanized wire	
Wire Diameter	Minimum Weight of Zinc Coating	Wire Diameter	Minimum Weight of Zinc Coating
Inches	Ounce per Square foot	Inches	Ounce per Sqaure foot
0.010-0.015	0.05	0.010-0.015	0.05
0.0155-0.027	.10	Over 0.015-0.028	.10
0.028-0.047	.20	Over 0.028-0.060	.20
0.048-0.054	.40	Over 0.060-0.090	.30
0.055-0.063	.50	Over 0.090-0.140	.40
0.064-0.079	.60	-----	--
0.080-0.092	.70	-----	--
0.093-larger	.80	-----	--

* From U.S. Specification RR-W-410C

TABLE 7: NOMINAL DIAMETERS AND MINIMUM WEIGHTS OF COATING FOR ZINC-COATED STEEL WIRES[a]
(Source ASTM Spec. A475-78)

Nominal Diameter of Coated Wire in the Strand, in. (mm)	Minimum Weight of Coating oz per ft^2 (g/m^2) of Uncoated Wire Surface			
	Type 1[b]	Class A[c]	Class B[d]	Class C[d]
0.041 (1.04)	0.15 (46)	0.40 (122)	0.80 (244)	1.20 (366)
0.052 (1.32)	0.15 (46)	0.40 (122)	0.80 (244)	1.20 (366)
0.062 (1.57)	0.15 (46)	0.50 (153)	1.00 (305)	1.50 (458)
0.065 (1.65)	0.15 (46)	0.50 (153)	1.00 (305)	1.50 (458)
0.072 (1.83)	0.15 (46)	0.50 (153)	1.00 (305)	1.50 (458)
0.080 (2.03)	0.30 (92)	0.60 (183)	1.20 (366)	1.80 (549)
0.093 (2.36)	0.30 (92)	0.70 (214)	1.40 (427)	2.10 (641)
0.100 (2.54)	0.30 (92)	0.70 (214)	1.40 (427)	2.10 (641)
0.104 (2.64)	0.30 (92)	0.80 (244)	1.60 (488)	2.40 (732)
0.109 (2.77)	0.30 (92)	0.80 (244)	1.60 (488)	2.40 (732)
0.113 (2.87)	0.30 (92)	0.80 (244)	1.60 (488)	2.40 (732)
0.120 (3.05)	0.30 (92)	0.85 (259)	1.70 (519)	2.55 (778)
0.125 (3.18)	0.30 (92)	0.85 (259)	1.70 (519)	2.55 (778)
0.130 (3.30)	0.30 (92)	0.85 (259)	1.70 (519)	2.55 (778)
0.143 (3.63)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.145 (3.68)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.150 (3.81)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.161 (4.09)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.165 (4.19)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.177 (4.50)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)
0.179 (4.55)	0.40 (122)	0.90 (275)	1.80 (549)	2.70 (824)

TABLE 7: NOMINAL DIAMETERS AND MINIMUM WEIGHTS OF COATING FOR ZINC COATED STEEL WIRES[a]

CONTINUED

Nominal Diameter of Coated Wire in the Strand, In. (mm)	Minimum Weight of Coating oz per ft^2 (g/m^2) of Uncoated Wire Surface			
	Type 1[b]	Class A[c]	Class B[d]	Class C[d]
0.188 (4.78)	0.40 (122)	1.00 (305)	2.00 (610)	3.00 (915)
0.200 (5.08)	0.40 (122)	1.00 (305)	2.00 (610)	3.00 (915)
0.207 (5.26)	0.40 (122)	1.00 (305)	2.00 (610)	3.00 (915)

[a]For intermediate sizes of wire in the strand, the weight designations are the same as for the next finer size shown in this table.

[b]Type 1 (formerly "Galvanized") coating applies to "Common" Grade of strand only.

[c]Class A, "Extra Galvanized" and "Double Galvanized" are equivalent terms.

[d]Class A, Class B, and Class C coatings apply to all grades of strand.

(Leo Fontaine, personal communication). To be conservative, we had both doors sand blasted before taking to City Galvanizers, a commercial galvanizer in Portland. Cost at Bumble Bee Shipyards (Astoria) was as follows:

11 sacks of green diamond sand	\$ 51.70
sand blasting for two 5x7 Vee doors	\$192.50
Total	\$244.20

Commercial Galvanizing

The total weight of the doors was approximately 2150 pounds. Each door was first dipped in a 180° F alkaline bath to remove any grease. Following that, each door was dipped in a 150°F bath of muritic acid to remove any remaining scale or rust. Because we had first sand blasted, this was a short rinse. A longer duration in this acid bath would tend to remove heavier amounts of rust, negating the need for sand blasting. Each door was then dipped in an 860° F zinc bath. The tank was sufficiently large to allow the entire door to be dipped at once. The objective of this galvanizer was to put 2 oz/ft^2 of zinc on each surface, giving a minimum thickness of 3.4 mils. In fact for doors such as these, the operator estimated an actual thickness closer to 4 or 5 mils. (Leo Fontaine, personal communication).

The cost of galvanizing varies with the shape and surface area of the item. In March of 1980, the cost for two doors was 18¢ per pound, resulting in a total cost of \$387.00 for two doors. Items having higher amounts of surface area (such as an expanded metal surface) requiring, therefore, more zinc, would have a higher price per pound.

Other Considerations

-- Each hollow structural piece (such as a pipe) must be vented or left open during construction before any galvanizing can take place. Venting avoids problems with potentially trapped moisture which could be explosive when vaporized. Note that the saturation pressure of water at a temperature of 700°F exceeds 3000 psi. The liquid zinc temperature of 860° F exceeds the critical point of water. Vent holes (such as those cut with an acetylene torch) can be later sealed up when galvanizing is completed.

-- The bail (or hinged arm to which cables are attached) should be continually "worked" or moved as the door is withdrawn from the zinc bath. Otherwise, the solidifying zinc will cause the bail to seize in one position. One of the doors we received had the bail in a working, loosened condition; the other was seized and had to be broken loose with a hydraulic jack.

-- Warpage of a large hot-dipped galvanized item is a potential problem. We did not find it to be a problem with our doors and it has not been a problem with fishermen who have galvanized doors of other designs (Leo Kuntz, personal communication).

Warpage becomes a potential problem if the zinc bath or kettle is small and the door must be dipped more than once to cover all surfaces. Uneven heating of the item under such extreme temperatures would cause warpage (ASTM, 1976). Recommendations on how to fabricate and shape items to avoid excessive warpage is given in the ASTM Specification A 384-76 (1976).

-- Hot-dipped galvanizing of trawl doors becomes a problem in remote areas distant from large commercial galvanizing companies. Gear is tied up for excessive amounts of time if it needs to be hauled large distances. One alternative which we did not have an opportunity to explore involves a spray-on zinc process, commercially available. It appears to be a potential viable alternative.

B. Lubrication

Virtually all new wire rope sold has individual wires and core prelubricated in manufacture. This lubricant serves both to lubricate the wires as they move against each other in service and to protect the wire surface from corrosion.

Past practice with wire rope used as drag cable has been to lubricate the wire with any one of a variety of lubricants. Suggestions include "pinion grease cut with a solvent," "Union Oil Cable Lub," "LPS No. 3," and others. Lubricant might be applied with a brush or a rag as the wire is reeled onto the winch; it might be simply poured onto the winch drum with some kind of a trough underneath to catch the drippings. Many shrimpers fishing only six months out of the year, will remove the winches and/or cable and give it a good dip or lubrication as it is stowed. Past practice reportedly was to store drag cable in vats of old crankcase oil (Fisher, 1974).

Lubrication of wire is a practice that is diminishing for several reasons (only 8 out of 21 questioned indicated some lubrication schedule). These include recent EPA and Coast Gaurd regulations against allowing lubricant to fall into the harbor; the reluctance of a crew to undertake messy, non-compensated work ashore; slippery or hazardous deck conditions resulting from spilled or dripping oil; oil residues getting into fish dumped on deck (Fisher, 1974). Removing wire from the boat to lubricate ashore and immersing rope in drums are options, but they would involve cost and labor. The benefits must obviously be quantified before pursuing such a practice.

British Ropes, Inc., a large manufacturer of wire ropes used in United Kingdom and European fishing industries, produces wire having two types of lubricants (Stewart, 1977). One is a "petrolatum" based lubricant which is light and serves to protect the zinc coating of the wire during that period of storage prior to use at sea. After about 300 hours of trawling, all of this has been leached from the warps and is gone. The other type of lubricant is a "bitumen" based lubricant which is much heavier. It will last through about 2,000 hours of trawling while still protecting the inside strands. Although the bitumenous lubricant is much preferable as far as the wire rope (and wire rope manufacturer) is concerned, many fishermen and other users specify the petrolatum lubricant instead, because it is less messy and "life is much easier for a rigger under these circumstances" (Stewart, 1977). One wire rope lubricant advertised in the British fishing press is "Rocol RD 105" manufactured by Rocol Limited of Leeds. It is applied either by an aerosol spray or as a liquid. Several U.S. options are undoubtedly available, although we did not document these or individual user experience. In a series of axial fatigue tests for wire rope in seawater, Heller et al. (1972) used wire rope lubricant identified as Citgo Premium Wire Rope Compound PGR17N. Whatever lubricants are used in a maintenance program, they must be sufficiently non-viscous on application to allow penetration to the core (British Ropes, undated-a.)

There appears to be a high potential to increase wire rope life with a regular lubrication schedule. Reinhart (1976) cites a few mid-ocean tests where lubricant sufficient to prevent corrosion at the center did not wash out of the center over the three year period of the test. If the difficulties could be surmounted, one veteran fisherman who formerly greased wire every three months, estimated that this practice could lead to doubling of wire life (Joe Easley, personal communication). The manager of Technical Services for the Broderick and Bascom Wire Rope Company (St. Louis) felt that the major need for prolonged use of wire rope in the fishing industry is for a regular maintenance program with grease (N. E. Freebourn, personal communication).

In a recent article, Freebourn (1980) describes three types of wire rope lubricants: oil, petrolatum base, asphalt base, with the asphalt being the most dense and heavy lubricant used for both corrosion protection and lubrication. Petrolatum base lubricants are often put on warm and diluted with a solvent. As the substance cools and the solvent evaporates, a semi-solid coating deposits on the wires. Freebourn stresses the importance of lubrication of wires constantly moving against each other, and that lubricants be applied at that point at which wire rope is being bent (as at a sheave), thus opening up gaps between wires to allow lubricant to flow to the center. He reports of large excavating machine maintenance schedules which recommend lubricating the entire length of some working ropes every eight hours. Freebourn feels that proper lubrication can double or triple the life of some ropes. It is conspicuous however that Freeman's recommendations state that "a rope should be dry -- free of water -- when lubricant is applied." This seems to disregard the unique problems faced by fishermen trying to set up a wire rope lubrication program.

There is a need to develop technology, already underway in the paint industry, to formulate a grease which would be a good conductor of electricity and would contain zinc powder or dust. A cable coated with such a grease would have a built-in cathodic protection system. A grease coating would seem to have several advantages over a galvanized coating: (1) fibre chemical attack would be minimized since the chemicals that are formed as the zinc is consumed would tend to be held by the grease away from the fibre; (2) such a grease would give increased protection to the crevices of the cable where corrosion occurs more often; (3) the grease would be easier to apply than galvanizing; (4) galvanized cable is easily damaged if it is scraped by hard surfaces, but a cathodically protecting grease would be more difficult to remove.

We learned very little in this project about any preferred practices or materials for wire rope lubrication and how they might affect wire rope life. It appears that this practice would be very worthwhile for maintenance programs. Two methods have been suggested involving equipment that, although perhaps too expensive for one fisherman, would be affordable by a fisherman's coop or port service. These are:

(1) Construct a truck-mounted powered reel that could be used to grease wire as it's reeled from the boat to the truck or to facilitate some dipping process while allowing the reel to drain on shore rather than on a fishing vessel deck.

(2) Evaluate use of a clamp-on device, described in a recent news article, that allows pressurized lubricant to be supplied to the wire as it is reeled onto

the winch (Anon., 1981). The lubricator is a sealed chamber that clamps around the wire. It is capable of supplying grease at 87 psi while the cable is pulled through at the rate of approximately 25 meters per minute. A potential difficulty with this pressure-grease unit is that the 25 fathom marker wires might get hung up in the end seals. Not counting the compressor necessary for operation, the device costs on the order of $2,500.

C. Use of Anodes

Sacrificial metal anodes made of zinc, magnesium, or a special aluminum alloy, have often been used to control corrosion of underwater metal in piplines, boat hulls and underwater structures. The effect of the anodes and the conditions under which each is most efficient varies with a number of conditions (Mallon and Kolbe, 1979). Zinc is the most common material used in the construction of these anodes as indicated in the applications described below:

1. Anodes on wire rope

Lennox et al. (1973) studied corrosion results on a number of different wire rope samples. Different materials were placed under various conditions in seawater. Their tests on galvanized steel wire rope having both hemp core and independent wire rope core (IWRC) are most applicable to the present situation. Immersion of four foot samples in relatively warm (average 73^{o}F) seawater indicated that:

(a) galvanized coating from the fiber core samples was essentially gone within three months for those wire rope samples having no other cathodic protection;

(b) samples having a small (½" x 1½" x 6") zinc anode firmly attached were essentially uncorroded after two years of immersion;

(c) the IWRC sample having no attached zinc anode had also lost its galvanized coating within a period of less than 6 months.

Our experiments with the wire rope samples on the Miss Mary indicated similar results. That is, the galvanized wire rope sample attached to what was essentially a large zinc anode (zinc-plated trawl door attached to the end) was also "essentially uncorroded" after more than a year in service. (Note, however, that the Miss Mary tests did not use continuously immersed samples.)

Thus direct attachment of zinc anodes at strategic locations along the length of an immersed wire rope (such as a towing cable) would appear to have merits for extending the galvanized coating, and thus life, of the wire rope. This is a scheme frequently employed in underground pipelines for long-term cathodic protection of metal pipe. Drisko (1969) and Waldron and Peterson (1965) report application of this concept to the anticipated five-year protection of a mooring chain and underwater wire rope mooring cable, respectively. Drisko's concept was to cast zinc around selected chain links in the mooring system (Drisko, et al., 1972), a design that successfully achieved the goal. Waldron and Peterson used a theoretical prediction to locate magnesium anodes at strategic junctions along the underwater cable mooring system (Peterson, 1962). Results, again, were fairly successful, as described by Wood (1971). Dardell (1981) developed a model with which to place zinc anodes for effective cathodic protection, based upon laboratory tests and the above reported research.

One difficulty with the use of anodes directly on hemp core wire rope, is that it leads to what has been described as "overprotection" (Mallon and Kolbe, 1979). An excess of hydroxide ions (OH^-) forms at the cathode areas which include the areas around inner wire layers. These combine with sodium ions in the seawater to form sodium hydroxide, an alkaline substance which tends to deteriorate the hemp core. This over-protection has been described by Wood (1971) and Lennox, et al. (1973). The latter investigators reported that for those hemp core wire rope samples that had been protected by attachment of a zinc anode for a period of 790 days in warm seawater, the hemp fiber core was easily broken by hand. Unprotected hemp core samples immersed for the same period of time had cores that could not be broken by hand (although the wire rope was very severely corroded and broken). It would appear that the polypropylene or nylon fiber core used in some of the newer wire rope available to the fishing industry would solve this apparent problem.

Several possibilities exist for the application of zinc anodes directly to the galvanized wire rope for the purpose of prolonging its life (assuming that overprotection problems experienced with hemp cores could be overcome.) This section discusses some of these possibilities and leaves for a later section, specific design recommendations for wire rope systems on fishing vessels.

(a) Direct application of anodes to wire rope.

"Crab pot zincs" are zinc anodes having dimensions approximately 1" x 1" x 8"; they are cast onto stiff wire that can be easily fastened to an underwater trap or pot. As indicated by a representative of Federated Metals Division, a major manufacturer of zinc anodes, similar anodes could be easily cast onto a more flexible wire rope strand (personal communication, Leonard Fortun). These strands then could be interwoven among the main strands in the towing warp allowing a long narrow zinc anode to be attached parallel to the main towing warp. It would have to be tight enough to prevent its hanging up and ripping out on adjacent obstructions; loose enough to allow it to ride over a towing block as it is pulled aboard.

A series of these anodes (distributed perhaps every 50 fathoms) along the main towing warp presents a few problems. Among these:

- Risk of hang-up, crushing, distortion, destruction on the main towing block or on various snatch block and level-winds along the way;
- Problems with even-spooling or bending on the winch. This might necessitate fixing anodes only on that lower wire portion (the lower 50 feet or so) that do not get wound on the winch;
- Distortion of the wire while inserting anode strands. This could create an area of potential weakness due

to broken or nicked wires, scraped-off galvanized coating or locally stress-hardened material. A similar situation is said to occur at those locations where 25 fathom marker wires are inserted in the same manner. When a wire fails it is often at one of these points (personal communication, Gordon White).

(b) Door-mounted anodes.

One way to avoid some of the difficulties posed by the previous option, would be to mount an anode to the bail. Then secure a copper wire between anode and eye splice to insure adequate electrical connection to the wire. Adequate electrical contact would only be assured however if the copper wire terminals were adequately sealed, a difficult measure in the expected environment.

(c) Zinc link.

A fairly good connection of zinc anodes of any desired size could be attached at the warp termination by mounting zinc anodes to a steel link inserted between the warp and trawl door.* This is only an option for those vessels having a gantry-mounted towing block. For these designs, the door does not pull up tightly against the towing block, a condition common to most of the smaller draggers.

We designed some zinc links (Figure 4) sized to accomodate one or two 11-pound anodes, and also sized to match or exceed

*This suggestion was originally made by Leo Kuntz, Garibaldi, Oregon.

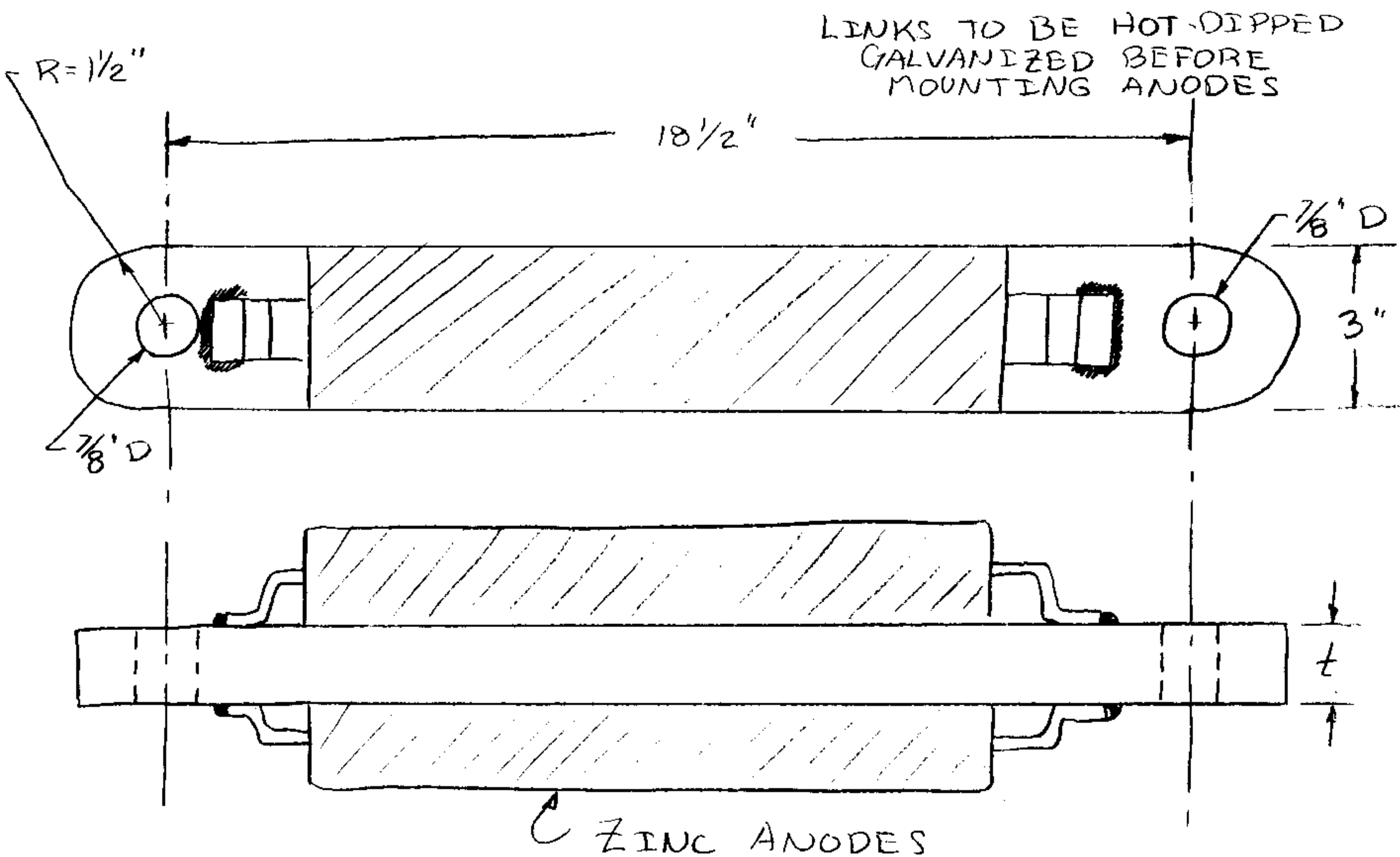


FIGURE 4

ZINC LINK FOR DOOR/WARP CONNECTION

the breaking strength of the towing warp. The variation of plate thickness with rope diameter and calculated tensile strength appear below:

Rope Diameter	Rope Breaking Strength (Table 2)	Plate Thickness, t	Calculated Maximum Link Tensile Force*
1/2 in.	19,200 lbs.	5/8 in.	19,900 lbs.
9/16	24,200	3/4	23,800
5/8	30,000	1	31,800

*Assumes metal yield stress of 60,000 psi.

A set of links, one galvanized and fixed with two 11-pound zinc anodes were given to a fisherman having a vessel with gantry-mounted towing blocks and relatively new wire rope. Unfortunately, the links were never used (for reasons unknown), so no experience with these devices had been collected.

(d) Yellow Pennant wire rope.

A commercially available "anode protected" wire rope is manufactured by Dawson and Usher Ltd., Hendon Rope Works, Sunderland SR1 2N3, England. Named "Yellow Pennant rope," the product has a single zinc wire running through each strand. The uncoated outer wires are said to last longer than galvanized rope because zinc protection cannot be rubbed off, as in conventional ropes. It is available in common diameters and construction (6x7 and 6x19). Its price reported by manufacturer and past and present distributors, has varied appreciably.

One known U.S. distributor is West Coast Wire Rope of Seattle. Little documented experience has been gained in this country. One east coast user operating in cold water has indicated very satisfactory service. Reported hesitations about use in warm water (Gulf of Mexico, for example) where corrosion rates are high, concern a rapid disappearance of the zinc wire causing possible collapse of the strand. More information and evidence are needed.

2. Anodes on Doors

The application of zinc anodes to the steel trawl door with the intent to protect the attached wire rope, is a different problem than the application of zinc anodes to effect cathodic protection of the door itself. In the latter case one would apply sufficient zinc to lower the polarized voltage from a nominal value of -.6 (the voltage of carbon steel relative to Ag-AgCl reference cell) to a voltage of -.85, considered an adequate voltage to protect steel (Mallon and Kolbe, 1979).

The free corroding voltage of zinc is -1.105. Thus even a well-protected door would be approximately 0.20 volts different from the initially well-galvanized wire rope directly attached.*

It appears then, that cathodic protection of the door must be somewhat in excess of usual cathodic protection measure to lend any protection of wire rope galvanizing. Figure 5 displays a somewhat qualitative picture of the assumed voltage distribution resulting from the cathodic protection scheme used with the <u>Oleta</u>

*Although cathodic protection of the door itself is not a major goal in this wire rope problem, it would be worthwhile in its own right.

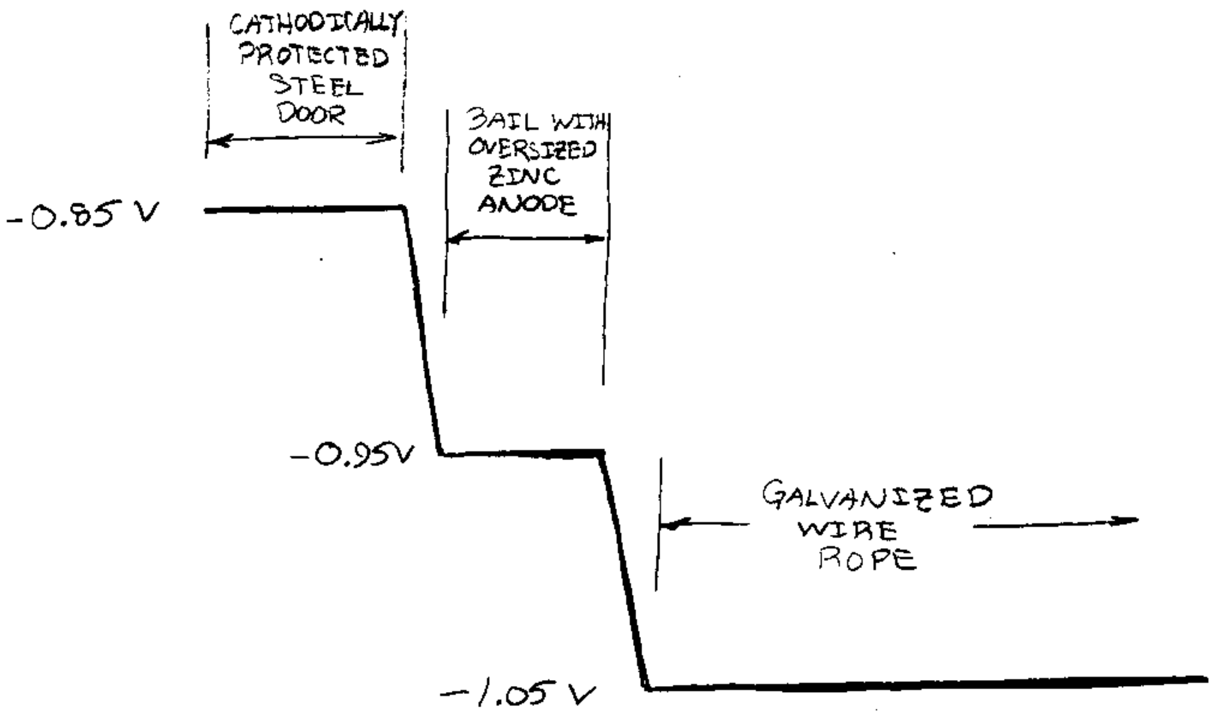


FIGURE 5

PERCEIVED VOLTAGE DISTRIBUTION AT TRAWL DOOR PROTECTED WITH ANODES

(VOLTAGE REF. TO Ag-AgCl CELL)

door. This assumes that the 22 pound zinc welded to the painted surface of the door kept door voltage at around -.85 volts and that the 11-pound zinc welded to the bail "overprotected," holding it at some value on the order of -.95 volts. The galvanized wire rope starting out with total galvanized coating would be at a value of -1.05 volts as observed with the new wire rope samples shown in Figure 2. The voltage drops pictured in Figure 5 represent the electrical resistances of the bail hinge and the (effective) point contact of the wire eye shackle fastened to the bail.

Figure 5 indicates that the situation could be improved by two schemes:

(a) break the connection between wire rope and bail, preventing any corroding current to flow between wire and door. This would be accomplished by use of insulators, discussed in a following section.

(b) Lower the voltage of the bail to approach that of the galvanized wire rope, thus lowering the voltage drop and flow of corroding current. This could be done by increasing the area ratio of the zinc anode to bare metal, either by increasing the size of the zinc anode, or coating the bail with zinc in a hot-dipped galvanized process. The latter would seem to be the better alternative.

The sizing of anodes to accomplish at least partial protection of wire rope according to the perceived voltage distribution shown in Figure 5, can be done following procedures described in Mallon and Kolbe (1979) and in SNAME (1976). According to calculations given in Appendix 2, one 22-pound zinc mounted on a 5x7 steel Vee door would effect a protecting voltage of -.85 volts. This assumes the door to have some coating of heavy paint. It is then suggested that an 11-pound zinc be welded to a hot-dipped galvanized bale.

Some have expressed concern that the 11-pound zinc mounted to the bail would somehow disturb the hydrodynamic performance of the door or its stability upon setting. In two instances where this was done, the fishermen reported no detrimental effects. Indeed an additional ten pounds (submerged weight) on top of the 60-pound (or so) weight of bail which is under a 5000-pound strain, would appear to have negligible effect, if any.

D. Coatings on Doors

The effect of a good coating is to seal the bare steel from seawater and to decrease the current density required to effect proper cathodic protection. The literature contains many examples of how coating types and quality affect required currents (Mallon and Kolbe, 1979). As paint or coating is scratched, worn, or chipped, the current density approaches that which would exist for a bare metal surface.

A good sealing coat would also help to decrease the door voltage toward the value of -1.05, the voltage of a completely galvanized wire rope (Figure 5) and this would conceivably increase the capability of the cathodically protected door to extend the life of galvanized wire.

This report does not go into details of paint systems and their relative merits. Any competent shipyard which would have good contacts with paint manufacturers, can supply information on available products and experience in their application.

Our at-sea experiments required coating of doors. The door tested on the Trego presents the best example of coating experience. The door was taken to Newport Shipbuilding (Newport, Oregon) to be sandblasted. It was then coated with an epoxy primer and a top coat of "coal tar epoxy" antifouling (as used on many boat hulls). They then welded two zinc anodes (a 22-pound anode and an eleven-pound anode) to the door surface and bail, respectively. The total bill for materials and labor for one door (February, 1980) was $248.00.

E. Insulators

Galvanic corrosion is due to the flow of current between two dissimilar metals. Cathodic protection of the wire could be established by preventing the flow of galvanic current between the wire rope and the door.

Unfortunately the use of an electric insulator generally implies a non-metallic material having properties of strength and ruggedness that are much less than what would be required under such circumstances. In addition, conventional trawler configurations have the trawl door pulled up tightly against the towing block, ruling out the use of most insulators one might devise.

During the course of our study, we came up with two options of potential use (but so far untried) on those trawler configurations where an overhead gantry suspends the towing block at least three feet above the door. One was constructed and is presently on hand; unfortunately we did not secure an opportunity to use this insulator in an at-sea test situation.

The two insulator options studied are the following:

1. Ceramic power company insulators:

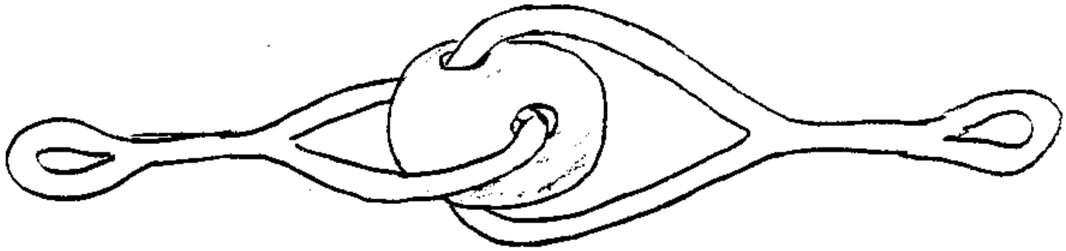
The electric utility companies have in the past used ceramic insulators for guy wires and stays to support power poles. These insulators, shown schematically in Figure 6a, have perpendicular holes so that in the event the insulator was to fail, the eyes would still be attached, preventing failure of the overall wire assembly.

Failure of the ceramic insulator in static stress might occur by crushing, although failure aboard a trawler would just as likely occur by impact of the device against the hull or door. The rated static strength of these different sized ceramic insulators donated by Central Lincoln PUD are as follows:

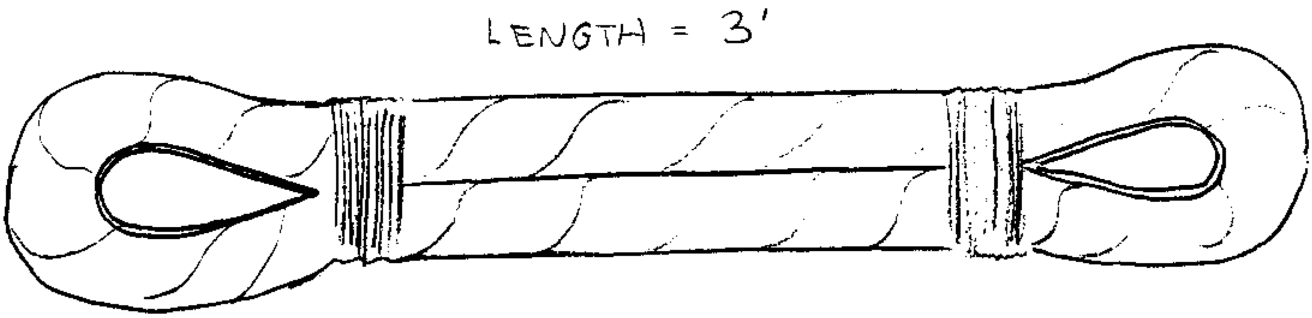
Hole Diameter	Ultimate Strength
5/8"	10,000 pounds
7/8"	12,000 pounds
1"	20,000 pounds

(Reference: Ohio Brass, 800 Northern Life Tower, Seattle, Washington 98101).

We did not have the occasion or opportunity to devise a rig suitable for use on a trawler or to run any independent breaking tests on these insulators. One could conceivably make up an assembly similar to that shown in Figure 6a having a total length of about three feet, and protect the insulator from impact using a PVC pipe section possibly filled with some kind of flexible foam to hold everything in place.



(a) CERAMIC TYPE
USED BY POWER COMPANIES



(b) SPLICED POLY-DACRON ROPE
LINK . CONTINUOUS LOOP OF
1¼" DIA. ROPE

FIGURE 6

WIRE ROPE INSULATORS

2. Rope sling insulator

The second insulator option was a rope link or sling made of synthetic rope comparable in strength to the weakest wire rope component in the system. It was felt that a short link would be better than a long stretch of rope because of elongation characteristics different from those of wire rope, and because of abrasion of the synthetic rope pulled over towing blocks.

With the hope of having an opportunity to install a rope insulator on an available West Coast dragger, we had a link constructed similar to the diagram shown in Figure 6b. The link was constructed in the form of an "endless sling" by the Pope Rigging Loft Inc. in Portland. The 1¼-inch Polydacron rope ("polypropylene interior; dacron exterior") has a rated breaking strength of 21,000 pounds. Because the sling or link is in a double rope form, the rated breaking strength of the link should be something on the order of 42,000 pounds, less perhaps 10 to 20 percent due to splice efficiency and small bending radius at the end (Haas, 1969). Although this represents approximately twice the breaking strength of the expected wire rope used in the same system, the "working loads" come out about the same because of the recommended safety factor for synthetic rope of around 9 or 10 (Haas, 1969), compared to around 5 for wire rope.

After making up the link diagrammed in Figure 6b, the Pope Company tested the link under a load of 12,000 pounds. Cost (February 1980) of the link was $61.00; cost of the breaking test was $35.00.

Because of lack of opportunity we have not tested the link in service nor have we tested the electrical resistance of this link after having been soaked in seawater over a period of time. It is expected that the electrical resistance would be more than adequate to effect adequate protection of the wire rope attached.

IV. MEASURES TO REDUCE WEAR AND INCREASE PERFORMANCE

Section III presented several cathodic protection options that could be imposed on commonly used wire rope to extend its useful life.

There are other factors relating to the construction, application and handling that should be understood to:

- allow one to avoid those practices that would tend to decrease the strength or the life of the wire rope; and
- maximize the economic return of wire rope life; that is, obtain the best and longest service with the least cost.

A. Wire Construction and Materials

One wire rope manufacturer has stated that "The solution to longer rope life is to evaluate its destructive forces" (Broderick and Bascomb, 1980). From tests and interviews, it appears that the predominant destructive force in wire rope used aboard draggers is that of corrosion, aggravated by other factors that tend to increase its rate.

Many other factors of course contribute, including abrasion, tension, torsion, axial stress, bending stress, crushing, and others. Although these may not be major destructive forces, they are contributors and take on varying degrees of significance depending upon the specific application.

The literature contains a discussion of many options in construction and materials that tend to diminish the effect of the various factors. It is difficult to know how they impact trawling operation because few controlled tests have ever been made to compare one construction, say, to another. As stated previously, many fishermen use the significantly cheaper Korean-built wire which is available in some fairly standard constructions and materials. The value of relatively "exotic" (at least to the fishing industry) possibilities at what would be a higher cost might be questionable.

However it is worthwhile posing some questions concerning tradeoffs between various options. In some cases, a minor departure from the usual practice may well be worthwhile.

1. Construction

(a) 6x7 or 6x19, or other?

The latter number in these designations gives the approximate number of wires in each strand of a 6-strand wire rope. In general the greater the number of wires in the wire rope, the greater will be the flexibility and thus resistance to bending fatigue (USN, 1968; Broderick and Bascomb, 1980; van de Moortel, 1969).* However at the same time, the fewer number of wires for a given wire diameter and strength, the greater their size and thus the greater the resistance to abrasion. One can observe a dramatic difference in abrasion and fatigue resistance between two wires of seemingly minor difference. For example, British Ropes, Inc. (undated-a) gives data showing such a difference between a 6 x 25 and

*This statement assumes "equal lay" (vs. "cross lay"), a distinction raised by British Ropes (undated-a) literature. In equal lay, all wires in the strand have the same lay length, or cycles, producing linear contact between all wires. In cross lay, wires in successive layers have the same lay angle, causing successive layers of wires in the strand to make point contact. It is believed that cross lay is not common.

6 x 37 construction. For best precautions against corrosion, British Ropes (undated-a) recommends the simplest construction possible "commensurate with other requirements of the installation." This would give the largest wires, and the smallest exposed surface area of steel. If flexibility is still important, high numbers of wires and large diameters on the outer layers of each strand can be achieved with a variation of design as discussed in a later section.

How important is flexibility to application on draggers? In general it appears that the number of bending cycles (due to bending over towing blocks and drums) over the life of the wire rope used on draggers, is well below the number of cycles shown in the literature to be significant. How axial fatigue (due to load fluctuations about some mean under tow) relates to a need for flexibility is still an open question.

(b) IWRC (Independent Wire Rope Core) or Fiber Core?

Users and outfitters in the fishing industry have often mentioned that fiber core is necessary to retain lubrication and to offer some "give" necessary for the varying axial loads and "snap loads" experienced in fishing. On the other hand, the SFE literature (1973) recommends IWRC "whenever the rope is submitted to jerking work." It additionally recommends IWRC when the rope is to be wound several times around a drum and operates under "extreme stress." However, this same catalog recommends fiber core for "trawling ropes." Heller and Metcalf (1974) found that in their seawater axial fatigue tests, core material was in general a relatively unimportant influence. The most important factors were mean load and the load range. Figure 7 describes improved fatigue life resuting from use of IWRC in one rope construction (British Ropes, undated-a). Gibson et al. (1972) found IWRC better for rope under difficult conditions (low factor of safety and sheave diameter); but they found fiber core better when conditions were less severe. No performance differences were noted for various core materials.

It is generally felt that wire rope with IWRC has better crushing resistance (USN, 1968; British Ropes, undated-a). Also IWRC adds approximately 7.5% to the strength of the wire (Broderick and Bascomb, 1980). Sharp (1976) found that wire rope with IWRC tolerates bending around a small radius bollard or sheave better than does a rope with fiber core. In general, IWRC give better performance with low sheave/rope diameter ratios, high fleet angles to the winch, worn sheave profile. Lennox, et al. (1973) found that those galvanized wires having an independent wire rope core seemed to retain galvanizing and therefore last a bit longer in seawater immersion than did the fiber (hemp) core samples, although the reason for this was not entirely clear (both had the same zinc coating thickness). Assuming the possibility of having a regular lubrication program, and depending somewhat on the relative ease of making an eye splice with IWRC rope, consideration of an IWRC galvanized wire rope for fishing might be worthwhile depending on initial costs.

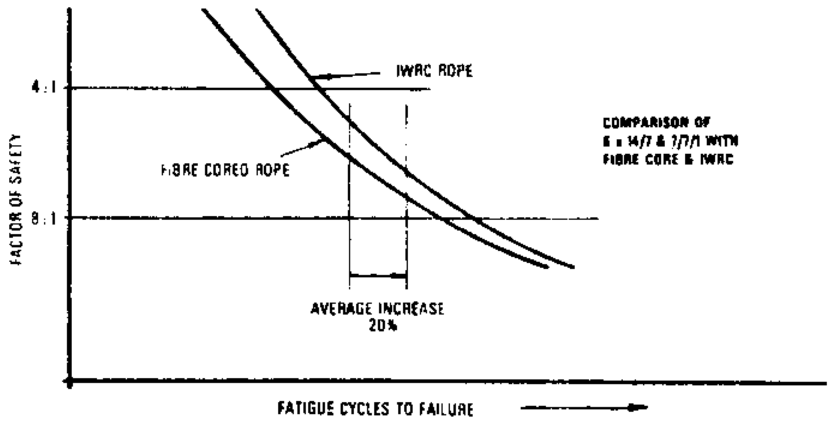


FIGURE 7

IMPROVED FATIGUE LIFE WITH IWRC CONSTRUCTION

(REF: BRITISH ROPES, UNDATED-a)

(c) Regular Lay or Lang Lay?

In regular lay the twisting direction of the wires in the strand is opposite that of the strand in the wire rope; in lang lay the direction of wire twists and strand twists are the same (Figure 8).* Most wires used in local industry are regular lay, identified by individual wires lying parallel to the axis of the wire rope.

Van de Moortel (1960) feels that lang lay comes out much better in fatigue tests but says that it is "limited in application" (although he does not elaborate). Figure 9 describes an improved fatigue life resulting from lang lay construction (British Ropes, undated-a). In their axial fatigue tests, Heller, et al. (1972) found that lang lay resisted axial fatigue better than did regular lay rope. Lang lay is felt to be better for abrasion resistance, because it has a larger length of exposed wires to take the abrasive load (USN, 1968; British Ropes, undated-a). Figure 10 further explains this phenomenon. Lang lay has better flexibility and resists bending fatigue better than ordinary lay (Broderick and Bascomb, 1980). But in certain applications, it does tend to "torque" or rotate (British Ropes, undated-a) and thus to kink and open up to expose inner wires to corrosion and dirt (USN, 1968). Regular lay is said to better resist crushing and distortion (Broderick and Bascomb, 1980).

Except for occasional crude tools used to effect level wind on winches and an occasional rubbing over stationery surfaces,

*Note that "right lay" and "left lay" are also options, the former being most common. These constructions occasionally influence best performance on winch winding direction (Universal, undated).

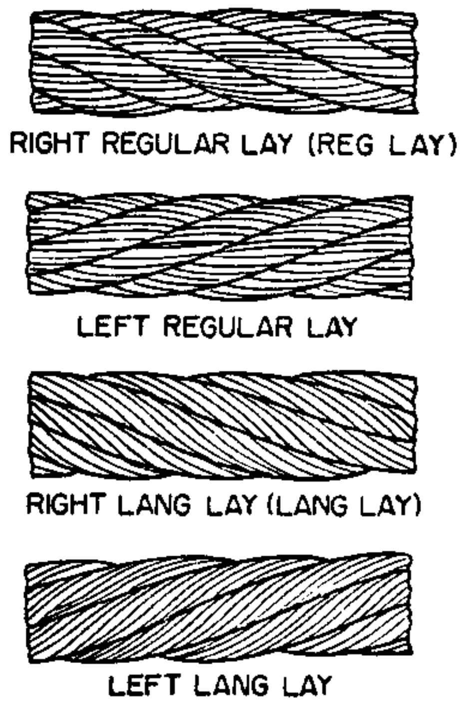


FIGURE 8

LAYS IN WIRE ROPE
(REF: US NAVY, 1968)

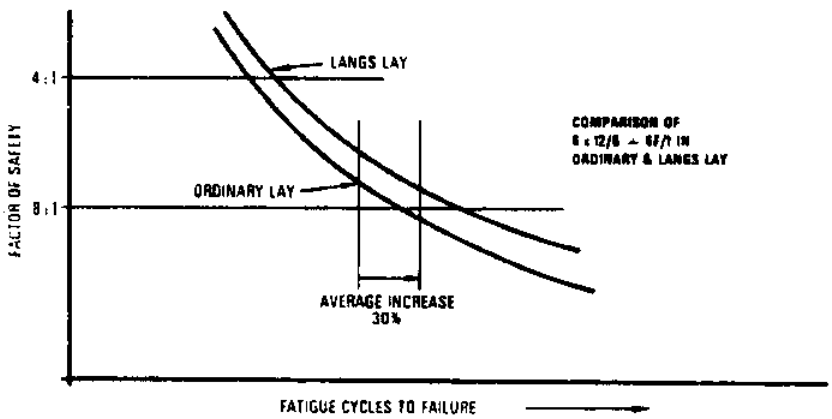


FIGURE 9

IMPROVED FATIGUE LIFE WITH LANG LAY CONSTRUCTION (REF: BRITISH ROPES, UNDATED - a)

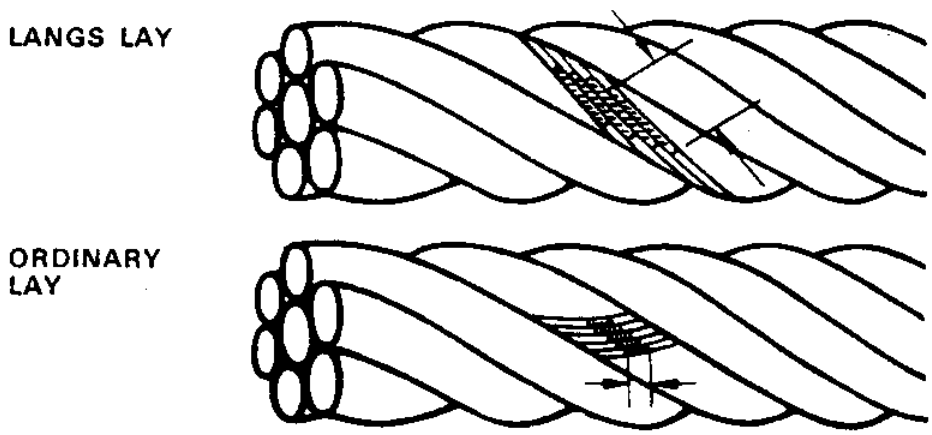


FIGURE 10

COMPARISON OF EXPOSED WIRE SURFACE IN LANG VS ORDINARY LAY CONSTRUCTION

(REF: BRITISH ROPES, UNDATED - a)

fishing rope does not generally encounter severe abrasive conditions and therefore may not benefit from any extra cost necessary to secure a lang lay construction.

Figure 11 summarizes relative fatigue life performance of lay and core construction (British Ropes, undated-a).

(d) Seale Construction?

Figure 12 represents simple construction of fiber core 6x7 and 6x19 wire rope where all wires in each strand are the same size. Note that all wire samples used in our at-sea tests were of 6x7 construction. It is also cheaper than 6x19.

As stated earlier the greater the number of wires in a given size rope, the greater its flexibility and resistance to bending and flexing fatigue. However the smaller outer wires are also more susceptible to breaking under abrasive conditions. For operations calling for wires having greater numbers (such as 6x19), a solution has been to modify construction by using the "Seale" construction pictured for 6x19 wire in Figure 13. And two further modifications are the "Warrington-Seale" (Figure 14) and the "filler wire" constructions (Figure 15), the latter having very small wires located in gaps between the major wires in each strand.

It has been generally stated (USN, 1968) that there is better fatigue resistance when the outer layer of wires is supported by smaller wires and especially when the lang lay is used. In addition, the greater wire diameter on the outside of each strand creates a better resistance to abrasion but decreases, somewhat, flexibility of the wire. Van de Moortel (1969) stated

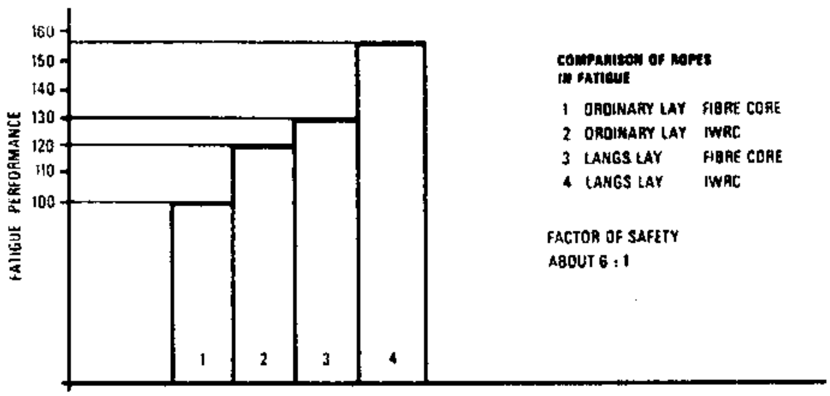
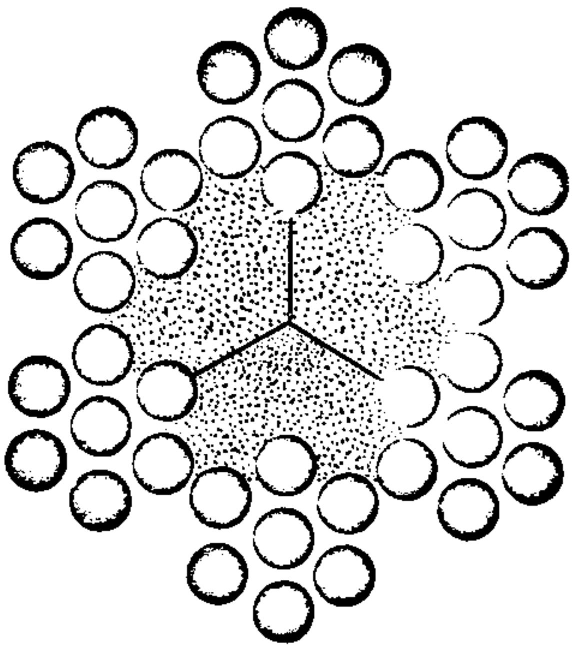


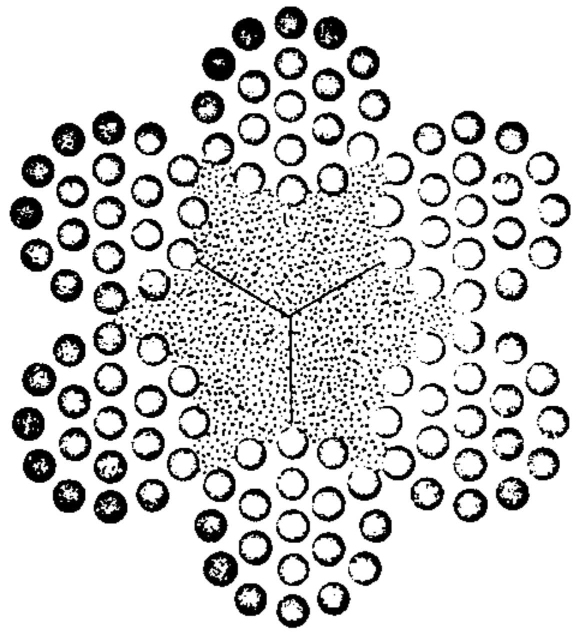
FIGURE 11

COMPARISON OF FATIGUE LIFE FOR ROPES OF VARIOUS LAY AND CORE CONSTRUCTION

(REF: BRITISH ROPES UNDATED - a)



CLASS 1
6 X 7



CLASS 2
6X19

FIGURE 12

TYPE I, GENERAL PURPOSE WIRE ROPE
(REF: US NAVY, 1968)

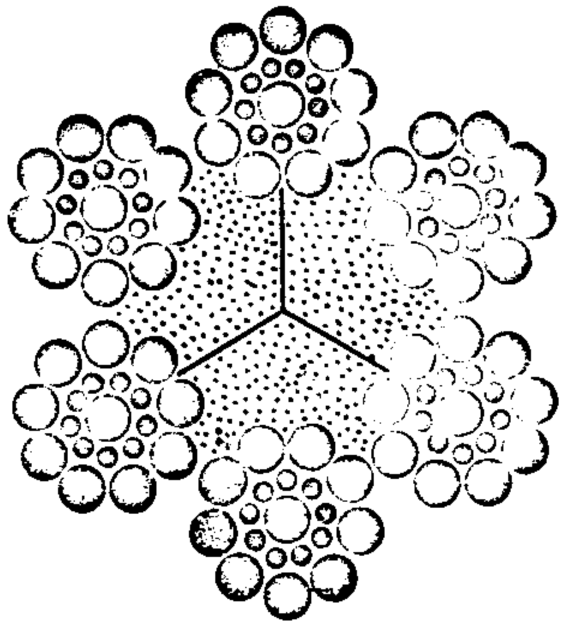


FIGURE 13

TYPE I, GENERAL PURPOSE, CLASS 2,
CONSTRUCTION 3, 6x19 (SEALE)

(REF: US NAVY, 1968)

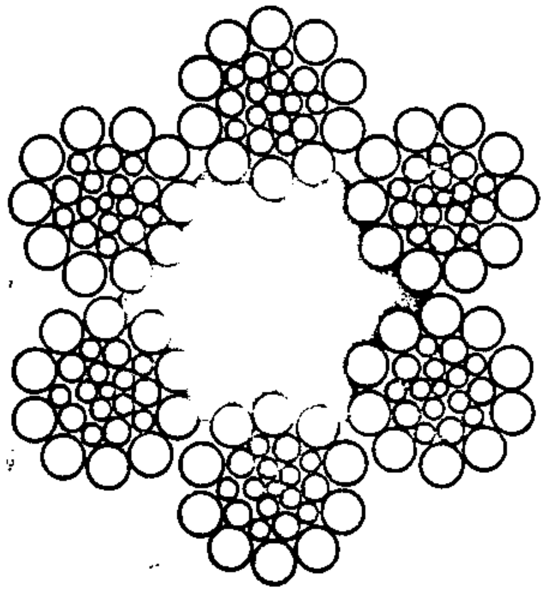


FIGURE 14

TYPE I, GENERAL PURPOSE, CLASS 2, CONSTRUCTION 5, 6X19 (WARRINGTON-SEALE)

(REF: US NAVY, 1968)

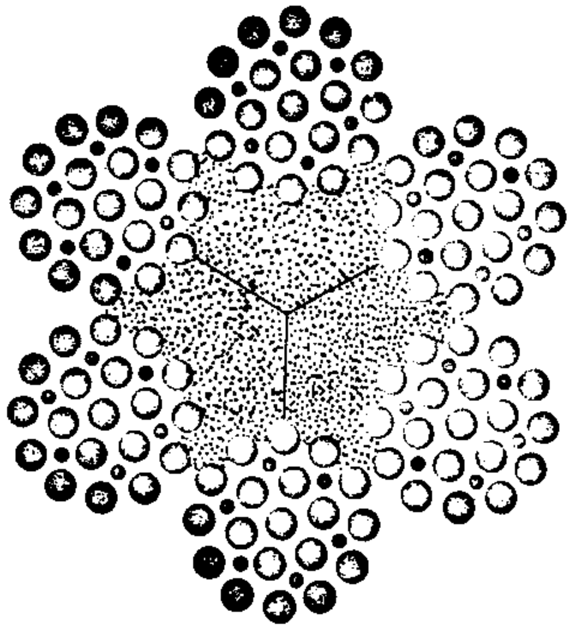


FIGURE 15

TYPE I, GENERAL PURPOSE, CLASS 2, CONSTRUCTION 4, 6X19 (FILLER WIRE)

(REF: US NAVY, 1968)

that the Seale-Warrington (a further minor modification to those mentioned) stood up much better to fatigue loading than did others even considering the design with filler wire.

Note that when one uses a criterion to discard rope (to be discussed in a later section) the number of broken wires, it is necessary to consider the particular construction of that wire rope. Obviously wire rope having the greatest wire diameter on the outside of the strand would be weakened more by a given number of broken outer wires than would a standard design with wires of smaller sizes.

(e) Flattened strand?

Figure 16 pictures a 6x27 flattened strand fiber core design similar to that produced by a number of manufacturers. It presents a much more spherical outer surface and therefore a much more even force distribution while riding around a sheave or bollard. Its design presents a more compact rope resulting in an approximate 10 percent increase in strength for the same outer diameter (Broderick and Bascomb, 1980). However its fatigue strength is quite a bit less than more standard constructions (British Ropes, undated-a).

2. Materials

Several variations of materials would allow perhaps a stronger wire, better corrosion resistance, and the ability to run a slightly smaller wire size for the same strength. Two examples are the following.

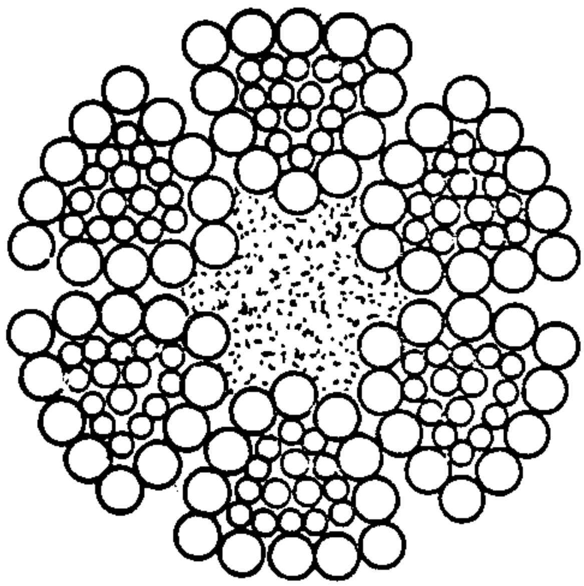


FIGURE 16

TYPE IV, MISCELLANEOUS, CLASS 3, FLATTENED STRAND, CONSTRUCTION 3, 6X27, STYLE H

(REF: US NAVY, 1968)

(a) Improved Plow Steel or Extra Improved Plow Steel?

Extra improved plow steel seems to add about 10 percent to the breaking strength (Table 2) but also adds approximately 10 percent to the cost (West Coast Wire Rope Company catalog data).

(b) Stainless Steel or Other Alloys?

Lennox, et al. (1973) tested a number of different alloy ropes and compared them with galvanized wire ropes. They found that aluminized steel, titanium and nickel-based alloys were quite good for more than two years of service in immersed seawater, even without cathodic protection. We've made no effort to determine cost of these wire rope alloys. Obviously the corrosion life and potential size reduction would be advantages. But in trawling, corrosion is not the only consideration. Hanging up of the gear could result in complete loss of even new wire, creating much greater financial risks. The economics and risk analysis has not been made and no further conclusions can be drawn.

B. Sheaves

Improper sizing, selection and maintenance of sheaves leads to shortened wire rope life. There are two areas of concern.

The first relates to undersized sheaves--a small diameter creates excessive bending forces, early fatigue and breaking of wires, leading to a shortened wire rope life. A following section will summarize and discuss some of the fatigue life results obtained in various experiments. It will also summarize recommended sheave diameters for various sizes and constructions of wire rope.

A second area of concern leading to wire rope wear and early failure relates to a profile of sheaves and condition of the surface. One handbook has stated that service life of wire rope can be reduced by 50 percent as a result of worn sheave surfaces (Universal, undated

1. Diameter Selection

(a) Some Background

Life of working rope is frequently described in terms of "fatigue life," which means life under conditions of fatigue. A shortened fatigue life is brought about by (among other things) continual bending stresses over sheaves, rollers or winch druns. In the case of trawling cables, these effects would be superimposed upon dynamic axial forces. Selection of adequate sheave and drum diameters can increase fatigue life.

Fatigue life results from a nonstatic force applied to a structural member, in this case a wire rope. The British Ropes Company has published a wire rope selection guide which describes this phenomenon quite well (British Ropes, undated-a). Fatigue loading or loading causing fatigue in wire rope can be diagrammed as shown in Figure 17. Fatigue is a condition where the material is no longer able to function. For most metals it results in fracture at a load considerably below the breaking load or strength of that material. In the case of wire rope, fracture of the entire structure does not occur simultaneously. Rather, individual wires will reach their fatigue limit and fail one by one, giving the operator sufficient warning that the life of the wire rope structure is being approached. The fatigue life will depend both upon the value of the average tension and the range between the minimum and maximum tension. As

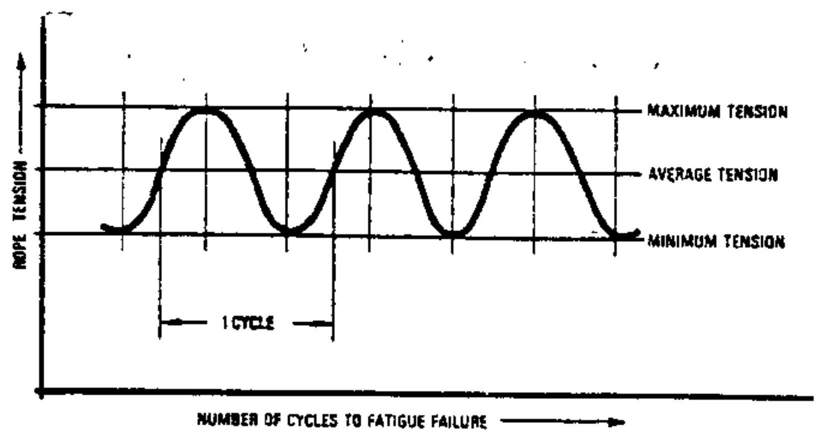


FIGURE 17

DESCRIPTION OF FATIGUE LOADING IN WIRE ROPE

(REF: BRITISH ROPES UNDATED - 9)

average tension and load range increase, the fatigue life will decrease. In general, the <u>range</u> has more of an effect upon wire rope fatigue life than does the average tension (British Ropes, undated-a).

Fatigue life is expressed as a function of the cycles-to-failure (or "number of cycles," or "number of bends to failure") and is characterized by a typical "S-N" curve on a semi-log plot shown in Figure 18. The ordinate might be "maximum stress," "yield" or "ultimate stress," or "factor of safety" representing applied force as a fraction of ultimate strength (Spotts, 1961; British Ropes, undated-a).

Drucker and Tachau (1945) devised a nondimensional parameter to be used in fatigue testing. It includes tensile strength of wires as well as both the rope and the sheave diameters and enables a plot of data from a number of different tests to fall within relatively narrow limits.

The parameter is $B = (2T)/(UDd)$, where

T = tension force in the wire rope (pounds)

U = ultimate tensile strength of wires (psi)

D = pitch diameter of sheave (inches)*

d = diameter of the wire rope (inches)

Figure 20 presents several curves derived by Drucker and Tachau for different wire constructions (Spotts, 1961). These curves are accurate only within specific ranges represented by the test data.

*Note that various data, experimental results, and recommendations are expressed in terms of either "pitch" or "tread" diameter of the sheave. The difference is noted in Figure 19.

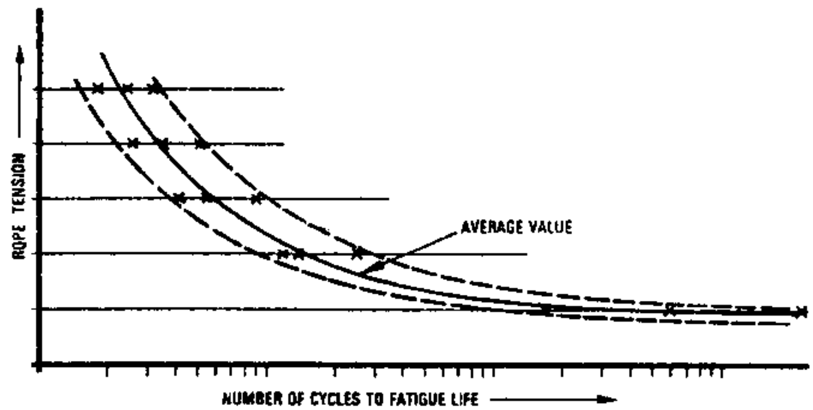


FIGURE 18

TYPICAL FATIGUE CURVE FOR ROPE SUBJECT TO VARIABLE TENSILE LOADING

(REF: BRITISH ROPES UNDATED-a)

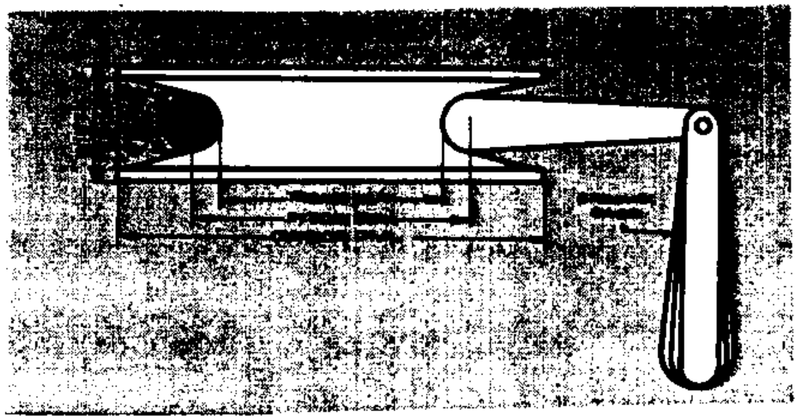


FIGURE 19

SHEAVE TERMINOLOGY
(REF: ROCHESTER, 1975)

As indicated by Figure 20 the number of bends to failure, at least in the case of pure bending stresses induced by travel of cable over a sheave, represents numbers on the order of 10^5 and 10^6. In a trawl warp situation, the number of cycles due to pure bending would generally not approach these numbers under ordinary conditions. For example, the following equation calculates the number of bends induced by towing blocks under some assumed conditions:

(3 yrs)(160 days/yr)(5 tows/day)(4 cycles/tow) = 9600.

Even if you count the winch drum as being one of the bends in the cycling, the number of pure bending cycles is far below that generally seen in common fatigue life diamgrams. However, if one further assumes that axial fatigue (that is unsteady tensile loads) common to net towing operations is superimposed on these pure bending cycles, the numbers of cycles would certainly approach those found on common fatigue life curves.

Gibson, et al. (1972) conducted a series of tests for the U.S. Navy to determine parameters affecting wear and fatigue of wire rope used in aircraft arresting cables aboard aircraft carriers. Figure 21 presents some of their data on a log-log plot. (They emphasize that these curves are applicable only within certain limits evaluated in the test program). Data indicated that because of new materials and methods of construction since 1945, their fatigue life curve was approximately 70 percent higher than that found by Drucker and Tachau.

Gibson, et al. (1972) also provided a better indication of how fatigue life varies with loads and sheave diameters, by expressing B in terms of these parameters:

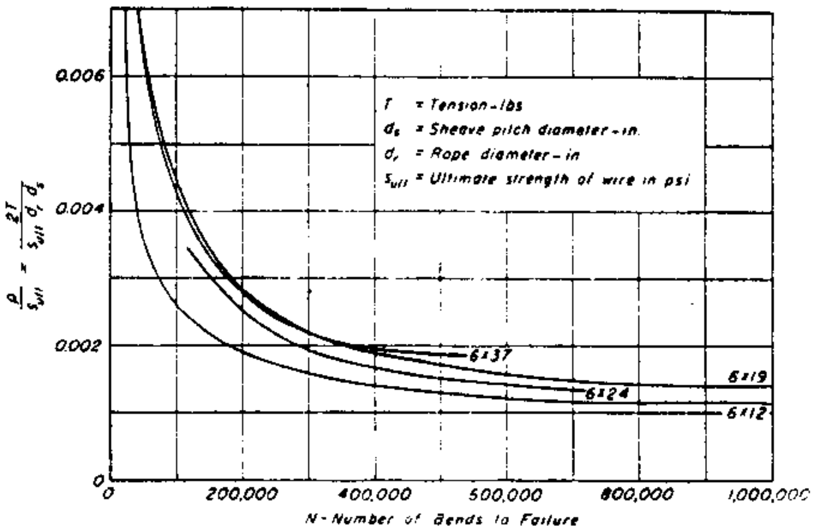


FIGURE 20

FATIGUE LIFE OF WIRE ROPE AS DETERMINED BY EXPERIMENTS

(REF: SPOTTS, 1961)

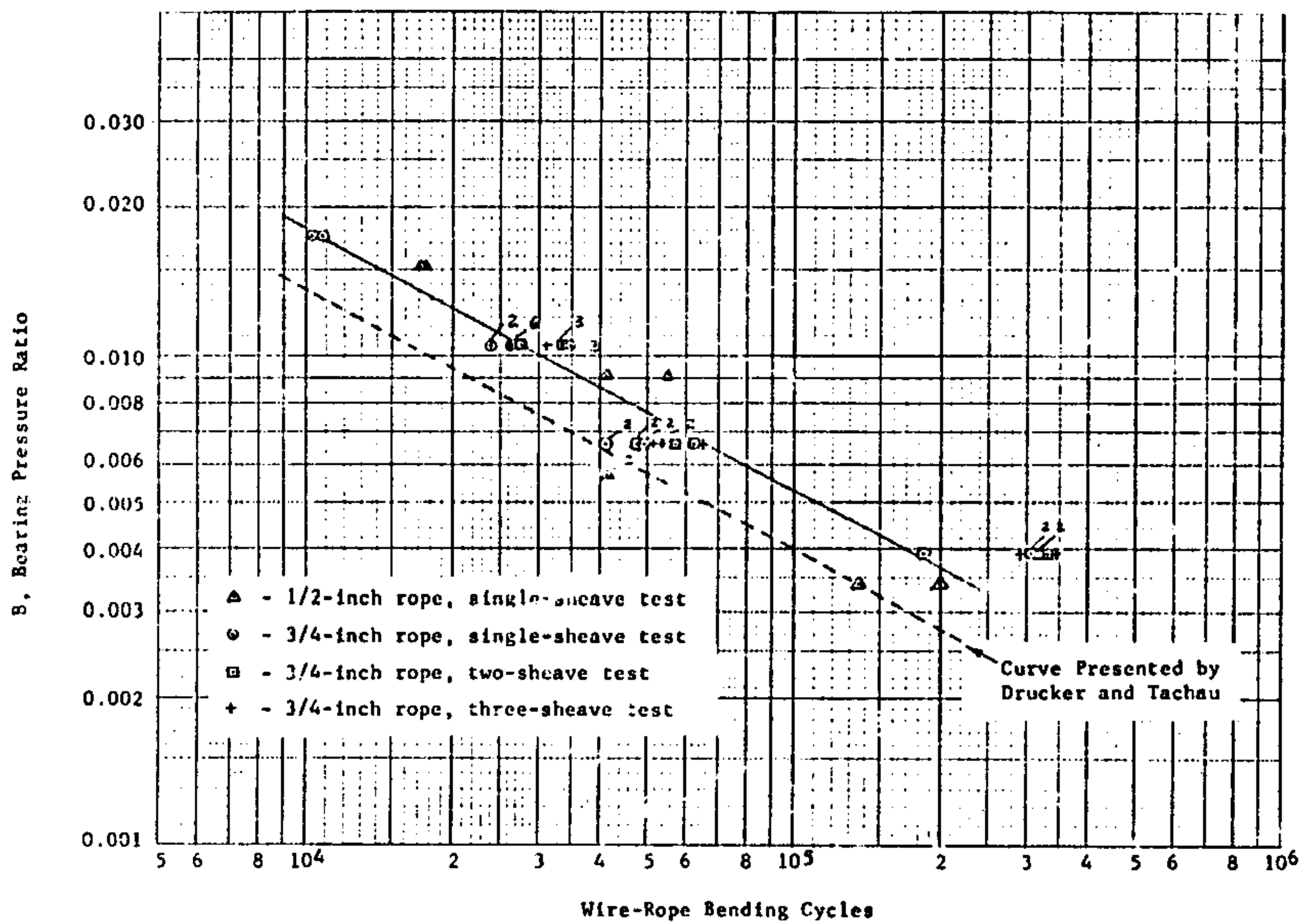


FIGURE 21 RESULTS OF SINGLE-SHEAVE AND MULTIPLE-SHEAVE FATIGUE LIFE TESTS OF 1/2-INCH AND 3/4-INCH IWRC WIRE ROPE. (REF: GIBSON ETAL, 1972)

$$B = \frac{K}{(FS)(D/d)}$$

where K = a constant. This form of the bearing pressure ratio B, when compared with the plot of results in Figure 21, shows directly how fatigue life increases with lower tension (higher factor of safety) and with a higher bending ratio D/d.

The British Ropes Co. (undated-a) explains in some detail why fatigue life reduces with the diameter of the sheave. Summarizing three reasons are:

- The smaller the sheave, the more acute is the bend and therefore the higher is the bending stress. Thus for a given constant tension, the total stress (tensile plus bending stress) is higher; as stated earlier, fatigue life reduces with higher tension and thus with lower diameter of sheave.
- Because bending stress is induced as the rope travels over the sheave and is removed when the rope leaves the sheave, bending stress is cyclical. The cycle increases in magnitude with a decrease in sheave diameter. As stated earlier, fatigue life reduces as the range of stress increases. Therefore the fatigue life reduces further with a decreasing diameter of sheave.
- A high pressure exists between rope and sheave surface. This is apparent by the rapid wear and indentation of sheaves on heavily worked machines.

As the sheave size reduces, this pressure increases; the additional stress on individual wires is added to the high bending and tensile stresses already in play. Thus fatigue life is even further reduced by a reduction in sheave diameter.

Note that the indicated effect of small sheave diameter is upon the rope life rather than on safety (British Ropes, undated-a). If one chose a sheave diameter that was "too small" for application to a new wire rope, the effect would be not to reduce the factor of safety, but to reduce the service life of that wire rope. This is true down to a bending ratio of around 5 (i.e., sheave pitch diameter is less than 5 times the rope diameter). At this limit, many rope constructions will risk kinking and thus ruining the rope. As a rough statement of effect: within limits of tests, rope life (fatigue life) varies as the square of the bending ratio $(D/d)^2$ (British Ropes, undated-a). This will be further examined in the following section.

(b) Bending Fatigue: Some Documented Experience

British Ropes (undated-a) have stated that fatigue life varies approximately as the square of the bending ratio. This substantial influence is pictured, particularly for the lower ratios, in Figure 22. Data of Gibson, et. al. (1972) were compared to handbook curves similar to that shown in Figure 22. In general, they found the least agreement under those test conditions that were least severe (high bending ratio of 25; high safety factor of 8), but better agreement under more severe conditions.

Wire rope handbooks also give comparative bending life of wire rope of different constructions. Table 8 is an example from the Rochester Wire Rope Company (1975).

Table 8. COMPARATIVE BENDING LIFE OF VARIOUS ROPE CONSTRUCTIONS BASED ON A VALUE OF 1.00 FOR 6x25 FILLER WIRE CONSTRUCTION

Rope Construction		Rope Construction	
6x7	.57	6x31	1.07
18x7 or 19x7	.67	6x36 Warrington-Seale	1.11
6x17 Seale	.73	8x19 Seale	1.14
6x19 Seale	.80	6x41 Filler Wire	1.22
6x21 Filler Wire	.87	8x19 Filler Wire	1.33
6x26 Warrington-Seale	.96	6x37 Two-Operation	1.33
6x25 Filler Wire	1.00	6x42 Tiller	2.00

Extremely high tensile loads appear to have a unique effect upon fatigue life. Gambrell (1969) conducted a series of tests, again for the U.S. Navy to learn about "purchase cables" used aboard aircraft carriers. He subjected them to extremely high tensions -- some in excess of 50 percent of breaking load (factors of safety slightly less than 2). This produced very high values of the Drucker parameter B. The results produced a break in the fatigue curves typified earlier in Figure 21. Gambrell's results, shown in Figure 23, give a drastic change in the slope caused apparently by plastic yield of individual wires riding on adjacent wires -- "wire nothching, and ductile type, cup-to-cone failures." As indicated in the figure, these altered fatigue characteristics would occur at a Drucker parameter B value greater than about 0.022.

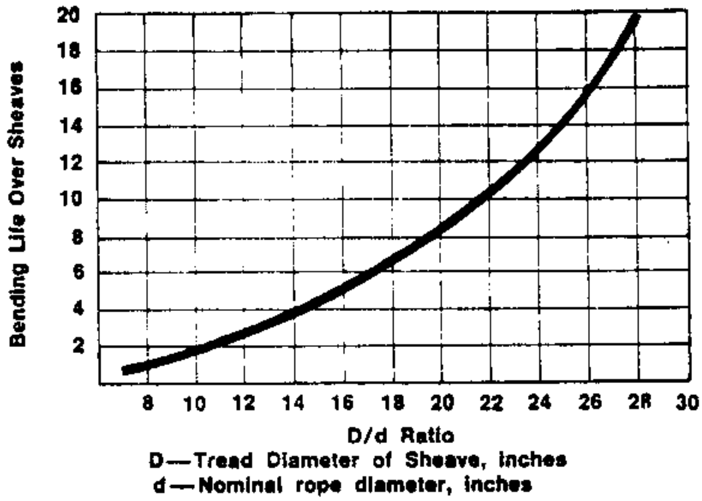


FIGURE 22

RELATIVE SERVICE LIFE OF ROPE RUNNING THROUGH SHEAVES UNDER 30 ROPE DIAMETERS

(REF: ROCHESTER, 1975)

Salt spray was found to influence fatigue life. Gardner (1971) looked at various wire rope materials stressed in fatigue under various atmospheric conditions, and concluded that the fatigue life of the galvanized wire rope samples in his tests was reduced by 61 percent as a result of service in a "salt fog" atmosphere.

The lap angle, or angle of sheave surface contacted by the wire rope, has less influence than one would generally assume. Bending stress on the wire rope is imposed as the wire begins to wrap around the sheave. Although it would seem that the lap (or wrap) angle would be significant, it turns out that one wrap angle is as severe as the next until the wrap angle decreases to a value of around 20 degrees (as reported by Drucker and Tachau (1945; TRC, 1974). In fact others have noted (Gibson, et al., 1972) that a wrap angle of 80 degrees is less severe than that of around 20 degrees which appears to be the worst case, as shown in Figure 24.

It should be pointed out that severe bending stress, as induced by undersized sheaves, has only a significant influence on wire rope life when <u>bending</u> is the significant mechanism of abuse (Rochester, 1975; British Ropes, undated-a). For those conditions where (for example) abrasion or corrosion are more significant wearing mechanisms, the bending fatigue life curves described in this section are less important.

(c) Recommended Sheave Diameters

Several wire rope handbooks give recommended minimum sheave diameters under various conditions of materials, construction and use. Table 9 is typical, taken from Universal Wire Rope Engineering

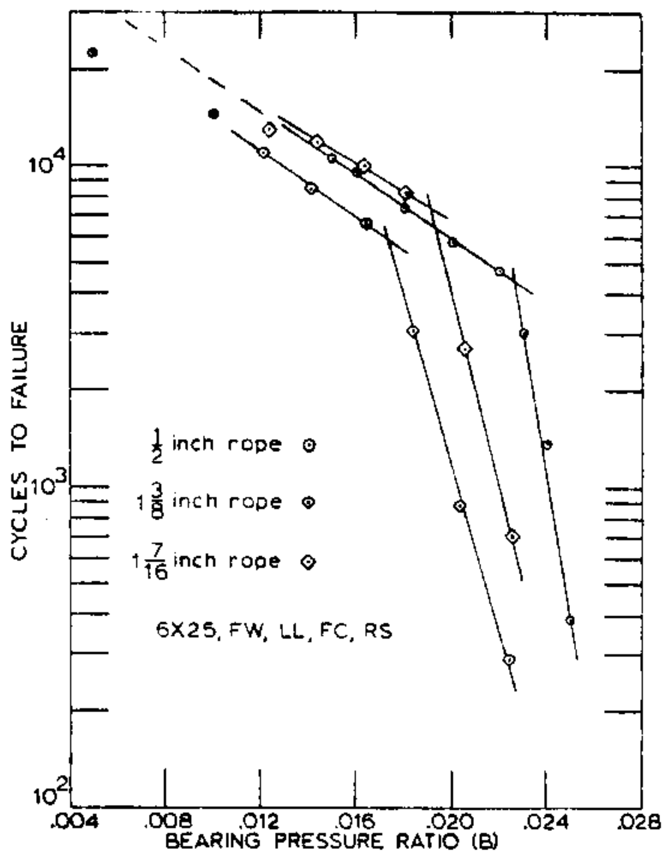


FIGURE 23

EFFECTS OF "B" VALUE ON FATIGUE LIFE -- MODEL AND PROTOTYPE

(REF: GAMBRELL, 1969)

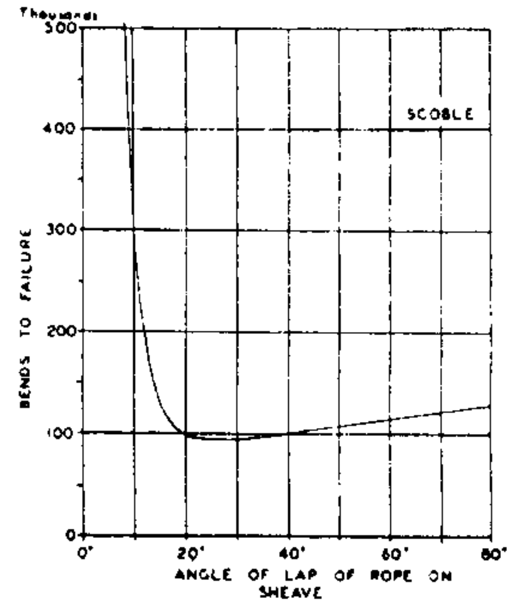


FIGURE 24

EFFECT OF ANGLE OF LAP ON FATIGUE LIFE
(REF: DRUCKER AND TACHAU, 1945)

Recommendations (undated). Other manufacturers (SFE, 1973; Broderick and Bascomb, 1976) include tables with very similar recommended values. However, one can find (Rochester, 1975; Broderick and Bascomb, 1980) other recommendations presumably for various operating conditions which are quite a bit more conservative, as shown in Table 10.

For flat roller diameters, Broderick and Bascomb (1980) recommend a dimension greater than 9 times the diameter of the wire. They state that roller diameters less than this desired minimum will cause detrimental vibration by following the contour of the rope.

2. Wheel Profile and Condition

The profile of the sheave must fit the radius of the wire rope that it is guiding. This means that it is important to avoid the flat wide surfaces found on many trawler towing blocks (personal communication, Dean McGuire). Vertical sides on sheaves are also discouraged (Universal, undated).

Recommended profile as well as a common tool used to measure that profile are pictured in Figure 19. There is a recommended groove diameter tolerance given in some handbooks. For example Universal (undated) gives a minimum of + 1/32" and a maximum of +1/16" for 3/8" - 3/4" diameter ropes.

Recommended support angle (not lap angle) of the rope is something on the order of 135 to 150 degrees of its circumference (Broderick and Bascomb, 1980) as shown in Figure 25. This results in a surface contact of around 42 percent of the rope circumference.

TABLE 9: Recommended Min. Tread Diameters*(in.) of Sheaves and Drums (Universal, undated)

Rope Diam.	6 x 7 (42d)	6 x 19 Seale (34d)	Flattened Strand and 6 x 19 Warrington(30d)	6 x 19 filler wire (26d)
7/16	18½	15	13-1/4	11-1/2
1/2	21	17	15	13
9/16	23½	19 - 1/4	17	14-3/4
5/8	26½	21½	18-3/4	16-1/4
3/4	31½	25½	22-1/2	19-1/2

* These values also given by SFE (1973) for Improved Plow Steel wire material

TABLE 10: MORE BENDING RATIOS (D/d) FOR WIRE ROPE

Wire Construction	Primary service is bending	Average installations where bending is not the only destructive mechanism
6 x 7	72	47
6 x 19 seale	51	34
6 x 19 Warrington seale	43	28
6 x 19 Filler wire	47	31

Rochester (1975)

Because of tremendous pressures and abrasion of rope on the sheave surface, the sheave and the rope begin to wear as demonstrated in Figure 26. As the rope wears and decreases in diameter the depth of the groove increases, with decreasing radius. When the rope is finally replaced with a new rope having a larger diameter, the worn sheave has a very adverse effect on the new wire resulting in a reported life reduction of something on the order of 50 percent (Universal, undated). Figure 27 shows a typical worn, scored, grooved sheave which should be discarded or repaired.

Although Drucker and Tachau (1945) stated that a soft sheave material was best for the longevity of the wire rope, Gambrell (1969) found that the opposite was true. When comparing various sheave alloy materials with a hardened tool steel sheave (both under very high stress conditions), a longer fatigue life resulted with a harder material as shown in Figure 28.

C. Winches

Wire rope manufacturers have made many recommendations related to winches, through handbooks and other literature. Winch design, spooling configuration, drum/groove layout and profile, etc. will not be covered in this discussion.

1. Drum Diameters

A small drum diameter having a severe (low) D/d (drum/rope diameter) ratio will have the same effect as small sheaves described in the previous section. Table 9 gives these minimum recommended diameters. Note that more restrictive diameters are given in Table 10. Generally speaking,

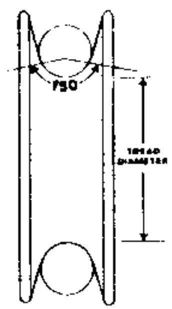


FIGURE 25

RECOMMENDED SUPPORT ANGLE OF WIRE ROPE IN SHEAVE

(REF: BRODERICK & BASCOM, 1980)

FIGURE 26

EFFECTS OF WORN SHEAVE ON NEW WIRE ROPE

(REF: ROCHESTER, 1975)

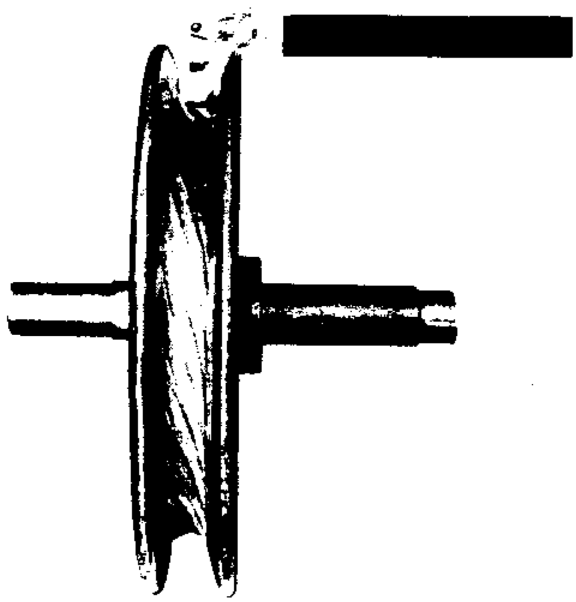


FIGURE 27

TYPICAL WORN, SCORED GROOVED SHEAVE

(REF: BRODERICK + BASCOM, 1976)

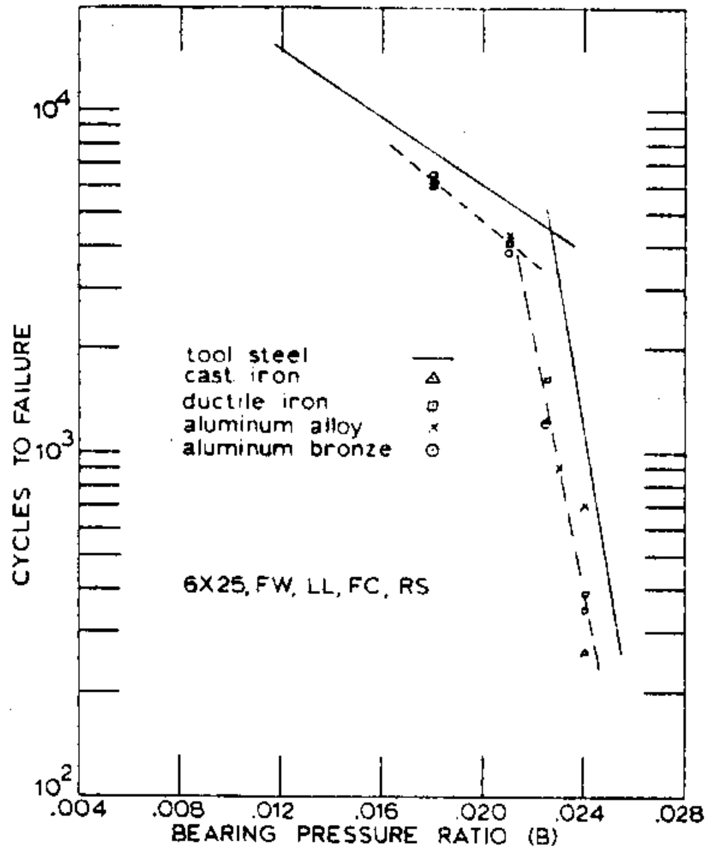


FIGURE 28

EFFECTS OF SHEAVE MATERIAL ON FATIGUE LIFE

(REF: GAMBRELL, 1969)

a bending ratio (D/d) of around 60 could be considered proper (Broderick and Bascomb, 1980). Note that a lesser diameter will not influence the safety factor, but rather the expected life of the wire rope, as explained previously.

Although not directly related to the subject at hand, the calculation of drum capacity is of frequent interest in wire rope system design. An equation taken from the SFE Rope Company literature (1973) is summarized in Appendix 3.

2. Fleet Angles

The fleet angle is the angle a spooling wire rope makes with an axis perpendicular to the winch drum axis, as shown in Figure 29. An excessive fleet angle will cause scrubbing of adjacent wraps causing wear and abrasion, adverse rotational characteristics or "torquing," and improper spooling. (Grubbing will also occur on the flanges of the winch.)

There exists both a maximum and a minimum recommended fleet angle, the usual limits being $1\frac{1}{2}^{\circ}$ and $\frac{1}{2}^{\circ}$, respectively, for smooth drums (Broderick and Bascomb, 1980). A larger maximum limit (2°) has been stated for grooved drums. The Broderick and Bascomb Handbook (1980) presents further details leading to recommendations for fleet angles actually less than the max $1\frac{1}{2}^{\circ}$ for specialized cases of large drum widths and for situations where wire is being pulled toward the adjacent wrap. In general they recommend that the total fleet angle be calculated to include the helix angle of the rope spooled on the drum as shown in Figure 30.

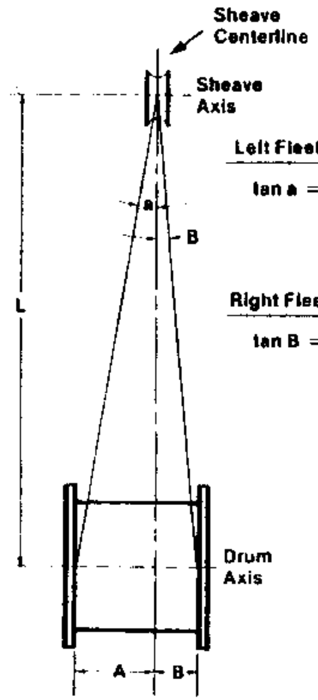
A "rule of thumb" for the distance from drum axis to the first fixed sheave, is to merely convert two times the total drum width in inches, to feet (Broderick and Bascomb, 1980). Another is that maximum fleet angle of $1\frac{1}{2}^{\circ}$ can be achieved if the lead sheave is located approximately 38 feet from the drum for each foot of drum width either side of the center line of the lead sheave (Figure 29). Thus, if the lead sheave is located opposite the center of a two foot wide drum (so that left and right fleet angles are equal), locating the sheave 38 feet away will achieve a maximum fleet angle of $1\frac{1}{2}^{\circ}$ (Broderick and Bascomb, 1976).

3. Levelwinds

The use of levelwinds can achieve proper spooling with fleet angles greater than those recommended and would in fact help regardless of fleet angle. Unfortunately, many of the levelwind devices on some of the smaller and older draggers consist of an iron pipe or bar used to manually direct the wire to the proper spooling location. Some of these bars have rotating outer pipes to minimize the scraping and abrasion as it pushes on the rope.

If one were to follow recommendations of wire rope manufacturers, flat rollers on manual or mechanically-driven levelwinds should have diameters of 8 or 9 times that of the wire rope (Broderick and Bascomb, 1976).

For single layers wound on smooth drums, there is a proper direction that will promote best spooling of the single layer.



Left Fleet Angle

$\tan a = \frac{A}{L}$

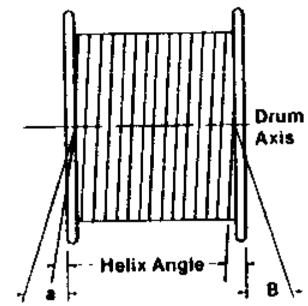
Right Fleet Angle

$\tan B = \frac{B}{L}$

L = distance drum axis to head sheave axis
A = distance sheave centerline on drum to left flange
B = distance sheave centerline on drum to right flange

FIGURE 29

DRUM FLEET ANGLE



Left total fleet angle

$\phi_L = a -$ helix angle

Right total fleet angle

$\phi_R = B +$ helix angle

where a = left fleet angle
B = right fleet angle

FIGURE 30

TOTAL DRUM FLEET ANGLE

(REF: BRODERICK & BASCOM, 1980)

It depends on the lay direction of the rope and is best described by Figure 31. For grooved drums and successive layers, these directions are not so important (Universal, undated).

D. Terminations

The type of termination used at the junction of rope with door can substantially affect the rated strength of the wire rope assembly. Efficiencies (a percentage of nominal rope strength) will vary with designs as shown in Table 11; the termination designs are pictured in Figure 32. Some additional comments related to terminal designs:

1. Splices

Spliced eyes are commonly used in the local fishing industry, often without thimbles. A long spliced eye can be readily made and is quite flexible, allowing it to be pulled through a towing block without damage. British practice reportedly is to splice eyes with the "Liverpool soft soft splice" (U.S. Navy, 1965; Skirving, 1974), although it is not known whether use of thimbles is common (personal communication, Jack Stewart).

Appendix 4 gives some references on wire rope splicing.

2. Swaged Fittings (called "mechanical splices" in Table 11)

Swaged fittings are applied with a mechanical or hydraulic press. One local rigger uses ESCO stainless steel swaged fittings which, he reports, develop a strength equal to 100 percent of that of the wire rope itself (data of Table 11 give values less than 100%).

Table 11. TERMINAL EFFICIENCIES BASED ON NOMINAL ROPE STRENGTHS AND STATIC LOADING

Method of Attachment	Approx. Efficiency IWRC Rope*	FC Rope**
Wire rope socket -- Zinc-Poured or Resin Poured	100%	100%
Swaged Socket (Regular Lay Ropes)	95 - 100%	(not established)
Mechanical Splices		
1" dia. and smaller	95%	92½%
1-1/8" dia. thru 1-7/8"	92½%	90%
2" and larger	90%	87½%
Hand-Tucked Splices		
¼"	90%	90%
5/16"	89%	89%
3/8"	88%	88%
7/16"	87%	87%
½"	86%	86%
5/8"	84%	84%
3/4"	82%	82%
7/8 thru 2½"	80%	80%
Wedge Sockets and Cappels (Depending on Design)	(Refer to Manufacturer) 75 - 90%	75 - 90%
Rope Clips***(U-Bolt or Fist Grip) (Number of clips varies with size of rope)	80%	80%

*IWRC = Independent Wire Rope Core

**FC = Fiber Core

***Typical Values when properly applied. Refer to Manufacturer for exact values.

Efficiencies of End Attachments. Not all end attachments develop the full strength of the wire rope. Through extensive testing, the Wire Rope Industry has determined the terminal efficiencies for the various types of end attachments.

Broderick and Bascomb (1980)

RIGHT LAY ROPE

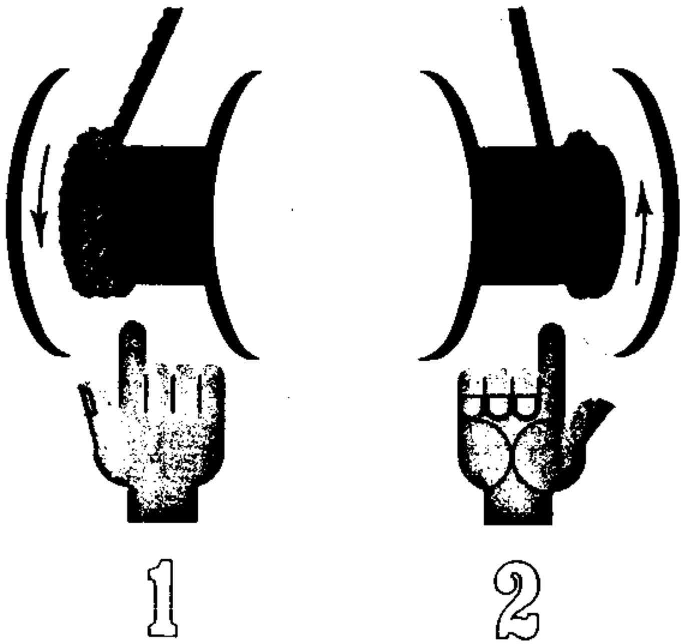


Figure 1

For overwinding, stand behind the drum extending right hand palm down with forefinger and thumb extended and the other fingers closed into a fist. The thumb points to the side at which the rope must be fastened.

Figure 2

For underwinding, stand behind drum extending right hand as in the figure. Thumb points to side where rope must be fastened.

LEFT LAY ROPE

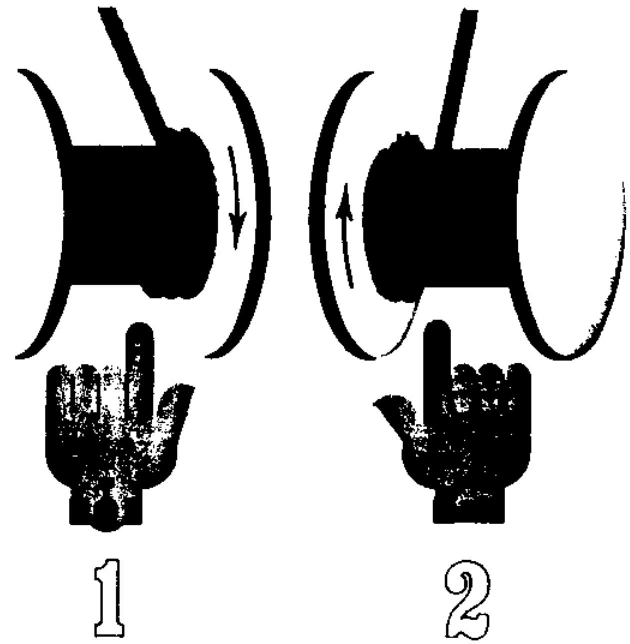


Figure 1

For overwinding, stand behind the drum extending left hand palm down with forefinger and thumb extended and the other fingers closed into a fist. The thumb points to the side at which the rope must be fastened.

Figure 2

For underwinding, stand behind drum extending left hand as in the figure. Thumb points to the side where rope must be fastened.

FIGURE 31 PROPER SPOOLING DIRECTION

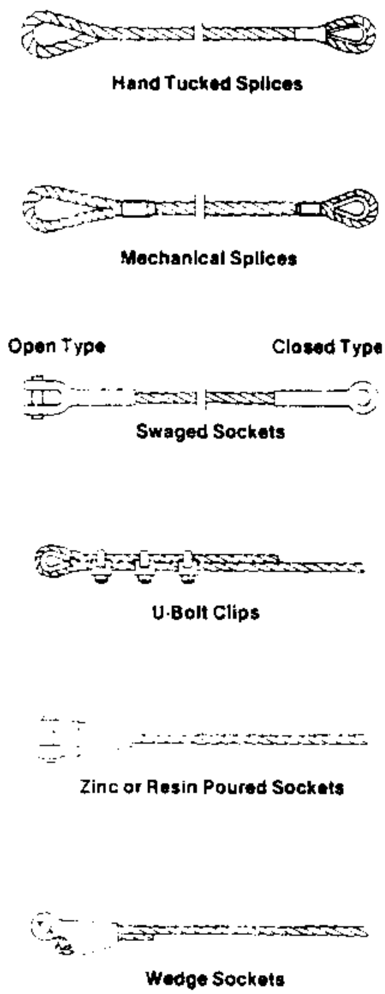


FIGURE 32

WIRE ROPE END ATTACHMENTS
(REF: BRODERICK + BASCOM, 1980)

Two cautions are given on eyes made with swaged fittings (personal communication, Dean McGuire):

- Galvanized wire presents a potential problem; corrosion of the galvanizing within the swaged fitting tends to loosen it;
- The swaged fitting adjacent to the eye creates a rigid section; pulling it over a sheave creates a severe localized bending stress which tends to both accelerate and concentrate breaks.

3. U-bolt Clips

These terminations are not recommended for operating ropes but should generally be only used for "field expediency" (Rochester, 1975). It is also doubtful whether they could be drawn over a towing block without some damage or loosening.

When they are used for standing rigging, or temporary or emergency installations, there are some very specific recommendations on application. Figure 33 shows the correct and incorrect method of application -- the base of the clip must be on the "live" or long end; the U-bolt bears against the "dead" or short end. It is generally recommended that distance between clips be equivalent to about 6 rope diameters. The numbers of clips, amount of "turn back" (length of the short end), and torque recommended for application of clips, are given in Table 12.

It is also (and obviously) recommended that, once the clips are applied, they be periodically inspected and retightened.

TABLE 12: APPLICATION OF U-BOLT CLIPS

Rope (Clip) size (in)	Min. No. of clips	Amount of Rope Turnback (in)	Torque (ft-lb)
3/8	2	6-1/2	45
7/16	2	7	65
1/2	3	11-1/2	65
9/16	3	12	95
5/8	3	12	95
3/4	4	18	130
7/8	4	19	225

(B & B 1980, Rochester 1975)

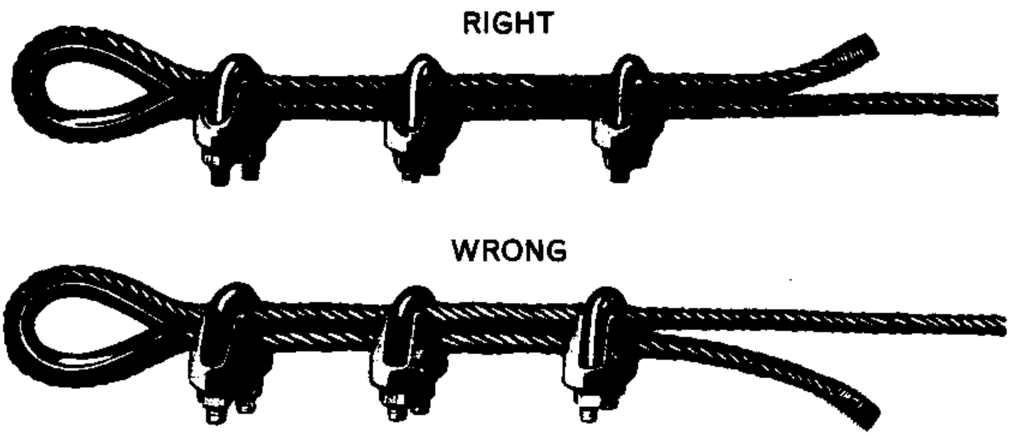


FIGURE 33

RIGHT AND WRONG WIRE ROPE
U-BOLT CLIP APPLICATION
(REF: SFE, 1973)

4. Zinc Poured Sockets

Application of this type of termination is detailed in several handbooks (for example Broderick and Bascomb, 1980). An alternative is a resin-poured socket. Because the rope does not turn a sharp corner at the eye, such a socket can develop 100 percent efficiency.

Two additional points should be made concerning application of wire rope terminals. The first relates to thimbles which, as stated previously, are frequently not used. One fisherman stated that they tended to crush under the loads imposed. It would also presumably be difficult to keep the thimble in the eye if a loose splice is used. However, it may be worthwhile to attempt to overcome these difficulties. The very severe bend taken by the wire at the connecting shackle causes a reduction in the strength of the wire rope as implied by Figure 34.*

The result of such severe bends can be observed on samples collected from our at-sea tests. The Miss Mary wire had thimbles in eyes made with swaged fittings. The Oleta used long spliced eyes with no thimbles and effect on the wire can be seen. Bend diameter with thimbles was something on the order of 5 times the wire rope diameter, a minimum as explained previously.

A second point relates to the rated strength of blocks, sheaves or otherhardware fastened to the wire rope assembly. Such hardware, particularly shackles, should be selected with the same

*Although it is not entirely clear, it would appear that the strength loss described by Figure 34 should be added to that given in Table 11.

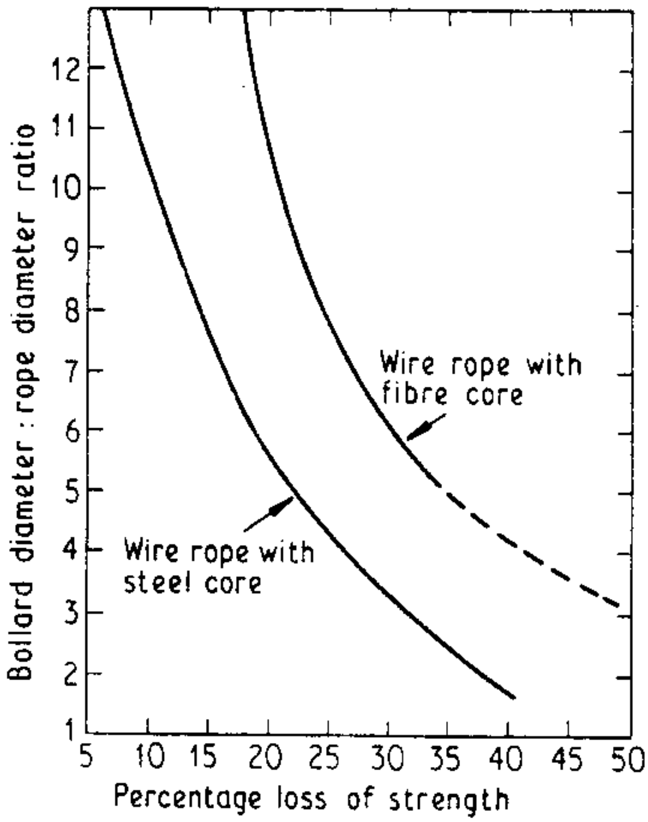


FIGURE 34

STRENGTH REDUCTION DUE TO SMALL BEND RADIUS

(REF: SHARP, 1976)

rated working load as the rope. Note that the rating for shackles is often stamped on the side, in tons. This working load assumes a safety factor of 5 or 6. If the shackle were rated at "WL2," the breaking load of that shackle would be on the order of 10 tons.

E. Use and Handling

This section describes a few points relevant to design, handling, and timely removal of the rope from service.

Most handbooks give general advice on rope handling -- how to undo a loop of wire rope, how to transfer rope from reel to drum, proper procedures for sizing and cutting (Broderick and Bascomb, 1976; Rochester, 1975; SFE, 1973; Universal, undated). These topics will not be repeated here. The Broderick and Bascomb Handbook (1980) also describes recommended inspection programs for wire rope in critical areas of service.

1. Safety Factors

Safety Factors, also known as "design factors" (Broderick and Bascomb, 1980) represent the ratio of ultimate wire rope strength to working load. Table 13 gives recommended minimum safety factors for various service. These can be seen to vary from 3 to 12.

For general wire rope use on fishing vessels, a safety factor of 5 is a commonly-used value (Broderick and Bascomb, 1976). Safety factors generally refer to a static design load. However note that as a rule-of-thumb used by one rigger's handbook, shock loads (as might be experienced on a crane lifting a sling) will double the stress on a sling (Broderick and Bascomb, 1976).

TABLE 13: Minimum Factors of Safety

Type of Service	FS	Type of Service			FS
		Hot ladle cranes			8
Track cables	3.2	Slings			8
Guys	3.5				
Mine shafts, 500-ft depth 1,000-2,000-ft depth 3,000 ft-depth and more	8 6 4	Elevators Carspeed, fpm	Pas-senger	Freight	Dumb-waiters
Miscellaneous hoisting equipment	5	50	7.50	6.67	5.33
Haulage ropes	6	150	8.20	7.32	5.98
Overhead and gantry cranes	6	300	9.17	8.20	6.88
Jib and pillar cranes	6	500	10.25	9.14	8.00
Derricks	6	800	11.25	10.02	
Small electric and air hoists	7	1,100	11.67	10.43	
		1,500	11.87	10.61	

(Ref: Spotts, 1961)

2. Rejection (Discard) Criteria

Several wire handbooks list recommended criteria for rejection of the rope, i.e., determination of when that rope is considered unsafe (based on a factor of safety around 5). Broderick and Bascomb (1976, 1980) give the following causes for discard of rope or removal of an end section:

- More than six randomly distributed broken wires in one rope lay (cycle) or three broken wires in one strand in one rope lay. Snagged, bent, or severely bent wires count as broken wires.
- Abrasion, scrubbing or peening causing loss of more than one-third the original diameter of outside individual wires.
- Evidence of rope deterioration from corrosion (a corroded wire will not withstand bending).
- Any evidence of heat damage such as caused by a welding arc.
- Any marked reduction in diameter either along the entire main length or in one section.
- Unlaying or opening up of a tucked splice.
- Core protrusion along the main length.
- Any indication of strand or wire slippage in end attachments.
- More than one broken wire in the vicinity of a zinced-on or swaged fitting.
- Strength loss of around 10 percent as indicated from non-destructive testing (electrical) methods.

The inspection of broken wires along the length of the wire rope can reveal major causes. The shape and nature of wire rope breaks are described and pictured in several handbooks including Broderick and Bascomb (1980), Rochester Wire Rope Company (1975) and the Ocean Engineering Handbook (Meals, 1969). Further notes on rejection criteria:

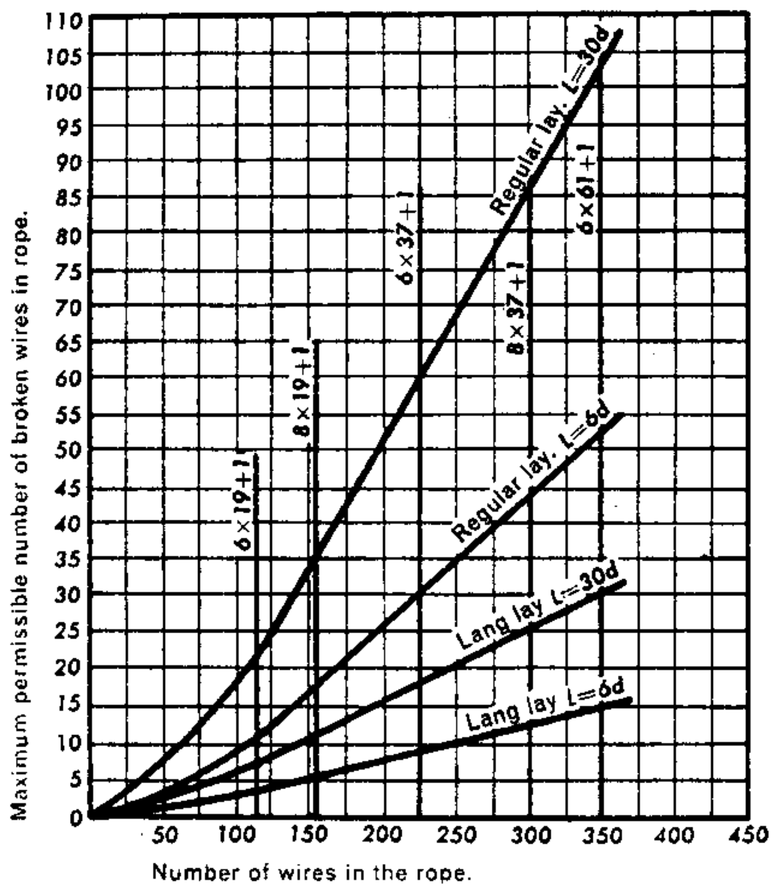
(a) Number of broken wires

The number of broken wires counted along the wire within a single lay is frequently given in wire rope handbooks as a major criterion for rejection. Examples are Table 14 and Figure 35. One handbook (Broderick and Bascomb, 1980) defines a "reserve strength" as that strength remaining after removal of all of the outer layer of wires. The reserve strength is given as a function of number of outside wires. Using this and counting broken or abraded wires, one can closely estimate the remaining strength at any time.

Note that the broken wire criterion does not account for accidental damage (such as kinks) or to potential internal weakness due to corrosion or internal wire breakage. This introduces the major concern with using number of broken wires as a replacement criterion. Gibson, et al. (1972) point out that this criterion is only good if bending-over-sheaves is the primary source of degradation. As stated by Gibson, et al.:

> "The reader is cautioned to note that...the use of observable broken wires as an indication of rope condition apply only to ropes which have bending-over-sheaves as the primary source of degradation. Other types of service resulting primarily in corrosion, fluctuating tension loads or lateral vibration (such as certain mooring lines, towing lines, and standing rigging) can result in wire breakage inside the rope, usually at points of interstrand wire notching. For these cases, many broken wires may accumulate and the remaining strength of the rope may be significantly reduced before a rope degradation can be noted by visual examination."

As referred in the figure ropes should be taken out of service when the most worn out part of them contains the maximum permissible broken wires.



Two different test lengths are examined, one of six and the other of thirty times the rope diameter; if either of them contains the number of broken wires indicated in the chart, the rope should be replaced.

FIGURE 35

REJECTION CRITERIA FOR WIRE ROPE

(REF: SFE, 1973)

TABLE 14: Replacement Guide for Wire Rope

Nominal rope diam., in.	Replace Rope When		
	Actual Diam. in.	No. of Broken wires	
		6 x 19 class	6 x 37 class
3/8	21/64	18	24
1/2	7/16	15	20
5/8	9/16	11	15
3/4	21/32	11	15
7/8	25/32	8	12
1	7/8	8	12
1-1/4	1- 1/8	7	10
1-1/2	1-11/32	6	8

(Ref: Meals, 1969)

(b) Stretch

Wire rope undergoes essentially three stages of stretch as shown in Figure 36:

- Initial, permanent, "constructional stretch." This results from initial stressing of the new wire rope, settling of the strands, and compression of the core. This stretch amounts to around 1/4 to 1/2 percent in a six strand IWRC rope; 3/4 to 1 percent in a six strand fiber core rope (Broderick and Bascomb, 1980).*
- Service stretch. This stretch varies from 0 (as shown in Figure 36) to a small amount of stretch over time due to the aging and wear of the wire.
- Final stretch. This is a rapid deterioration due to wear and fatigue of the wire as it nears ultimate failure.

Superimposed upon the service stretch is an elastic stretch, a phenomenon obeying Hooke's Law. It is a nonpermanent stretch, returning to original length once the stress is removed. The elastic stretch limit (that is, the yield strength) represents something on the order of 55 to 65 percent of the normal strength (that is, the ultimate strength) of bright wire. The equation describing elastic stretch and data on elastic modulus and cross-

*Some new wire rope is sold as "prestretched" (Broderick and Bascomb, 1980) which means that it is preloaded to 40 percent of its breaking strength. (At a safety factor of 5, this represents double the design load.) This has been said to extend life of wire rope. The Naval Research Laboratory has found that initially overloading a rope to 2-2½ times its design load will impose local compressive stresses that inhibit growth of minute cracks in individual wires (Wick, 1976).

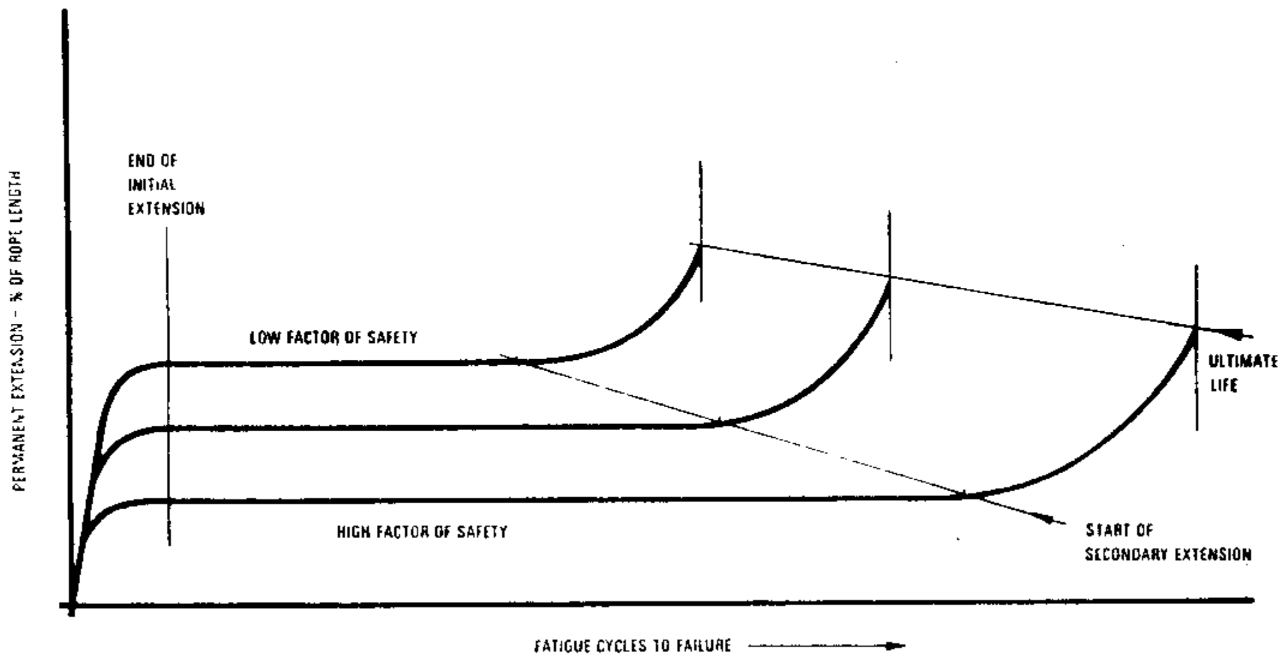


FIGURE 36
THREE STAGES OF WIRE ROPE STRETCH
(REF: BRITISH ROPES UNDATED - a)

sectional area for different wires are given in various handbooks such as that of Broderick and Bascomb (1980).

Note that stretch is critical only when the length is critical. In fishing ropes, it would be important if two different wires, or wires from two different lots, sizes, or designs are used on either side, an uncommon practice.

(c) Nondestructive testing

The Broderick and Bascomb (1980) handbook briefly mentions two different nondestructive test methods that can be applied on moving wires. Both are electrical in nature. The DC (direct current) devices indicate the effect of the number of broken wires; the AC (alternating current) devices indicate loss of metallic area. Both will determine the projected loss of strength. Neither should be used alone but rather along with other inspection criteria and judgment of the operator.

V. WARP CONFIGURATION UNDER TOW

During a preliminary look at potential causes of accelerated corrosion of towing cables, it was suggested that one cause was the continual scraping of the lower wires against the rough sea bottom. This action would presumably remove protective coatings of zinc, ferrus oxide, and grease lubricants, and possibly cause penetration of abrasive soil grains between wires. However, there was strong disagreement about this point among several experienced trawl fishermen And, of the 21 questionnaires returned, 6 stated that the wire occasionally touches bottom; 8 stated that this does not happen.

We attempted therefore to investigate the potential of this bottom-scraping and the conditions under which it was likely to occur. Such information could serve to guide fishermen to avoid certain conditions or equipment.

Two approaches were considered: theoretical and experimental. We chose to consider only the theoretical approach because of the time and expense involved with the alternative. Although an experimental test would be the most convincing answer in this situation, we felt that a theoretical description could contribute some valuable information as well.

A. Theoretical Description of Towing Cable Configuration

1. Background

Many analyses assume that the warp between vessel and doors approaches a straight line (see for example, Taber, undated). Some attempt has been made to physically model towing warp catenaries using mechanical devices in the lab (Kondrat'ev, 1973; Fridman, 1969; Baranov, 1969).

Some mathematical models attempt to account for the curvature (or catenary) of the warp resulting from the combination of cable weight and hydrodynamic drag, by modifying exact equations (Baranov, 1969, pp. 526-531; Baranov, 1970, pp. 155-157; Fridman et al., 1973, pp. 104-109, 144-159). In fact, due to the complex interaction of non-linear differential equations which describe this problem, the most exact analysis may best be performed by computer model. Stengel and Kroplin (1976) summarize some attempts along that line; one program was developed by National Institute of Oceanography (undated) and is available through the National Oceanographic Data Center (Department of Commerce, Washington, D.C.). Finally, Leonard (1979) provides a numerical solution of a series of non-linear coupled equations describing a cable towed in a circular fashion.

Professor Leonard, of the Oregon State University Department of Civil Engineering, was interested in revising the circularly-towed cable description to address the present trawl warp situation, and to rewrite the program for a desk-top mini computer. The model, describing a two dimensional situation is described further by Leonard (1981):

> "the response of a tether element to hydrodynamic loads, even in a quasi-static load environment, is complex and does not lend itself readily to exact mathematical analysis. Tethers are load adaptive members in that they prefer to change geometry in response to load changes rather than to increase stress levels. This implies non-linear equations of motion. Numerical analysis is needed.

In this (approach) a method of numerical analysis based on iterative solutions of quasi-linearized differential equations describing the behavior of complete tether segments is developed. The method is applied to the problem of prediction of stresses, locations and orientations of warps for mid-water and bottom trawling. Steady state towing is assumed. Arbitrary variations in fluid properties, flow descriptions and tether cross-sectional and material properties along the scope of the warps are allowed. Parametric studies of cable and fluid property effects on trawl response are reported.

The solution method is implemented in a computer program developed for use on small computer facilities, such as minicomputers and desktop computers. Because of the direct integration approach inherent in the iterative solution method, large systems of matrix equations, as would occur in a finite element analysis, are avoided. The algorithm is developed from a stiffness, rather than flexibility, point of view, and thus leads to the inclusion of these three-dimensionally curved segments as super elements, along with other element types, in non-linear finite element programs."

The input data required by Leonard's model includes:

- drag force vs. towing velocity characteristic of the load at the end of the warp (in our case to include net, doors and ground cables);
- towing velocity;
- wire rope diameter;
- wire rope weight per length ratio;
- length of warp;
- depth of water.

The program was written in BASIC for a Hewlett-Packard 9845, with a future option to adapt to a smaller HP85. A listing of the calculation program and plot program are included in Leonard and Kruchoski (1982).

2. Parameters of interest to Oregon fishery

Table 1 indicates the range of net designs, depths of water, scope ratios of wire and other parameters affecting what is assumed to be typical bottom trawling practice on the Oregon Coast. We selected five net designs for which details of drag vs. dynamic pressure were determined. Note that dynamic pressure, = q, is calculated from the equation

$$q = \frac{1}{2}\rho v^2$$

where ρ = seawater density

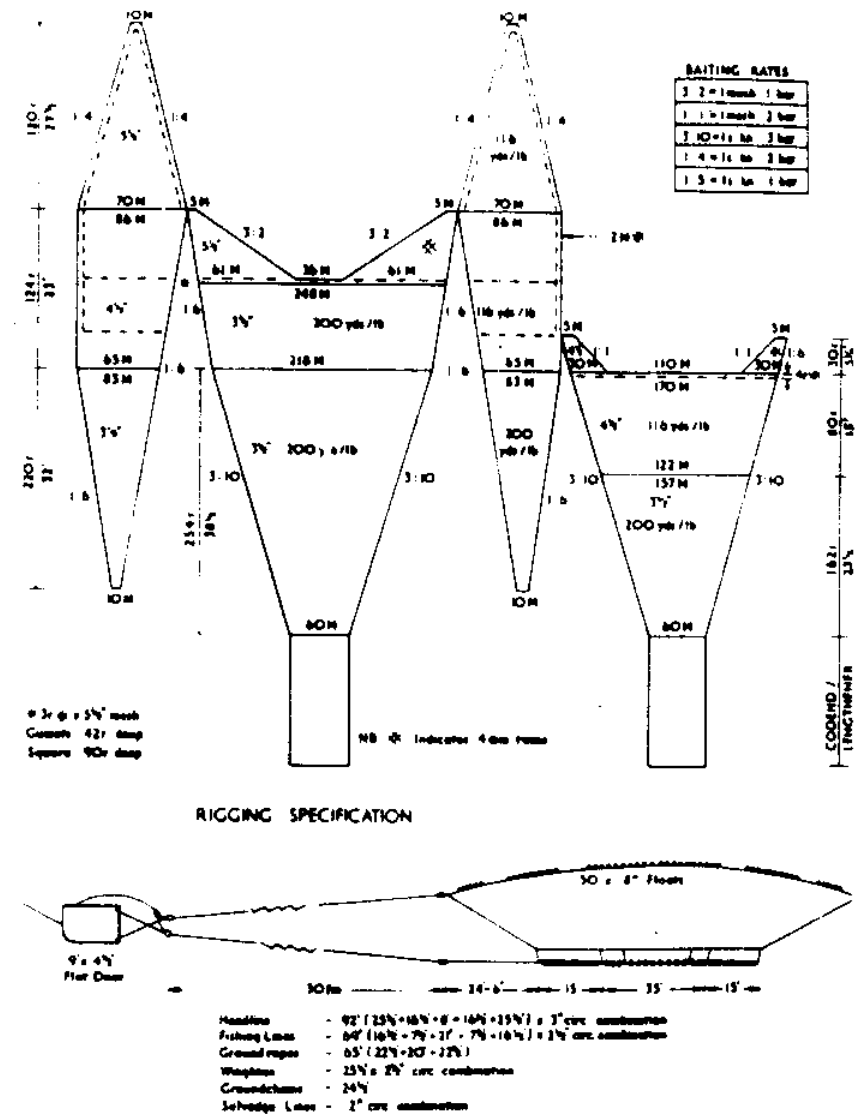
v = tow velocity.

The nets considered are described below.

(a) Aberdeen Trawl, 92 foot head rope (Figure 37). Drag data for this trawl, obtained from Dennis Lodge (private conversation), is given in the following table:

Speed (knots)	q (lb/ft^2)	Tension at Boat (tons) Per Side	Total Tension (lb)
3	25.5	1.8	8064
3.5	34.7	2.2	9856
4	45.3	2.8	12,544

This trawl has been recommended for the horsepower range of 500-800 and is frequently referred to as a "600 horsepower" trawl.



Constructional details of one of the Marine Laboratory's range of four-panel trawl nets, the 92-ft headline North Sea trawl.

FIGURE 37

ABERDEEN TRAWL
(REF: ANON. 1977)

(b) Atlantic Western IIA (Figure 38). The data below describing performance of the Atlantic Western IIA, was obtained by scaling data obtained for the Atlantic Western III (Figure 39, Table 15) by Carrothers et al. (1969, 1972 a, b).

Towing Speed (knots)	Total Drag of Net and Doors (lb)	Total Drag at The Boat (lb)
2.5	4,800	4,950
3	5,925	6,150
3.5	7,125	7,350
4	8,475	8,850
4.5	10,050	10,650
5	11,775	12,750

The scaling factor is the square of the ratio of the number meshes around the throat of the nets. This assumes drag varies as the total number of meshes in the net which varies roughly with the square of the number around the throat (private conversations, Jerry Jurkovich, Tom Crocker).

This is admittedly crude, because exact account is not made for the different float arrangement, ground lines, bottom condition, etc. However, it is close enough for the intended purpose -- that is, a description of range of drag characteristics typical of nets used in west coast fishing.

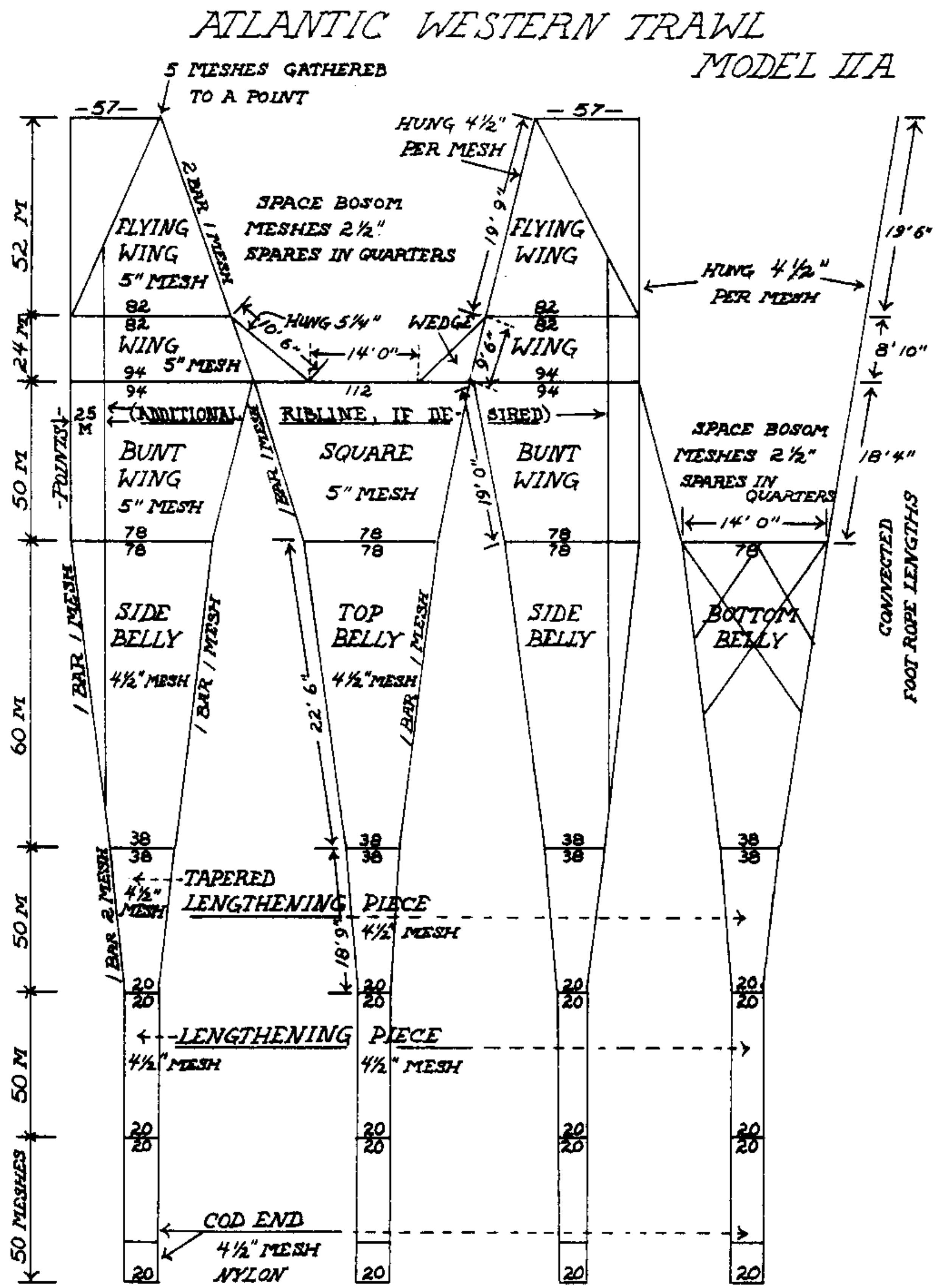


FIGURE 38

ATLANTIC WESTERN TRAWL
MODEL IIA
(REF: FISHER, 1974b)

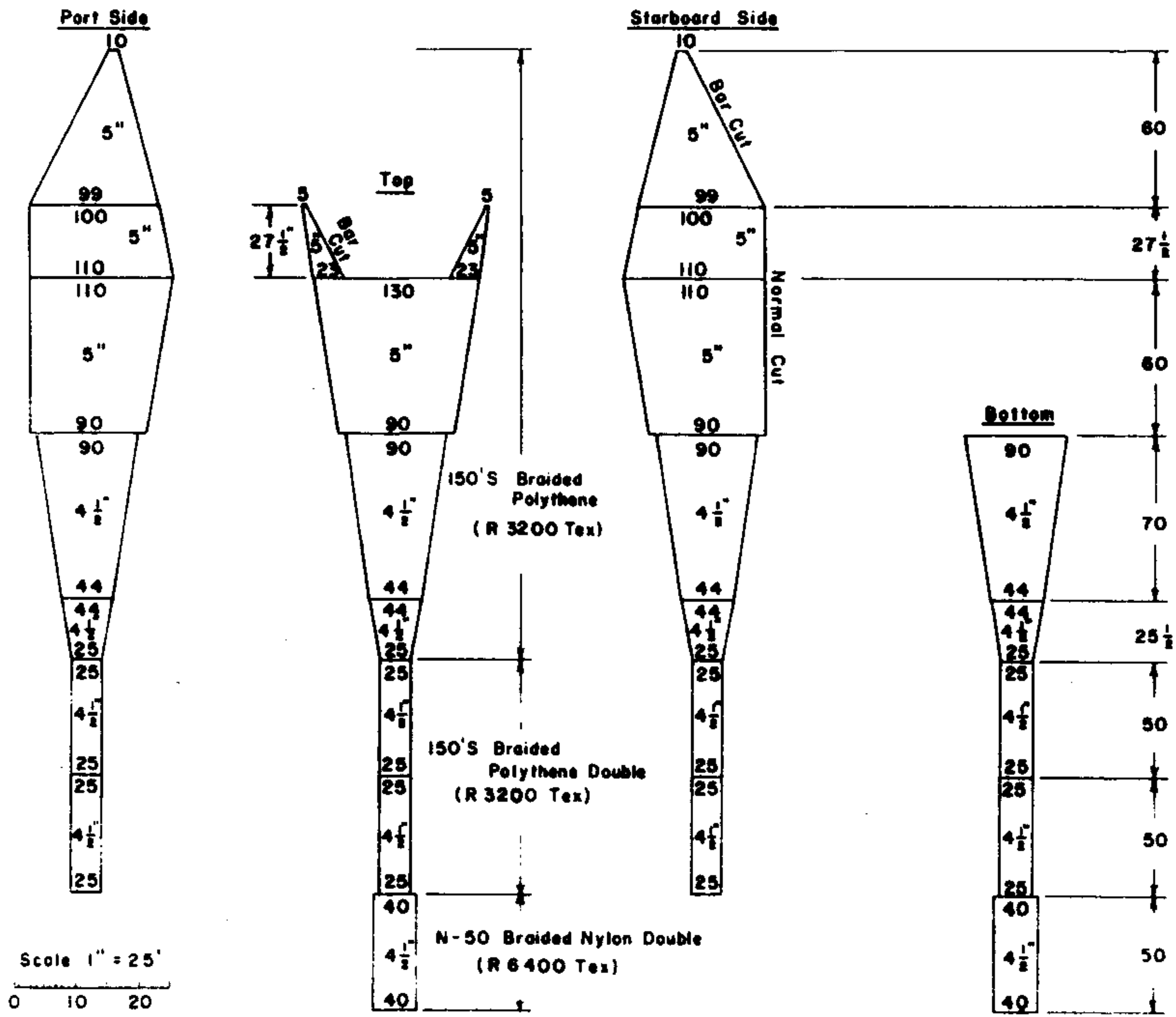


Fig. 39 Atlantic Western III polythene box trawl

(REF: CARROTHERS ET AL, 1969)

Table 15. Atlantic Western III braided polyethylene trawl

Carrothers et al 1969

Line	Length x Diameter	Material	Attachments
Headline	79 ft	Galv. wire	Floats:
Bosom	17.5 ft x 5/8 in. -6/19	- braided	Bosom: 23 x 8-in. diam. cast aluminum
Each wing	10.5 + 20.3 ft x 5/8 in.	Nylon cover	Each wing: 10 + 17 x 8-in. diam. cast aluminum
Footrope	115 ft	Galv. wire	Bobbin gear:
Bosom	16 ft x 7/8 in. -6/19		Bosom: 8 rubber rollers, 21-in.diam. x 5.3-in. wide, and 7-in. diam. rubber spacers
Each wing	20.5 + 9.5 + 19.5 ft x 7/8 in.		Each wing: 5 rubber wing bobbins, 18-in. diam., and 7-in. diam. rubber spacers
Fishing line	16 ft	Combination	Each lower wing tip: 1 rubber wing bobbin, 18-in. diam., between bridle and wing
Bosom	16 ft x 7/8 in.		
Each wing	None		
Hanging line	76 ft x 1 in.	Mono. Prop.	
Wing lines	23 ft x 7/8 in.	Combination	
Belly & Rib	111.5 ft x 1 in.	Mono. Prop.	
Wing bridles		Galv. wire	
Upper	91 ft x 5/8 in.		
Lower	90 ft x 1 in.		
Ground warps	180 ft x 7/8 in. -6/19	Galv. wire	
Door legs		Galv. wire	Doors: Standard rectangular
Upper	9 ft x 3/4 in. -6/24		10 ft x 4.5 ft x 3.5 in.,
Lower	9 ft x 3/4 in. -6/24		1600 lb
Towing warps	7/8-in diam. -6/19	Galv. wire	

(c) Atlantic Western IVA (Figure 40).

Drag data, below, was similarly scaled from the data of Carrothers et al. (1969) for the Atlantic Western III.

Towing Speed (knots)	Total Drag of Net and Doors (lb)	Total Drag at The Boat (lb)
2.5	3,008	3,102
3	3,713	3,854
3.5	4,465	4,606
4	5,311	5,546
4.5	6,298	6,674
5	7,379	7,990

(d) Yankee #35 (Figure 41 and Table 16).

Drag data for this net was obtained directly from Carrothers et al. (1969).

Towing Speed (knots)	Total Drag of Net and Doors (lb)	Total Drag at The Boat (lb)
2.5	2,300	2,600
3	2,900	3,200
3.5	3,500	3,800
4	4,400	4,800
4.5	5,500	5,800

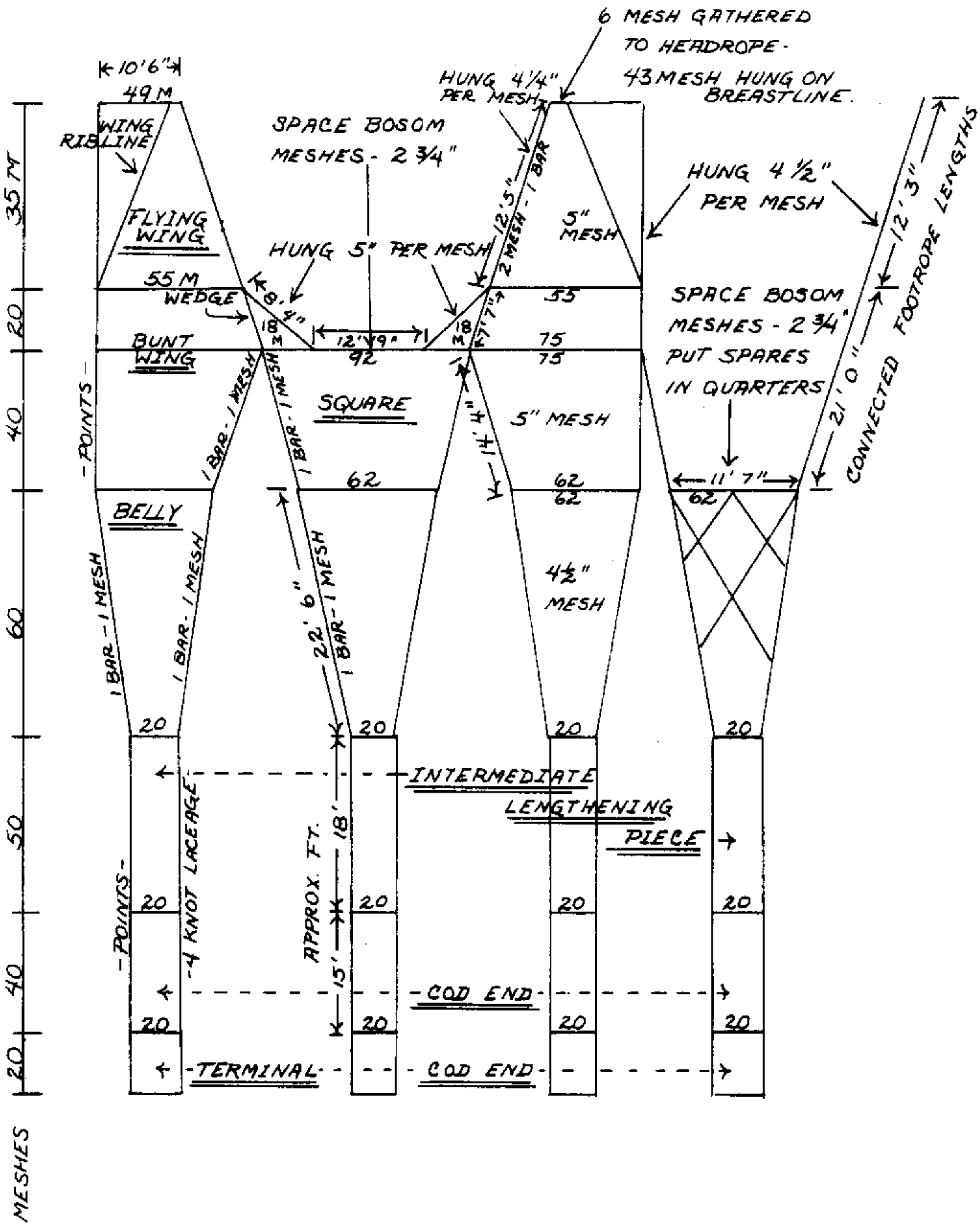


FIGURE 40

ATLANTIC WESTERN TRAWL
MODEL IV A
(REF: FISHER, 1974 b)

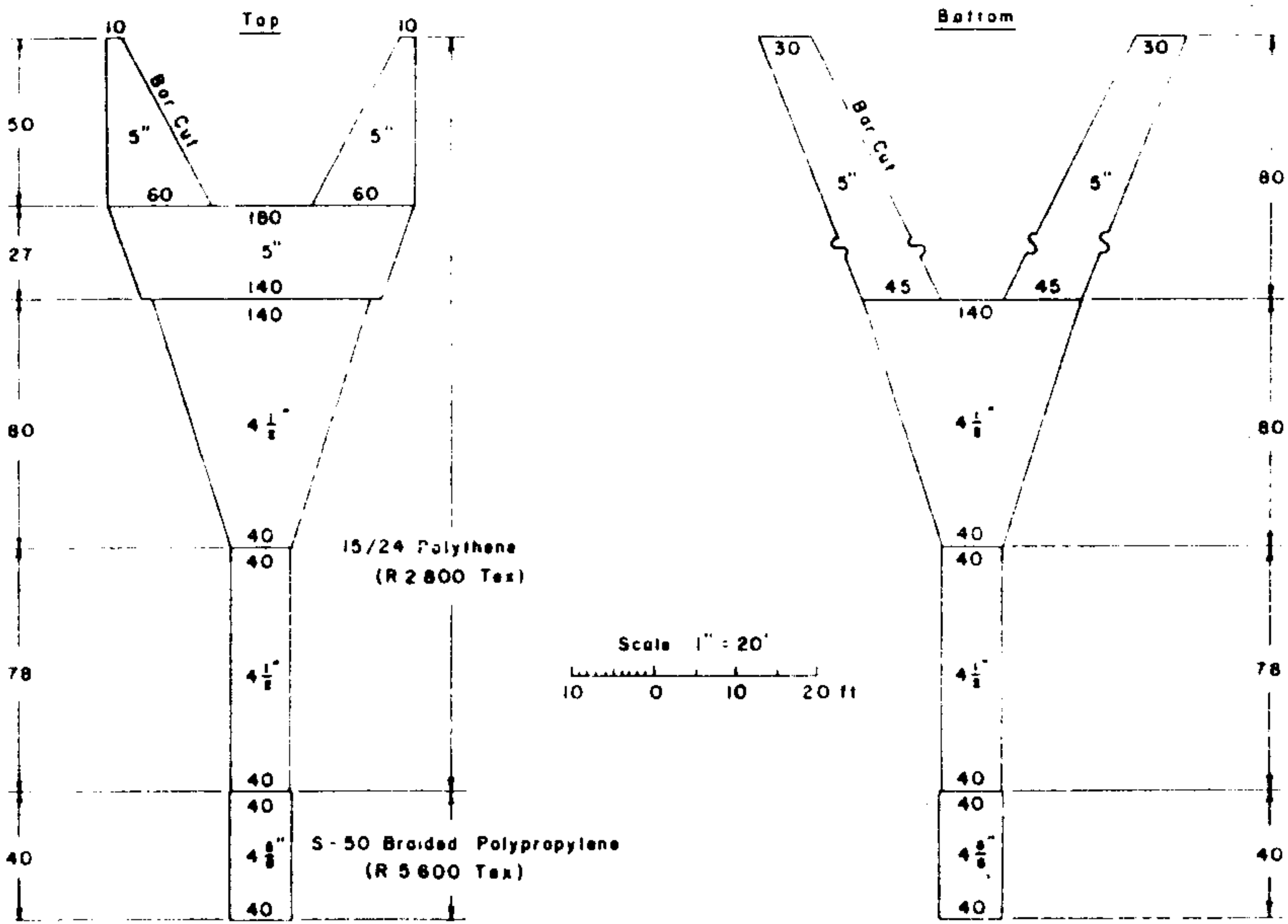


Fig. 41 Yankee 35 polythene trawl

(REF: CARROTHERS ET AL, 1969)

Table 16. Yankee 35 laid polythene trawl

Carrothers et al 1969

Line	Length x Diameter	Material	Attachments
Headline	52 ft	Combination	Floats: 18 x 8 in. diam. cast aluminum
Bosom	12 ft x 5/8 in.		
Each wing	20 ft x 5/8 in.		
Footrope	76 ft	Galv. wire	Bobbin gear: 4-in. diam. rubber discs, full length of footrope. Steel-banded wooden bobbin, 14-in. diam. X 5-in. wide, diametrically on wing end of lower wing bridles.
Bosom	12 ft x 5/8 in. -6/24		
Each wing	32 ft x 1/2 in. -6/24		
Fishing line			
Bosom			
Each wing			
Hanging line	76 ft x 15/32 in.	Manila	
Wing lines	8 ft x 5/8 in.	Mono. Prop.	
Belly & Rib	80 ft x 5/8 in.	Mono. Prop.	
Wing bridles			
Upper	30 ft x 1/2 in. -6/24	Galv. wire	
Lower	31 ft x 1/2 in. -6/24	Galv. wire	
Ground warps	90 ft x 1/2 in. -6/24	Galv. wire	
Door legs			Doors: Standard rectangular
Upper	7 ft x 1/2 in. -6/24	Galv. wire	3.5 ft x 6.5 ft x 2.5 in.,
Lower	7.2 ft x 1/2 in. -6/24	Galv. wire	450 lb
Towing warps	5/8 in. -6/19	Galv. wire	

(e) Atlantic Western IV A-3/4 (Figure 42).

Drag versus speed data was obtained by, again, scaling data from the Atlantic-Western III.

Towing Speed (knots)	Total Drag of Net and Doors (lb)	Total Drag at The Boat (lb)
2.5	1,664	1,716
3	2,054	2,132
3.5	2,470	2,548
4	2,938	3,068
4.5	3,484	3,692
5	4,082	4,420

This net is referred to as acceptable for vessels having 45-165 horsepower (Fisher, 1974b).

Data for the five trawls is plotted in Figures 43 and 44. The straight-line form of the drag vs. dynamic pressure curves indicates that drag, or tension, varies approximately with the velocity squared. The non-zero y-intercept indicates that a constant static drag term (due to gear interacting with the bottom) is added to the hydrodynamic drag imposed by velocity.

Based upon questionnaire data and discussions with various net manufacturers and fishermen, Table 17 indicates the range of conditions considered possible with these nets in the Oregon drag fishery.

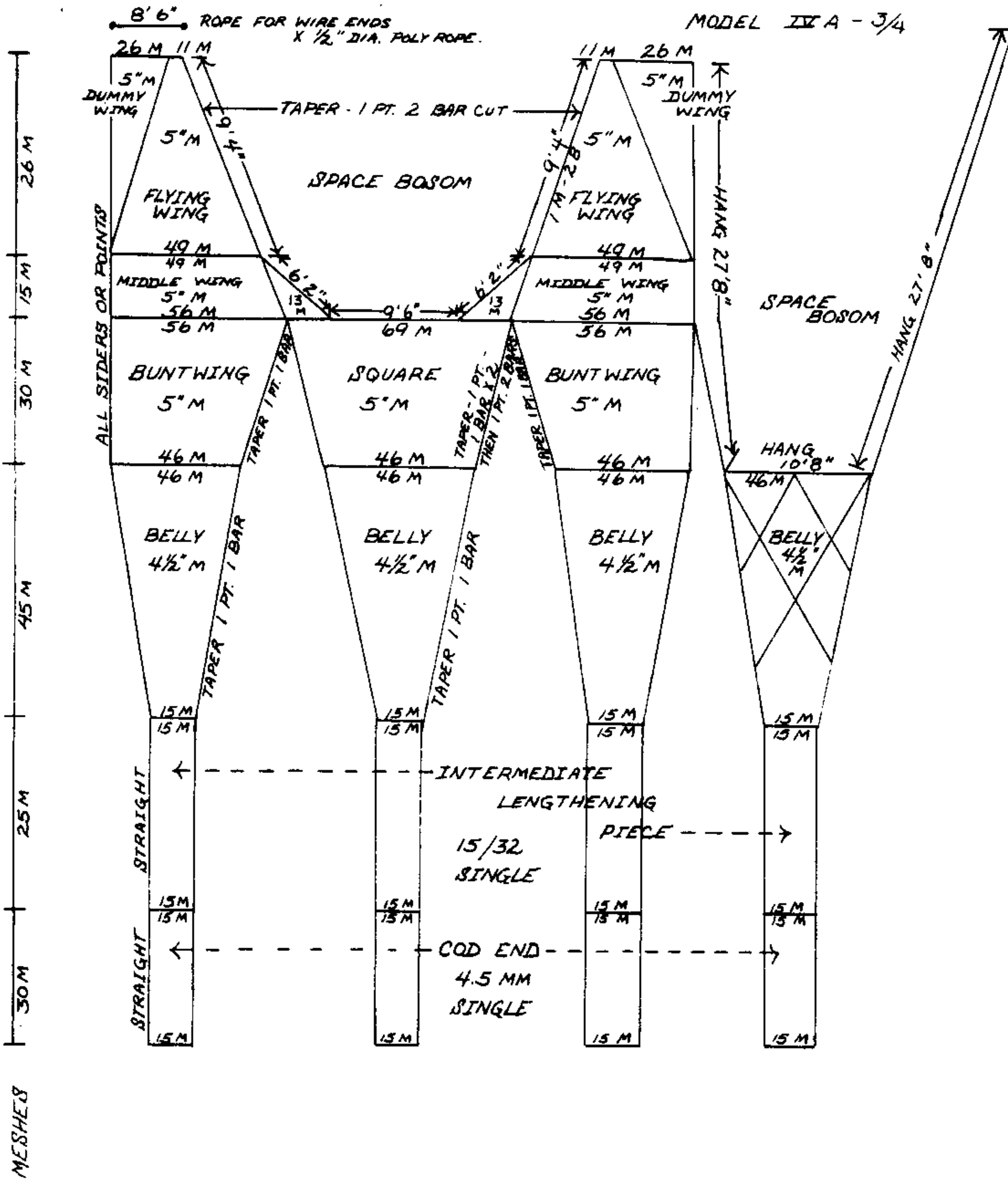


FIGURE 42

ATLANTIC WESTERN TRAWL
MODEL IV A - 3/4

(REF: FISHER, 1974 b)

TABLE 17 RANGE OF TRAWL PARAMETERS IN OREGON FISHERY

Trawl	Speed (knots)	Wire Diam. (in)	Depth (ftm)	Scope Ratio
Aberdeen	1½, 2, 3, 4	9/16, 5/8, 3/4	50, 100, 200, 300	5, 3, 2, 1½
At. Western IIA	1½, 2, 3, 4	9/16, 5/8, 3/4	50, 100, 200, 300	5, 3, 2, 1½
At. Western IV A	1½, 2, 3, 4	7/16, 9/16, 5/8	30, 100, 150	5, 3, 2
Yankee 35	1½, 2, 3, 4	7/16, 1/2, 9/16	30, 100, 150	5, 3, 2
At. Western IV A 3/4	1½, 2, 3, 4	3/8, 7/16, 1/2	20, 80, 100	5, 3, 2

6 x 19 (Fiber Core) Galv. Wire Diameter	Weight per Length (lb/ft)*	Scope Ratios
7/16	.32	5:1 $D < 50$ ftm
1/2	.42	3:1 $50 < D < 150$ ftm
9/16	.53	2:1 $D > 150$ ftm
5/8	.66	
3/4	.95	

* (Broderick & Bascom 1980)

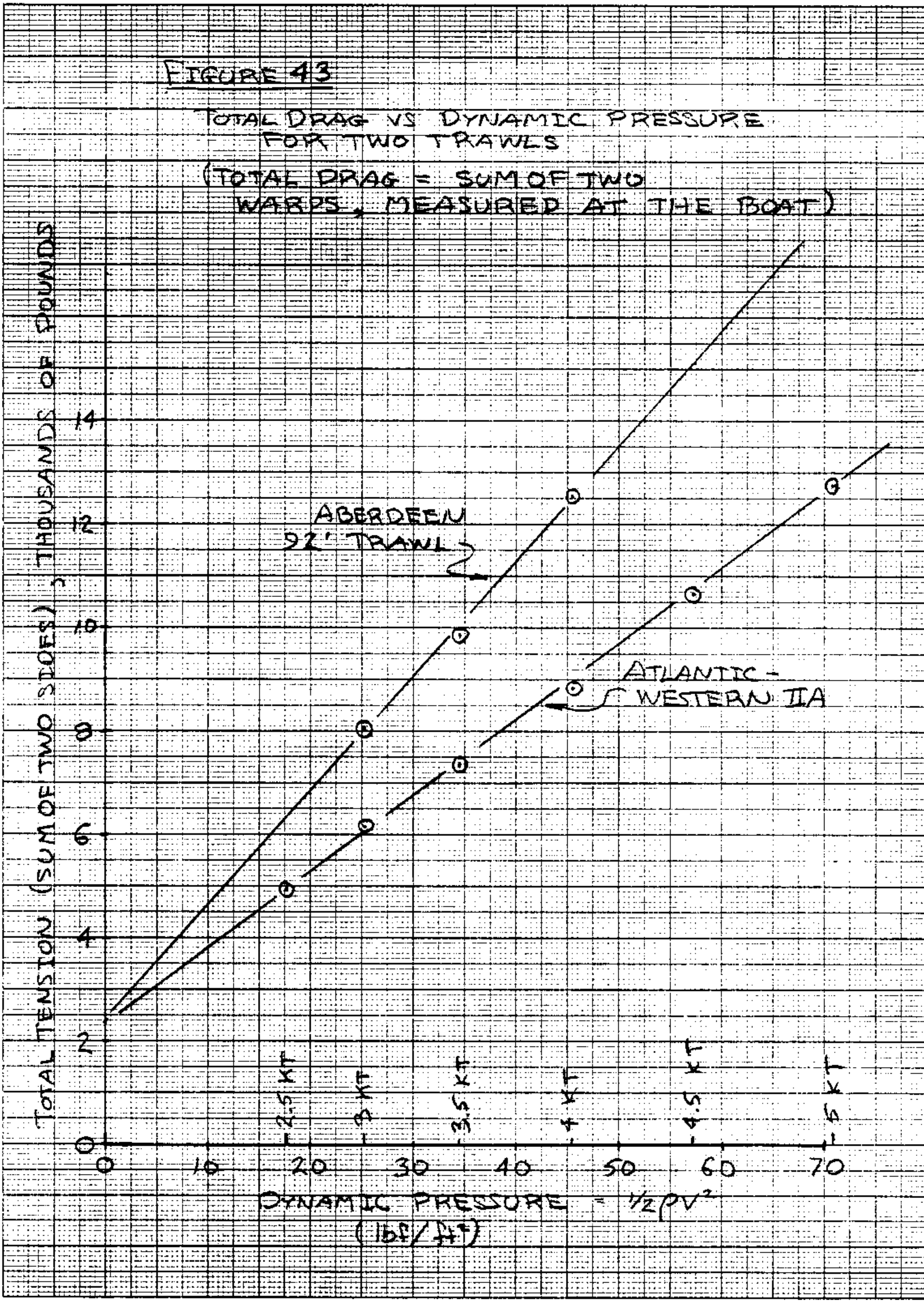
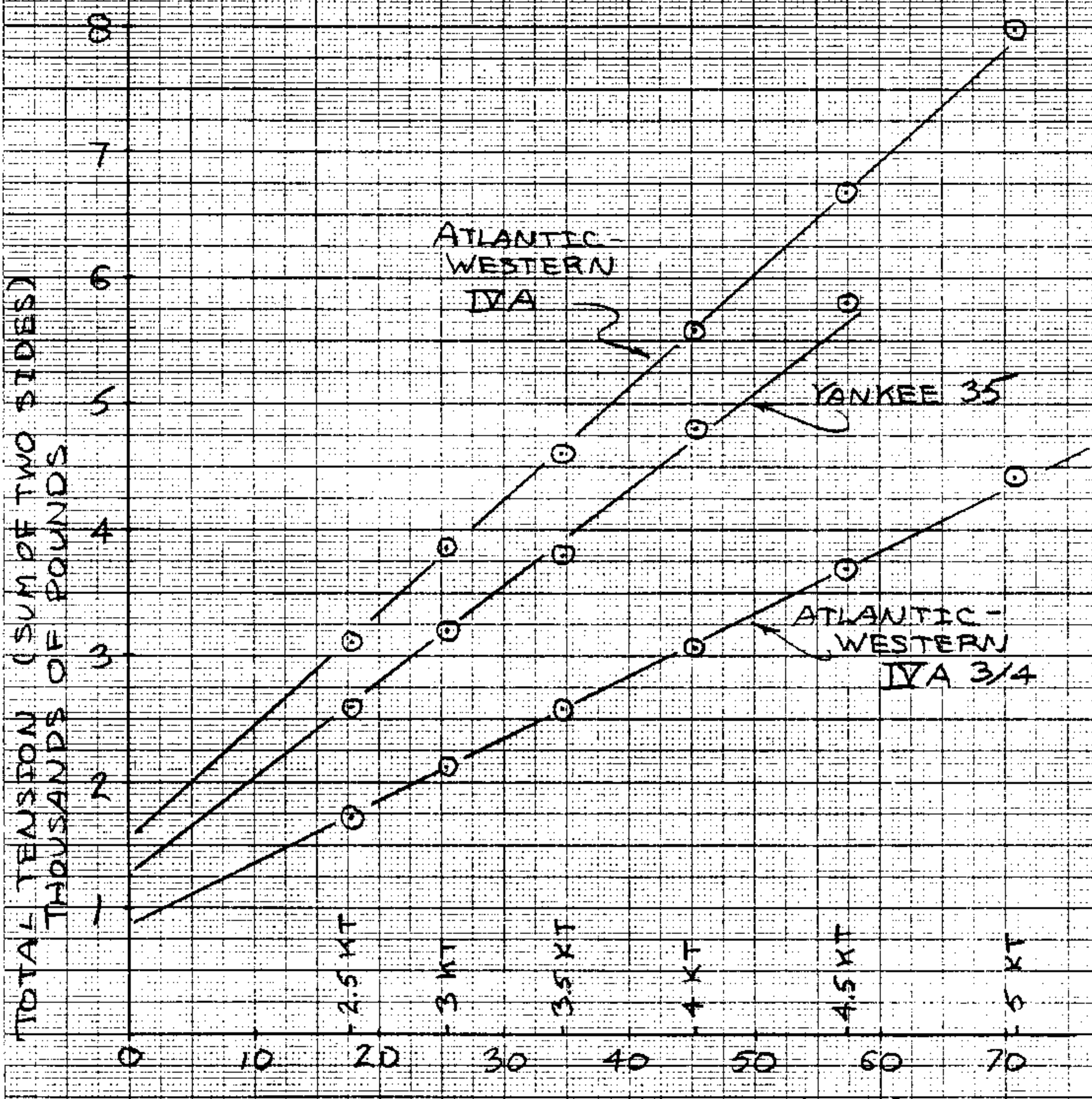


FIGURE 43
TOTAL DRAG VS DYNAMIC PRESSURE FOR TWO TRAWLS
(TOTAL DRAG = SUM OF TWO WARPS, MEASURED AT THE BOAT)
ABERDEEN 92' TRAWL
ATLANTIC - WESTERN IIA
TOTAL TENSION (SUM OF TWO SIDES), THOUSANDS OF POUNDS
0
2
4
6
8
10
12
14
2.5 KT
3 KT
3.5 KT
4 KT
4.5 KT
5 KT
0
10
20
30
40
50
60
70
DYNAMIC PRESSURE = ½ρV²
(lbf/ft²)

FIGURE 44

TOTAL DRAG VS DYNAMIC PRESSURE FOR THREE TRAWLS

(TOTAL DRAG = SUM OF TWO WARPS, MEASURED AT THE BOAT)



These also represent some of the combinations of parameters used in the warp configuration calculations.

3. Results

As described by Leonard and Kruchoski (1982), the model was firs checked using data for a Yankee Model 41-5 trawl, reported by Carrothers et al. (1969). There was good agreement between calculated and measured values of on-board warp tensions and warp angles (vs. speed).

Using the developed model and modified data for the Yankee 41-5 they found that potential bottom contact of the towing warps (or, a horizontal warp angle at the doors) might be expected under the following conditions:

Yankee Model 41-5

Trawl door: flat, wooden design

1600 lb weight

4.5 ft x 10 ft size

Wire rope diameter = 7/8 in

Net is very lightly loaded

Hard bottom conditions; minimal friction forces between gear and sea floor.

Length of cable out = 167 ftm

At speed of:	Bottom contact will likely occur when depth is less than: (or when scope is greater than):
3 knots	32 ftm (5.3:1)
2.4 knots	45 ftm (3.8:1)
1.8 knots	60 ftm (2.8:1)

At Depth (Scope) of:	Bottom contact will likely occur when speed is less than:
67 ftm (2½:1)	1.5 knots
55 ftm (3:1)	1.9 knots
48 ftm (3½:1)	2.2 knots
42 ftm (4:1)	2.5 knots
37 ftm (4½:1)	2.7 knots

Following this analysis, Leonard and Kruchoski (1982) looked at three of the five locally-used trawl types characterized in Figures 43 and 44. They assumed the trawls to have different warp sizes according to the following schedule:

Trawl	Warp size (in.)
Atlantic Western IIA	5/8
Atlantic Western IVA	9/16
Yankee 35	1/2

The cable configuration model was then run for each trawl with a range of speeds (.6 - 3 knots), cable lengths (167 - 400 ftm), depths (33 - 200 ftm), and scope ratios* (2 - 5).

*Note that "scope ratio" is the ratio of wire rope length paid out to depth of water.

Results were printed graphically for various combinations of parameters, an example of which is shown in Figure 45. Results of several combinations investigated are given in Table 18.

4. Discussion

Results of Table 18 seem to correspond to the experience reported by a number of fishermen, i.e., that under common fishing conditions, the warp would not be expected to touch bottom, but that under certain conditions of slow towing speeds in shallower depths using a high length-to-depth ratio, bottom scraping could very likely occur. Not shown in the results are their sensitivity to variations in parameters. Of course, some experimental varification is needed for this analytical procedure. However it is felt that it represents a tool capable of indicating conditions under which contact may occur. It can also indicate the expected change in configuration resulting from minor changes that may tend toward a worse situation, e.g.,

- decrease in drag due to a change in door design;
- increase to next warp size;
- increase in scope ratio;
- decrease in relative water speed due to changing currents;
- decrease in speed or depth due to rough sea conditions.

B. Possible Experimental Approach

Measurements of trawl warp shape under tow could be made by instrumentation at the low r warp area, to indicate conditions under

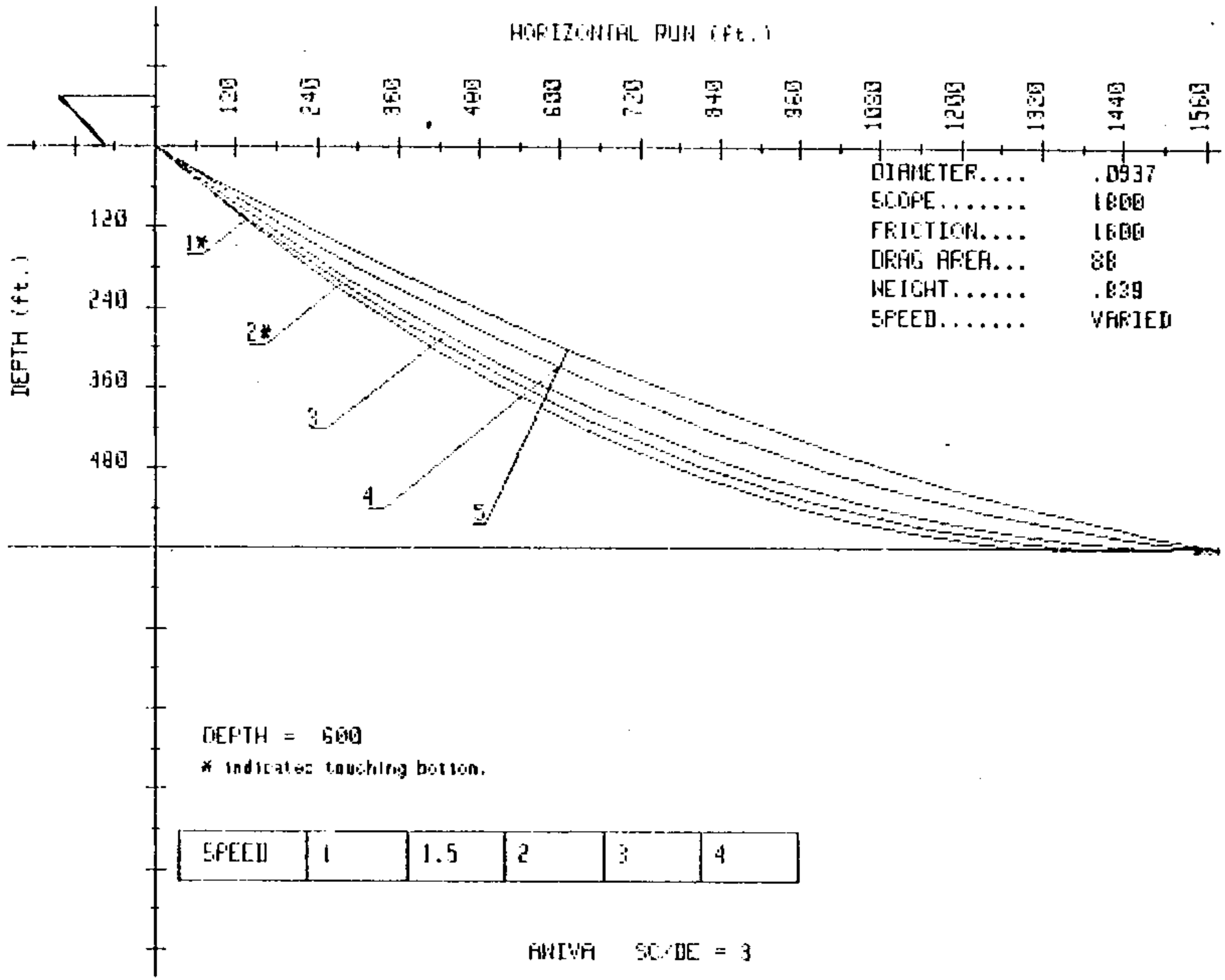


FIGURE 45 TYPICAL GRAPHICAL RESULTS OF WARP CONFIGURATION MODEL (REF: LEONARD AND KRUCHOSKI, 1982)

TABLE 18: SOME CONDITIONS UNDER WHICH TRAWL WARP BOTTOM CONTACT MIGHT BE EXPECTED

Trawl	Depth of water (ftm)	Scope Ratio	Speed (knots)	Is warp expected to touch bottom?
Atlantic-Western IIA (Warp diameter = 5/8 m.)	200, 150	2:1	0-2.4	no
	100	3:1	0-2.4	no
	50	5:1	>1.2	no
			≤1.2	yes
	34	5:1	0-2.4	no
Atlantic-Western IVA (Warp diameter = 9/16 in.)	200, 150	2:1	0-2.4	no
	100	3:1	> .9	no
			≤ .9	yes
and	50	5:1	> 1.8	no
			≤ 1.8	yes
Yankee 35 (warp diameter = 1/2 in.)	34	5:1	> .9	no
			≤ .9	yes

Ref: Leonard and Kruchoski, 1982

which the lower warp would reach a zero angle. Sophisticated inclinometers with recorders and/or acoustic links or hard wire to the towing vessel could provide this data. However, collection of information over the vast range of operating condition combinations would be probably more expensive than the information warrants.

Conceivably a more suitable technique for measuring inclination at lower wire ends could be obtained by the gelatin or wax-filled container mentioned in conversations with several gear specialists. The concept involves a liquid contained within a small cylinder fastened tightly to the wire. The liquid would solidify perhaps 15 to 20 minutes after the gear is shot; the free surface in the hardened condition would roughly indicate the inclination at the time that the gelatin or wax solidifies. Documentation of a device similar to this is described by Carruthers (1963). It is difficult to estimate the expected accuracy compared with use of a theoretical description to describe the actual performance under a variety of conditions.

VI. MODELING CATHODIC PROTECTION

Summary:

A model synthesizing the corrosion of galvanized trawling cable has been developed by Peterson (1962) and later modified by Dardel (1981). In this model it is visualized that a galvanized wire rope is connected to a bare steel door. The rope loses zinc by two mechanisms: 1) by galvanic action with the door and 2) by normal sea water corrosion.

In this model a longitudinal cut in the wire rope is considered at a distance "x" from the point of contact with the door and an expression is derived that give the time for complete loss of zinc as a function of position along the wire. Of particular interest is the time in which all of the zinc would be lost from the entire wire rope up to some distance "x." This time is denoted as t_{final} in the following expression:

$$1/(t_{final}) = (X/t)_{x=\infty} + (c)(g)(E)(\exp - (gR_L)^{\frac{1}{2}}(x))$$

Here:

$(X/t)_{x=\infty}$ represents the percent of mass loss per unit time due to the influence of the door at end of the wire rope.

E is the difference between measured potential and corrosion potential.

R_L is the resistance of metallic wire rope per unit of length.

c & g are constants which are a function of the Faraday, the molecular weight of zinc and the valence of zinc, along with the galvanic current.

This equation has been plotted in Figure 46 using parameters evaluated from dock-side tests. From this figure one can see that for a cable of 100 meters in length, all of the zinc coating is gone in about 40 - 50 days.

In this model, galvanized wire rope is considered without any organic or other type of coating. A greased rope would modify the results significantly because of an electrical resistance effect. Such an effect would cause galvanic currents to be spread over the rope more uniformly and cause the "g" term in the equation to become quite small. Greasing the rope would also reduce normal seawater corrosion whether a door was present or not.

Conclusions:

The model that has just been discussed suggests that it is bad practice to couple galvanized trawling cable to bare steel doors. In such situations most of the zinc coating on the calbe or rope is lost within one to two months. Greasing the cable would help protect the galvanized coating but one might question the merit of even using galvanized rope in that case since the grease alone might offer enough protection for the strands of rope to keep them from rusting.

The model also implies that improvement would be realized if the steel doors had separate zinc anodes since then most of the galvanic action would occur between the door and the separate anodes instead of between the door and the galvanized rope.

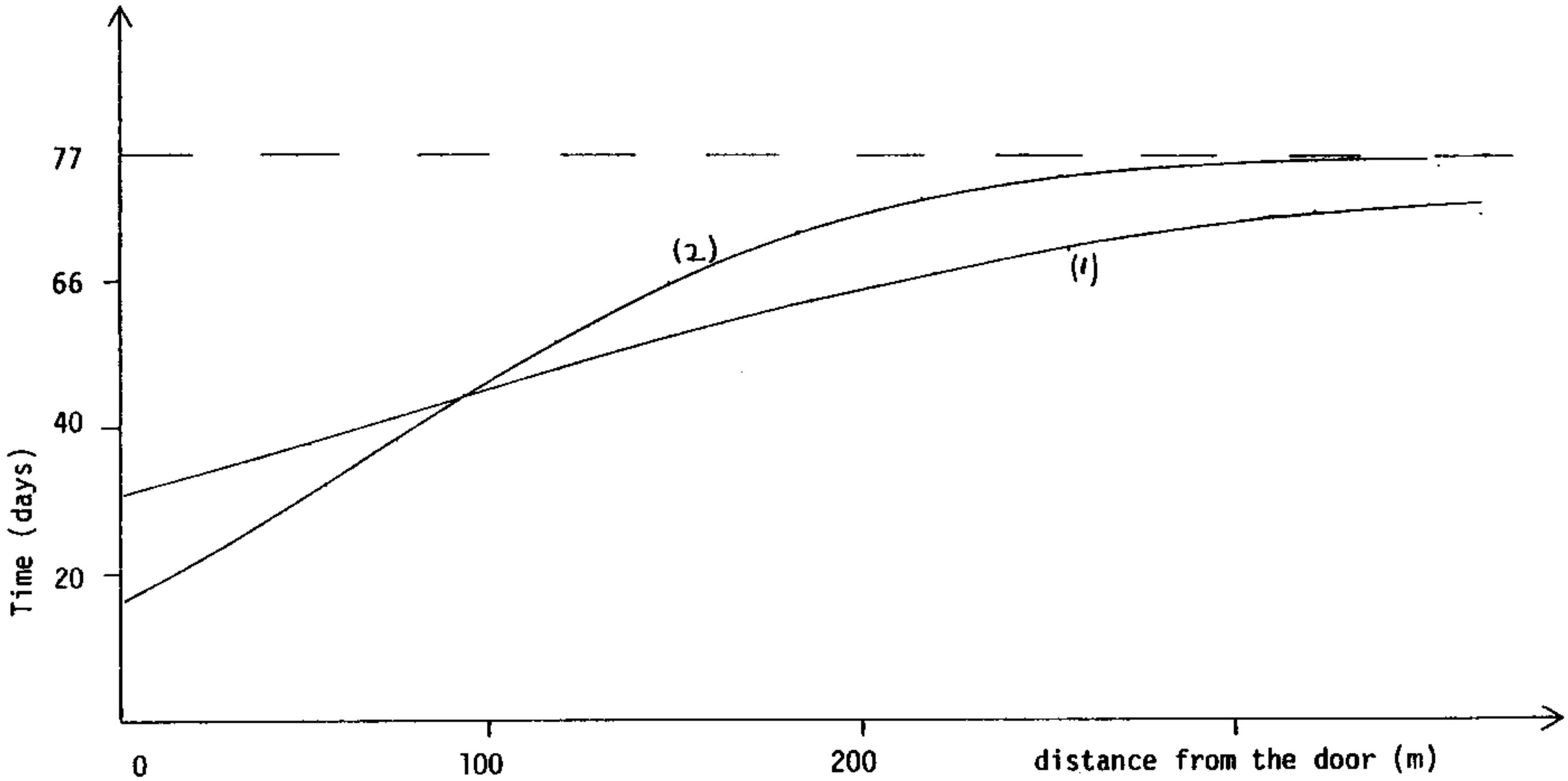


Figure 46 Time to Corrode Completely the Zinc Coating versus the Distance from the Bare Steel Trawl Door

(1) at rest

(2) simulation of the real trawl line

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IX. ACKNOWLEDGEMENTS

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APPENDIX A-1

Sample Preparation for Weight Loss Measurement (Dardel, 1981)

One foot samples are cut with an acetylene torch; ends are ground to get a square clean cut, necessary to precisely measure sample length. Each sample is then unwound and individual wires collected.

The sample must be completely cleaned and degreased. Independent wires are dipped in trichlorobenzene to dissolve greases; they are then dried before weight measurement.

Corroded samples must have oxides dissolved without attacking the base metal. Although oxides are soluble in dilute HCl, zinc is also strongly attacked if HCl is not neutralized in time. The procedure is as follows: Ready two solutions--10% HCl and 10% NaOH. Wires are dipped in HCl for 1 to 2 seconds after which they are quickly dipped in NaOH to neutralize the acid action. They are then rinsed and dried for 1 hour at 105^{o}C before weight measurement. Wires are first inspected under a x100 microscope to ascertain removal of all oxides.

APPENDIX A-2

Cathodic Protection of a 5x7 Door
(Reference Mallon and Kolbe, 1979; SNAME, 1976)

Assume 5 mA/ft^2 needed on "poorly painted steel"

Area of door (2)(5)(7) = 70 ft^2

Current needed (.005 A/ft^2)(70 ft^2) = .35 A

A 22 lb anode can deliver up to .40 amps at its polarized potential.

So one 22 lb anode is sufficient for maintaining "poorly painted" door @ -.85 volts necessary for adequate cathodic protection.

$$\text{wt} = \frac{(\text{life})(\text{Area})(\text{current density})(\text{anode consumption rate})}{\text{Anode Utilization Factor}}$$

wt = 22 lb

Area = 70 ft^2

Current density = 5 mA/ft^2

Anode consumption rate = 24.8 lb/Amp year

(@ 95% galvanic efficiency)

Anode utilization Factor = .85

(assumed fraction that is used)

So

$$\text{Life} = \frac{(\text{wt})(\text{Anode Uitilization Factor})}{(\text{Area})(\text{Current Den.})(\text{Anode Consumption Rate})}$$

$$= \frac{(22\ \text{lb})(.85)}{(70\text{ft}^2)(.005\ \text{A})\ (24.8\ \text{lb/A year})}$$

$$= 2.15 \text{ years}$$

of immersed time.

APPENDIX A-3

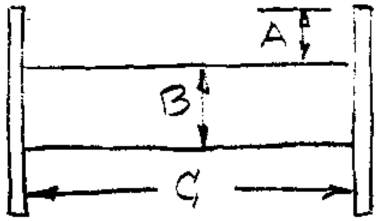
Drum Capacity

The length of wire rope that can fit on a drum, is given approximately by the equation (SFE, 1973)

$$L = \frac{(A)(C)(B+A)}{d^2} = (Pi)(.9)$$

where d = rope diameter

A.B.C. = drum dimensions defined in the following diagram



This has been simplified to the following (approximate) form (Broderick and Bascomb, 1980).

L - (A)(C)(B+A)(M)

Where L is in feet, when A,B,C are in inches and M is the conversion factor given in the following table:

Rope Diameter (in)	M
3/8	1.58
7/16	1.19
1/2	.925
9/16	.741
5/8	.607
3/4	.428
7/8	.308
1	.239

APPENDIX A-4

Wire Rope Splicing -- References

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