# Axial Fatigue of Wire Rope

Final Report

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13. ABSTRACT

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core

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## ABSTRACT

Axial fatigue tests in air were conducted on wire rope, strand, and single wires under the same load spectrum with an Amsler Vibrophore machine. The wire rope tests permitted a comparison of lang and regular construction with independent wire rope core (IWRC) and polypropylene core, showing Lang IWRC to give the best performance. Results of single wire and strand tests do not agree well enough with the wire rope data to permit use of the wire or strand as predictors of rope performance. A possible frequency effect was noted in the strand tests and the lack of other wire rope data does not permit determining frequency effects in wire rope.

## AUTHORIZATION

This fatigue study was performed under U. S. Navy Contract No. N00024-70-C-5439 and monitored by Mr. William Wischhoefer, NAVSEC 6162. The experiments were performed in the Fatigue Testing Laboratory, Civil and Mechanical Engineering Department, The Catholic University of America, Washington, D. C., 20017.

## INTRODUCTION

Examination of a wire rope[1] which has failed in service often reveals that the cause was fatigue failure of individual wires and strands. The definition of a wire rope fatigue failure is arbitrary, but is usually stated as the number of broken wires per linear measurement of rope. Such a failure is the result of cyclic loading below the breaking load. The repetitive load application can result from strumming, dancing, shock loads, bending over sheaves, and axial loading. Five different modes of fatigue failure in rope wires have been identified by Gibson (1). The orientation of the fracture surface, either normal or inclined to the wire axis, separates two types of failure, while the fatigue crack initiation site defines all five failure modes. A recent survey by Chase (2) disclosed that 20 percent of all wire rope failures in oceanographic work were attributed to fatigue. Respondents in this survey, both users and manufacturers of wire rope, listed only unsuitable construction as being a more frequent (28 percent) cause of wire rope failure. Fatigue failure of wire ropes has been cited by Stimson (3) as one of three primary causes of deep-sea mooring losses and buoy system failures. The response of attendees at a recent conference on wire rope also accented the importance of wire rope fatigue (4).

One reason that fatigue failure of wire rope is such a problem is the lack of sufficient empirical information on which to base design or selection of construction types. Wilson (5), in discussing moorings, notes that the untrod ground of wire rope fatigue testing has forced designers to estimate fatigue life on the basis of solid specimen tests. This scarcity of information on the dynamic endurance of wi e rope is claimed by Richardson (6) to make the selection

1 For a discussion of wire rope terms and construction refer to Appendix A.

of the correct wire rope a difficult task. Some work has been performed in the reversed bending mode by Gambrell (7) for the special case of arrest cables on aircraft carriers. Brief studies have also been conducted to evaluate the effect of surface coatings or core material on the fatigue life of wire ropes (8, 9, 10). Oceanographic instrument mooring cables have received special attention from one of the world's principal users, Woods Hole Oceanographic Institute (11).

A second reason that wire rope fatigue failure is a problem is the lack of theoretical models for predicting fatigue failure. Only a single prediction model, that by Drucker and Tachau (12), has wide use, but it is limited to the bending-over-sheaves loading mode. A preliminary attempt by Allen (13) to predict fatigue failure under axial loading of a single strand has many admitted restrictions which must be eliminated before the model can be useful. The lack of empirical fatigue data for strands makes it impossible to verify this model.

This bleak picture is the justification and background for the present study. The scope of the test program reported here is briefly previewed in the following paragraph.

There are a number of variables which can affect the fatigue life of wire rope.

1. environment
2. grade of steel wire
3. surface coating
4. end grips
5. preloading
6. construction
7. core
8. load spectrum

In this study the first four variables were kept constant while the last four were varied to study their effect on fatigue life. All ropes and strands were manufactured from the same heat of steel and were tested in air. No surface coatings were used and all specimens were gripped by pressed-on aluminum bushings. For the wire ropes, the preloading, a constant percentage of the breaking load (BL), was applied for the same amount of time. Both regular and lang lay construction were tested as well as independent wire rope (IWRC) and polypropylene (POLY) cores. The load spectrum, characterized by mean load and load range, was also varied. The table below shows the design of the experiment used for the wire rope tests.

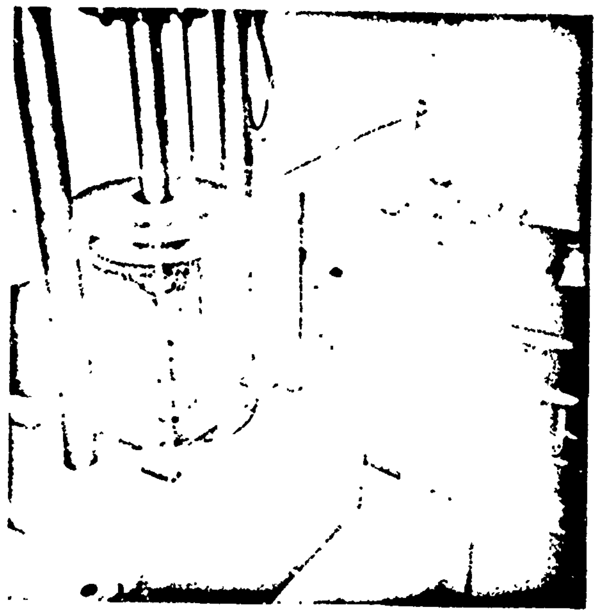
| Construction core | Lang | | Regular | |
|---|---|---|---|---|
| | IWRC | POLY | IWRC | POLY |
| Load range | (Two levels: 30 & 40% of BL) | | | |
| Mean load | (Two levels: 20 & 30% of BL) | | | |

An analysis of variance performed on the fatigue life data permits a greater generalization of conclusions to the wire rope population. The interpretation of test results is intended to provide some immediate assistance to designers of systems using wire rope and at the same time indicate areas requiring additional research. Single strands used in the construction of the above wire ropes were also tested in axial fatigue under the same load spectrum. Finally, single wires used in wire ropes were tested in axial fatigue.

## DESCRIPTION OF TEST FACILITY

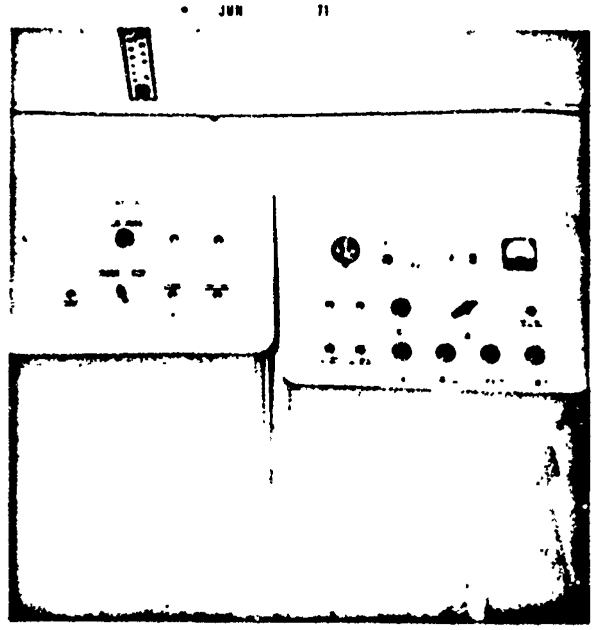
The general arrangement of the test facility and its components are illustrated in Figure 1. The test room, which is actually an acoustical, i.e., isolated, enclosure, contains a ten ton capacity Amsler High Frequency Vibrophore, model 10 HFP, operating consoles, a temperature strip chart recorder, work bench, and tool shelf. The vibrophore operates on the resonance principle; the test frequency always coincides with the natural frequency of the vibrating mass.

Figure 1 Test Facility




Amsler Vibrophore Testing Machine

NOT REPRODUCIBLE




Control Consoles

In this case, the vibrating mass is composed of the specimen and the weight disks installed above the specimen. The mean load acting on the specimen is applied by raising the cross arm while the fluctuating load is applied by an electromagnet. The load acting on the specimen is measured by an optical dynamometer and displayed on a scale. The machine calibration was checked; the method and results are shown in Appendix B. The mean load on the specimen is kept constant by a Load Maintainer unit which has a sensor on the cross arm and a console to control the machine. The fluctuating load is kept constant by a photocell feedback circuit working in conjunction with the dynamometer light beam. A synchronous counter accumulates and displays the number of load cycles.

## PREPARATION OF SPECIMEN

Wire rope specimens were prepared from 1000 ft. reels of 6 x 25 right lang and left regular construction rope with IWRC and POLY cores. The 1 x 25 strand specimens were prepared from a 1000 ft. reel of right wound strand. All of the rope and strand came from the same heat of improved plow steel. The lubricant specified for closing the strand and wire rope was Citgo Premium Wire Rope Compound. The single wires tested were also of improved plow steel, but of a different heat. The reason for this discrepancy will be discussed later.

The breaking load (BL) in thousands of pounds (metric tons) of the four wire ropes used were: lang IWRC 26.3 (12 m.t.), lang POLY 24.1 (11 m.t.), regular IWRC 25.7 (11.7 m.t.), and regular POLY 22.8 (10.3 m.t.). The BL of the strand was 5,200 lbs. (2.4 m.t.), computed from the BL of single wires in the strand and then reduced by 10% to account for the helix construction. The BL of prepared single wire specimens was 946 lbs. (.43 m.t.).

Although standard threaded ends were used for the single wire tests, the wire rope and strand specimens required special grips. The wire rope and strand specimen were cut from a reel in 14 inch lengths. Two inches at each end were cleaned in kerosene using a brush and ultrasonic bath to remove the lubricant from the wires. Aluminum bushings, previously machined and annealed, were slipped on the specimen ends and pressed on using a 60 ton capacity hydraulic press. Prior to pressing on the second bushing, a pair of adaptors were slipped on the specimen. The bushings on the specimen assembly were then machined to fit into the adaptors, completing the preparation of a specimen.

The adaptors were machined from a 1040 steel, while the bushings were made from 6061 aluminum which was annealed before pressing. Drawings of specimen components and method of assembly can be found in Appendix C.

The laboratory for specimen preparation is illustrated in Figure 2.

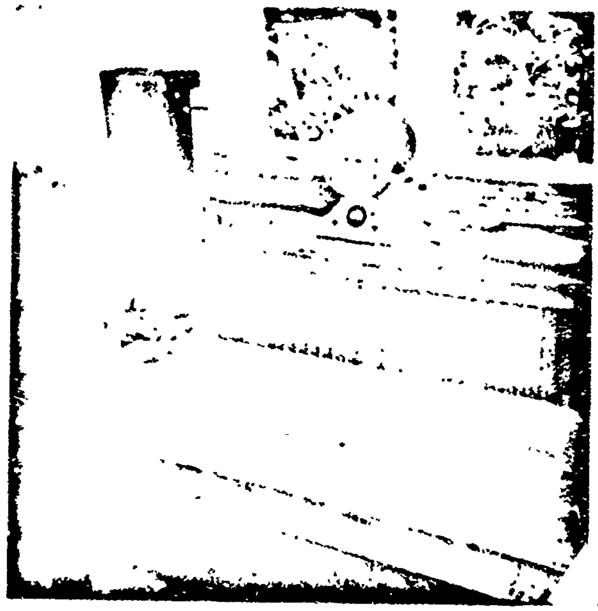
## TESTING PROCEDURE

1. Half-inch diameter 6 x 25 wire rope tests. Table 1 displays the $2^4$ factorial experimental design used to evaluate the main effect and interactions of variables important to wire rope fatigue life.

Table 1 Experimental Design for Wire Rope Tests

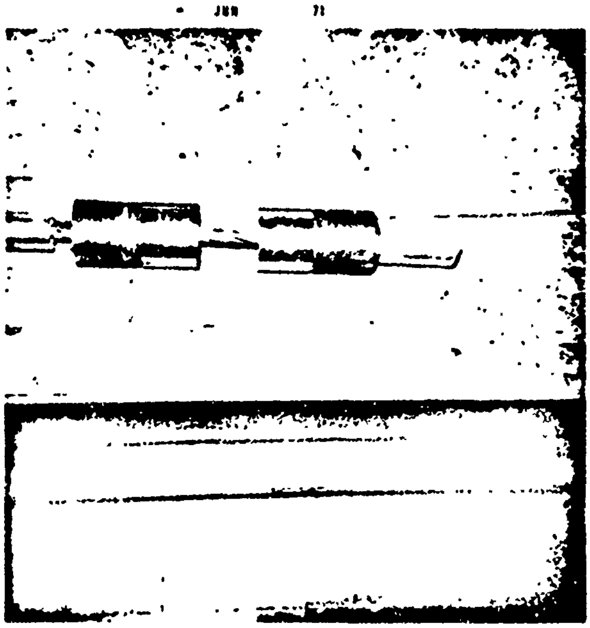
| Factor | Levels | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A. construction | lang | | | | regular | | | |
| B. core | IWRC | | POLY | | IWRC | | POLY | |
| C. load range % BL | 30 | 40 | 30 | 40 | 30 | 40 | 30 | 40 |
| D. mean load % BL | 20 30 | 20 30 | | | | | | |
| no. replications | 2 2 | 2 | 2 2 | 2 | | | | |

Figure 2 Preparation of Wire Rope Specimen



Specimen Preparation Bench





Completed Wire Rope Specimen Ready to Mount in Machine

The prepared specimen was mounted in the Amsler Vibrophore test machine and locked in. A preload of 42% BL was then applied for 30 minutes. This served to tighten up the rope and reduce the scatter in fatigue life (14). The mean load was then adjusted to the desired value and set with the automatic load maintainer. At this time, the air gap on the electromagnet was adjusted and the driving signal turned on. The machine was tuned to give the desired fluctuating amplitude and set with the photocell control device. The number displayed on the cycle counter was recorded in the test log along with other pertinent information about the specimen. The machine then ran continuously at 80 Hz until the specimen had failed.

As mentioned earlier, the failure criterion is arbitrary. Initially, "failure" was defined as failure of one complete strand; i.e., fracture of all wires in a strand. It soon became evident that such an ideal situation could seldom be found. What actually occured was fracture of many wires in different strands. This damage so changed the wire rope specimen that its natural frequency would decrease. The machine could be tuned to follow this drop in frequency for only about 5 to 10 Hz. It then became necessary to interrupt the test and place more weights on the machine. This permitted tracking the natural frequency of the specimen to the lower limit of the machine, 60 Hz. At this time, the damage was so great (one or two strands almost completely fractured) that it was impossible to continue testing the specimen. Thus, the criterion adopted for this study is failure has occurred for the rope or strand when damage causes the natural frequency of the specimen to drop more than 5 Hz.

Three specimens were tested to the lower frequency limit of the machine to determine whether or not a constant percentage of the final number of cycles occurred after the initial drop in natural frequency. This was not found to be the case; it ranged from 1% to 20% of the total number of cycles.

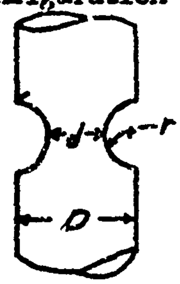
Recent tests at the laboratory have shown that the natural frequency of a wire rope under tension is proportional to the percent of BL applied to it. Thus one would expect that a drop in the BL of a rope which has incurred fatigue damage would result in a corresponding drop in its natural frequency.

Some of the IWRC specimens tested had a thermocouple attached to measure the surface temperature as a function of operating frequency and load range. All of the polypropylene core specimens had the thermocouple attached and were also enclosed in an aluminum cylinder. A non-corrosive antifreeze (Dow therm 209) was pumped through the sleeve as a coolant to keep the temperature below 70° C. Early attempts at testing the polypropylene specimens in air resulted in a softened core. Loss of core support caused the strands to warp and the specimen to slip out of its grips. With the cooling system, testing of polypropylene core ropes was completed without damage to the core.

2. <u>1 x 25 strand of wire ropes</u>. In fatigue testing the 1 x 25 strand, only the load range and mean load were examined. The testing proceeded as in the wire rope tests. Some specimens had their surface temperature measured under the different loading conditions and frequency to help identify the regions of greatest friction.

3. <u>Single wire tests</u>. The single wires used in the construction of the strand and wire rope tested had such low breaking loads (276 lbs.) that it was not possible to fatigue test these wires even with the two ton dynamometer in the vibrophore machine. Therefore some .126 inch diameter wire of improved plow steel for construction of 4 inch diameter rope was obtained. The wire was machine straightened and cut into 10 inch sections. The two ends were threaded to permit mounting in the machine as a bar specimen. To assure failure in the

gage length a circular groove was machined on the specimen. The root radius of the groove was .025 inches, a value determined by testing not to diminish fatigue life. The wire specimen configuration is shown below.




D = .126 in.

d = .063 in.

r = .025 in.

BL = 946 lbs.

RESULTS OF WIRE ROPE TESTS

The axial fatigue lives of the various wire ropes tested are shown in Table 2. As can be seen by the computed averages, the type of construction (lang or regular), core (IWRC or POLY) and load range have an effect on the fatigue life while mean loads used do not, except for regular poly rope. The effect of mean load can be seen more clearly in Figure 3. The strong effect of load range makes plotting fatigue life as a function of maximum load confusing, so the actual data points are plotted as a function of load range in Figure 4. An analysis of variance (ANOVA) was performed on the wire rope data to determine the statistical significance of the main effects and interactions on axial fatigue life. The ANOVA summary is shown in Table 3. The cumulative frequency distribution computed by order statistics (15) is presented in Figure 5.

The surface temperature of the wire ropes was mainly dependent on load range. The temperature variation with frequency and load range is shown in Figure 6.

Table 2 Axial Fatigue Lives of Wire Rope in Millions of Cycles

| A Construction | Lang | | | | | | | | Regular | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B Core | IWRC | | | | POLY | | | | IWRC | | | | POLY | | | |
| C Load Range $ BL | 30 | | 40 | | 30 | | 40 | | 30 | | 40 | | 30 | | 40 | |
| D Mean Load $ BL | 20 | 30 | 20 | 30 | 20 | 30 | 20 | 30 | 20 | 30 | 20 | 30 | 20 | 30 | 20 | 30 |
| Two specimens | 5.3 | 19.5 | 0.376 | 0.517 | 3.8 | 10 | 0.110 | 0.170 | 1.25 | 1.2 | 0.24 | 0.20 | 5.31 | 0.985 | 0.28 | 0.316 |
| each level | 16.1 | 10.0 | 0.481 | 0.60 | 3.5 | 2.4 | 0.1[illegible] | 0.258 | 1.5 | 2.5 | 0.291 | 0.291 | 13.6 | 4.79 | 0.97 | 0.28 |
| Average | 10.71 | 14.75 | 0.428 | 0.558 | 3.65 | 6.2 | 0.150 | 0.214 | 1.37 | 1.85 | 0.265 | 0.255 | 9.49 | 2 88 | 0.629 | 0.302 |
| Pooled | 12.734 | | 0.493 | | 4.91 | | 0.182 | | 1.612 | | 0.260 | | 6.190 | | 0.465 | |
| Average | 6.61 | | | | 2.546 | | | | 0.936 | | | | 3.327 | | | |

Figure 3 Axial Fatigue life of Wire Ropes

as a Function of Mean Load

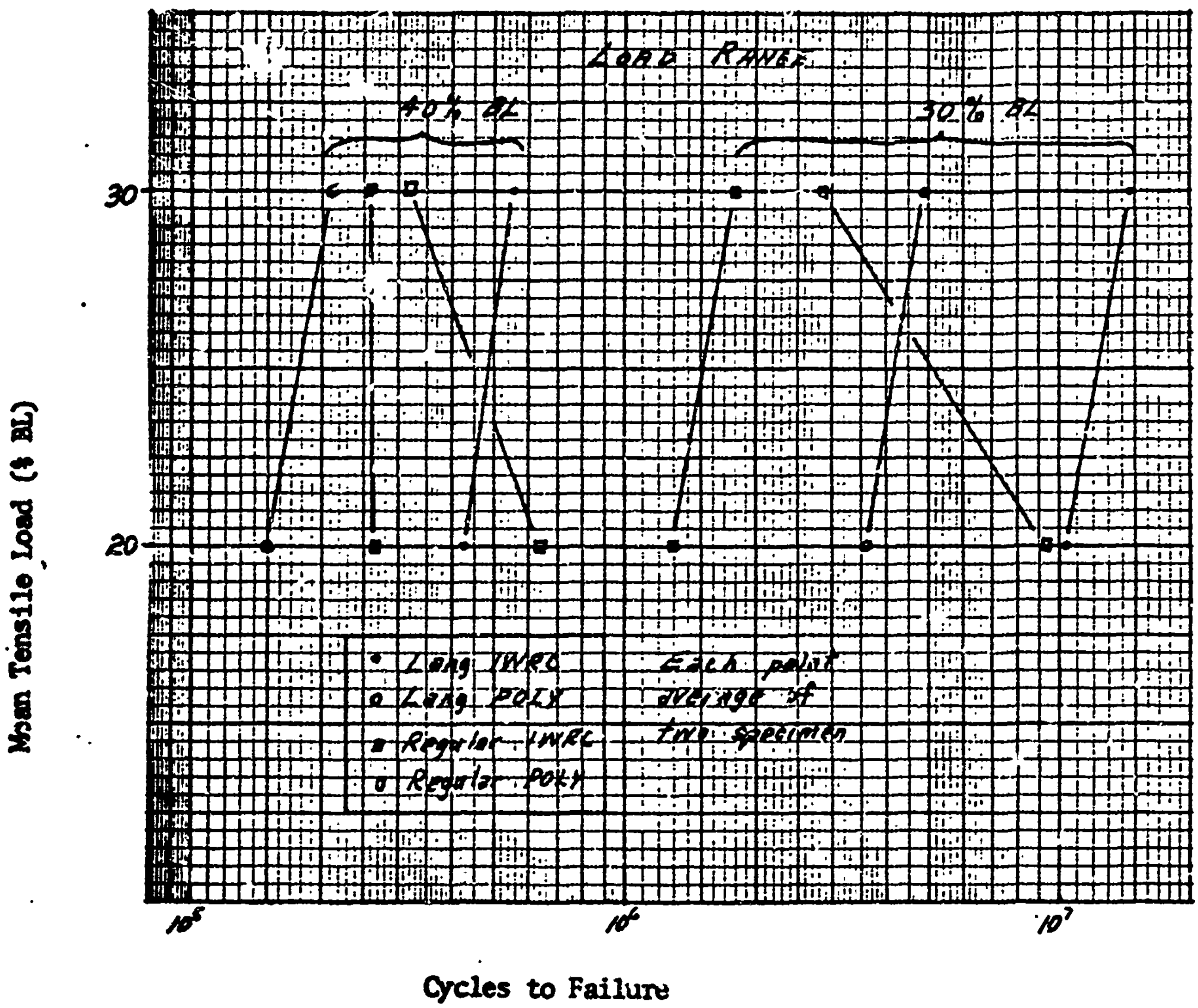


Figure 4 Axial Fatigue Life of Wire Rope versus Load Range

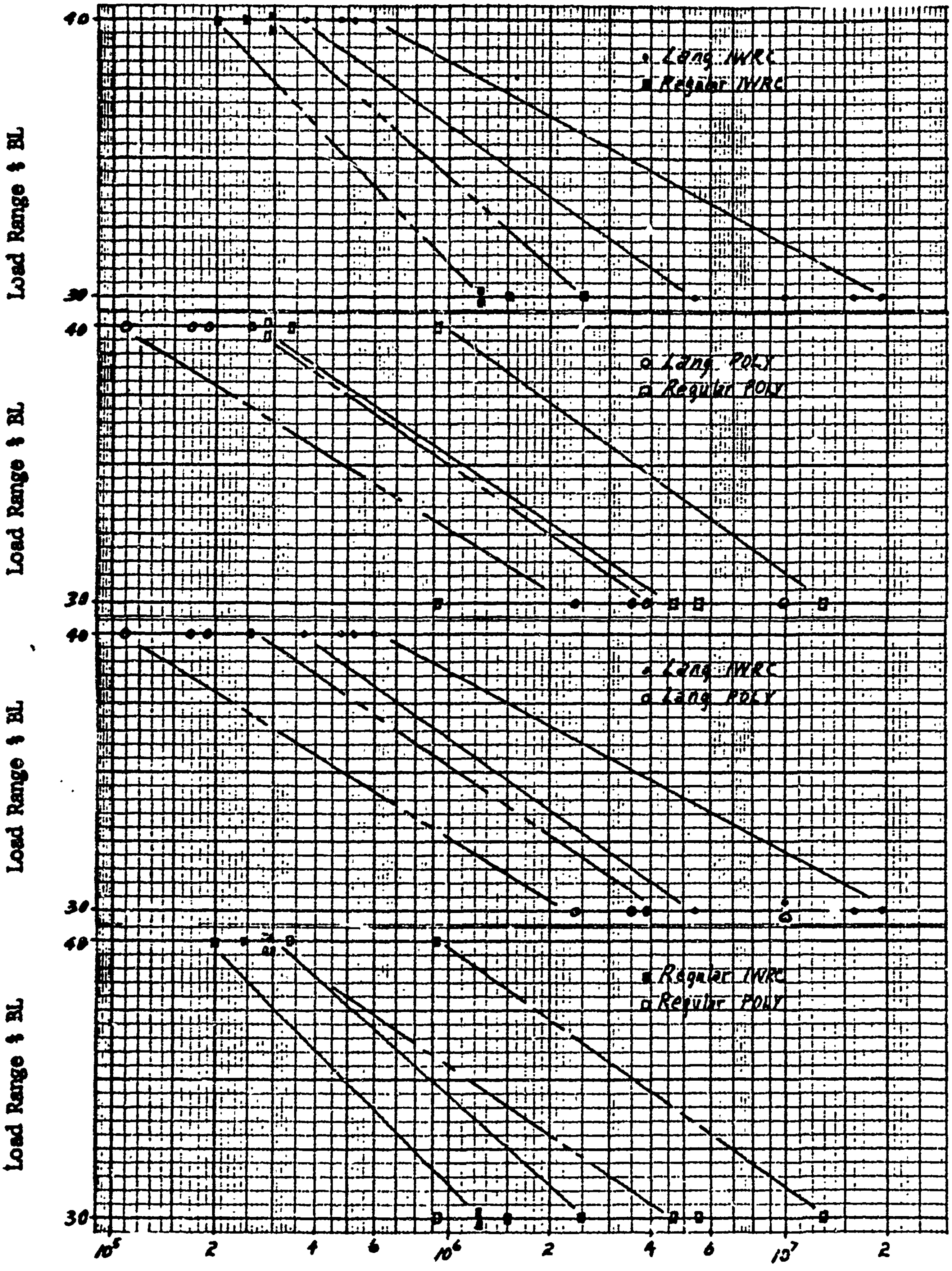


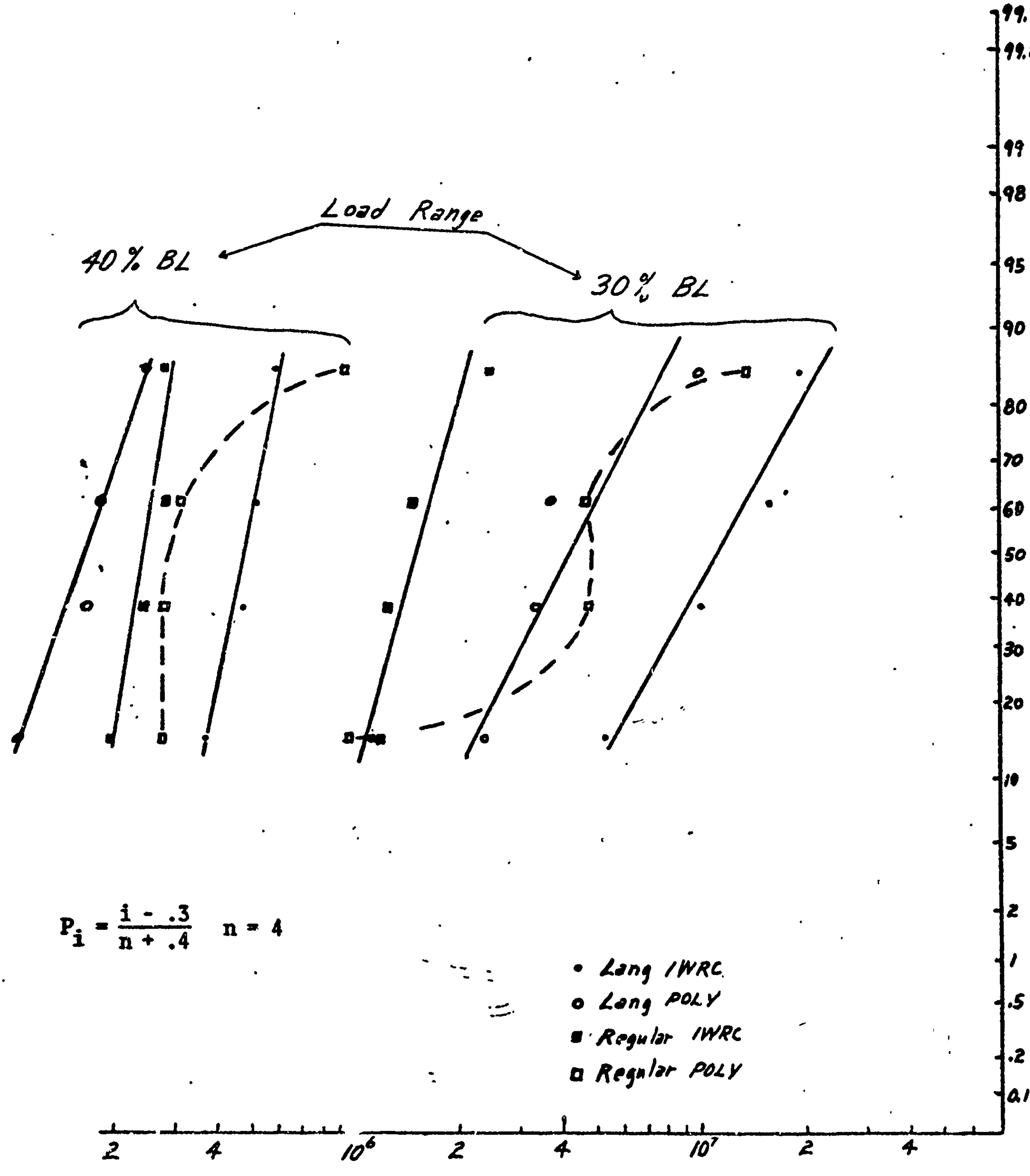
Table 3 $2^3$ Factorial ANOVA Summary

| SOURCE | M.S. | D.F. | F-Ratio | Sig. Level |
| --- | --- | --- | --- | --- |
| TOTAL | 25.528 | 31. | | |
| BETWEEN | 78.551 | 7. | | |
| A | 48.263 | 1. | 4.7963 | 0.0364 |
| B | 5.600 | 1. | 0.5566 | 0.5308 |
| C | 288.991 | 1. | 28.7198 | 0.0001 |
| AB | 82.899 | 1. | 8.2385 | 0.0083 |
| AC | 49.082 | 1. | 4.8777 | 0.0350 |
| BC | 4.916 | 1. | 0.4886 | 0.5021 |
| ABC | 70.108 | 1. | 6.9673 | 0.0137 |
| WITHIN | 10.062 | 24. | | |

Figure 5

Cumulative Frequency Distribution

of Axial Fatigue Life




$$P_i = \frac{i - .3}{n + .4} \quad n = 4$$

## RESULTS OF STRAND TESTS

The 1 x 25 strand fatigue life data is shown in Table 4.

Table 4 Axial Fatigue Life of 1 x 25 Strand in Millions of Cycles

| Load Range | 30% BL | | 40% BL | |
|---|---|---|---|---|
| Mean Load | 20% BL | 30% BL | 20% BL | 30% BL |
| Two specimen | 0.387 | 0.236 | 0.262 | 0.053 |
| each level | 0.383 | 0.400 | 0.210 | 0.104 |
| Average | 0.385 | 0.318 | 0.241 | 0.078 |
| Pooled Average | 0.351 | | 0.159 | |

The fatigue life data is plotted in Figure 7 as a function of load range. Also shown in this figure are 1 x 25 strand data obtained by Woods Hole Oceanographic Institution (11) and a trend line reported by a leading wire rope manufacturer. The failure criterion for the manufacturer and Woods Hole was the first wire break, while the criterion used for tests reported here, based on shift in resonance frequency, resulted in two or more broken wires. The testing frequency of the other data shown is also different.

Once again temperature was primarily dependent on load range. The strand temperature is shown in Figure 8. On two specimens, the temperature doubled during the last minute before failure. This rise in temperature near the end of the fatigue life of axially loaded strands has been observed elsewhere.

## RESULTS OF SINGLE WIRE TESTS

Table 5 shows the axial fatigue life of single wires tested under the same load spectrum employed in the strand and wire rope tests. The fatigue data points are plotted in Figure 9 as a function of load range.

Figure 7 Axial Fatigue Life of 1 x 25 Strand as a function of Load Range

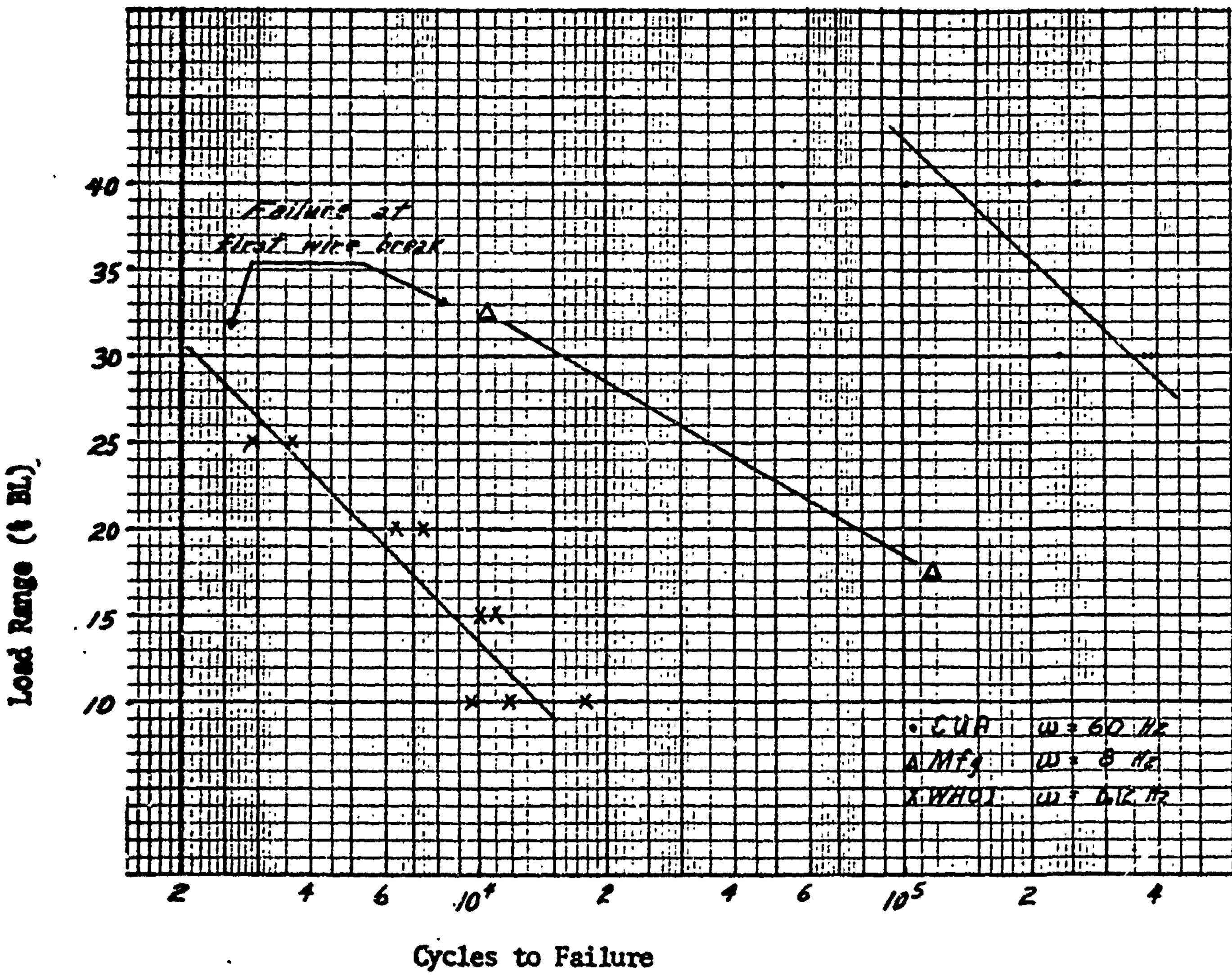


Figure 6 Wire Rope Surface Temperature as a Function of Load Range and Frequency

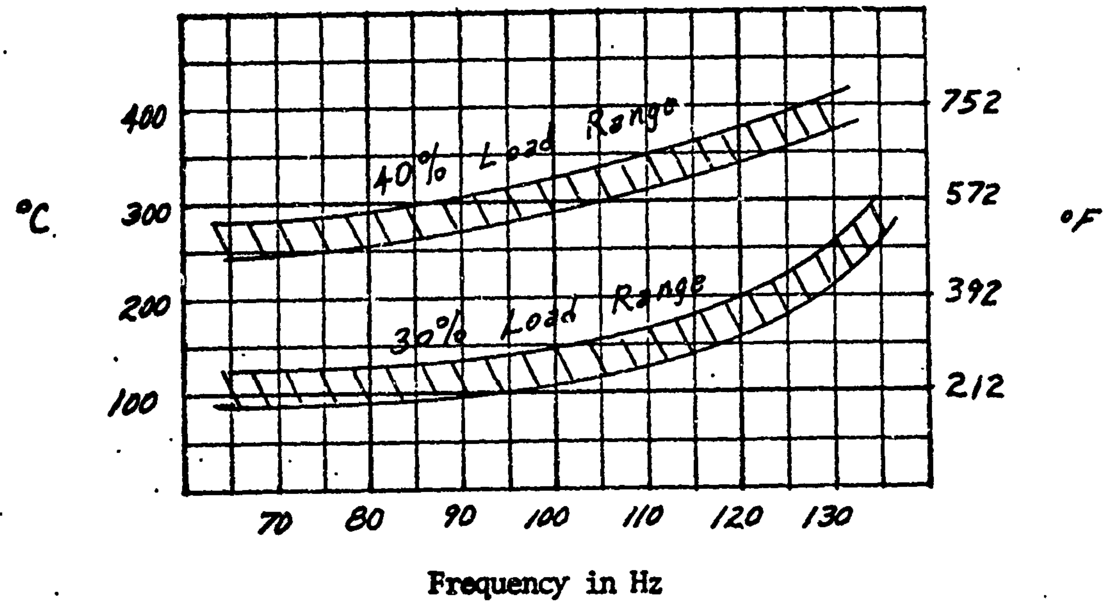



Figure 8 1 x 25 Strand Surface Temperature as a Function of Load Range and Frequency

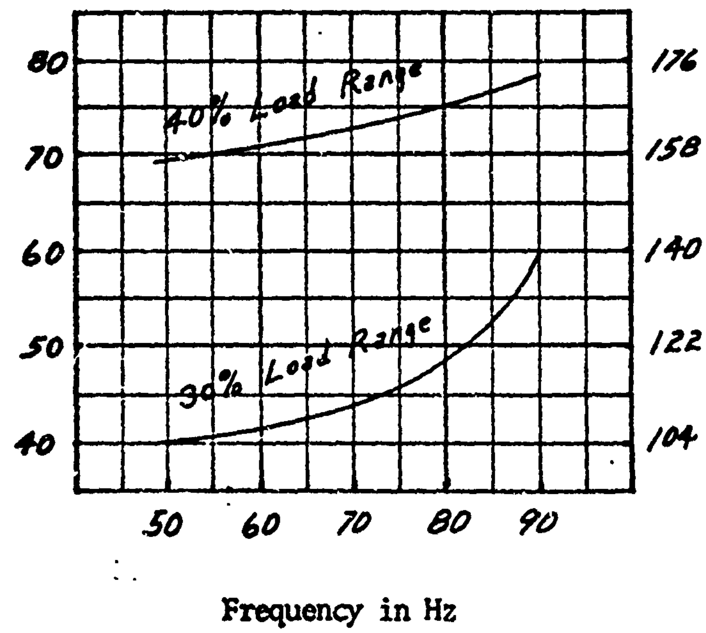


Figure 9 Axial Fatigue Life of Single Wires as a Function of Load Range

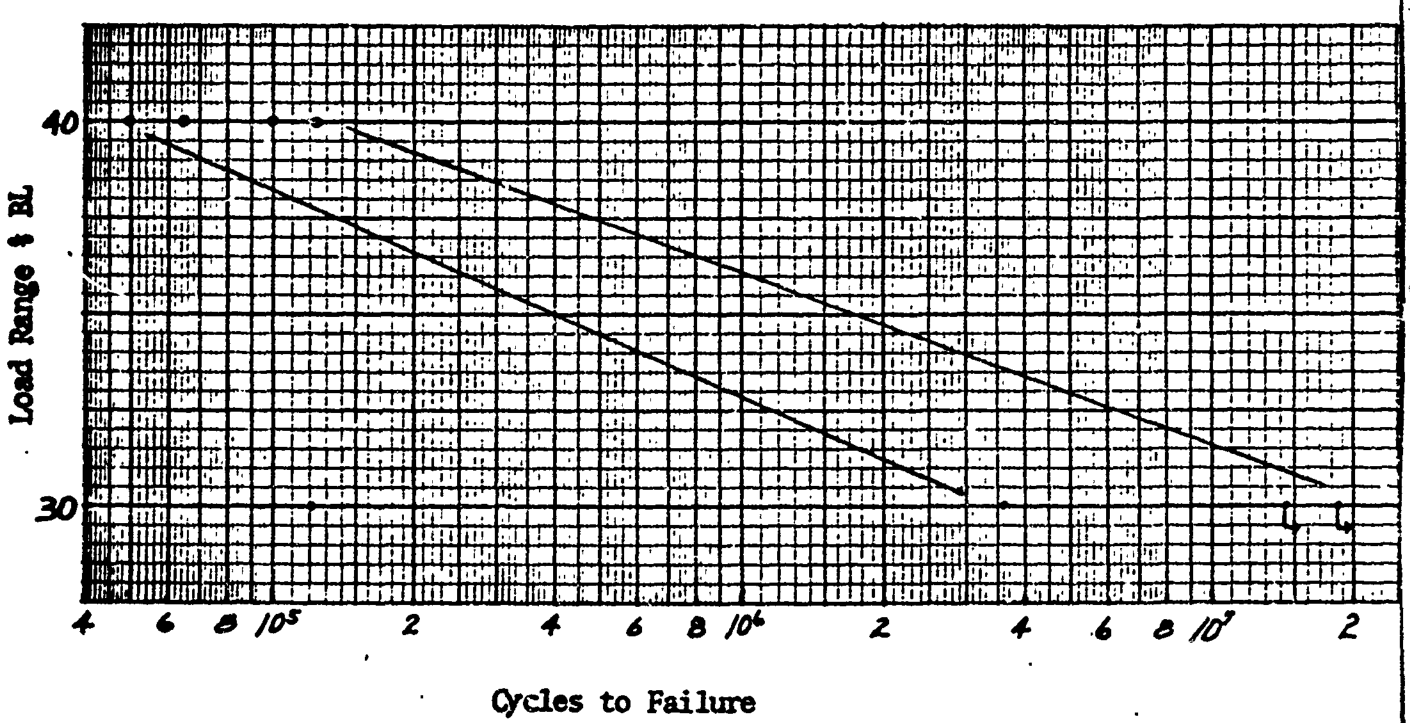


Table 5 Axial Fatigue Life of Single Wires in Millions of Cycles

| Load Range | 30 | | 40 | |
|---|---|---|---|---|
| Mean Load | 20 | 30 | 20 | 30 |
| Two Specimen | 14.360 | 3.6 | 0.050 | 0.125 |
| each level | 18.505 | 0.121 | 0.067 | 0.100 |
| Average | 16.432 | 1.860 | 0.058 | 0.112 |
| Pooled Average | 9.146 | | 0.85 | |

## DISCUSSION OF RESULTS

### 1. Wire Rope

The major aim of this study was to determine the effect of four different factors on the axial fatigue life of wire rope. As shown by tabulated and graphical presentation of the data, construction, core and load range have quite noticeable effects, while mean load did not. Only the regular poly wire rope reacted with a lower fatigue life when the mean load was increased. The effect of mean load on the regular, poly core rope was more noticeable at the lower load range condition.

Construction and core had sufficient effect on the fatigue lives to separate each of the four groups of wire rope at the various load conditions. Lang construction gave the best performance when combined with an IWRC core, while regular and lang construction with a poly core gave the poorest performances. The interaction of construction and core is a factor to consider in view of the performance of the regular construction poly core rope. The great spread in fatigue data of this rope, however, precludes any definite statement on its value.

The factor of load range had the greatest and overriding effect on all four wire ropes. The 10 percent increase in load range from 30 to 40 generally resulted in a 90 percent to 98 percent decrease in axial fatigue life as computed from the pooled averages.

To permit generalizing the results of this test to the whole wire rope population, a statistical analysis of the data was performed. The ANOVA summary in Table 4 shows the statistical significance of each factor considered and interactions. The significance level column shows the probability that the results obtained here are purely random.

2. 1 x 25 strand

The results of the 1 x 25 strand tests show that load range had a much greater effect than mean load. The mean load had a noticeable effect only at the higher load range. Of most importance is the low axial fatigue life of the strand compared to the wire rope. One might suspect that the BL of the strand, 5,200 lbs. (2.4 m.t.) was too high; that is, if the BL was taken higher than the actual value, then the tensile loads applied, which were a percent of the BL, would be higher than stated here. Thus the fatigue life would be shorter. This would not appear to be the case, however, if one notes that the ropes composed of six strands had a BL of 22,800-26,800 lbs. (10-12 m.t.). Since the core supposedly carries no tensile loads this would yield about 4,500 lbs. (2 m.t.) per strand. If one then adds the manufacturers estimate of BL loss due to helix winding about the core, the 5,200 lbs. (2.4 m.t.) figure seems reasonable.

Test data on 1 x 19 strand from two other sources are plotted on the same graph as the present data. Both the manufacturer's and the WHOI results are lower than those of this study. This may be attributed in part to the differences in failure criteria and the differences in test frequencies. The apparent frequency effect on the strand data is shown in Figure 10. A comparison of wire, strand, and rope axial fatigue leads to the possibility, shown in Figure 11, that closing the strands about the core of wires into the strand, and subsequently closing into a rope, are of great benefit in terms of increasing resistance to axial fatigue damage.

Another possible explanation for the difference in strand and wire rope fatigue lives is suggested by the surface temperature recorded for each. As shown in Figures 6 and 8, the wire rope operated at about three times the temperature of the strand. Current speculation in the fracture mechanics community is that higher temperature may account for longer fatigue life. This point of view does not account, however, for the performance of the poly core ropes which ran at temperatures below 70° C.

3. Single Wires

Once again the strong effect of load range is noticeable in the single wire data. Mean load had a reversed effect at the two load ranges. Figure 11, mentioned earlier, shows how the axial fatigue life of the prepared wire specimens compares with the strand and wire rope data. Only at the lower load range does the single wire data and pooled average rope data agree.

Figure 10 Axial Fatigue Life of 1 x 25 Strand as a Function of Frequency at a 30% Load Range

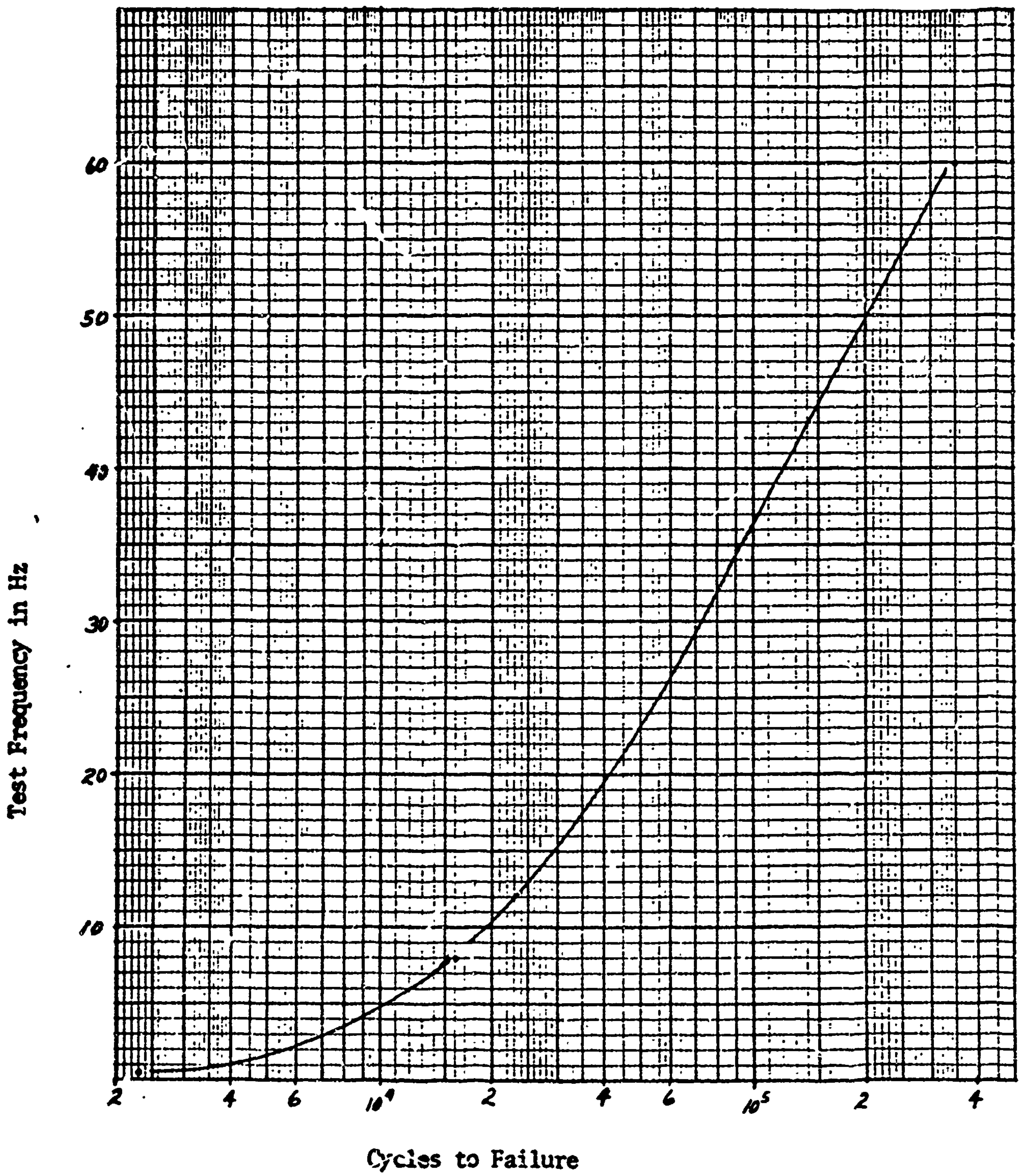
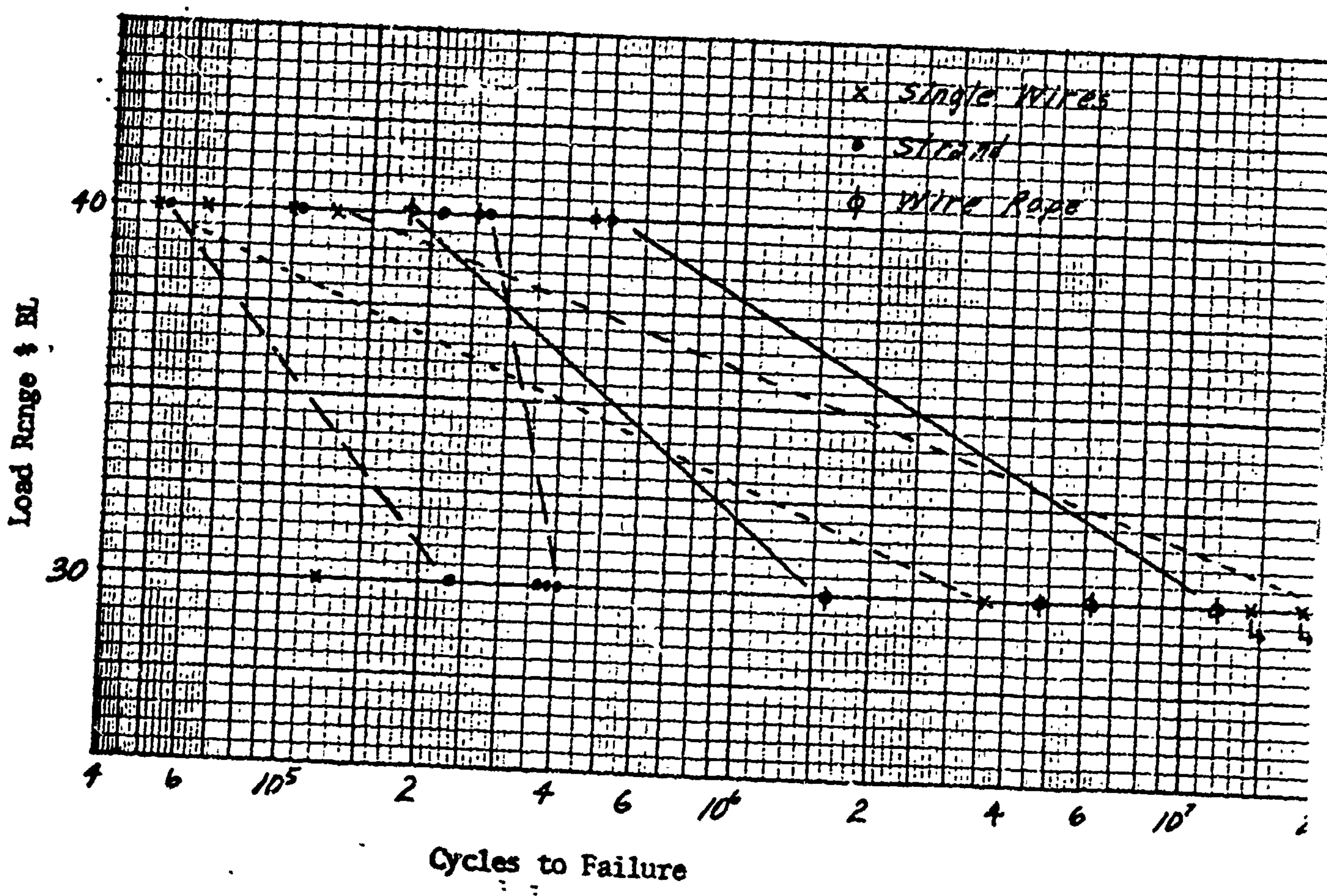


Figure 11 Axial Fatigue Life of Wire, Strand and Rope as a Function of Load Range



## CONCLUSIONS

On the basis of this experiment the following tentative ranking in order of resistance to axial fatigue failure of the four wire ropes tested can be made.

1. Lang, IWRC
2. Regular, POLY
3. Lang, POLY
4. Regular, IWRC

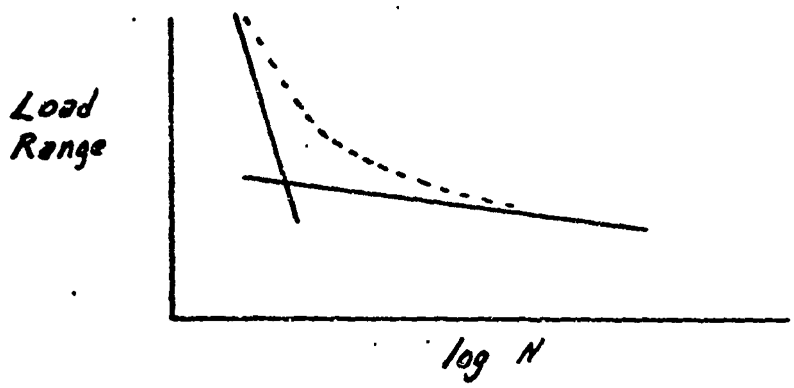
Furthermore, it appears that mean load is not a significant factor in axial fatigue testing of wire rope.

The effect of frequency shown by the three sets of strand data suggests that its effect probably is present in the wire rope data. Information from other testing facilities would be of value here in determining the influence of test frequency on axial fatigue life.

From the data generated in this study, it appears futile to attempt to predict wire rope fatigue life from tests on strand or single wires. The strand data are far too conservative. Although the wire data agreed with the rope data at the 30 percent load range, it deviated sharply at the 40 percent level and the slopes of the two data bands were quite different.

In order to evaluate the significance of factors considered in this study in the ocean environment it would be desirable to repeat this experiment, replacing air with a synthetic sea water solution. The test specimen would come from the same reels as in the present study and so permit a more precise determination of sea water effects on fatigue life.

It is also deemed appropriate to conduct another separate study solely of wire rope at load ranges above and below the ones reported here. This would permit plotting the dashed curve shown below which can then be used to determine the intersection of the two solid lines. These last two lines are the plastic and elastic universal slope lines discussed by Manson (16) in his method of predicting fatigue life on the basis of tensile properties of the specimens.



## Acknowledgment

The authors wish to thank Dr. H.H. Vanderveldt for initiating this study and Mr. Guillermo Ome for his help in preparing specimens and collecting data. Thanks are also due Mr. Louis Winneberger, Mr. Wallford Fiske, and Mr. Gary French for machining the grips and other fixtures necessary in the preparation of the specimens.

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# Appendix A

## Definition of Wire Rope

## Terminology

## From Bethlehem Steel's Wire Rope Handbook

## DEFINITION OF TERMS

Explanation of a few basic terms may be helpful to the user. We will use as our example one of the most common constructions, that of the 6 x 19 Class. The full, specific designation of our example is 6 x 25 filler wire Type W with IWRC, regular lay, Form-Set, Purple Strand.

**Class**—This is a nominal grouping of basically similar wire ropes having approximately the same number of wires in the strand, and the same number of strands per rope. The 6 x 19 Class is made up of wire ropes having anywhere from 15 to 26 wires per strand.

**Construction** — Wire rope is referred to first by the number of strands per rope, then by the number of wires per strand, then by the specific makeup of the strand, and finally the type of core, lay, and other information.

The rope is made up of 19-wire strands. The strands are each laid 12-6-1; that is, 12 outer wires, six inner wires, and one center wire. The six filler wires, of course, are in addition to these 19 wires.

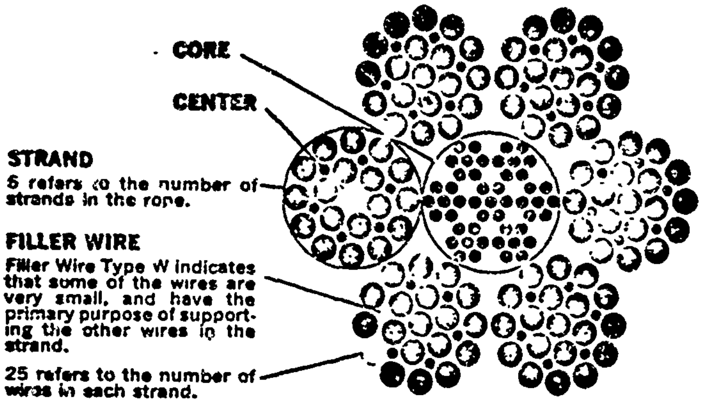
**IWRC** — Independent wire rope core, around which the strands of the rope are laid.

**Regular lay** — Refer to the discussion of lay on page 6.

**Center** — Term applied to the center of a strand.

**Form-Set** — Bethlehem's trade name for preformed wire rope. Form-Set means that during manufacture the wires and strands have been preset in the helical shape they take in the rope. (More detailed description — page 4.)

**Purple Strand** — Indicates the strength grade of the steel, and is Bethlehem's trade name for improved plow steel.




**Strand**—Strand is made of wires, and is usually referred to by the number of wires it contains. Thus, a 7-wire strand has 6 wires laid around a single, center wire.

## GRADES OF WIRE ROPE

While there are many different grades of wire rope, the vast majority of ropes fall into one of the categories described below. The others fill highly specialized requirements.

**Purple Plus** — Bethlehem's trade name for *extra improved plow steel*, the strongest rope available. Usually identified with *two* Purple Strands.

**Purple Strand** — Bethlehem's trade name for *improved plow steel*, used for most operating applications. Usually identified with *one* Purple Strand.

**Plow**—Formerly the basic grade of wire rope, this grade is now only specified where service requirements are not severe.

**Aircraft**—Aircraft rope and strand are made to a special strength grade, usually referred to as "Aircraft Grade."

**Elevator ropes**—The various ropes used for elevators are discussed in detail on page 80. The special grades manufactured by Bethlehem for elevator use are Extra High Strength Traction Steel, High Rise Special Traction Steel, Traction Steel, and Iron.

## FORM-SET

**Form-Set** is Bethlehem's trade name for preformed wire rope. Form-Set means that the wires and strands have been preset during manufacture into the permanent helical shape they take in the completed rope. **Unless otherwise specified, wire ropes are normally furnished Form-Set.**

Preforming greatly reduces internal stresses; eases rope handling. Cut ends need not be seized or served to prevent unwinding. Preformed ropes run smoother and truer than non-preformed, are less susceptible to bending fatigue, and give longer service life.

## WIRE ROPE CORES

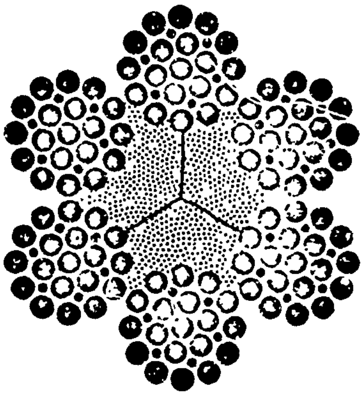
The term *core* applies only to the center of a wire rope. There are many kinds of cores, some of which are listed below. The primary purpose of the core is to support the strands of the rope during its service life.

**Fiber core**—Either of Polypropylene or other fibrous plastic material, or of fibrous vegetable material. In the latter case, the core closely resembles the familiar manila rope. Fiber core material is chosen for toughness and resilience, rather than strength.

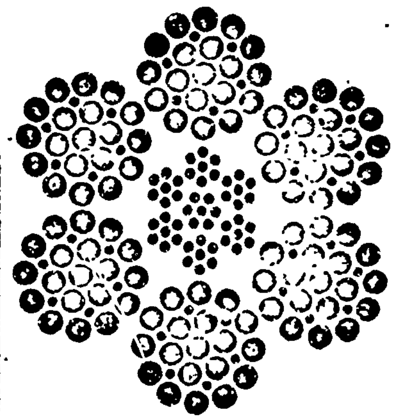
**Independent wire rope core (IWRC)**—IWRC may be either a 6 x 7 wire rope with a fiber core or a 6 x 7 wire rope with a wire-strand core (7 x 7 wire rope). An IWRC is somewhat less flexible than fiber core, but has much greater resistance to crushing plus additional rope strength.

**Wire strand core (WSC)**—May or may not be of the same construction as the outer strands of the rope. The WSC gives the smoothest and most solid support for the outer strands, and is used where loads or bearing pressures are greatest. Ropes with WSC are the least flexible of all, and are seldom used on operating ropes.

**Special cores**—Made to suit special requirements of specific applications, their content and makeup vary widely.



Rope with fiber core.



Rope with an independent wire rope core, usually referred to as IWRC.

## EXPLANATION OF LAY

Lay is sometimes an undeservedly confusing wire rope term, and its meaning is important to know. Essentially, the term derives from the way in which the rope is put together. Contrary to first appearance, wire rope is *not twisted* together from wire and strand. Rather, it is *laid* in position. Indeed, great care is taken in the manufacture of wire rope to ensure that no twist is imparted to the wires or the strand.

The term lay is used in two ways.

1. To describe a rope's appearance or construction as regards the *direction* of its spiral.
2. In measuring the *length* of the spiral of the rope.

When used in the first context, the terms *right* and *left* refer to the way the strands rotate around the rope, and the terms *regular* and *lang* refer to the way the wires rotate in the strands in relation to the direction of the strands in the rope.

In *right* lay, strands rotate around the rope in a clockwise direction, as the threads do in a right-hand bolt.

In *left* lay, the strands rotate counterclockwise, as in a bolt with left-hand threads.

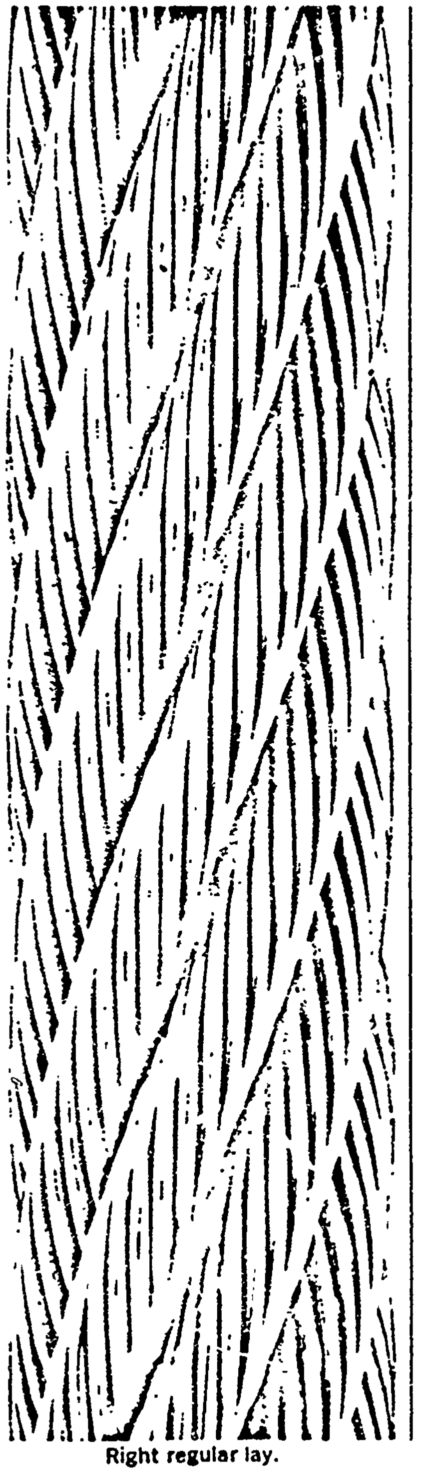
*Regular* lay means that the wires in a strand rotate in a direction opposite to the direction in which the strand rotates around the rope. On a rope with strands laid to the right, "regular" would mean that the wires in each strand were laid to the left. The net result of regular lay is that the wires run roughly parallel to the center line of the rope. (Most users of wire rope are familiar enough with terminology to understand that when we say "regular lay," throughout this booklet, we imply "*right* regular lay." This is common practice throughout the industry. For those who may not be fully aware of this practice, we have noted it at the bottom of all pages listing suggested ropes.)

*Lang* lay is just the reverse of regular. Wires in a lang lay rope rotate in the same direction as the strands, giving the appearance of spiraling diagonally around the rope.

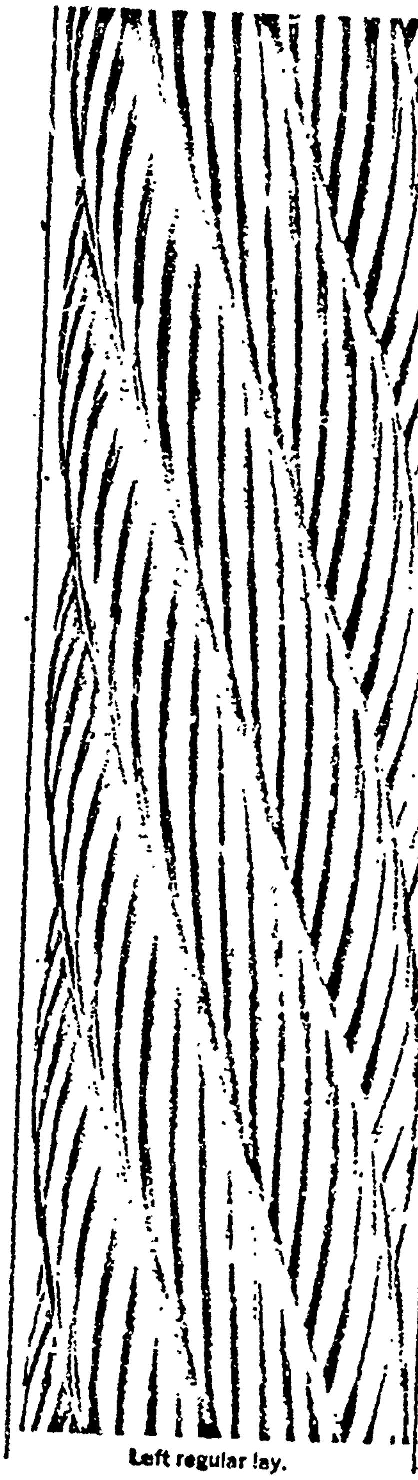
In its second meaning, as a unit of measure, rope *lay* means the lengthwise distance a single strand covers in making one complete turn around the rope. Lay length is measured in a straight line parallel to the center line of the rope, *not* by following the strand as it spirals around the rope. Lay length is directly related to rope diameter, providing a convenient basis for rope inspection. An example of the use of this would be in the requirement that a rope be removed from service after a certain number of wires are broken in one rope lay. Such a requirement would be more dependable than one requiring removal on the basis of broken wires per foot.

"Lay" as a unit of measure


Showing how "one rope lay" is the lengthwise distance in which a strand makes one complete turn around the rope.

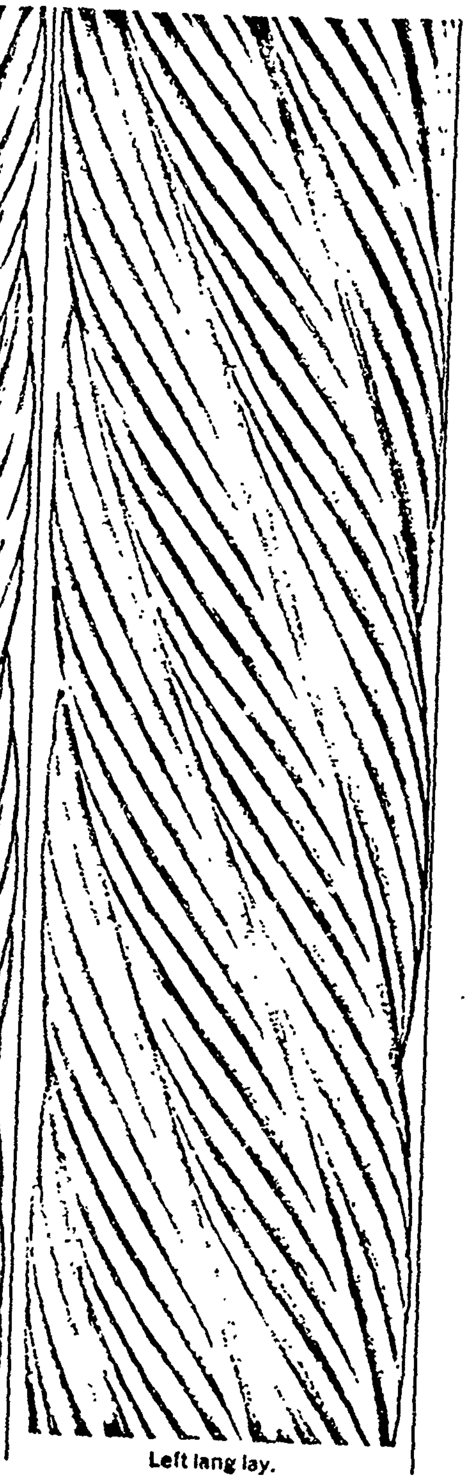


Right regular lay.



Left regular lay.

Right lang lay.



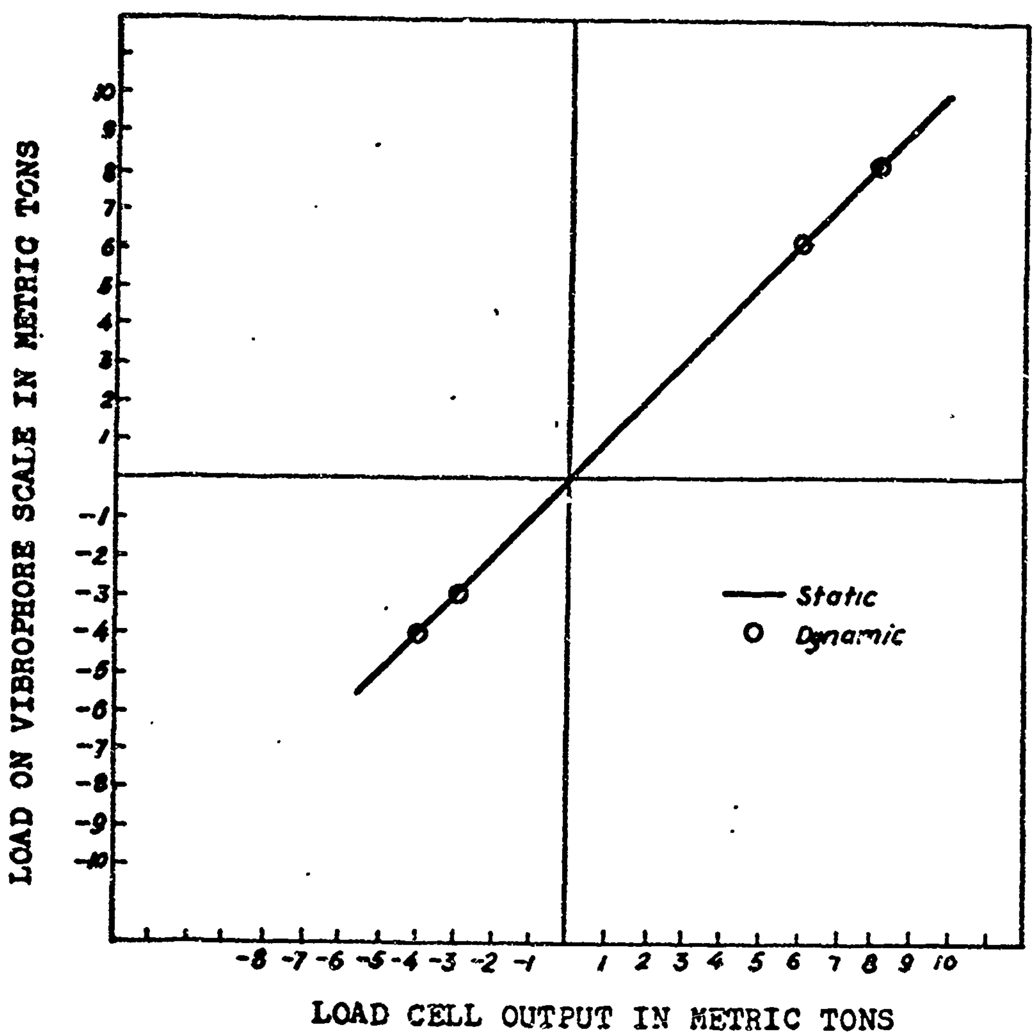
Left lang lay.

# Appendix B

## Calibration of Testing Machine

STATIC AND DYNAMIC CALIBRATION CHECK

OF AMSLER VIBROPHORE TESTING MACHINE



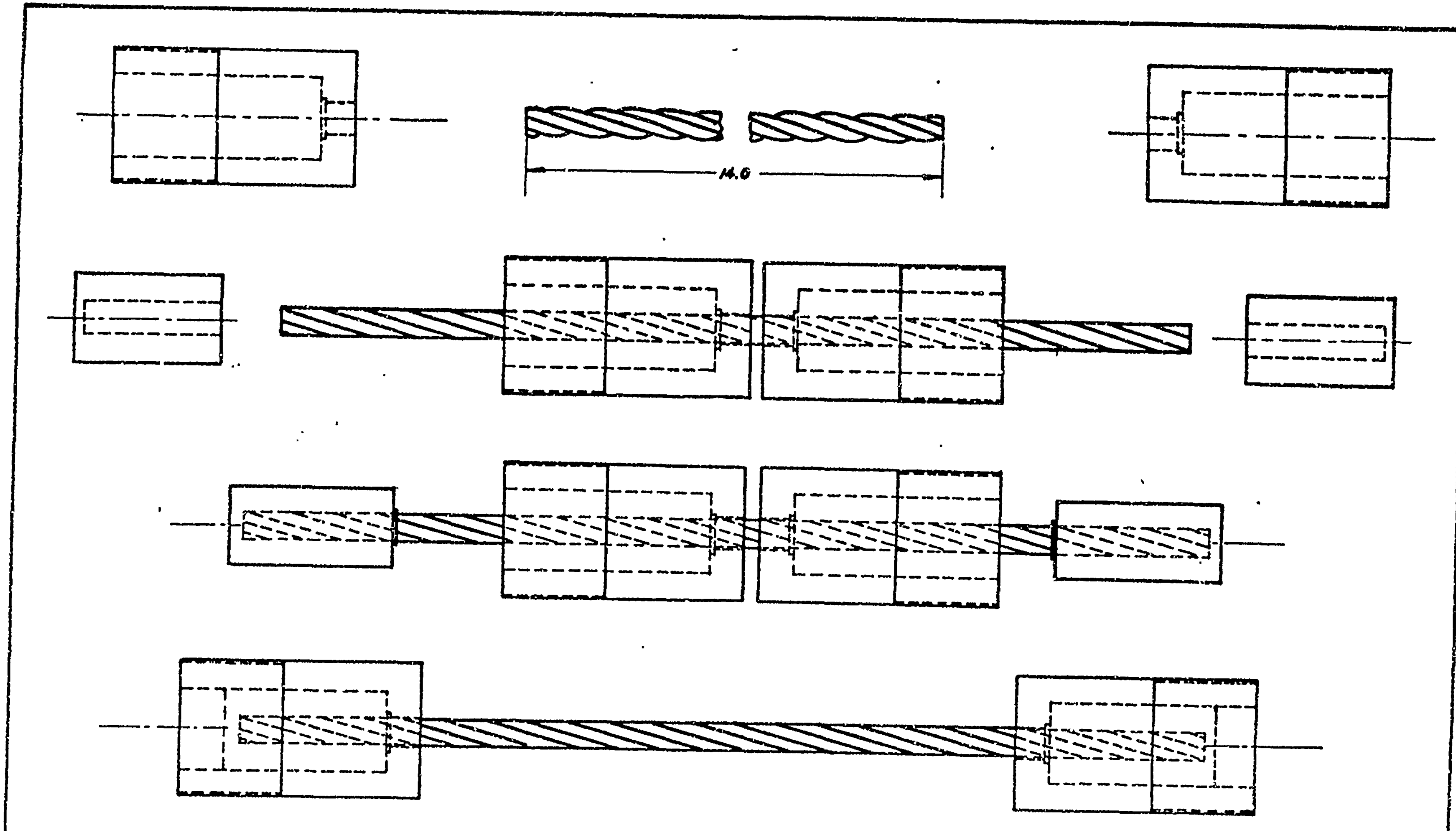

Calibration Procedure: Two different load cells were used to obtain all the calibration data points. One cell had a 10K capacity, the other 50K; both gave a 2 mv/v signal. The signal was processed by a Honeywell Accudata 105 Gage Control Unit and then fed into a Digital Voltmeter or an oscilloscope. The Digital Voltmeter yielded the static readings while the oscilloscope gave the dynamic readings.

Date: 15 Feb 1971

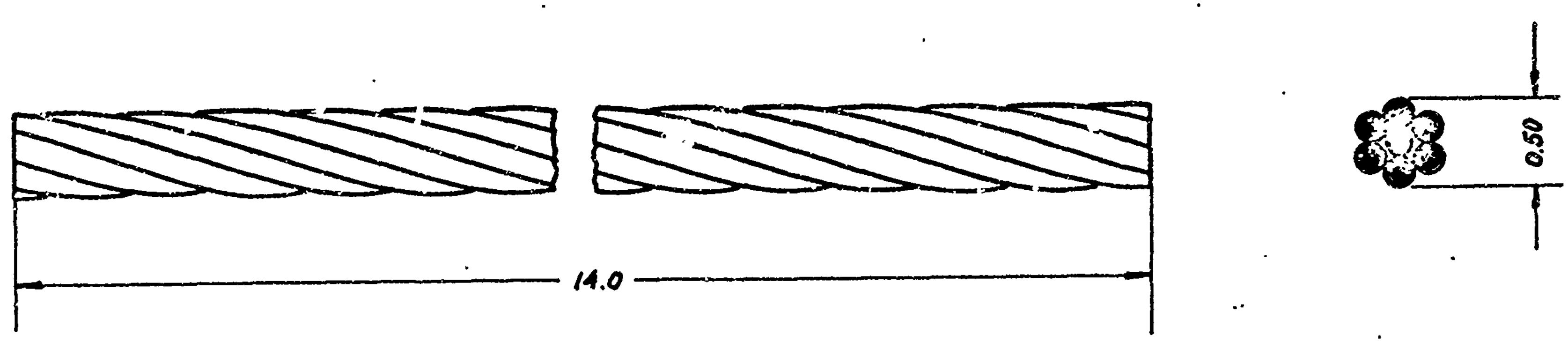
F. Matanzo

# Appendix C

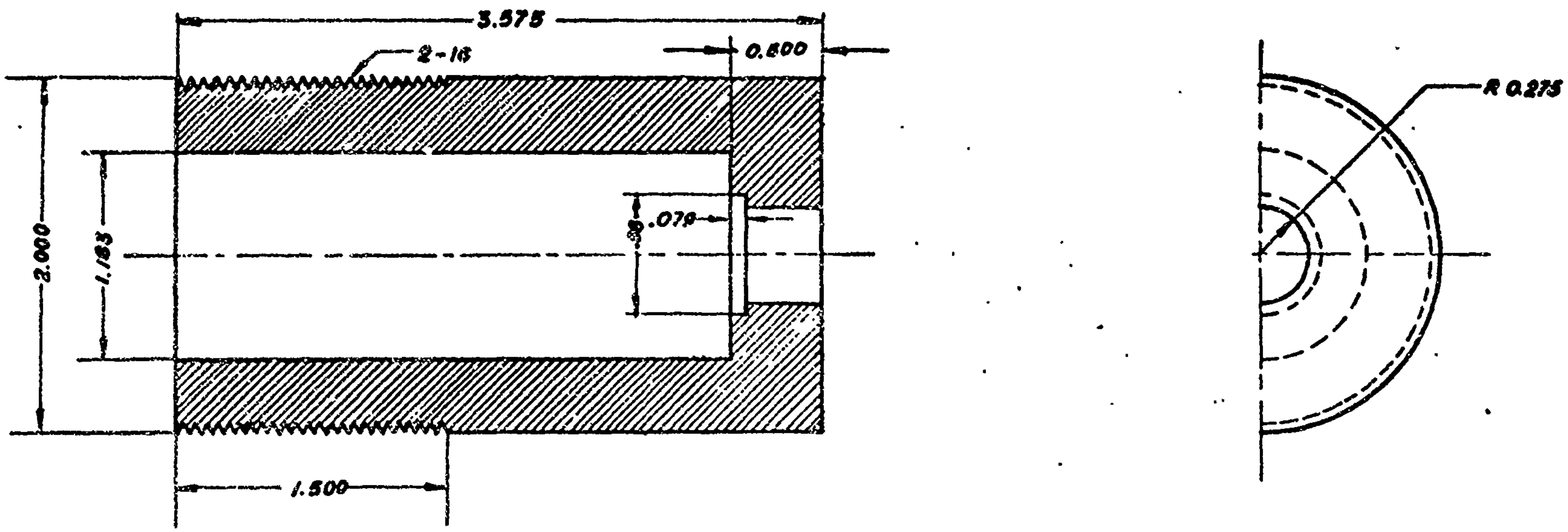
## Preparation of Wire Rope Specimen



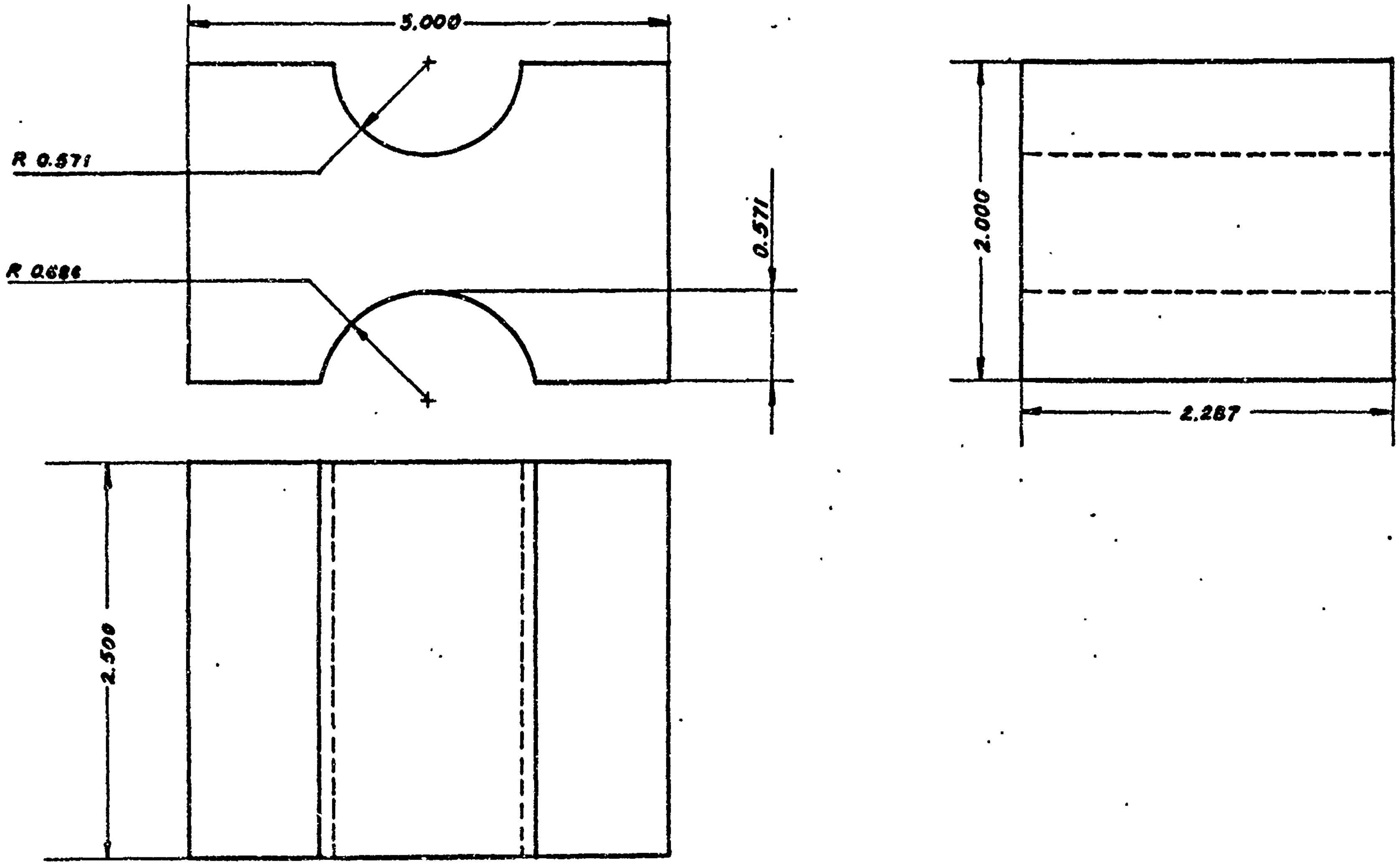

| | | |
|---|---|---|
| Contract No. N00024-70-C-5439 | Name: SPECIMEN ASSEMBLY | Date: May 21, 1971 |
| Matl. | Drawing No. 1 | Drawn by : G. Orne |
| | Scale 1:2 | Checked by: F. Motonzo |




| | | |
|---|---|---|
| Contract No. N00024-70-C-5439<br>Matl. : Improved plow steel | Name : SPECIMEN DIMENSIONS<br>Drawing No. 1<br>Sca 1:1 | Date : May 19, 1971<br>Drawn by : G. Ome<br>Checked by : F. Matanzo |

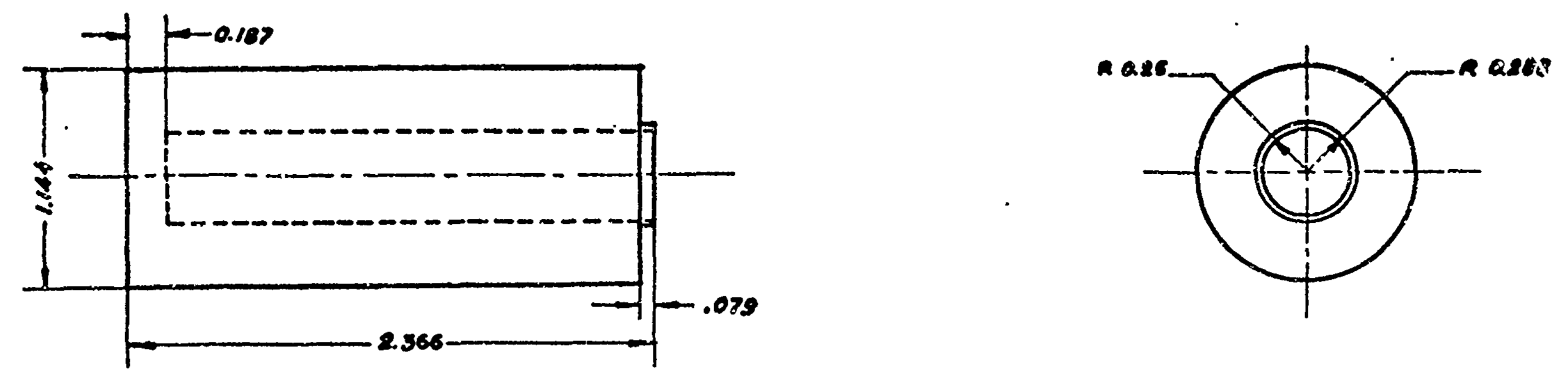



| | | |
|---|---|---|
| Contract No. N00024-70-C-5439 | Name : Adaptor | Date : May 17, 1971 |
| Matl. 1040 Steel | Drawing No. 1 | Drawn by : B. Ome |
| | Scale 1:1 | Checked by : F. Matonzo |



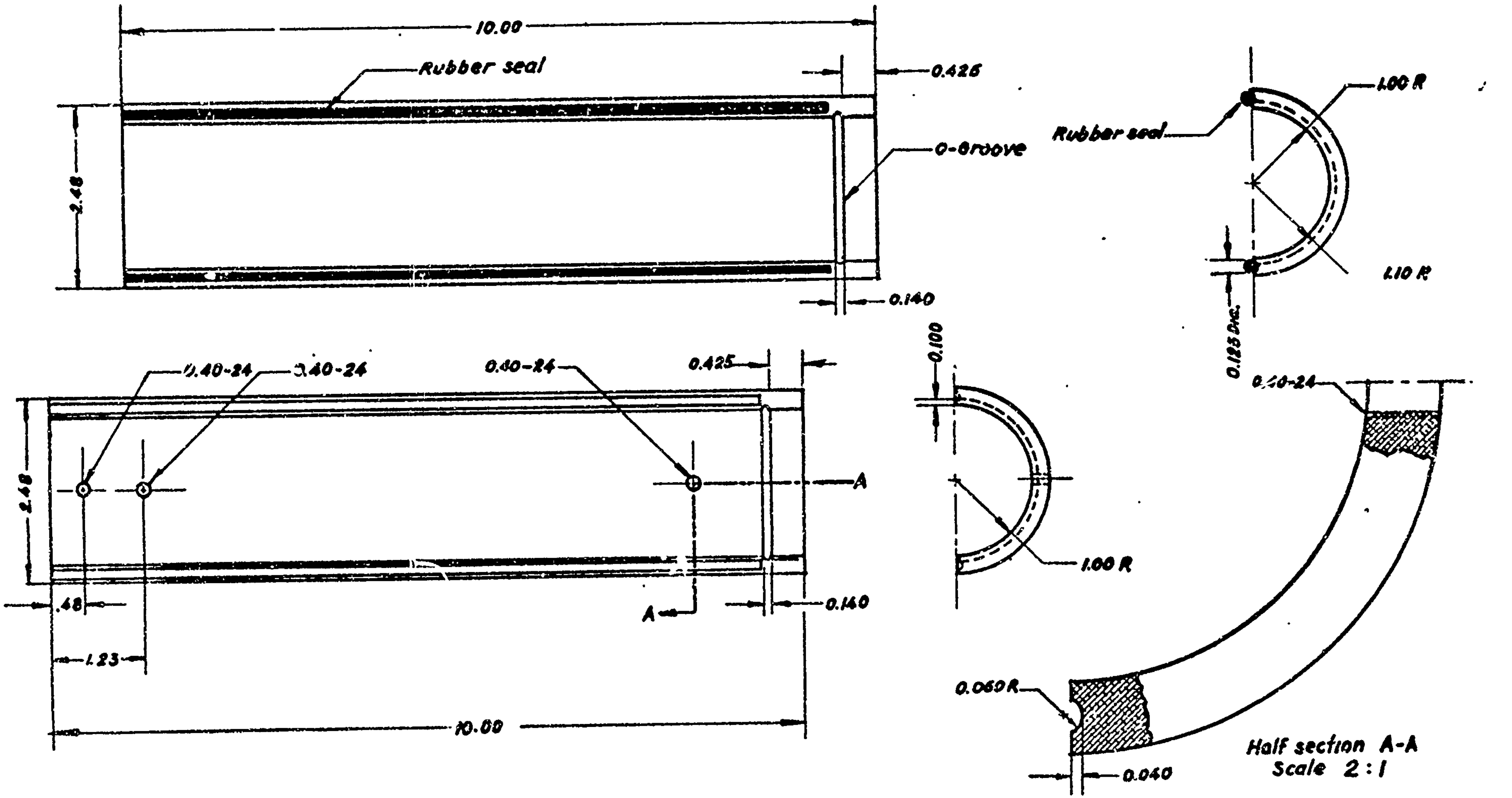

| | | |
|---|---|---|
| Contract No. N00024-70-C-5439 | Name : PRESSING DIE | Date : May 18, 1971 |
| Matl. 4340 Steel | Drawing No. 1 | Drawn by : S. Ome |
| | Scale 1:1 | Checked by : F. Motonzo |


Bushing' before pressing




Bushing after pressing

| | | |
|---|---|---|
| Contract No. H00024-70-C-5439<br>Matl.: 6061-T651 Alum.; Ann. @ 775°F for 2 hrs. | Name : Aluminum bushing<br>Drawing No. 1<br>Scale : 1:1 | Date : May 17, 1971<br>Drawn by : G. Ome<br>Checked by : F. Matanzo |




| | | |
|---|---|---|
| Contract No. N00024-70-C-5459 | Name COOLANT SLEEVE | Date: May 20, 1971 |
| Matl. Aluminum. | Drawing No. 1 | Drawn by: G. Ome |
| | Scale 1:2 | Checked by: F. Matanzo |