WIRE ROPE TERMINATIONS

EFFICIENCY AND SERVICE LIFE OF WIRE ROPE TERMINATIONS

VOLUME I

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16. Abstract (Limit: 200 words)

Nine wire rope terminations were pull and fatigue tested to destruction to measure the termination efficiency and relative fatigue life. The terminations were selected on the basis of mine site visits and the specimens were assembled in a manner similar to industrial slings. To measure a termination's sensitivity to poor workmanship, both standard and modified assembly specimens were tested. Lang and regular construction of the 6 by 19 and 6 by 37 class wire ropes were used in diameters of 13 mm (½ in), 19 mm (3/4 in), 25 mm (1 in), 38 mm (1½ in), and 51 mm (2 in). In static pull tests rope class, construction, and diameter interacted with the termination to influence the efficiency of the termination. In axial fatigue tests using only the 6 by 19 class rope, the effect of rope construction was negligible since failure was primarily dependent on the termination type. The swaged socket, a termination requiring a high-capacity hydraulic press, gave the best overall performance in terms of efficiency and fatigue life; the short body length of the zinc poured socket was attributed with the short fatigue life. The use of thermosetting resins as a replacement for zinc was demonstrated successfully for some socket designs. The fatigue life of the termination, expressed as a percentage of the fatigue life of the wire rope, was shown to be a guide for the retirement of the wire rope in those applications were the wire rope is primarily in axial loading.

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FOREWORD

This report was prepared by Engineering Services Company, Damascus, Md. under USBM Contract number H0166079. The contract was initiated under the Metal & Non-Metal Mine Health & Safety Program. It was administered under the technical direction of the Pittsburgh Mining & Safety Research Center with Edwin Ayres acting as Technical Project Officer. Frank Naughton was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period September 1976 to August 1978. This report was submitted by the authors on August 10, 1978.

The assistance and cooperation of the subcontractors on this project is acknowledged with gratitude. The hospitality of mining personnel during the mine site visits is hopefully repaid by information in this report that may improve the safety of mine workers. The informal participation of several wire rope manufacturers and manufacturers of wire rope terminations is also acknowledged. Finally, a word of thanks to the mining consultant on this project, Mr. Wallace Barlow, who arranged for and participated in the mine site visits.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CBL	Catalog Breaking Load
ETE	Expected True Efficiency
MCA	Multiple Classification Analysis
Mod. 1	Modified Assembly Procedure No. 1
Mod. 2	Modified Assembly Procedure No. 2
MSHA	Mine Safety and Health Administration
RLC	Residual Load Capacity
SL	Service Life (fatigue life)
SLE	Service Life Efficiency
SWL	Safe Working Load
Stnd.	Standard Assembly Procedure
TBL	True Breaking Load
TE	True Efficiency
TSL	True Service Life (fatigue life)
WRT	Wire Rope Termination

SUMMARY

Wire Rope Terminations (WRT) used in the mining industry were evaluated through a comprehensive laboratory test program. Eight WRTs were identified during mine site visits while a ninth is a recently developed WRT. The nine WRTs considered are shown in Figure 1. The WRTs were evaluated with respect to True Efficiency from pull tests, Service Life from axial fatigue tests, and Sensitivity to Poor Workmanship from comparison in pull and fatigue tests of standard and modified assembly procedures. The analysis of the True Efficiency data detected the interaction effects of rope construction, rope class, and rope diameter with WRT Type. An approximate linear model is presented that predicts an Expected True Efficiency value for a particular combination of WRT Type with a rope of specified diameter, construction, and class. In this regard, only rope diameters of 13 mm (½ in.), 19 mm (3/4 in.), 25 mm (1 in.), 38 mm (1½ in.), and 51 mm (2 in.) were considered. All ropes were of either Lang or Regular construction, 6x19 or 6x37 class with independent wire rope core, and improved plow steel except for extra improved plow steel in the 51 mm (2 in.) diameter. The failure mode information disclosed typical or characteristic failures for the WRTs due to static loading or pull tests. The typical failure mode for a WRT was not always the same in fatigue testing. The Service Life data provided a relative standing on the expected field service of a WRT.

The assembly procedures developed in this program were put into a training manual which is a companion report to the final contract report. The True Efficiency, Service Life, and Sensitivity to Poor Workmanship were used to prepare a WRT selection and inspection guide which is also a companion report to the final report.

The major conclusions and implications of the study were:

1. The True Efficiency of a WRT is affected by rope class, construction, diameter, and the interaction of these factors with themselves and the WRT Type. When True Efficiency is to be optimized these factors should be considered.

2. The failure modes exhibited by a WRT in pull tests are not always the failure modes exhibited in fatigue tests. Therefore, field inspection of WRTs should not rely only on pull test failure modes.

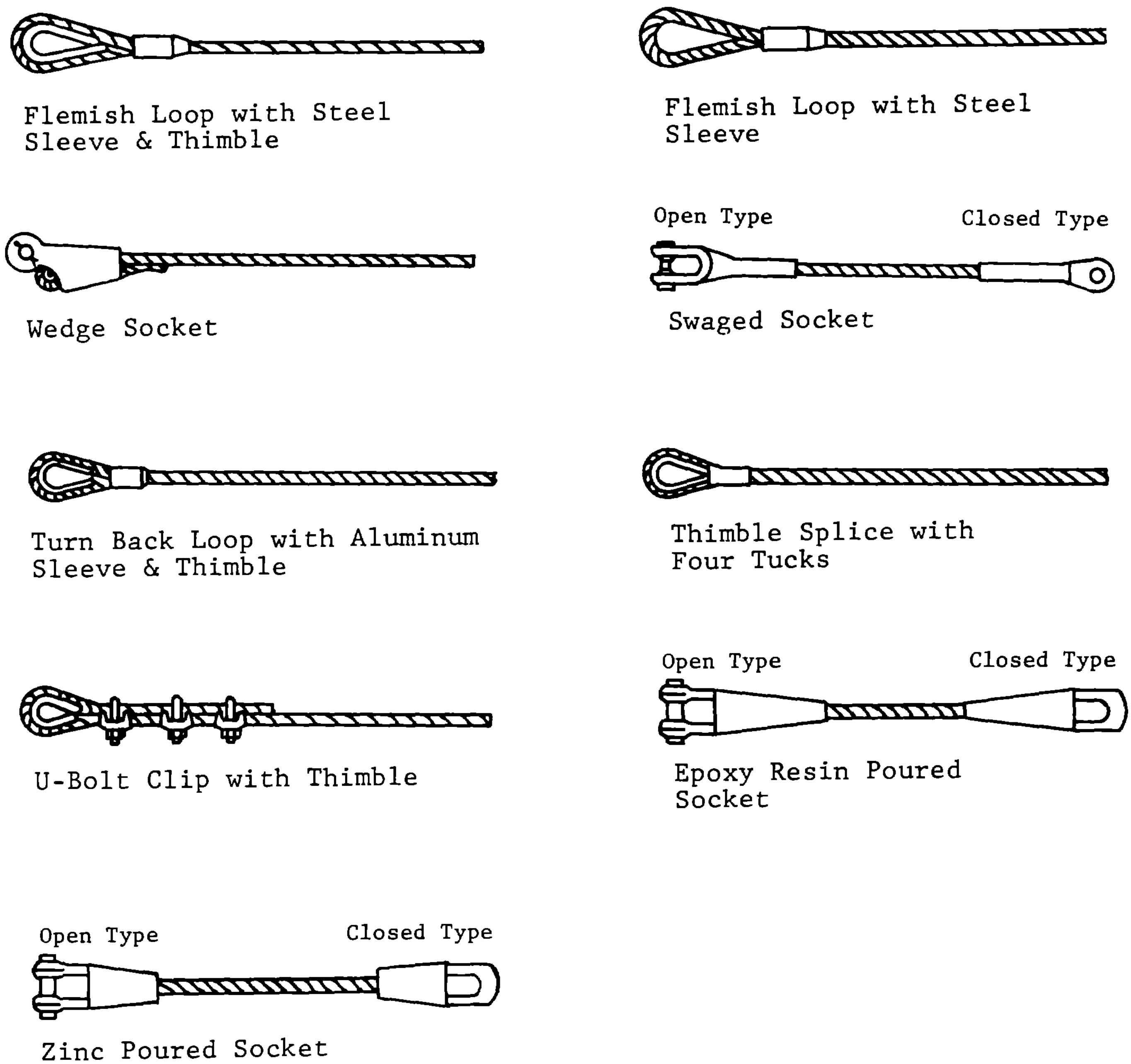


Figure 1 Wire Rope Terminations Considered

3. The use of epoxy and polyester resins to socket wire rope was demonstrated. With some reservations, these two thermosetting resins can replace zinc in preparing WRTs in the field.

4. Of the nine WRTs evaluated, the Swaged Socket gave the longest Service Life more consistently than any other. Since this WRT requires a high capacity hydraulic press, use of the most reliable WRT is still limited to those applications where the wire rope and WRT are ordered together from the wire rope manufacturer or local distributor.

5. The construction of a wire rope did not appreciably affect the Service Life of the WRT. Rope construction can thus remain a factor to be selected in response to other requirements of the rope application.

6. Although some WRTs are simple to assemble, there is not a completely "fool proof" termination. For this reason mine personnel responsible for assembling WRTs should receive some training.

7. The test program answered many questions, but also raised some new ones or was unable to resolve all questions with the data available. To provide answers for these questions several areas of further research are recommended.

1.0 INTRODUCTION

1.1 Background

The improvement of working conditions in the mining industry has received increased attention in the past few years in response to some very tragic accidents. One area in which the Bureau of Mines and the Mine Safety and Health Administration have collaborated is the use of wire rope. Since wire ropes are a major load carrying component in mining machinery and are used to carry men into the mines, any improvement in safety would be a significant contribution.

An effort completed by Battelle in 1971 evaluated hoisting and nonhoisting applications in underground coal mining (1)*. This report concluded that although wire rope usage is only a small part of a total mining operation, it is an important part. Much of the production output is tied to the capacity of slope and shaft hoists and a rope failure can stop production completely. The safety record for hoisting in U.S. coal mines is admitted to be good, but the authors contend that possible improvements should not await a disastrous accident as happened in some foreign countries. A second study by Battelle focused on safety catches in hoisting operations and developed a set of criteria for eliminating the inadequacies of existing devices (2). A handbook on inspection and maintenance of hoisting equipment was the output of a third study by Battelle (3). This report identified four WRTs used on hoist ropes: Solid Thimble & Clamps, Short Coupled Thimble, Reliance Cappel, and Zinc Poured Socket. Battelle has also studied the state of the art in the lubrication of wire rope (4) and wire rope usage on surface mining equipment (5). Still to be completed is a study by Midwest Research Institute on wire rope retirement criteria (6).

The manner in which the wire rope is attached to the load was the specific area addressed by the present study. The reliability and safety of a wire rope application depend both on the wire rope and the wire rope terminations (WRT) attached to the end of the rope. The safe use of a WRT is affected by the type of rope it is attached to, the loading conditions and the skill of the personnel that assemble the termination. The bibliography to this report lists publications which discuss one or more aspects of WRT usage, but no publication could be found that studied WRTs in the detail and extent of this project.

*Numbers in parentheses correspond to references.

1.2 OBJECTIVES

The requirement of this effort was to determine operational limitations of WRTs and develop procedures for the assembly and inspection of WRTs at the mine site. Unlike wire rope which is manufactured by machinery and under tight quality control measures, WRTs are assembled by personnel using machines and hand tools. Introduction of human variability and error into the assembly can make a WRT the weak link in load carrying wire ropes. The performance which could be expected from a correctly assembled WRT was determined by pull tests and axial fatigue tests. The degraded performance introduced by poor workmanship was determined by comparing test data of standard and modified assembly procedures.

In addition to evaluating the operational limits of WRTs the project also undertook the development of a training manual for WRTs and a selection and inspection guide for WRTs. Both of these manuals were directed to the WRT user in the field and are bound in separate volumes.

2.0 APPROACH

2.1 Overall Approach

To reach the stated objective it was first necessary to identify the various types of WRTs used in the mining industry. A selection of WRTs for inclusion in the test program was made, as well as a selection of the wire ropes to be used in making the WRT specimens. Next, procedures were developed for standard assembly and modified assembly, the latter representing poor work practices. The assembled WRT specimens were then submitted for pull testing and fatigue testing in accordance with an experimental design that would permit a statistical analysis of the data. The results of the field trips, literature review, and laboratory testing permitted the preparation of a training and inspection manual for the assembly of WRTs and a selection and inspection guide for WRTs.

2.2 Mine Site Visits

Through our mining industry consultant visits were arranged to five coal mine companies. Later, through the help of the Denver Mine Safety and Health Administration (MSHA) office, two metal mines were also visited. The mine sites visited are listed in Table 1. Information was obtained about the WRTs, the wire ropes used with the WRTs, and the loading conditions imposed on the WRTs. In general the mining personnel were cooperative and provided us with all of the information they had. The WRT loads and cycling frequency were estimated from the size of the bucket or shovel on surface mines and the observed cycling of the machine. The WRT loads and cycling frequency for underground mines were estimated from the capacity of the load carrying unit, such as a man-trip-car or elevator, and the observed cycling. The types of ropes and WRTs used were noted by examination, observation, and queries to the mining personnel. Appendix A contains illustrations of WRTs used in the mine fields. The information on WRTs is summarized in Table 2 and the wire rope inventory at one surface mine is shown in Table 3. The above information, plus data in the catalogs of wire rope manufacturers was used in selecting the types of WRTs and wire ropes for the testing program. The information on who prepared the WRTs and their skill level was used in preparing the assembly procedures, both standard and modified. The actual steps of assembly were based on the recommendations of wire rope manufacturers since the mine companies relied completely on these recommendations. Visible deviations from the recommended correct procedure were observed during the mine visits, but never on a WRT that directly endangered the lives of mine personnel.

TABLE 1 MINE SITES VISITED

U.S. Steel Corp., Uniontown, Pa.
Mt. Braddock Underground Mine
Ginger Hill Processing Plant

AMAX Coal Comp., Evansville, Ind.
Ayrshire Surface Mine
Wright Surface Mine

Clinchfield Coal Comp., Dante, Va.
Moss II Underground Mine
Moss III Underground Mine

C & K Coal Comp., Clarion, Pa.
Clarion Surface Mine

Peabody Coal Comp., St. Louis, Mo.
Pit No. 3 and No. 6 Surface Mines
Baldwin Underground Mine

Climax Molybdenum Underground Mine, Climax, Co.

Henderson Molybdenum Underground Mine, Henderson, Co.

TABLE 2 SUMMARY OF MINE VISIT DATA

Termination	Wire Rope	Application	Working Load[a]	Assembler
Zinc Poured Socket	1-1/8, 6x41	Car Retarder	-	Field Mechanic
	2-3/4, 6x55	Dragline Hoist	10	Rope Mfg.
	2-3/4, 6x55	Dragline Rope	-	Rope Mfg.
	3-1/4, 6x46	Boom Support	20	Rope Mfg.
U-Bolt Clip	3/8, 6x25	Hand Rail	-	Field Mechanic
	1/2, 6x25	Sled Haul Line	-	Field Mechanic
	5/8, 6x19	Conveyor Roller Support	-	Field Mechanic
	3/4, 6x19	Conveyor Roller Support	-	Field Mechanic
	1-1/4, 6x19	Brake Car Hoist	-	Field Mechanic
	1-1/2, 6x19	Shaft Hoist	-	Field Mechanic
	2-1/4, 6x27	Shaft Hoist	-	Field Mechanic
Wedge Socket	7/8, 6x41	Driller Hoist	-	Field Mechanic
	1-1/8, 6x43	Shovel Boom Hoist	-	Field Mechanic
	1-3/4, 6x43	Shovel Bucket Hoist	-	Field Mechanic
	2-3/4, 6x55	Dragline Rope	-	Field Mechanic
	3-3/8, 6x57	Dragline Rope	-	Field Mechanic
	4, 6x49	Dragline Rope	26	Field Mechanic
	4, 6x49	Dragline Hoist	14	Field Mechanic
Loop Splice	1-3/4, 6x37	Shovel Hoist	-	Field Mechanic
Closed Swaged Socket	1-3/8, 6x19	Boom Support	-	Rope Mfg.
Flemish Loop	1, 6x25	Sling	-	Rope Mfg.
Turn Back Loop with Aluminum Sleeve	1, 6x25	Sling	-	Rope Mfg.

[a] The Working Load is given as a percent of the Catalog Breaking Load. The load was axial in all cases and the cycling frequency never faster than one cycle per minute.

TABLE 3 WIRE ROPE INVENTORY OF A SURFACE MINE

Rope Description[a]		Application
1-1/4,	6x41	Hoist
1-3/8,	6x41	Hoist
1-1/2,	6x41	Retract
1-1/2,	6x41	Crowd
1-5/8,	6x41	Hoist
1-5/8,	6x43	Hoist
1-3/4,	6x41	Hoist
1-3/4,	6x49	Hoist
1-3/4,	6x41	Hoist
2,	6x41	Drag
2,	6x41	Hoist
2,	6x49	Crowd & Retract
2-1/8,	6x49	Hoist
2-1/8,	6x41	Retract
2-1/4,	6x49	Hoist
2-1/4,	6x41	Hoist
2-1/2,	6x49	Hoist
2-1/2,	6x25	Drag
2-5/8,	6x49	Crowd & Retract
2-5/8,	6x49	Hoist
2-3/4,	6x41	Hoist
2-3/4,	6x49	Hoist
2-7/8,	6x41	Drag
3,	6x55	Hoist
3,	6x49	Vip. Cable
3-1/4,	6x49	Hoist & Drag
3-1/2,	6x49	Drag
3-5/8,	6x57	Hoist
3-5/8,	6x55	Hoist
4,	6x49	Drag
4,	6x49	Hoist
4,	6x55	Drag
4-3/8,	6x37	Hoist & Drag
4-3/4,	6x37	Hoist & Drag

[a] All ropes had IWRC core and were made of Bright Wire.

For the most part, the terminations found on surface mining equipment were selected and installed by the manufacturer of the piece of equipment. These included open and closed Swaged Sockets and open and closed Zinc Poured Sockets. On dragline ropes the Wedge Socket was used by the mine operator for retermination after the rope failed or became damaged at the original termination. When an entire hoist or drag rope was replaced, the rope was ordered with appropriate terminations already attached. This attachment was performed by the rope manufacturer or by the rope manufacturer's distributor in that region. Boom support ropes are also usually ordered complete with terminations from the rope manufacturers. When a Zinc Poured Socket termination was required without the replacement of the entire rope, some mine operators relied on the supervision of a wire rope manufacturer's representative.

In underground mines the wire rope terminations are installed by mine personnel. These include Zinc Poured Sockets, U-Bolt Clips, and the special Hitch Loop on slusher equipment. The terminations on wire rope slings used in underground mines come with a completely assembled sling from the rope manufacturer or a distributor.

The working loads estimated for the various applications were found to be based on a design factor of four or five. That is, the Safe Working Load (SWL) for any termination did not exceed 1/4 or 1/5 of the Catalog Breaking Load (CBL) of the rope on which it was used. The mode of loading at all terminations was axial and the cycling frequency never exceeded one cycle per minute. The wire ropes used in the mining industry usually were of the 6x19 or 6x37 class, with an independent wire rope core (IWRC), and of bright (ungalvanized) improved plow steel (IPS) wire. The diameter of load carrying ropes ranged from 13 mm (½ in.) to 121 mm (4.75 in.), the larger diameter ropes being found in surface mine operations. Some ropes, 51 mm (2 in.) and larger in diameter are fabricated only with extra improved plow steel (EIPS) wire.

The procedures for wire rope maintenance and termination replacement are not at all standardized. The importance given to timely rope retirement or termination replacement varied as much as the skill level of the personnel assigned such tasks. Although the term field mechanic was used by many mine operators, it is doubtful that they all possessed the same skill level. Some were the machine operators and others maintenance foreman. One common factor that would appear to exist in all operations is a desire to minimize the down time of equipment. For this reason rope termination replacement was accomplished as quickly as possible. Such a practice would suggest that whenever a less skilled mechanic attached a termination he might bypass or skip steps in the assembly procedure that a more skilled mechanic would not. This assumption was the basis for some of the modified assembly procedures developed to measure a particular termination's sensitivity to poor workmanship.

The mine site visits provided information used in the following subsequent tasks.

1. Selection of WRTs to study.

2. Selection of wire ropes to be used with WRTs.

3. Development of modified assembly procedures.

4. Selecting the testing mode of WRTs.

5. Development of the training and inspection manual.

2.3 WRT Assembly Procedures

Since the mine operators rely on the wire rope and hardware manufacturers for specifying the correct assembly procedures for WRTs, the appropriate catalogs and publications were obtained to develop the standard assembly procedures. Since there was not always agreement among the wire rope catalogs the judgment of our principal subcontractor, The James Walker Company, and our own engineering staff was used to resolve differences of opinion and arrive at a standard assembly procedure for preparing the test specimen. These procedures were studied by ourselves and the plant supervisor at The James Walker Company to make sure they were compatible with mine site operating practice which may not be the same as that of a major wire rope manufacturer. Our human factors experience and the plant supervisor's years of experience in training and supervising assembly personnel were used to develop two different modified assembly procedures for each WRT. The standard and modified assembly procedures for each of the WRTs are enclosed in Appendix B and the material sources are identified in Appendix C.

This report assumes that the reader is familiar with wire rope terminology. A glossary is included in this report, but some may find it beneficial or necessary to review wire rope information in some of the wire rope catalogs identified in the bibliography.

2.4 Pull Test Procedures and Equipment

The static pull tests were performed in accordance with the experimental design originally proposed and the test matrix as shown in Table 4. The independent variables for this experiment were the termination types, wire rope construction; Lang and Regular, wire rope class; 6x19 and 6x37, and wire rope diameter: 13 mm (1/2 in.), 19 mm (3/4 in.), 25 mm (1 in.), 38 mm (1½ in.) and 51 mm (2 in.). All other wire rope variables were held constant with one exception. That is, all ropes were made of bright, ungalvanized wire, with an IWRC core, preformed wires, right hand lay for the strands, and of IPS for all sizes except the 51 mm (2 in.) diameter rope which was of EIPS. The dependent variable was the True Efficiency (TE) of the termination as described in the following paragraph.

The static efficiency of a WRT is defined as that proportion of the rope's load carrying capacity which the termination can support. It is generally computed as a percent of the Catalog Breaking Load (CBL) of the rope or as a percent of the True Breaking Load (TBL) of the rope if available. Efficiency values reported in the literature are usually less than or equal to 100%, and are often expressed as a percent of the CBL. In these tests, the specimens breaking loads were in many cases well above the CBL, yielding Catalog Efficiency values over 100%. Because such efficiency values would be confusing and are not the accurate proportion of the rope's load carrying capacity, the efficiency values reported here are a percent of the rope's True Breaking Load (TBL). The TBL values were estimated from gage length failures of pull test specimens and from the maximum breaking load sustained by some specimens even though they were failures associated with the termination. To emphasize that the static efficiency values reported are computed as a percent of the TBL, the term True Efficiency (TE) is used throughout this report as opposed to Catalog Efficiency. The TE values range from 0% to 100% and are computed by the equation:

$$TE = \frac{\text{Specimen Breaking Load}}{\text{True Breaking Load of Rope}} \times 100$$

The pull tests of the 13 mm (½ in.), 19 mm (3/4 in.), and 25 mm (1 in.) diameter rope specimens were performed on a horizontal bed National Pull Test Machine at The James Walker Co. This machine is rated at 113,398 kg (250,000 lb.) and has a maximum load rate of 30.5 cm (12 in.) per minute. The actual load rate used was 5 cm (2 in.) per minute. The machine was calibrated prior to and during the pull test program. The calibration load cell has a certificate traceable to the National Bureau of Standards.

TABLE 4 MATRIX FOR WRT PULL TEST[a]

Diameter	Wire Rope Construction	Class	Termination Type[b] 1	2	3	4	5	6	7	8	9
13 mm (½ in.)	Lang	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
	Regular	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
19 mm (3/4 in.)	Lang	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
	Regular	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
25 mm (1 in.)	Lang	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
	Regular	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
38 mm (1½ in.)	Lang	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
	Regular	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
51 mm (2 in.)	Lang	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3
	Regular	6x19	3	3	3	3	3	3	3	3	3
		6x37	3	3	3	3	3	3	3	3	3

(a) Three specimens for each test cell defined by a particular combination of rope diameter, construction, class, and termination type.

(b) WIRE ROPE TERMINATIONS
1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

The pull tests of the 38 mm (1½ in.) and 51 mm (2 in.) diameter rope specimens were performed on the Tinius Olsen Test Machine at the Pittsburgh Testing Laboratories. This vertical machine is rated at 544,311 kg (1,200,000 lb.). A load rate of .127 cm (.05 in.) per minute was used in these pull tests. The machine was calibrated several times during the test program and the calibration certificate is traceable to the National Bureau of Standards.

The specimens were pull tested in a random manner partly by design and partly as a consequence of fabrication and delivery schedules. Since wire ropes of all types required were not immediately available the assembly order of the specimens could not be controlled. Specimens ready for testing on the National Pull Test machine at The James Walker Company were put in random order. Those specimens tested at Pittsburgh Testing Laboratories were tested in no particular order. At both test facilities it was necessary to test in sequence specimens whose end loading configuration fit the load connector that was on the machine at the time. This reduced the number of times the load connectors had to be changed. The spacing of the load heads on both machines also necessitated testing in sequence specimens of similar length. This reduced the number of times the head spacing was changed.

The configuration of the specimens for the pull tests and fatigue tests was simply a specified length of wire rope with a specified WRT at each end. The specimens could fail at either end or in the gage length between the ends. The maximum load sustained by the specimens was defined as the breaking load. The only deviation from the specimen configuration given above was for the 38 mm (1½ in.) and 51 mm (2 in.) diameter U-Bolt Clip specimens. The length of this WRT made it necessary to place a Swaged Socket on one end so that the specimens could be mounted in the pull test and fatigue test machines.

2.5 Fatigue Test Procedures and Equipment

The fatigue life of a rope under dynamic loading is defined in this report as the True Service Life and would normally be measured in terms of the number of load cycles sustained at some specified dynamic load. To determine the True Service Life (TSL) the rope would be tested until it failed. At normal working loads a rope under laboratory test conditions would last several million cycles. Since the objective of this study was to make a relative comparison of the WRTs, the dynamic test loads were increased to values which would result in a specimen failure in one million cycles or less. The maximum number of cycles at a specified load resulting in a gage length failure would then be the TSL of a particular rope. If a particular rope did not fail in the one million cycles, testing was terminated and the TSL was assigned the value of the "run out" test, one million cycles.

The fatigue tests were performed in accordance with the test matrix shown in Table 5. The dynamic loads used for each rope diameter are shown in Table 6 as a percent of the CBL. A sinusoidal load function was used on all fatigue test machines so that the minimum and maximum load were equidistant from a mean load. The difference between the minimum and maximum load is the load range and was the loading parameter of greatest interest.

Because of the elastic properties of the nine different WRTs and five rope diameters it became necessary to test specimens on different machines. The majority of the 13 mm (½ in.) and 19 mm (3/4 in.) specimens were tested on a hydraulic MTS 810 machine rated at 45,359 kg (100,000 lb.). The majority of the 25 mm (1 in.) and 38 mm (1½ in.) diameter rope specimens were tested on an electromechanical Shenck machine rated at 45,359 kg (100,000 lb.).

Part of the 38 mm (1½ in.) and a majority of the 51 mm (2 in.) diameter rope specimens were tested on a hydraulic test system using a 163,293 kg (360,000 lb.) MTS actuator. The 25 mm (1 in.) and 38 mm (1½ in.) diameter Thimble Splice with Four Tucks WRT specimens were tested on a hydraulic machine rated at 49,895 kg (110,000 lb.). The 51 mm (2 in.) diameter Thimble Splice with Four Tucks WRT specimens were tested on a hydraulic machine rated at 90,718 kg (200,000 lb.). All of these machines are regularly calibrated and have certificates traceable to the National Bureau of Standards.

The test frequency for the fatigue tests ranged from a low of .33 Hz for the 51 mm (2 in.) Thimble Splice with Four Tucks WRT to a high of 25 Hz for the 25 mm (1 in.) Swaged Socket WRT. The test frequency depended on the elastic behavior of the specimen, the mass of the WRT hardware at each end, and the machine response to the specimen characteristics. There was a motivation to test the specimens as fast as possible to stay within the time frame and budget of the program. At the same time there existed an interest in not overheating the specimens. The effect of heat was a particular concern with the Thimble Splice with Four Tucks WRT due to the high friction in the splice area. The Epoxy Resin Poured Socket was also sensitive to heat which at 93 C (200 F) might destroy the mechanical properties of the cured resin. An attempt was made to test at about the same frequency all WRT specimens of the same diameter, since the objective was to make a relative comparison between WRTs. This was accomplished within the limits imposed by the test conditions described above.

TABLE 5 MATRIX FOR WRT FATIGUE TEST[(a)]

Wire Rope Diameter	Wire Rope Construction	Termination Type[(b)] 1	2	3	4	5	6	7	8	9
13 mm (½ in.)	Lang	1	1	1	1	1	1	1	1	1
	Regular	2	2	2	2	2	2	2	2	2
19 mm (3/4 in.)	Lang	1	1	1	1	1	1	1	1	1
	Regular	2	2	2	2	2	2	2	2	2
25 mm (1 in.)	Lang	1	1	1	1	1	1	1	1	1
	Regular	2	2	2	2	2	2	2	2	2
38 mm (1½ in.)	Lang	1	1	1	1	1	1	1	1	1
	Regular	2	2	2	2	2	2	2	2	2
51 mm (2 in.)	Lang	1	1	1	1	1	1	1	1	1
	Regular	2	2	2	2	2	2	2	2	2

(a) One or two specimens for each test all defined by rope diameter construction and termination type.

(b) WIRE ROPE TERMINATIONS

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

TABLE 6 DYNAMIC LOADS FOR AXIAL FATIGUE TESTS

Rope Diameter mm (in.)	Catalog Breaking Load in Kg (lbs.)	Load Range as % of CBL
13 (½)	10,432 (23,000)	(20-55) 35%
19 (3/4)	23,224 (51,200)	(20-55) 35%
25 (1)	40,732 (89,800)	(5-30) 25%
38 (1½)	89,720 (197,800)	(5-30) 25%
51 (2)	179,620 (396,000)	(4-26) 22%

3.0 RESULTS OF TESTS

3.1 Pull Test Results

True Breaking Loads for the different ropes tested are shown in Table 7 in both kilograms and pounds and represent the largest breaking load sustained by a particular rope of specified diameter, class, and construction. Fourteen of the twenty values reported are based on the largest breaking load of a gage length failure while six values are based on the largest breaking load of failures associated with the termination. A gage length rope failure was defined as failure of one or more strands at any location at least one inch from the termination. Most TBL gage length failures were in the middle of the gage length and involved three or more strands. These True Breaking Loads are for ropes of Improved Plow Steel (IPS) except for the 51 mm (2 in.) ropes which were of Extra Improved Plow Steel (EIPS). Although IPS had been specified for all ropes, the rope manufacturer had available only EIPS for ropes of 51 mm (2 in.) diameter or larger. This is due to a trend by the wire rope manufacturers toward the exclusive use of EIPS and away from IPS.

The TE values obtained in this program are presented in Table 8 organized for each WRT by rope diameter, construction, and class. An examination of this table discloses the range of TE values obtained for each WRT for the twenty different combinations of the three rope variables. To obtain more information from this data one must rely on statistical techniques, hopefully with the assistance of a calculator or better yet a computer program. The latter method was used, employing an ANOVA statistical package accessed through a local computer facility.

3.1.2 Pull Test Failure Modes

In the pull tests each WRT failed in more than one manner but all had a most frequent mode of failure. Those WRTs that gripped the rope with a pressed sleeve or socket usually sustained a multiple strand break of the rope inside or at the base of the sleeve. This same failure mode was also typical of the Wedge Socket and Zinc Poured Socket WRTs. The Thimble Splice with Four Tucks usually failed in the splice area while the U-Bolt Clip with Thimble WRT usually sustained multiple strand breaks at the clip furthest from the thimble. The results of the U-Bolt Clip with Thimble WRT agree with test results conducted by a leading manufacturer of U-Bolt Clips (7). The Epoxy Resin Poured Socket usually sustained multiple strand breaks in the gage area. The failure modes and their relative frequency of occurrence are presented in Table 9. The Thimble Splice with Four Tucks, U-Bolt Clip with Thimble, and Turn Back Loop with Aluminum Sleeve & Thimble are the most consistent, followed by the Flemish Loop WRTs, Swaged Socket, and Wedge Socket. The Zinc Poured Socket and Epoxy Resin Poured Socket were the least consistent.

TABLE 7 TRUE BREAKING LOAD IN KILOGRAMS (POUNDS)

Construction of IWRC Wire Rope	Wire Rope Diameter mm (in.) 13 (½)	19 (3/4)	25 (1)	38 (1½)	51 (2)[c]
6x25 Lang	13,268[a] (29,250)	34,246[a] (75,500)	54.432[a] (120,000)	119.295[a] (263,000)	194,589[a] (429,000)
6x25 Regular	13,721[a] (30,250)	33,566[a] (74,000)	50,530[a] (111,400)	99,790[a] (220,000)	188,694[a] (420,000)
6x36 Lang	14,515[a] (32,000)	X	X	X	X
6x37 Regular	13,494[a] (29,750)	X	X	X	X
6x41 Lang	X	34,473[b] (76,000)	55,339[a] (122,000)	114,757[a] (253,000)	X
6x41 Regular	X	34,927[a] (77,000)	53,977[b] (119,000)	103,873[b] (229,000)	X
6x49 Lang	X	X	X	X	203,438[a] (448,500)
6x49 Regular	X	X	X	X	180,303[b] (397,500)

[a] Gage length failure.

[b] Maximum load attained even though a termination failure.

[c] EIPS for 2 in. dia. only, all others IPS.

TABLE 8

TRUE EFFICIENCY VALUES

Rope Dia. mm (in.)	13 (½)				19 (3/4)				25 (1)				38 (1½)				51 (2)			
Construction	Lang		Regular		Lang		Regular		Lang		Regular		Lang		Regular		Lang		Regular	
Class	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37
	Flemish Loop with Steel Sleeve & Thimble																			
Replications	89	83	88	87	72	91	92	97	83	85	94	93	78	94	92	90	72	85	**79**	**90**
	91	89	90	84	74	94	97	97	83	85	94	95	96	95	92	91	85	86	70	**84**
	87	89	88	91	83	95	100	97	86	93	94	97	79	93	90	90	82	89	**75**	**86**
	Flemish Loop with Steel Sleeve																			
Replications	92	81	90	91	85	86	93	88	62	86	88	88	71	81	93	89	77	88	80	87
	91	84	93	88	76	86	96	94	71	87	88	87	77	94	91	89	86	88	85	73
	93	88	91	90	68	91	96	91	81	88	87	91	73	89	94	88	85	90	79	86
	Wedge Socket																			
Replications	89	75	88	87	81	79	77	71	82	87	84	76	62	69	70	73	66	68	58	63
	85	69	86	82	78	82	72	65	81	79	77	71	65	72	75	73	66	67	64	61
	76	84	79	81	82	77	79	84	75	84	77	74	65	72	74	73	93	67	57	63

TABLE 8 (cont.)

TRUE EFFICIENCY VALUES

Rope Dia. mm (in.)	13 (½)				19 (3/4)				25 (1)				38 (1½)				51 (2)			
Construction	Lang		Regular		Lang		Regular		Lang		Regular		Lang		Regular		Lang		Regular	
Class	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37
Swaged Socket																				
Replications	95	86	95	93	77	89	95	82	83	86	99	99	100	93	99	96	97	85	97	100
	98	91	98	94	79	89	93	86	94	90	99	99	84	92	100	98	93	83	97	99
	100	90	98	93	77	88	93	84	94	90	91	89	86	92	96	99	98	85	97	98
Turn Back Loop with Aluminum Sleeve & Thimble																				
Replications	92	91	91	91	79	85	93	81	88	87	94	94	78	90	92	92	86	82	90	85
	96	91	93	88	76	88	92	77	84	91	90	90	75	83	95	93	87	80	92	88
	94	88	94	91	76	85	93	77	88	85	92	93	77	87	73	91	87	89	78	92
Thimble Splice with Four Tucks																				
Replications	74	75	79	73	82	84	73	88	61	67	83	76	64	77	86	86	67	69	77	89
	67	64	76	78	73	66	77	90	62	80	76	78	65	72	75	82	61	68	63	81
	70	72	77	75	74	75	73	87	67	69	85	81	57	66	82	83	72	73	84	86

TABLE 8 (cont.) TRUE EFFICIENCY VALUES

Rope Dia. mm (in.)	13 (½)				19 (3/4)				25 (1)				38 (1½)				51 (2)			
Construction	Lang		Regular		Lang		Regular		Lang		Regular		Lang		Regular		Lang		Regular	
Class	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37	6x19	6x37
	U-Bolt Clip with Thimble																			
Replications	79	84	79	81	81	100	87	84	80	94	96	88	79	92	72	84	80	94	77	92
	74	79	83	78	82	95	85	86	85	88	93	84	82	91	74	60	92	91	93	86
	80	77	84	82	86	95	87	83	88	90	95	88	74	85	67	74	87	93	59	89
	Zinc Poured Socket																			
Replications	92	73	96	97	86	66	89	90	91	91	97	96	36	100	55	100	100	100	99	99
	92	84	60	98	82	66	85	87	88	98	97	92	68	90	99	98	98	30	98	99
	91	19	88	98	69	82	80	87	93	94	98	100	37	91	99	100	98	95	99	98
	Epoxy Resin Poured Socket																			
Replications	100	92	98	98	82	93	97	71	100	89	99	99	69	76	58	99	83	68	100	80
	100	90	84	99	94	82	97	98	80	90	99	95	40	80	89	83	87	83	99	94
	99	100	100	100	100	28	96	100	93	90	99	97	48	90	55	91	96	87	79	100

TABLE 9 WRT FAILURE MODES FOR PULL TESTS

Termination Type/Failure Mode	Percent of Total
Flemish Loop with Steel Sleeve & Thimble	
Multiple strand breaks inside or at base of steel sleeve	83%
Multiple strand breaks in gage area	13%
Rope pulled out of loop	4%
Flemish Loop with Steel Sleeve	
Multiple strand breaks inside or at base of steel sleeve	82%
Multiple strand breaks in gage area	8%
Multiple strand breaks in crown of loop	6%
Rope pulled out of loop	4%
Wedge Socket	
Multiple strand breaks inside or at base of socket	72%
Socket cracked	19%
Wedge pulled out of socket	9%
Swaged Socket	
Multiple strand breaks inside or at base of socket	76%
Multiple strand breaks in gage area	19%
Rope pulled out of socket	5%
Turn Back Loop with Aluminum Sleeve & Thimble	
Multiple strand breaks inside or at base of aluminum sleeve	89%
Aluminum sleeve cracked	7%
Multiple strand breaks in gage area	4%
Thimble Splice with Four Tucks	
Multiple strand breaks in splice	95%
Multiple strand breaks in gage area	5%
U-Bolt Clip with Thimble	
Multiple strand breaks at clip furthest from thimble	90%
Multiple strand breaks at clip second furthest from thimble	5%
Rope pulled out of clips	5%
Zinc Poured Socket	
Multiple strand breaks inside or at base of socket	55%
Multiple strand breaks in gage area	40%
Rope pulled out of socket	5%
Epoxy Resin Poured Socket	
Multiple strand breaks in gage area	48%
Multiple strand breaks inside or at base of socket	27%
Rope pulled out of socket	18%
Socket cracked	7%

The failure modes identified the high stress areas of each WRT and also uncovered some unusual failures and hardware weaknesses in two WRTs. As generally accepted, the high stress area with compression type WRTs is inside the sleeve or at the base of the sleeve. In the Wedge Socket the high stress area is at the base of the socket while in the Thimble Splice it is in the splice area. Typical failures are illustrated in Figures 2 and 3.

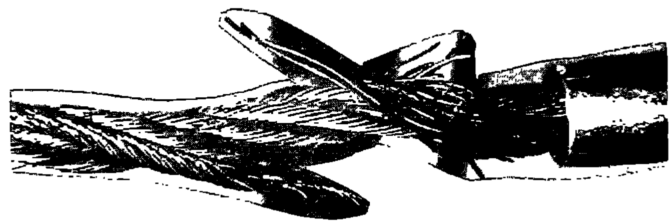
The U-Bolt Clip with Thimble results point to the clip closest to the live part of the rope, the one furthest from the thimble, as the high stress point. The other clips, even though torqued to the same value, do not experience the full load. This finding has also been confirmed by a leading manufacturer of U-Bolt Clips (7). This implies that the other U-Bolt Clips are not as critical, perhaps with regard to the respective location of the saddle and clip on the live and dead parts of the rope. Such an implication is later confirmed by test results of the modified specimens. It appears that the clips, other that the first one, primarily prevent the rope from slipping. Perhaps higher efficiency could be obtained if the torque value was highest at the clip nearest the thimble and gradually decreased at each successive clip so that the lowest torque value would exist at the first clip. Such a method of assembly would appear to more evenly distribute the load over the entire number of clips used. More than likely such a procedure has been considered by U-Bolt manufacturers, but discarded as impractical. In the field it is difficult enough to ensure that all clips are placed correctly and torqued to a specified value. To specify different torque values for each clip on the same WRT would probably meet with little success. The idea is brought out however, for possible consideration by applications that might have the skilled personnel to carry out this procedure and possibly gain some benefits. This idea should receive further study.

The Zinc Poured Socket and Epoxy Resin Poured Socket are able to distribute the load more uniformly among the wires of all strands and thus yield a high percentage of multiple strand breaks in the gage area, or the live part of the rope away from the WRT.

The loads developed in these pull tests were well above those normally seen in service so that it may be that some of the failure modes produced by these tests have never been observed in the field. In addition these tests produced cracked socket failures in the Wedge Socket and Epoxy Resin Poured Socket. Figure 4 illustrates some of the unusual failures.

Multiple strand breaks inside or at base of the steel sleeve on a Flemish Loop with Steel Sleeve & Thimble WRT.

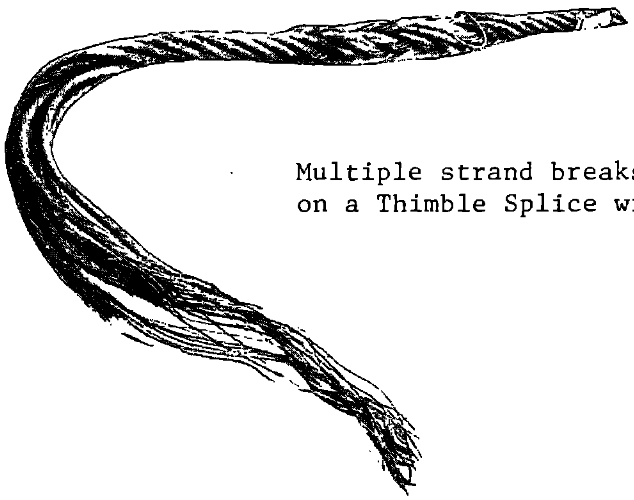
Multiple strand breaks inside or at base of the socket on a Wedge Socket WRT.



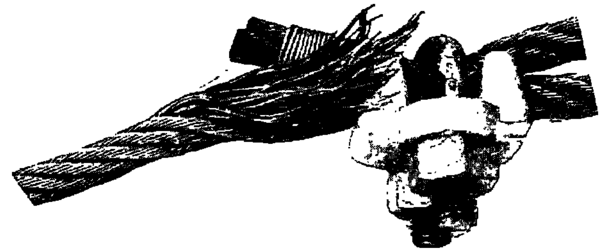
Multiple strand breaks inside or at base of the socket on a Swaged Socket WRT.

Multiple strand breaks inside or at base of the aluminum sleeve on a Turn Back Loop with Aluminum Sleeve & Thimble WRT.

Figure 2 Typical Pull Test Failures

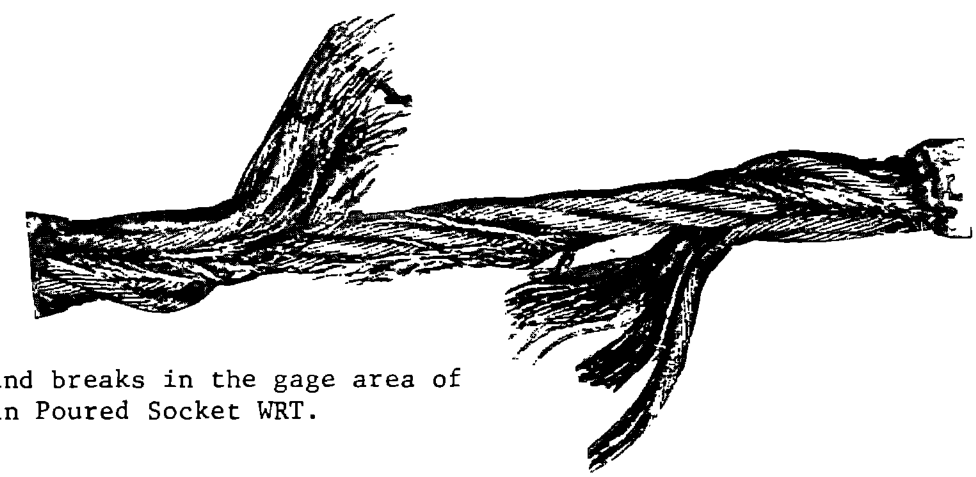


Multiple strand breaks in the splice on a Thimble Splice with Four Tucks WRT.



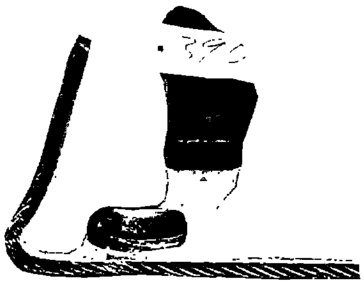
Multiple strand breaks at the clip furthest from the thimble on a U-Bolt Clip with Thimble WRT.

Multiple strand breaks inside or at the base of the socket on a Zinc Poured Socket WRT.



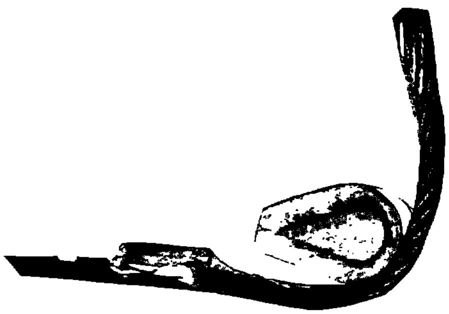
Multiple strand breaks in the gage area of an Epoxy Resin Poured Socket WRT.

Figure 3 Typical Pull Test Failures

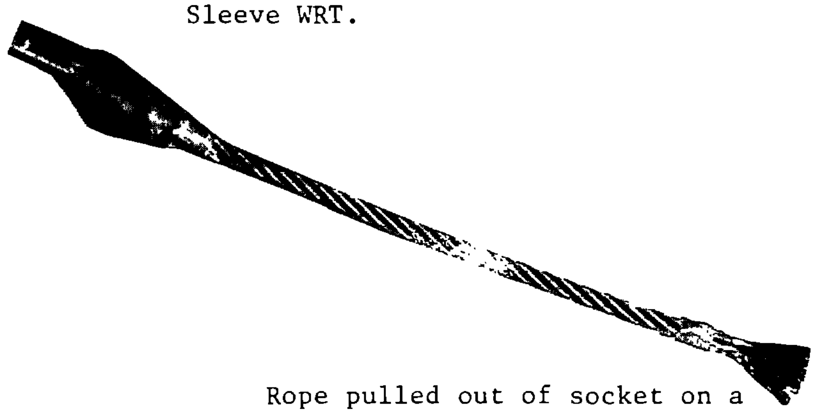


Wedge pulled out of socket on a Wedge Socket WRT.

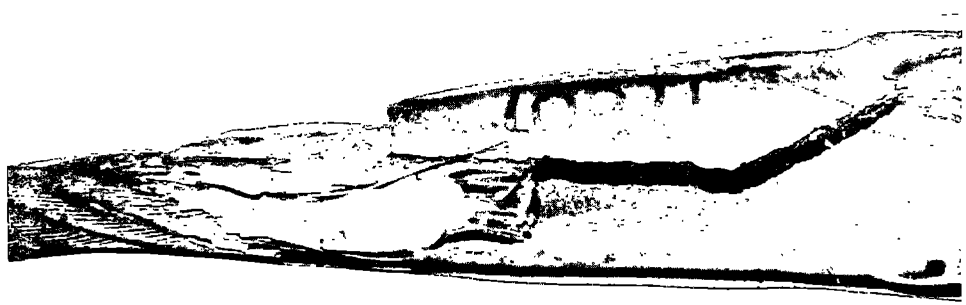
Multiple strand breaks in crown of loop on a Flemish Loop with Steel Sleeve WRT.



Aluminum sleeve cracked on Turn Back Loop with Aluminum Sleeve & Thimble WRT.



Rope pulled out of socket on a Zinc Poured Socket WRT.



Socket cracked on an Epoxy Resin Poured Socket WRT.

Figure 4 Unusual Pull Test Failures

3.1.3 Alternate Procedures for Zinc Poured Socket

The standard socket used in the Zinc Poured Termination is designated as the RR-S-550 Steel Forged Socket. The assembly procedure of most users of this socket involves the degreasing and acid etching of the wires in the "broom" followed by a neutralizing bath. After this project was well underway it became known that at least one wire rope manufacturer found it beneficial to follow the neutralizing bath with a bath in a zinc ammonium chloride flux solution. To provide some test data in this report on this assembly procedure eight specimens were so prepared using the 25 mm (1 in.) diameter rope. The pull test results in terms of the TE value and failure description are shown in Table 10. Although the TE values obtained for the Zinc Poured Socket with Flux WRT were not necessarily higher than those obtained with the standard Zinc Poured Socket, the values were all equal to or above 90% and the number of strands breaking at failure suggests a more uniform bonding between the rope wires and the molten zinc. For this reason the flux bath procedure is recommended.

Another method of attaching the RR-S-550 socket to wire ropes has recently been developed which employs a polyester resin instead of the molten zinc. Use of the resin requires only that the broom wires be completely free of any lubricant. The curing time for the resin is normally several hours, but can be accelerated by applying heat to the socket after the resin has been poured. Heat can be applied with a gas torch or electric heat tape to raise the surface temperature of the socket to about 131 C (250 F). This can be accomplished in less than ten minutes with a gas torch and in about twenty-five minutes with heat tape assuming the socket is wrapped in insulation during the heating period.

Eight Polyester Resin Poured Socket specimens were prepared with 25 mm (1 in.) diameter rope and six of these had one end heated to accelerate the resin cure. The eight specimens are identified in Table 10 using the letters "HT" and "T" for heat tape and gas torch respectively. The results of pull testing these eight specimens in terms of TE values and gage failures show them to be as good as the Zinc Poured Socket with Flux WRT. These tests also demonstrated that accelerating the resin cure has no detrimental effect and can develop the full load carrying capacity of the WRT in less than forty-five minutes.

TABLE 10 PULL TEST DATA OF RR-S-550 SOCKET

I.D. No.	Construction and Class		TE[a] %	Description of Gage Failure
	Zinc Poured Socket With Flux			
1130	Reg.	6x19	98	3 strands & core
1131	Reg.	6x19	94	5 strands & core
1132	Lang	6x19	91	5 strands & core
1133	Lang	6x19	90	3 strands & core
1134	Reg.	6x37	97	6 strands & core
1135	Lang	6x37	100	6 strands & core
1136	Lang	6x37	96	6 strands & core
1137	Lang	6x37	98	6 strands & core
	Polyester Resin Poured Socket			
1116 (HT)	Reg.	6x37	92	6 strands & core
1117 (T)	Lang	6x37	97	6 strands & core
1118 (HT)	Reg.	6x19	99	6 strands & core
1119 (HT)	Reg.	6x37	96	4 strands & core
1120 (T)	Reg.	6x37	97	4 strands & core
1121	Lang	6x19	88	2½ strands & core
1123 (T)	Reg.	6x19	92	3 strands & core
1124	Lang	6x19	90	3 strands & core

[a] TE: True Efficiency equals the breaking load divided by the rope's True Breaking Load.

3.2 Fatigue Test Results

The fatigue life or number of cycles to failure of a WRT is termed Service Life (SL) in this report to facilitate the transfer of this fatigue test information to use in the field. The SL data are presented in Table 11, with one value for Lang construction, two values for Regular construction, and the mean SL value for Regular construction.

3.2.1 Fatigue Test Failure Modes

In the fatigue tests the WRTs sustained many of the same types of failures as they had in the pull tests, but with a different frequency of occurrence. Some failure modes observed in the pull tests for a particular WRT did not occur in the fatigue tests. The failure modes and their relative frequency of occurrence are presented in Table 12. Once again the Flemish Loop with Steel Sleeve & Thimble failed primarily by multiple strand breaks inside or at the base of the steel sleeve. There were no failures by the rope pulling out, reflecting the lower tensile loads. The thimble however, reached the end of its fatigue life before the rope in 6% of the specimens and once it had cracked or deformed severely, the strands in the crown of the loop would break. This latter failure mode was the most frequent, 87%, for the Flemish Loop with Steel Sleeve, showing the benefit of the thimble. The Wedge Socket was the second most consistent in its failure mode with 94% of them being the multiple strand breaks inside or at the base of the socket and cracked sockets occurred less frequently than in the pull tests. Although the Swaged Socket again failed primarily by multiple strand breaks inside or at the base of the socket, 27% of the specimens sustained gage length failures and 27% did not fail at all.

In the Turn Back Loop with Aluminum Sleeve & Thimble, 53% of the failures were the result of the aluminum sleeve splitting and releasing the rope. It is the opinion of some fabricators that use of the aluminum pressed sleeve is not as satisfactory as a steel sleeve because of this failure mode. One of the photographic illustrations presented in this section is of a Turn Back Loop with Aluminum Sleeve recovered from the field, where the sleeve is cracked. The cracking of the aluminum sleeve is a gradual one, and in no instance was a catastrophic type failure observed. In fact, the fatigue failure for this WRT had to be redefined to include as part of the failure criteria, a sleeve crack at least two thirds the length of the sleeve.

TABLE 11 SERVICE LIFE OF WIRE ROPE TERMINATIONS[(a)]

Wire Rope		Termination Type[(b)]								
Diameter	Construction	1	2	3	4	5	6	7	8	9
13 mm (½ in.)	Lang	676	294	128	574	292	160	203	70	653
	Regular	603	293	142	10^6	342	214	85	163	252
		817	538	189	10^6	480	337	91	183	10^6
	mean	710	416	166	10^6	411	276	88	173	625
19 mm (3/4 in.)	Lang	173	168	129	277	135	105	121	54	195
	Regular	309	283	83	278	223	76	172	136	598
		358	294	99	524	230	102	241	225	10^6
	mean	334	289	91	401	226	89	206	180	799
25 mm (1 in.)	Lang	298	47	381	900	191	33	228	39	10^6
	Regular	482	42	245	900	204	40	196	42	10^6
		536	49	327	900	509	114	267	56	10^6
	mean	509	46	286	900	356	77	232	49	10^6
38 mm (1½ in.)	Lang	457	404	215	385	342	75	305	89	472
	Regular	197	241	201	460	351	65	327	177	214
		334	317	205	466	383	121	432	294	240
	mean	266	279	203	463	367	93	759	236	227
51 mm (2 in.)	Lang	272	40	226	140	87	39	146	200	133
	Regular	162	27	138	456	106	43	223	26	203
		201	29	190	549	141	46	231	52	304
	mean	182	28	164	502	124	44	227	39	254

(a) Service Life is expressed as the number of cycles to failure x 10^3 , except for run out values of 1 million cycles (10^6).

(b) WIRE ROPE TERMINATIONS

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

TABLE 12 WRT FAILURE MODES FOR FATIGUE TESTS

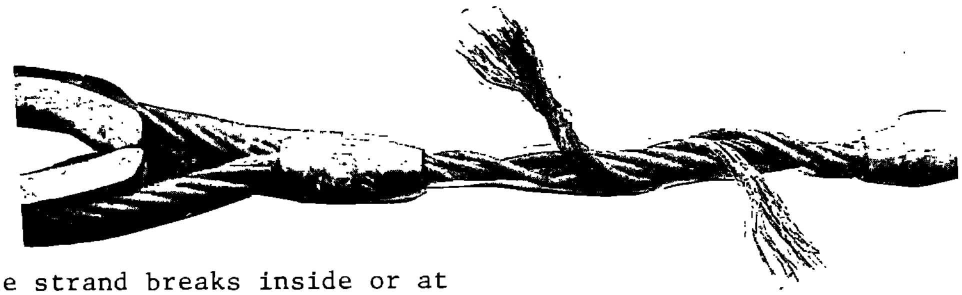
Termination Type/Failure Mode	Percent of Total
Flemish Loop with Steel Sleeve & Thimble	
Multiple strand breaks inside or at base of steel sleeve	88%
Multiple strand breaks in gage area	6%
Thimble cracked and strands in crown of loop broke	6%
Flemish Loop with Steel Sleeve	
Multiple strand breaks in the crown of the loop	87%
Multiple strand breaks inside or at the base of steel sleeve	13%
Wedge Socket	
Multiple strand breaks inside or at base of socket	94%
Socket cracked	6%
Swaged Socket	
Multiple strand breaks inside or at base of socket	46%
No strand breaks; run out	27%
Multiple strand breaks in gage area	27%
Turn Back Loop with Aluminum Sleeve	
Aluminum sleeve cracked	53%
Multiple strand breaks inside or at base of aluminum sleeve	47%
Thimble Splice with Four Tucks	
Multiple strand breaks in splice	100%
U-Bolt Clip with Thimble	
Multiple strand breaks at clip furthest from thimble	80%
Multiple strand breaks inside or at base of swaged socket	14%
Rope pulled out of swaged socket	6%
Zinc Poured Socket	
Multiple strand breaks inside or at base of socket	100%
Epoxy Resin Poured Socket	
Socket cracked	72%
No strand breaks; run out	22%
Multiple strand breaks in gage area	6%

The Thimble Splice with Four Tucks failed in the splice area 100% of the time. The failure mode of the U-Bolt Clip with Thimble should actually be considered to be 100% of multiple strand breaks at the clip furthest from the thimble. The test results show that a few failures occurred at the specimen end terminated by a Closed Swaged Socket. The Closed Swaged Socket was used to simplify the preparation of this WRT and also to keep the specimens length short enough to fit into the test machines. The unexpected failures at the Closed Swaged Socket end illustrate that even for one of the most reliable WRTs, performance can vary. The Zinc Poured Socket, as expected, failed 100% of the time by multiple strand breaks inside or at the base of the socket.

The Epoxy Resin Poured Socket suffered a cracked socket failure in two thirds of the specimens and yielded gage length failures only 6% of the time. The run out (no failure) specimens accounted for 27% of the specimens tested.

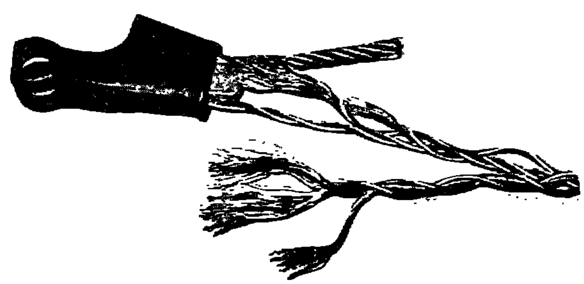
Typical fatigue failure modes for the WRTs are shown in Figures 5a, 5b, and 5c. Some unusual fatigue failures are shown in Figure 6.

The predominant failure modes for the WRTs are amenable to visual field inspection. In those applications where the rope fails at the WRT before it fails in the working length, inspection of the WRT would be of considerable value. Both Flemish Loop WRTs can be inspected by examining the wires at the base of the steel sleeve. An examination of the wires at the socket base of the Wedge Socket would serve the same purpose. Inspection of the wires at the base of the socket of the Swaged Socket and sleeve of the Turn Back Loop with Aluminum Sleeve & Thimble would similarly apply. In the above five WRTs the inspection can become more thorough if the rope is twisted open and also bent from side to side. The Thimble Splice with Four Tucks requires inspection of wires in the splice area and should involve careful use of a marline spike or splicer's dagger to permit separating the strands without loosening the splice. In the U-Bolt Clip with Thimble WRT inspection of the rope at the clip furthest from the thimble should suffice. The clip should be removed to facilitate the inspection and then remounted tightening the nuts to the required torque. The Zinc Poured Socket should be inspected in the same manner as the Swaged Socket, but at more frequent intervals when this WRT is in a dynamic load situation. The Epoxy Resin Poured Socket should be inspected by carefully going over the entire surface of the socket with a magnifying glass or by using a dye penetrant kit to detect surface cracks.



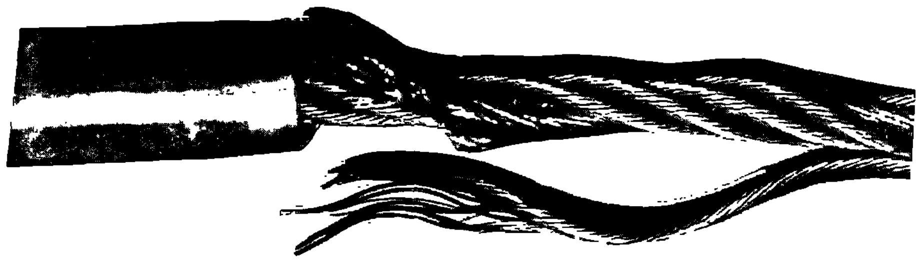
Multiple strand breaks inside or at
base of steel sleeve on a Flemish
Loop with Steel Sleeve & Thimble WRT.

Multiple strand breaks in the crown of
loop on a Flemish Loop with Steel Sleeve WRT.

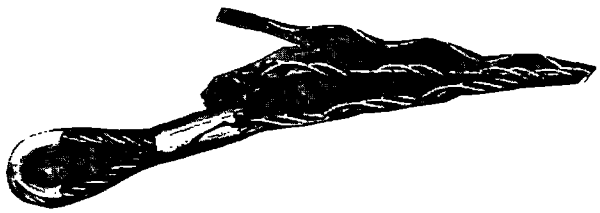


Multiple strand breaks inside or
at base of socket on a Wedge
Socket WRT.

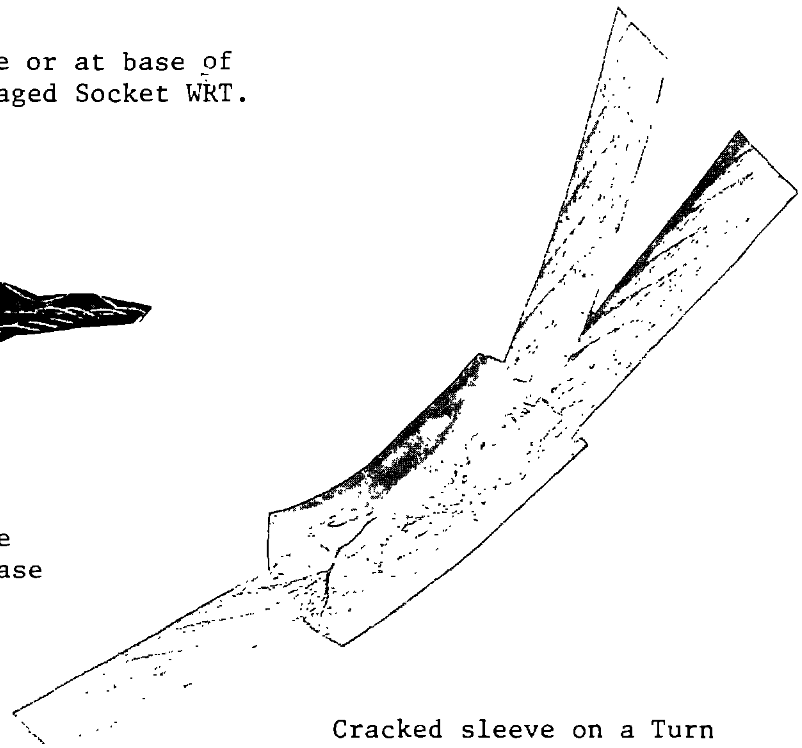
Figure 5a Typical Fatigue Test Failures



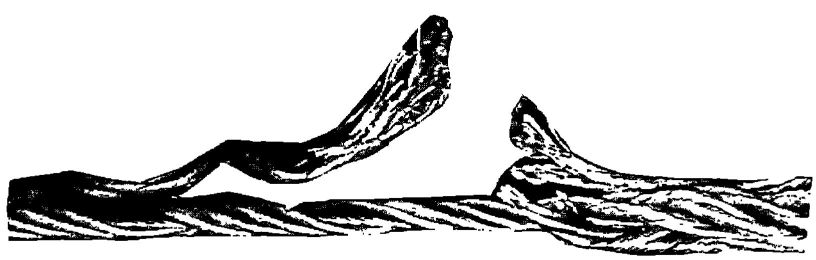
Multiple strand breaks inside or at base of swaged socket on a Closed Swaged Socket WRT.



Aluminum sleeve cracked, thimble cracked, and multiple strand breaks inside or at base of the aluminum sleeve on a Turn Back Loop with Aluminum Sleeve & Thimble WRT.

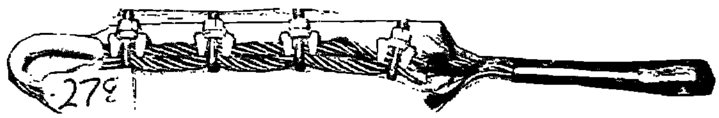


Cracked sleeve on a Turn Back Loop with Aluminum Sleeve WRT recovered from the field.

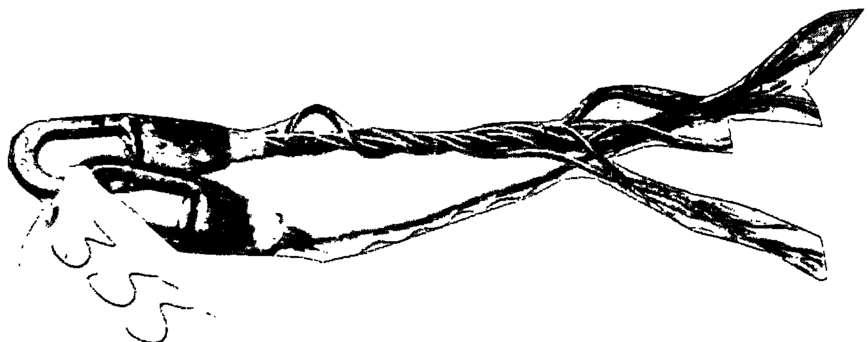


Multiple strand breaks in splice of a Thimble Splice with Four Tucks WRT.

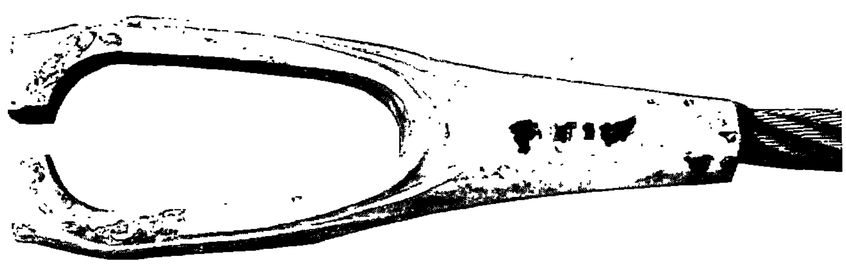
Figure 5b Typical Fatigue Test Failures



Multiple strand breaks at the clip furthest from the thimble on a U-Bolt Clip with Thimble WRT.



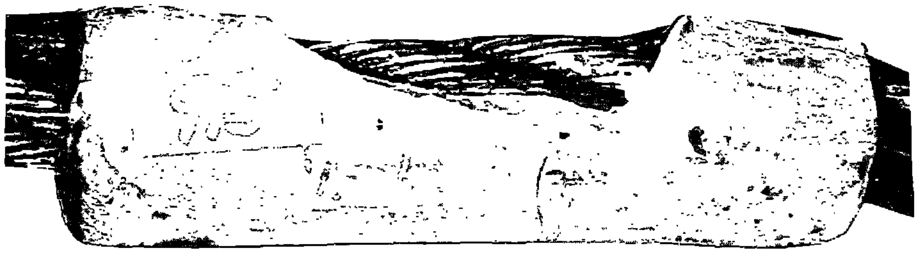
Multiple strand breaks inside or at the base of socket on a Zinc Poured Socket WRT.



Cracked socket on an Epoxy Resin Poured Socket WRT.

Figure 5c Typical Fatigue Test Failures.

Cracked lug on Wedge Socket WRT.



Cracked sleeve on Turn Back Loop with Aluminum Sleeve & Thimble WRT.

Figure 6 Unusual Fatigue Test Failures.

3.2.3 Effect of Heat on Service Life of Zinc Poured Socket

One of the reasons for testing the Epoxy Resin Poured Socket was the expectation that it would give a longer Service Life than the Zinc Poured Socket. As the data in Section 3.2 show, this expectation was fulfilled. This increase in the number of load cycles to failure could be attributed to the longer tapered body of the Epoxy Resin Poured Socket, or to the use of a low temperature epoxy resin or to both. For some time the temperature of the molten zinc, approximately 510 C (950 F) has been suspected of contributing to the low SL of the Zinc Poured Socket. Although the heat treating temperature for steel is above 593 C (1100 F) the stress relieving temperature is in the 150 C (300 F) range so it seemed that perhaps the hot zinc might be a factor. The question was addressed along two avenues of investigation. One was to perform a metallurgical analysis of wires in ropes which had been socketed with zinc, wires in ropes which had been socketed with zinc and subsequently fatigue tested, and of wires from a section of new rope. The second approach was to compare the SL values of identical rope sections: two terminated by the standard RR-S-550 socket with molten zinc (Zinc Poured Socket), two terminated by the standard RR-S-550 socket with epoxy resin, two terminated by the Epoxy Resin Poured Socket with molten zinc, and two terminated by the standard Epoxy Resin Poured Socket.

The metallurgical analysis found that the grain structure of wires which had undergone the 80% reduction in diameter at the manufacturing plant, was unchanged by exposure to the hot zinc or to the fatigue testing. This analysis included chemical etching of the wires, examination under an optical microscope, and examination under a Scanning Electron Microscope. No other changes were noted in the wires examined so it was concluded that the molten zinc did not change the mechanical properties of the wire.

The SL values of the four sets of specimens were obtained on the same machine, at identical loads, and very similar test frequencies. The rope used for the eight specimens was a 19 mm (3/4 in.) diameter, 6x25 Regular, IWRC, IPS, BRT, Preformed, FW, Type W. The load range was 20-50% CBL, or 35%. This allowed use of the test data from the main fatigue tests of the Zinc Poured Socket.

The results of the fatigue tests are shown in Table 13 with SL shown as the cycles to failure and a brief description of the failure. The test frequency for the Epoxy Resin Poured Socket was 3 Hz below the other six specimens to avoid raising the temperature inside the socket above 66 C (150 F), a precaution against the sensitivity of the epoxy resin to high temperatures. As the data illustrates, the Epoxy Resin Poured Socket values are about five times those obtained with the Zinc Poured Socket, fulfilling the expectations.

To assign the proper importance to the socket body and binding material one can use the other data provided. The number of cycles to failure of the WRTs with Epoxy Resin in the RR-S-550 socket were similar to those yielded by the Zinc Poured Socket. This result would point to the shorter socket body of the RR-S-550 socket as responsible for the shorter SL of the Zinc Poured Socket. The WRTs with zinc poured in the Epoxy Resin Poured Socket gave cycles to failure higher than the Zinc Poured Socket WRTs, but below those obtained for the Epoxy Resin Poured Socket. The failures for these two specimens were rather unfortunate since neither was associated with the rope at the WRT in question. In one the socket cracked with no broken wires visible, suggesting that a few more thousand cycles might have been attained with the longer tapered socket had it not cracked. In the other specimen, the rope failed at the end where a socket had cracked earlier, the rope had been cut, and resocketed with a Swaged Socket. The SL value of 488,520 cycles is within the SL range obtained with the Swaged Socket (Type 4) in the main fatigue test. Thus the suggestion is again present that the long tapered socket might have attained many more cycles.

Based on this test data it is concluded that molten zinc does not contribute to shorter SL values, but rather that the short body of the RR-S-550 socket is responsible. The benefit of the Epoxy Resin Poured Socket in attaining high SL values is attributed to the long tapered body of the socket and not necessarily to the socketing material. It should be noted that because of the long tapered body of the Epoxy Resin Poured Socket, it is possible, and indeed of benefit, to open the rope into a configuration other than the standard "broom" of the Zinc Poured Socket. The configuration of the rope in the Epoxy Resin Poured Socket makes a more gradual transition from the separated wires, to the separated strands, and finally to the rope. Also the longer socket is able to accommodate well within the socket base a section of rope which still retains its original configuration and arrangement of strands.

TABLE 13 FATIGUE TEST DATA FOR HEAT EFFECT EXPERIMENT

Termination Type	Test Freq. in Hz	Cycles to Failure	Description of Failure
Zinc in RR-S-550 Socket	9	135,900	Multiple strand breaks at base of socket
Zinc in RR-S-550 Socket	9	225,430	Multiple strand breaks in base of socket
Epoxy Resin in RR-S-550 Socket	9	265,720	Multiple strand breaks at base of socket
Epoxy Resin in RR-S-550 Socket	9	267,430	Rope pulled out of socket
Zinc in Epoxy Resin Poured Socket	9	388,270	Socket cracked
Zinc in Epoxy Resin Poured Socket	9	488,520	Multiple strand breaks at base of Closed Swaged Socket on other end
Epoxy Resin Poured Socket	6	1,016,000	Run out
Epoxy Resin Poured Socket	6	1,000,000	Run out

4.0 ANALYSIS OF DATA AND DISCUSSION

4.1 True Efficiency of WRTs

The True Efficiency (TE) data presented in the Pull Test Results was the dependent variable in a Four Factor experimental design and the performance measure to now be analyzed. The analysis is directed at finding out which of the independent variables affected the dependent variable TE, and in what manner. These four independent variables were Termination Type, Rope Diameter, Rope Construction, and Rope Class. As discussed earlier other rope variables were held constant since they were not considered to be as important as those mentioned. The experiment was planned as an orthogonal factorial design with three replications or data points for each of the 180 test cells so that the data could be analyzed by a Four Factor Analysis of Variance (ANOVA). The ANOVA, available as a computer program in the Statistical Packages for the Social Sciences (8) was accessed through a local computer facility. The ANOVA is the most efficient statistical technique applicable to TE for detecting statistically significant main effects from the four independent factors and any two, three or four-way interaction effects of the main factors.

4.1.1 Analysis of Variance

The results of the ANOVA are presented in Table 14, where the first column identifies the independent factors or sources of variation exhibited by the dependent factor, TE. Listed are the four main effect factors, Termination Type, Rope Diameter, Rope Construction, and Rope Class. Also listed are two-way, three-way, and four-way interactions between and among the main factors, as well as the explained variation and the residual variation, that due to experimental error. The second column lists the Sum of Squares, which is a measure of the deviation of the TE values for each source of variation from the mean or average value of all the TE values. "DF" stands for degrees of freedom of the source of variation and in this case is equal to one less than the number of levels of the source. For each interaction the degrees of freedom (df) is the product of the df of each factor involved in the interaction. The values in the Mean Square column are simply the result of dividing the Sum of Squares values by the corresponding degrees of freedom. The "F" column reports the "F ratios" computed by dividing the Mean Square value of each source by the Mean Square value of the Residual source of variation. This ratio is compared to tabulated values under the "F" distribution at the corresponding

TABLE 14 ANALYSIS OF VARIANCE OF TRUE EFFICIENCY VALUES

SOURCE OF VARIATION			SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS			23173.107	14	1655.222	34.730	.001
TYPE			17337.070	8	2167.134	45.471	.001
DIAM			2303.841	4	575.960	12.085	.001
CONSTR			2982.150	1	2982.150	62.572	.001
CLASS			550.046	1	550.046	11.541	.001
2-WAY INTERACTIONS			17784.872	57	312.015	6.547	.001
TYPE	DIAM		10549.226	32	329.663	6.917	.001
TYPE	CONSTR		2924.967	8	365.621	7.672	.001
TYPE	CLASS		834.337	8	104.292	2.188	.028
DIAM	CONSTR		740.507	4	185.127	3.884	.004
DIAM	CLASS		2637.019	4	659.255	13.833	.001
CONSTR	CLASS		98.817	1	98.817	2.073	.151
3-WAY INTERACTIONS			9990.948	76	131.460	2.758	.001
TYPE	DIAM	CONSTR	2769.293	32	86.540	1.816	.005
TYPE	DIAM	CLASS	4511.515	32	140.985	2.958	.001
TYPE	CONSTR	CLASS	832.633	8	104.079	2.184	.028
DIAM	CONSTR	CLASS	1877.507	4	469.377	9.849	.001
4-WAY INTERACTIONS			3192.959	32	99.780	2.094	.001
TYPE	DIAM CLASS	CONSTR	3192.959	32	99.780	2.094	.001
EXPLAINED			54141.887	179	302.469	6.346	.001
RESIDUAL			17157.333	360	47.659		
TOTAL			71299.220	539	132.281		

540 CASES WERE PROCESSED.
0 CASES (0 PCT) WERE MISSING.

degree of freedom. From the "F" table (9) one obtains the significance level of the F ratio, or the probability level at which one can reject the null hypothesis, i.e., the mean value of a particular sample equals the population mean. For most factors or sources of variation in this ANOVA, the probability level is .001. This significance value is also defined as the risk of rejecting the null hypothesis when it is true, i.e., committing a Type I error, a risk level of .01, one in one hundred, or .05, five in one hundred is generally quite acceptable. The risk of accepting the null hypothesis when it is false is the Type II error. For more details on ANOVA and other statistical techniques used in this report the reader is referred to references 9, 10, and 11.

In order to avoid claiming an effect from any of the main factors or their interactions when the effect may be marginal, an acceptable risk level or significance value of .01 is adopted. At such a level, all four main factors are declared to have an effect on the independent variable TE because their computed probability levels are below the probability value of .01 of the risk level adopted. Furthermore, the two-way interactions of WRT Type and Rope Diameter, WRT Type and Rope Construction, Rope Diameter and Rope Construction, and Rope Diameter and Rope Class, are declared to have an effect on TE. All the three-way and four-way interactions are also declared to have an effect on TE, except for the three-way interaction of WRT Type, Rope Construction and Rope Class. Only three effects are considered nonsignificant.

It had been expected that TE would be affected by the WRT Type, Rope Diameter and Rope Construction. Since most manufacturers report the same CBL for the 6x19 class and 6x37 class, Rope Class was not expected to have an independent effect. The significant interaction effects are of considerable interest since there has not been anything published which alerts a wire rope user to consider carefully the combination of all four wire rope characteristics in selecting a rope and in selecting a termination. The fact that the interaction sources of variation are significant means that the effect of any one main source of variation is not uniform across the different categories, or levels, of any of the other main sources of variation. For example, the effect on TE for the nine WRT Types is not the same for all five levels or values of Rope Diameter. These interaction effects were observed in a laboratory test and it may be that they would not be noticeable in the field. However, they would still be contributing to the performance of a WRT. For this reason wire rope engineers and equipment manufacturers specifying a particular combination of wire rope and WRT may want to consider the interaction effects to be discussed in this section. The reader interested in a more general analysis of the data may want to simply read the conclusions based on the ANOVA and then study the Multiple Classification Analysis.

Besides identifying the statistically significant sources of variation in TE, the ANOVA table also provides information necessary to compute what percent of the variation in TE can be attributed to a particular source. The computation is simply the division of the Sum of Squares value of each source by the Total Sum of Squares. The resulting percentages, listed in Table 15, give a better indication of what main effects and interactions are of more practical importance. The most important effect is of course WRT Type, accounting for 24 percent of the variation in TE. The next most important effect is the two-way interaction of WRT Type and Rope Diameter, accounting for 15 percent of the variation. The total of the three-way interactions account for 14 percent of the variation while the four-way interaction accounts for 5 percent of the variation. The three-way and four-way interactions together account for 19 percent of the variation in TE, but as the table indicates this is primarily due to the interaction of WRT Type and Rope Diameter. Therefore, the detailed analysis will commence with the two-way interaction of Rope Diameter and Rope Class.

In order to plot the two-way interaction of rope class and diameter for each of the two constructions, the mean value will be computed for the three data points in each of the 180 test cells. These data points were examined and those below an arbitrarily selected TE value of 70% are identified in Table 16 along with a brief description of the failure. This step was used to identify data points that were considered unrepresentative of the particular WRT because of the failure mode. The two data points listed for the Flemish Loop with Steel Sleeve are considered typical failure modes of this WRT while the rope slipping or pull out failures in the U-Bolt Clip with Thimble and Zinc Poured Socket are not considered typical. All the specimens listed for the Thimble Splice with Four Tucks had suffered typical failures.

TABLE 15 PERCENT OF VARIATION IN TE ATTRIBUTED TO SOURCES

Source of Variation	Percent	
Main Effects		32
Type	24	
Diameter	3	
Construction	4	
Class	1	
2-Way Interactions		25
Type Diameter	15	
Type Construction	4	
Type Class	1	
Diameter Construction	1	
Diameter Class	4	
Construction Class	0	
3-Way Interactions		14
Type Diameter Construction	4	
Type Diameter Class	6	
Type Construction Class	1	
Diameter Construction Class	3	
4-Way Interactions		5
Type Diameter Construction Class	5	
Explained Variation (Sum of above)		76
Residual (Experimental Error)		24
TOTAL		100

TABLE 16 SPECIMENS WITH LOW TE VALUES

I.D. No.	Dia. mm (in.)	Construction/ Class	TE %	Description of Failure in Brief
		Flemish Loop with Steel Sleeve		
56	19 (3/4)	L 6x19	68	Broken strands
143	25 (1)	L 6x19	62	Rope pulled out
		Wedge Socket		
530	13 (½)	L 6x37	69	Broken strands
379	19 (3/4)	R 6x37	65	" "
804	38 (1½)	L 6x19	62	Socket cracked
805	"	L 6x19	65	Broken strands
806	"	L 6x19	65	" "
810	"	L 6x37	69	" "
824	51 (2)	L 6x19	66	Socket cracked
825	"	L 6x19	66	" "
829	"	L 6x37	68	" "
830	"	L 6x37	67	" "
831	"	L 6x37	67	" "
815	"	R 6x19	58	" "
816	"	R 6x19	64	Broken strands
817	"	R 6x19	57	Socket cracked
826	"	R 6x37	63	Broken strands
827	"	R 6x37	61	" "
828	"	R 6x37	63	Socket cracked
		Thimble Splice with Four Tucks		
79	13 (½)	L 6x19	67	Broken strands
521	"	L 6x37	64	" "
506	19 (3/4)	L 6x37	66	" "
155	25 (1)	L 6x19	61	" "
157	"	L 6x19	62	" "
158	"	L 6x19	67	" "
159	"	L 6x37	67	" "
161	"	L 6x37	69	" "
536	38 (1½)	L 6x19	64	" "
537	"	L 6x19	65	" "
538	"	L 6x19	57	" "
525	"	L 6x37	66	" "
832	51 (2)	L 6x19	67	" "
833	"	L 6x19	61	" "
835	"	L 6x37	69	" "
836	"	L 6x37	68	" "
543	51 (2)	R 6x19	63	Broken strands

L: Lang R: Regular

TABLE 16 (cont) SPECIMENS WITH LOW TE VALUES

I.D. No.	Dia mm (in.)	Construction / Class	TE %	Description of Failure in Brief
		U-Bolt Clip With Thimble		
601	38 (1½)	R 6x19	72e	Rope slipped
602	"	R 6x19	74e	" "
603	"	R 6x19	67e	" "
604	"	L 6x19	79	" "
583	"	L 6x19	74e	" "
580	"	R 6x37	84e	" "
581	"	R 6x37	60e	" "
582	"	R 6x37	74e	" "
607	"	L 6x37	85e	Break @ Swaged Socket end
549	51 (2)	R 6x19	77e	Rope slipped
552	"	R 6x19	59e	" "
		Zinc Poured Socket		
587	13 (½)	L 6x19	73e	Rope pulled out
585	"	L 6x19	19e	" " "
356	"	R 6x19	60e	" " "
346	19 (3/4)	L 6x19	69e	" " "
588	"	L 6x37	66	Broken strands
590	"	L 6x37	66	Rope pulled out
592	38 (1½)	L 6x19	36e	" " "
593	"	L 6x19	68e	" " "
594	"	L 6x19	37e	" " "
411	"	R 6x19	55	Broken strands
		Epoxy Resin Poured Socket		
1012	19 (3/4)	L 6x19	82e	Rope pulled out
1006	"	L 6x37	28e	" " "
1009	"	R 6x37	71e	Socket cracked
1027	25 (1)	L 6x19	80e	Rope pulled out
1034	"	R 6x37	95	" " "
1030	"	L 6x37	90	Socket cracked
1056	38 (1½)	R 6x19	58e	Rope pulled out
1058	"	R 6x19	55e	Socket cracked
1060	"	L 6x19	69e	Rope pulled out
1061	"	L 6x19	40e	" " "
1062	"	L 6x19	48e	" " "
1068	"	L 6x37	90	" " "
1082	51 (2)	L 6x19	83	" " "
1085	"	L 6x37	63e	Socket cracked
1087	"	L 6x37	87	" "
1073	"	R 6x19	79e	Rope pulled out
1078	51 (2)	R 6x37	80e	" " "

e: Data values excluded from analysis.

The criteria for specimen failure review was raised to 85% for the U-Bolt Clip with Thimble, Zinc Poured Socket and Epoxy Resin Poured Socket when the initial review at the 70% criteria disclosed unrepresentative failures at higher TE values. For the U-Bolt Clip with Thimble the low TE values were the result of the rope slipping, reflecting possible poor workmanship in the test procedure requiring that the nuts be retorqued to a specified value when 20 percent of the CBL had been reached. One U-Bolt specimen failed when the rope broke at the end terminated by the Closed Swaged Socket, the only failure that contradicted the assumption made when these WRTs were prepared, i.e., the rope or termination failure would be at the U-Bolt end and not at the Closed Swaged Socket end. The Zinc Poured Socket suffered several unrepresentative failures when the rope pulled out of the socket. This failure mode also was present for the Epoxy Resin Poured Socket, which also experienced five cracked sockets. Those TE values associated with unrepresentative failures were excluded from the following analysis unless the TE values were within five points of the other representative values, or higher. The TE values excluded are identified in Table 16 with the letter "e". As will be seen in the following analysis the exclusion of unrepresentative data points required interpolating two mean values for the U-Bolt WRT, one mean value for the Zinc Poured Socket WRT, and one for the Epoxy Resin Poured Socket WRT.

The computed mean values for the 180 test cells are presented in Table 17, tabulated by class, construction and diameter for the nine WRTs. These data values were then used to plot the two-way interaction of Rope Diameter and Rope Class. The following graphs each contain two sets of two-way interaction plots, one set for Lang construction and one set for Regular construction. The two-way interaction, if it exists, is displayed by the difference in TE for each of the two classes of each construction, at the five diameter values. The absence of a two-way interaction effect from rope class and rope diameter will be seen by plots that are parallel to each other or nearly superimposed on each other.

TABLE 17 TRUE EFFICIENCY OF WIRE ROPE TERMINATIONS

Wire Rope Diameter	Construction	Class	Termination Type[a] 1	2	3	4	5	6	7	8	9
13 mm (½ in.)	Lang	6x19	89	92	83	98	94	70	78	92	100
		6x37	87	84	76	89	90	70	80	84	94
	Regular	6x19	89	91	84	97	93	77	82	92	94
		6x37	88	90	83	93	90	75	80	98	99
19 mm (3/4 in.)	Lang	6x19	76	76	80	78	77	76	83	84	96
		6x37	93	88	79	89	86	75	97	74	88
	Regular	6x19	96	95	76	94	93	74	86	85	97
		6x37	97	91	73	84	78	88	84	88	99
25 mm (1 in.)	Lang	6x19	84	71	79	90	87	63	84	91	96
		6x37	88	87	83	89	88	72	91	94	90
	Regular	6x19	94	88	79	96	92	81	95	97	99
		6x37	95	89	74	96	92	78	87	96	97
38 mm (1½ in.)	Lang	6x19	84	74	65	90	77	62	80	95i	92i
		6x37	94	88	71	92	87	72	89	94	82
	Regular	6x19	91	93	73	98	87	81	94i	84	89
		6x37	90	89	73	98	92	84	88i	99	91
51 mm (2 in.)	Lang	6x19	80	83	75	96	87	67	87	99	92
		6x37	87	89	67	84	84	70	93	97	85
	Regular	6x19	75	81	60	97	87	75	93	99	100
		6x37	87	82	62	99	88	86	89	99	97

[a] WIRE ROPE TERMINATIONS

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

i Interpolated Value

The Flemish Loop with Steel Sleeve and Thimble data are shown in Figure 7. There the TE values for all four cases: Lang 6x19, Lang 6x37 and Regular 6x19, Regular 6x37, are clustered at the 13 mm (½ in.) diameter. As the diameter increases to 19 mm (3/4 in.) the TE value of Lang 6x19 and Lang 6x37 diverge, then converge at the 25 mm (1 in.) diameter, diverge at the 38 mm (1½ in.) diameter, and remain separated at the 51 mm (2 in.) diameter. The difference in the Lang 6x19 and Lang 6x37 classes as the rope diameter changed demonstrates the two-way interaction effect of rope class and rope diameter. This interaction effect is absent for the Regular 6x19 and Regular 6x37, whose plots remain parallel and one percentage point apart until the 51 mm (2 in.) diameter value is reached. There a difference of twelve TE points exists, but both plots have a negative slope. Based on this data one ought to avoid using 19 mm (3/4 in.) Lang 6x19 construction and 51 mm (2 in.) Regular 6x19 construction on the Flemish Loop with Steel Sleeve & Thimble.

Figure 8 displays the data plots for the Flemish Loop with Steel Sleeve, again demonstrating the two-way interaction effect of Rope Class and Rope Diameter for the Lang construction. Although not parallel the Regular 6x19 and 6x37 plots follow each other closely enough to permit concluding that no two-way interaction effect exists in this case. Except for the 13 mm (½ in.) and 51 mm (2 in.) diameter, use of Lang 6x19 construction rope ought to be avoided for this WRT.

The Wedge Socket data is shown in Figure 9 where the two-way interaction effect exists for Lang construction, but is absent for Regular construction. All four types of ropes stay within a band 9 TE points wide until the 51 mm (2 in.) diameter is reached and the Lang 6x19 rope data diverges upward from the other three ropes. Reviewing the failure descriptions in Table 16 for the Wedge Socket shows that at the 38 mm (1½ in.) diameter one cracked socket yielded a TE of 62%, but was not excluded since it was within five points of the 65% value of the other two identical specimens. At the 51 mm (2 in.) diameter eight of the twelve specimens failed when the socket cracked. The resulting TE values are very close to those of typical failure specimens, with the exception of the one TE of 93% for a Lang 6x19 specimen. Furthermore, this large a number of cracked sockets, purchased through regular channels, should be considered representative, and so supports the decision to include this data in the analysis. The variation in the data plots at the 51 mm (2 in.) diameter cannot of course be attributed any longer to any interaction effects nor to an increase in diameter, except in the context that large diameter Wedge Sockets cause lower TE values.

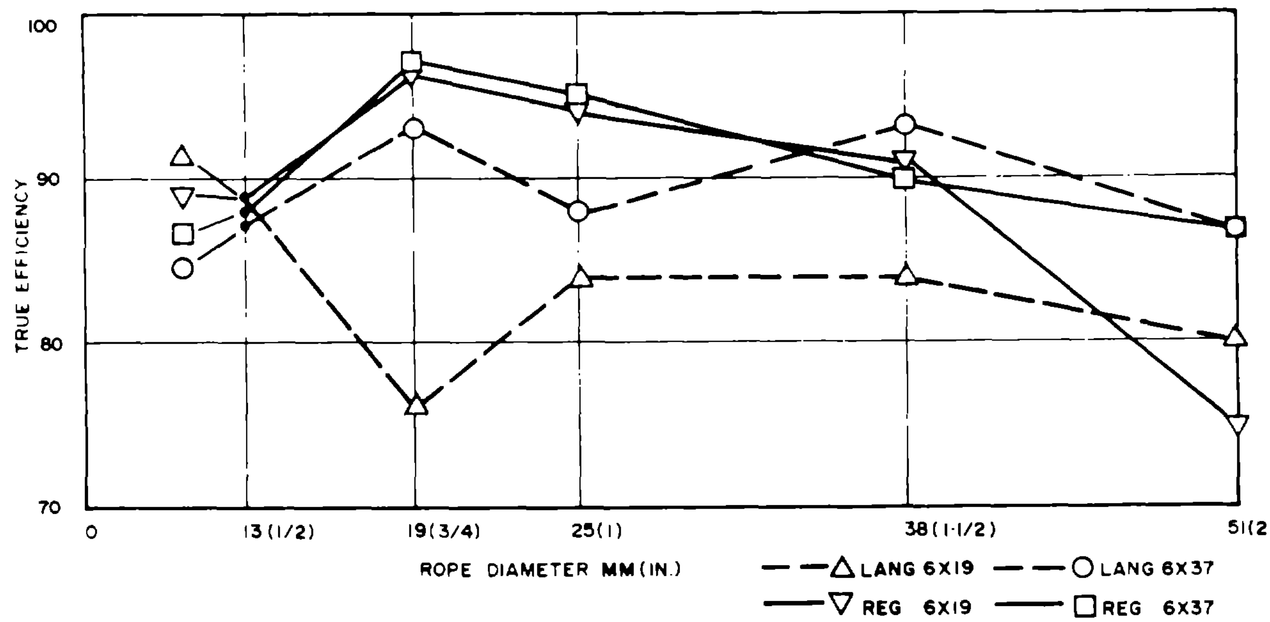


Figure 7 TE Plot for Flemish Loop with Steel Sleeve & Thimble

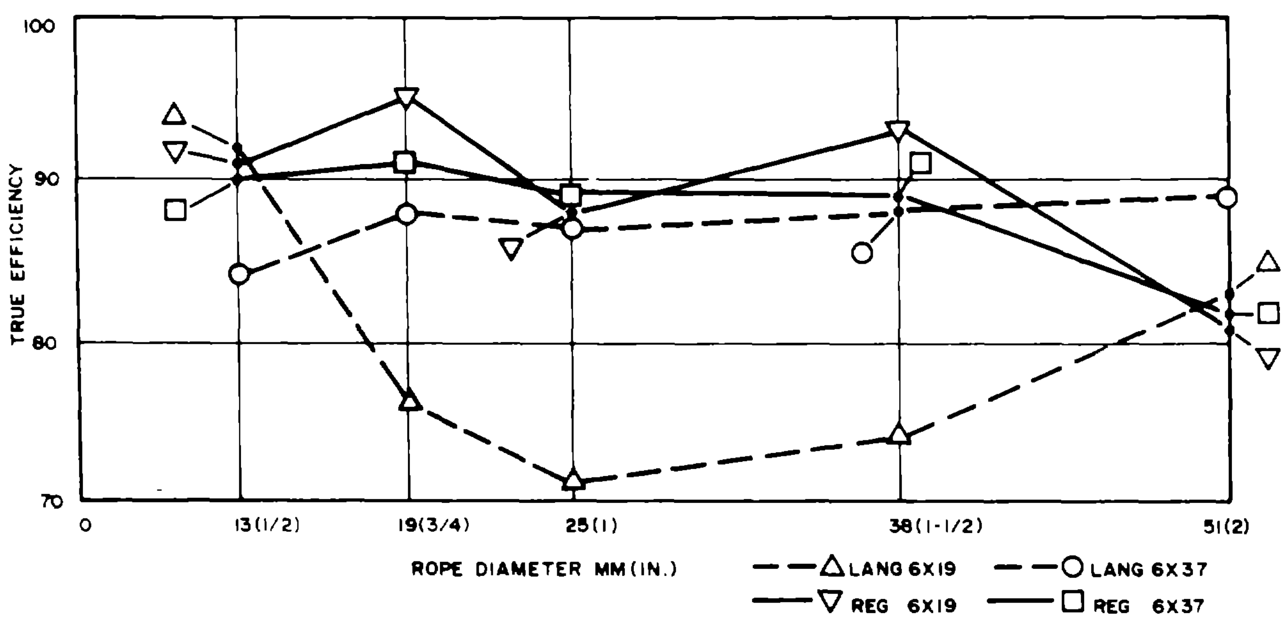


Figure 8 TE Plot for Flemish Loop with Steel Sleeve

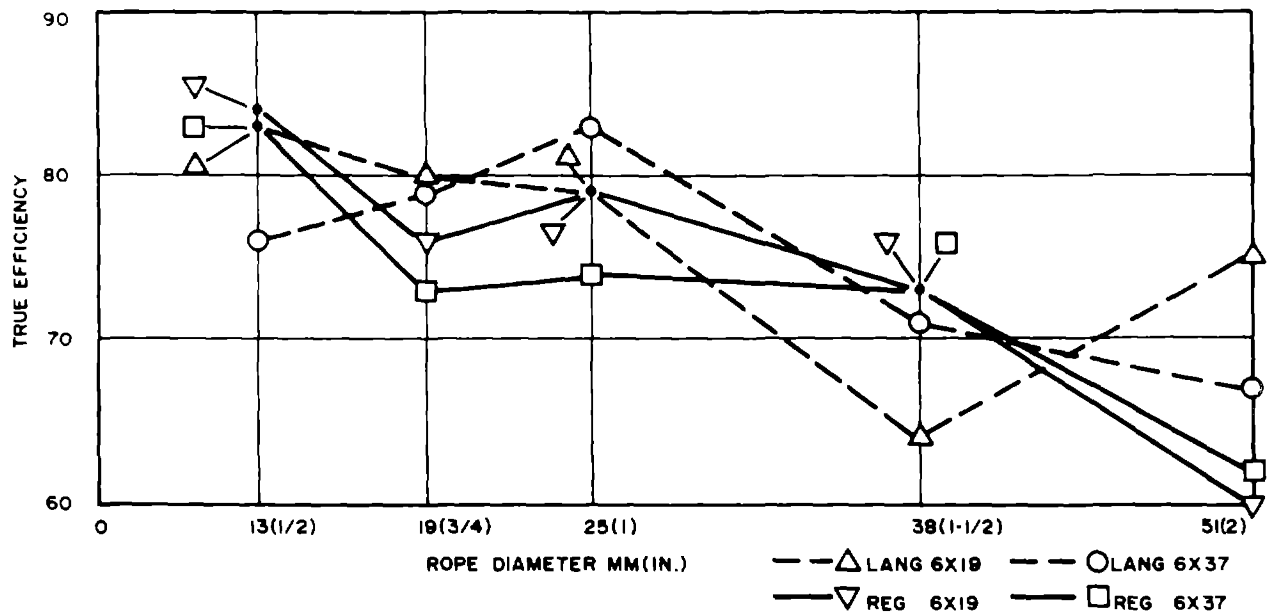


Figure 9 TE Plot for Wedge Socket

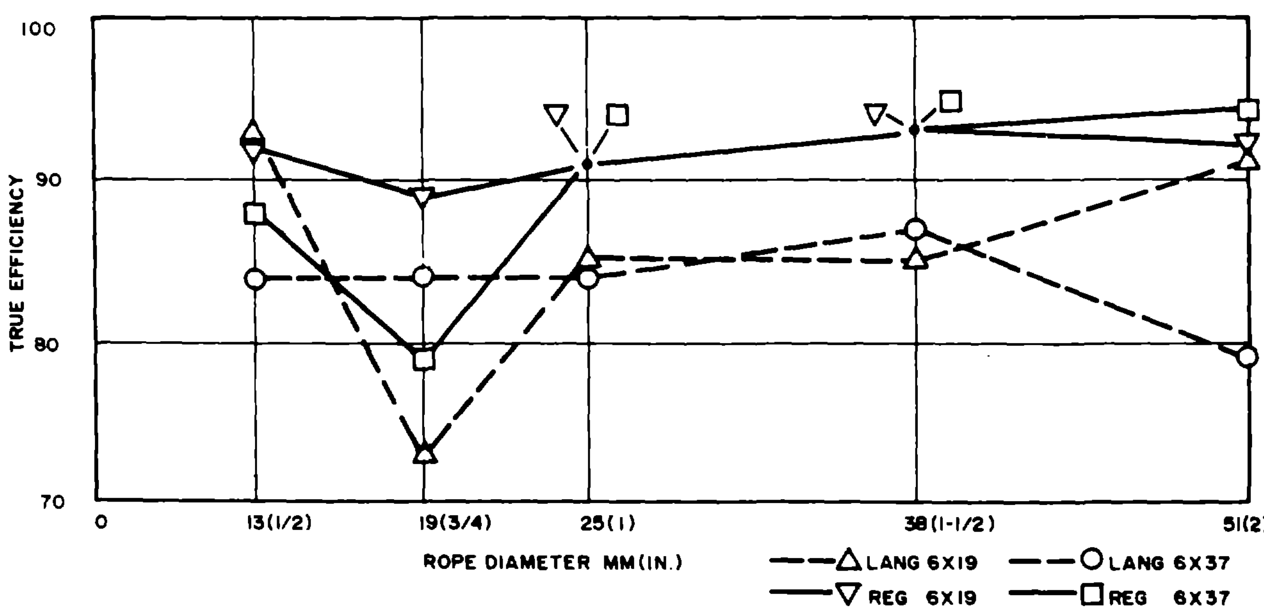


Figure 10 TE Plot for Swaged Socket

For the Swaged Socket, the data plots are shown in Figure 10 and the Lang construction again displays the two-way interaction effect. Except for the divergence at the 19 mm (3/4 in.) diameter the Regular construction does not exhibit the two-way interaction for Rope Class and Diameter. Again it is cautioned that 19 mm (3/4 in.) Lang 6x19 rope is to be avoided for this WRT.

Figure 11 shows the data plots for the Turn Back Loop with Aluminum Sleeve & Thimble and again the Lang construction displays the two-way interaction effect of Rope Class and Diameter. The Regular 6x19 also repeats the drop in TE value at the 19 mm (3/4 in.) diameter. This is the fourth WRT that has exhibited poor performance with the 19 mm (3/4 in.) Lang 6x19 rope. All four of these terminations grip the rope with a pressed sleeve, which may be a factor in the resulting lower TE values, combined with wire size and history. However, since all the TE data is normalized, that is, it is a percentage of the highest TE value for each type of rope, any effect attributed directly to the rope would have to assume a variability in the quality control of this particular rope.

The data for the Thimble Splice with Four Tucks WRT shown in Figure 12 displays the two-way interaction of Rope Class and Diameter for Regular construction and to a lesser degree for Lang construction. The Lang 6x19 rope is at least 18 TE points below the Regular 6x19 rope for both the 25 mm (1 in.) and 38 mm (1½ in.) diameters. The seventeen data points below 70% listed in Table 16 were all considered typical and included in this analysis.

In Figure 13 the U-Bolt Clip with Thimble data exhibits a two-way interaction effect for the Lang construction rope. As with the Thimble Splice with Four Tucks, the 19 mm (3/4 in.) Lang 6x19 rope has actually increased its TE value. In this plot the Regular 6x19 and 6x37 TE mean values at the 38 mm (1½ in.) diameter are interpolated values since the original data were excluded due to the rope slipping failure mode.

For the Zinc Poured Socket, the plots shown in Figure 14 reflect TE mean values calculated without several data points considered unrepresentative at the 13 mm (½ in.), 19 mm (3/4 in.) and 38 mm (1½ in.) diameters. There is no interaction effect for the Lang construction, nor for the Regular construction, since the 84% mean value of the Regular 6x19 rope at the 38 mm (1½ in.) diameter is the result of combining two TE values of 99% and one TE value of 55% from a representative failure. The TE drop by all four rope types at the 19 mm (3/4 in.) diameter remains an unexplained result.

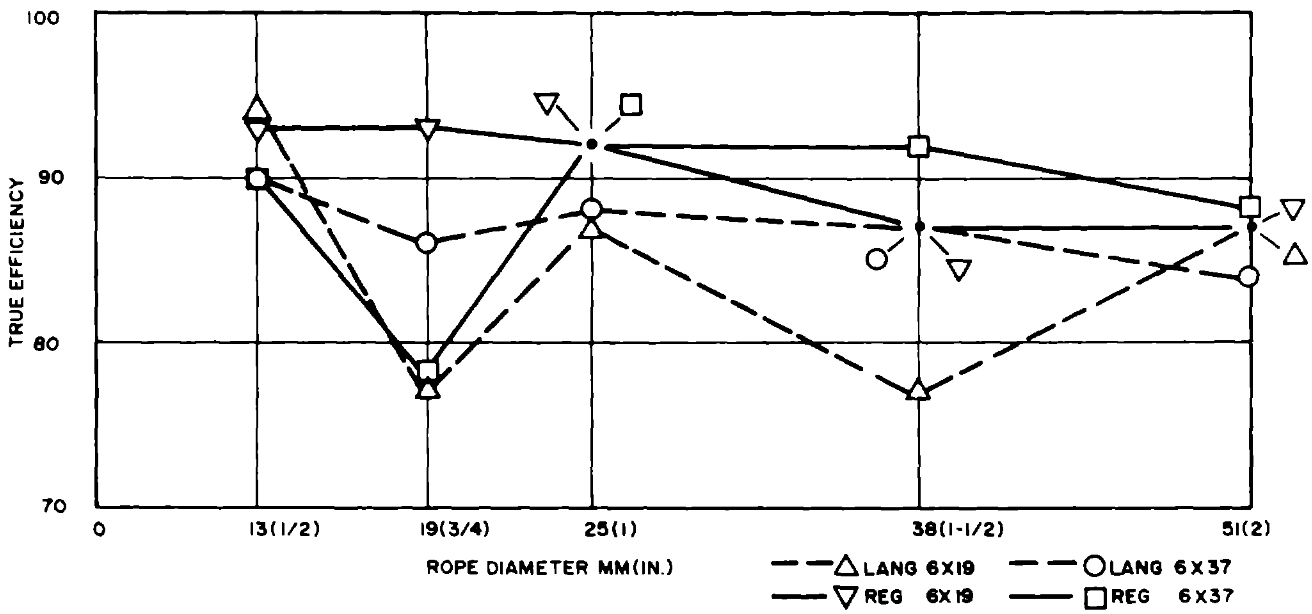


Figure 11 TE Plot for Turn Back Loop with Aluminum Sleeve & Thimble

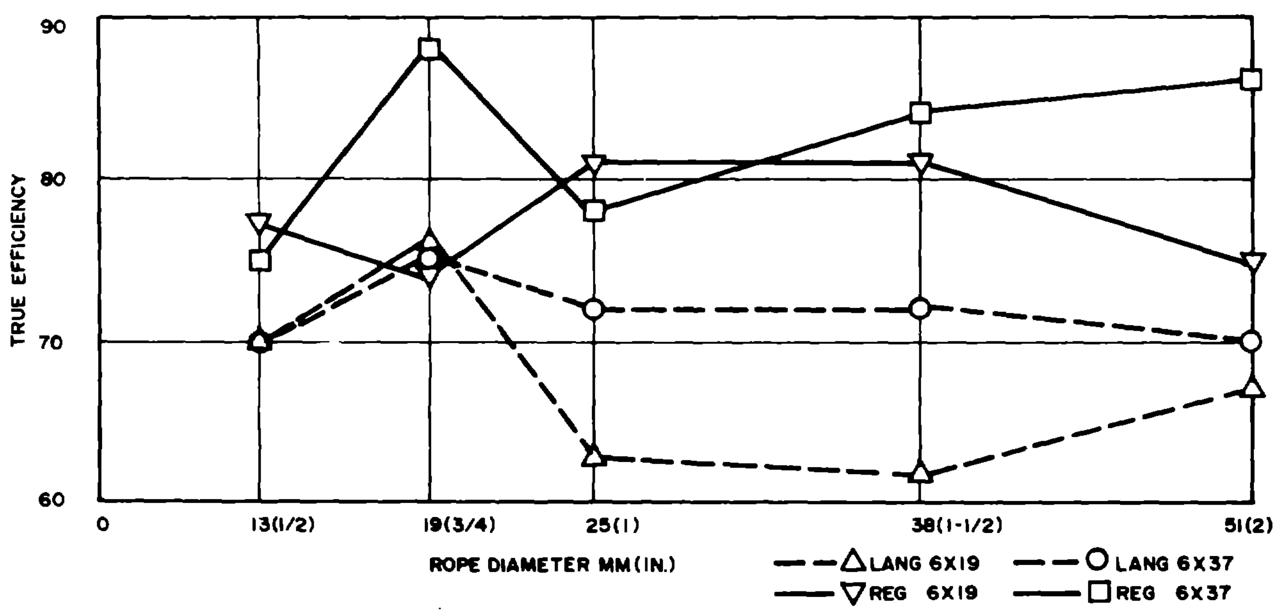


Figure 12 TE Plot for Thimble Slice with Four Tucks

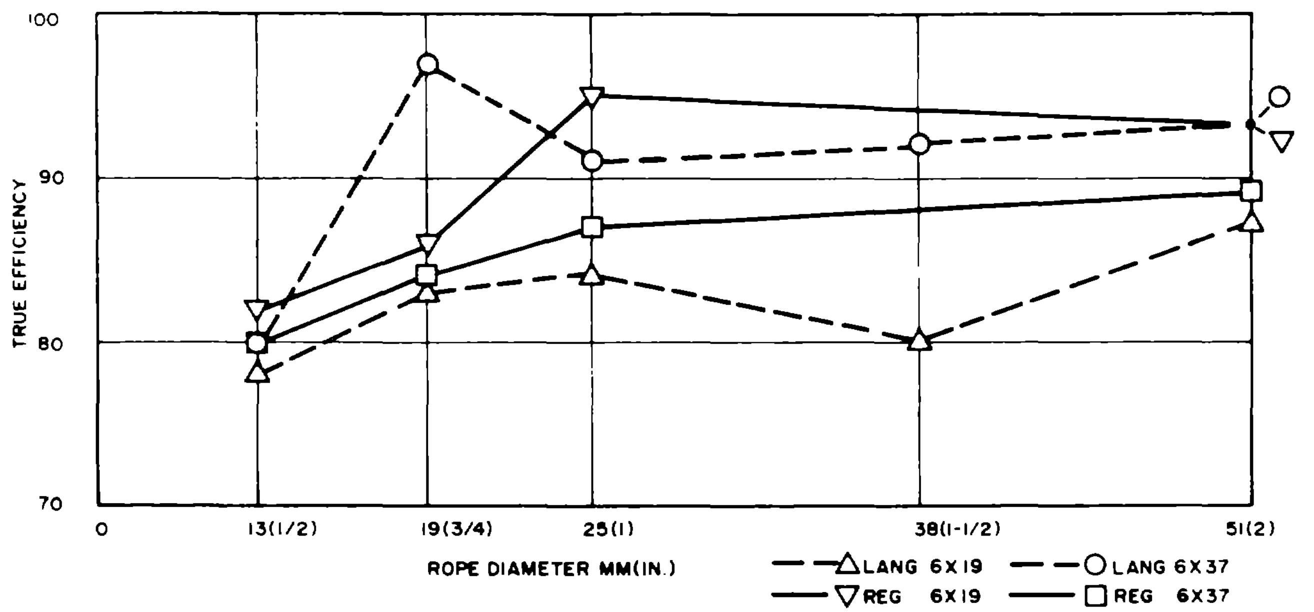


Figure 13 TE Plot for U-Bolt Clip with Thimble

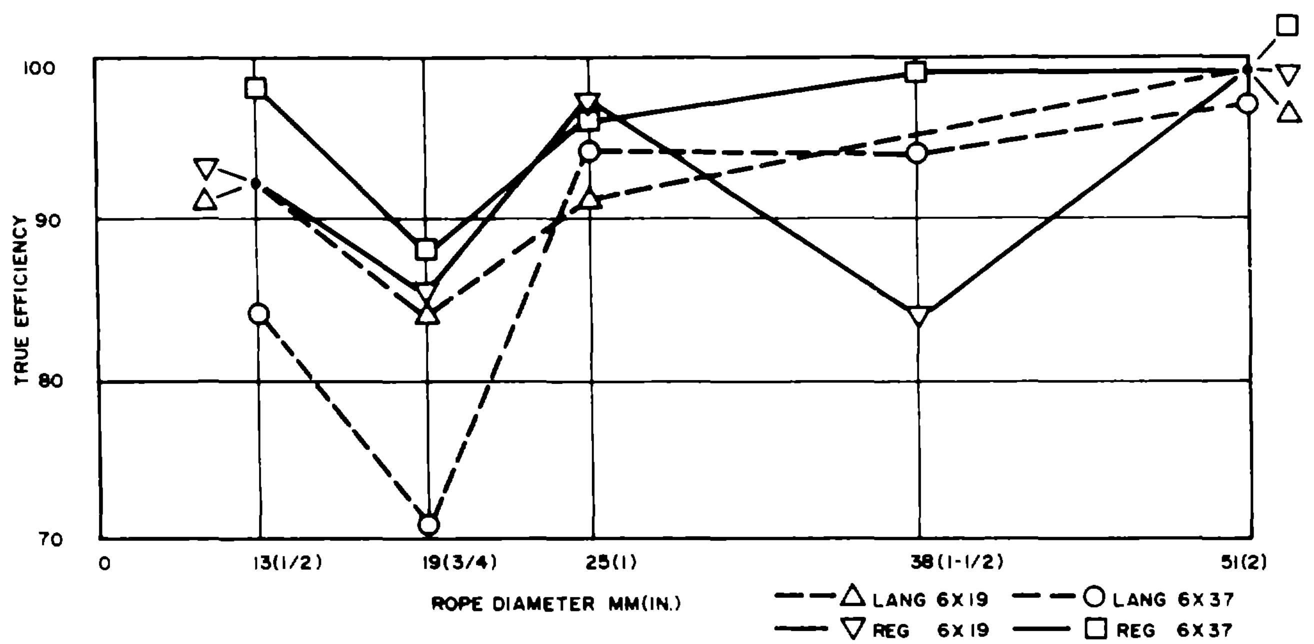


Figure 14 TE Plot for Zinc Poured Socket

Finally, the TE values for the ninth WRT tested, the Epoxy Resin Poured Socket, are plotted in Figure 15. As with the Zinc Poured Socket, the mean TE values were calculated without several data points which were considered unrepresentative. Actually twelve TE values were excluded or one fifth of the sixty specimens tested. These results suggest poor quality control in fabrication of the socket and poor workmanship in the assembly of the WRT, or both. The data plots do not display the two-way interaction effect, but do show a difference between the 6x19 and 6x37 class of Lang construction ropes. The 6x19 and 6x37 class ropes for Regular construction have TE values within three points of each other except at the 13 mm (½ in.) diameter.

A review of the preceding analysis is appropriate at this point before commencing with the analysis of the two-way interaction effect of WRT Type and Construction and WRT Type and Diameter. The two-way interaction effect of Rope Class and Diameter was claimed to exist for the WRTs and constructions listed below. The list also identifies those cases where the effect existed only at the 19 mm (3/4 in.) diameter.

Flemish Loop with Steel Sleeve & Thimble--Lang
Flemish Loop with Steel Sleeve--Lang
Wedge Socket--Lang
Swaged Socket--Lang, Regular (19 mm)
Turn Back Loop with Aluminum Sleeve & Thimble--Lang (19 mm)
Thimble Splice with Four Tucks--Lang, Regular
U-Bolt Clip with Thimble--Lang
Zinc Poured Socket--None
Epoxy Resin Poured Socket--None

Therefore, it is legitimate to pool or combine the 6x19 and 6x37 class data under the Lang construction for the Zinc Poured Socket and Epoxy Resin Poured Socket. Under the Regular construction the 6x19 and 6x37 data can be pooled for all the WRTs except the Swaged Socket and Thimble Splice with Four Tucks. Thus for nine of the eighteen cases (9 WRTs x 2 Constructions) one is able to legitimately pool the rope class data. Furthermore, if one is willing to discount the interaction effect at the 19 mm (3/4 in.) diameter, for the purpose of permitting an overall comparison, then two more sets of 6x19 and 6x37 class data can be pooled, bringing the total number of pooled data groups to eleven of eighteen cases.

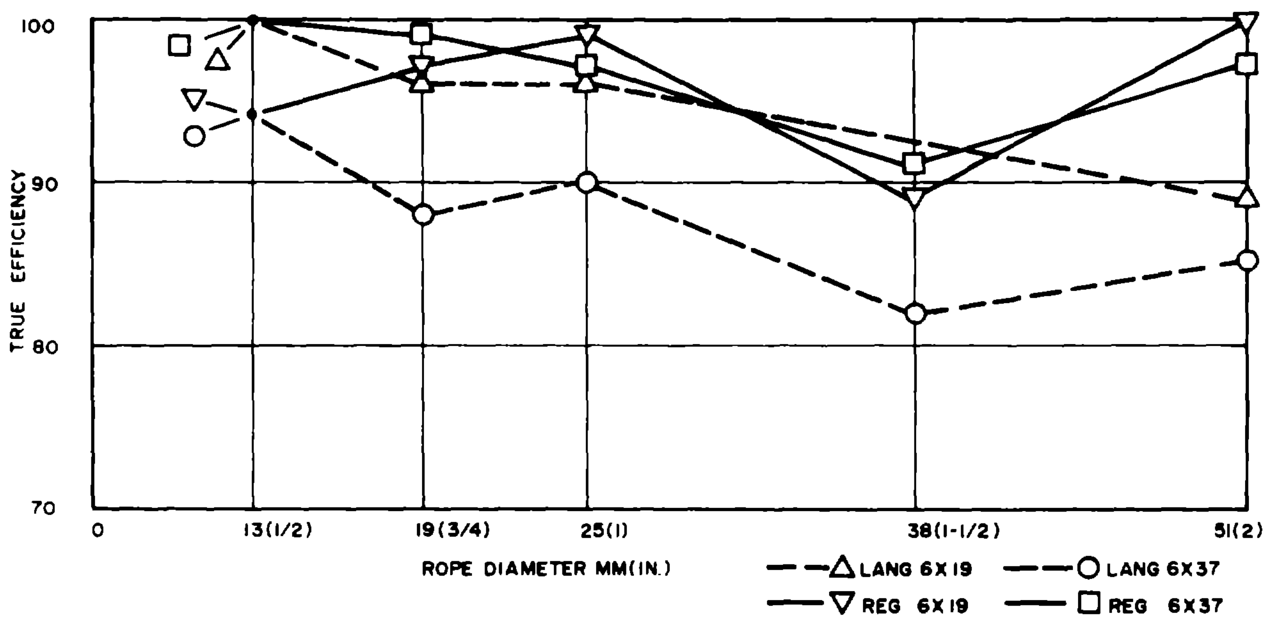


Figure 15 TE Plot for Epoxy Resin Poured Socket

The result of pooling, and computing the mean TE values for all the eighteen cases is presented in Table 18. Use of these mean values must recognize the averaging over of the demonstrated two-way interactions and the difference between the 6x19 and 6x37 classes, independent of any interaction effect with rope diameter. The mean values for Lang and Regular construction of each WRT Type can be used to examine the two-way interaction effect of WRT Type and Rope Construction, which accounted for four percent of the variation in TE. For each of the five diameters, the mean TE values are plotted in Figures 16, 17, 18, 19 and 20, as bar graphs, with the WRT Type identified by the number assigned in Table 18. These graphs show quickly which WRTs are best suited for Lang or Regular construction ropes or which WRTs perform equally well with either construction. Examining these bar graphs in sequence as rope diameter increases will be the closest approximation that is possible to a graphic illustration of the three-way interaction of WRT Type, Rope Construction, and Rope Diameter, an effect also accounting for four percent of the variation in TE. If one is willing to accept anything less than a five percentage point difference as noncritical, then the following observations can be made about the WRTs.

1. At the 13 mm (½ in.) diameter, Regular construction yields higher TE values for the Thimble Splice with Four Tucks and the Zinc Poured Socket. All other WRTs perform equally well with Regular or Lang construction.

2. At the 19 mm (3/4 in.) diameter, Regular construction yields higher TE values for the two Flemish Loop WRTs, Swaged Socket, Thimble Splice, Zinc Poured Socket, and Epoxy Resin Poured Socket. The Wedge Socket and U-Bolt Clip perform better with Lang construction. The Turn Back Loop with Thimble performs about the same with either construction.

3. At the 25 mm (1 in.) diameter, Regular construction yields higher TE values for the two Flemish WRTs, Swaged Socket, Thimble Splice with Four Tucks, and Epoxy Resin Poured Socket. All other WRTs perform about the same with either construction.

4. At the 38 mm (1½ in.) diameter all but three WRTs attained higher TE values with Regular construction. The Flemish Loop with Steel Sleeve & Thimble, Zinc Poured Socket, and Epoxy Resin Poured Socket performed about the same with either construction.

TABLE 18 TRUE EFFICIENCY OF WIRE ROPE TERMINATIONS AVERAGED OVER CLASS AND CONSTRUCTION [a]

Wire Rope Diameter	Wire Rope Construction	Termination Type [b] 1	2	3	4	5	6	7	8	9
13 mm (½ in.)	Lang	88	88	80	94	92	70	79	88	96
	Regular	88	90	84	95	92	76	81	95	96
	Mean	88	89	82	94	92	73	80	92	96
19 mm (3/4 in.)	Lang	84	82	80	84	82	76	90	78	92
	Regular	96	93	74	89	86	81	85	86	98
	Mean	90	88	77	86	84	78	88	82	95
25 mm (1 in.)	Lang	86	79	81	90	88	68	88	92	93
	Regular	94	88	76	96	92	80	91	96	98
	Mean	90	84	78	93	90	74	90	94	96
38 mm (1½ in.)	Lang	89	81	68	91	82	67	86	94	87
	Regular	90	91	73	98	90	82	91	92	90
	Mean	90	86	70	94	86	74	89	93	89
51 mm (2 in.)	Lang	84	86	71	90	86	68	90	98	88
	Regular	81	82	61	98	88	80	91	99	98
	Mean	82	84	66	94	87	74	90	98	93

(a) True Efficiency is defined as the termination's breaking load divided by the rope's True Breaking Load.

(b) Wire Rope Terminations

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

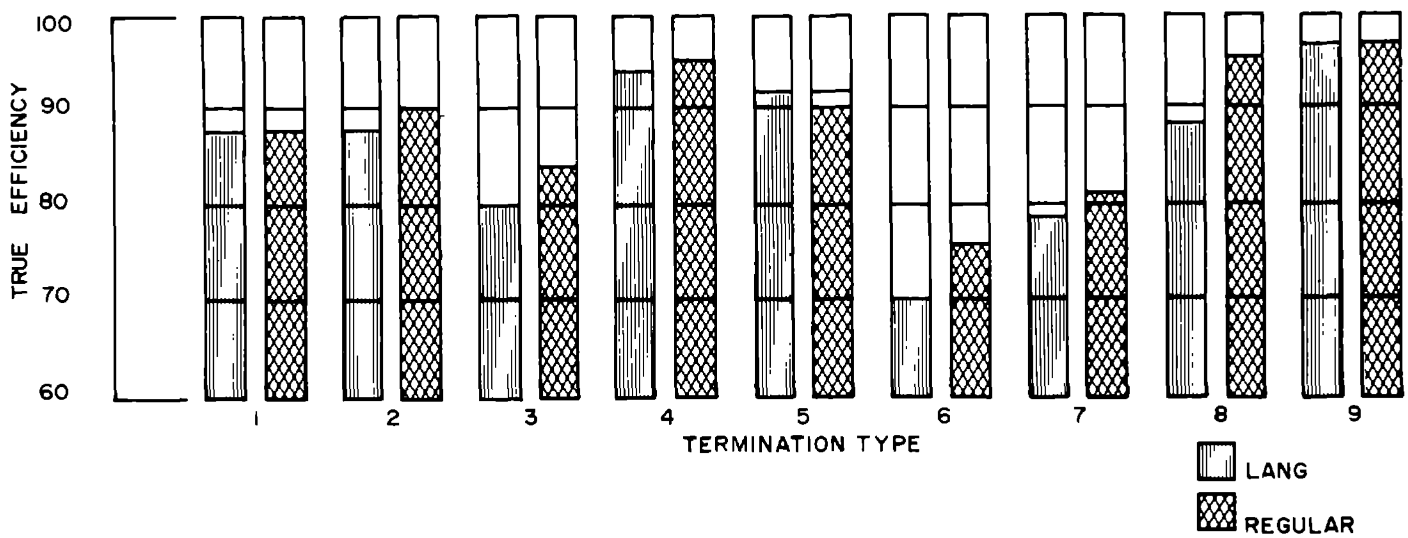


Figure 16 Bar Graph of TE for Lang and Regular Construction at 13 mm (½ in.) diameter.

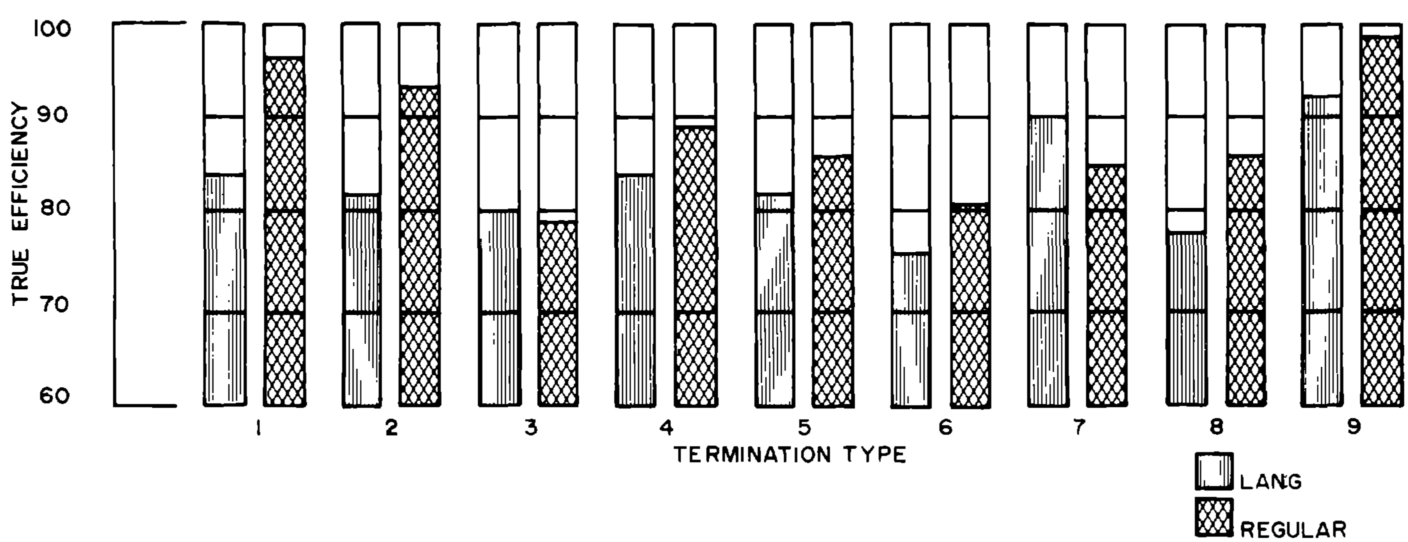


Figure 17 Bar Graph of TE for Lang and Regular Construction at 19 mm (3/4 in.) diameter.

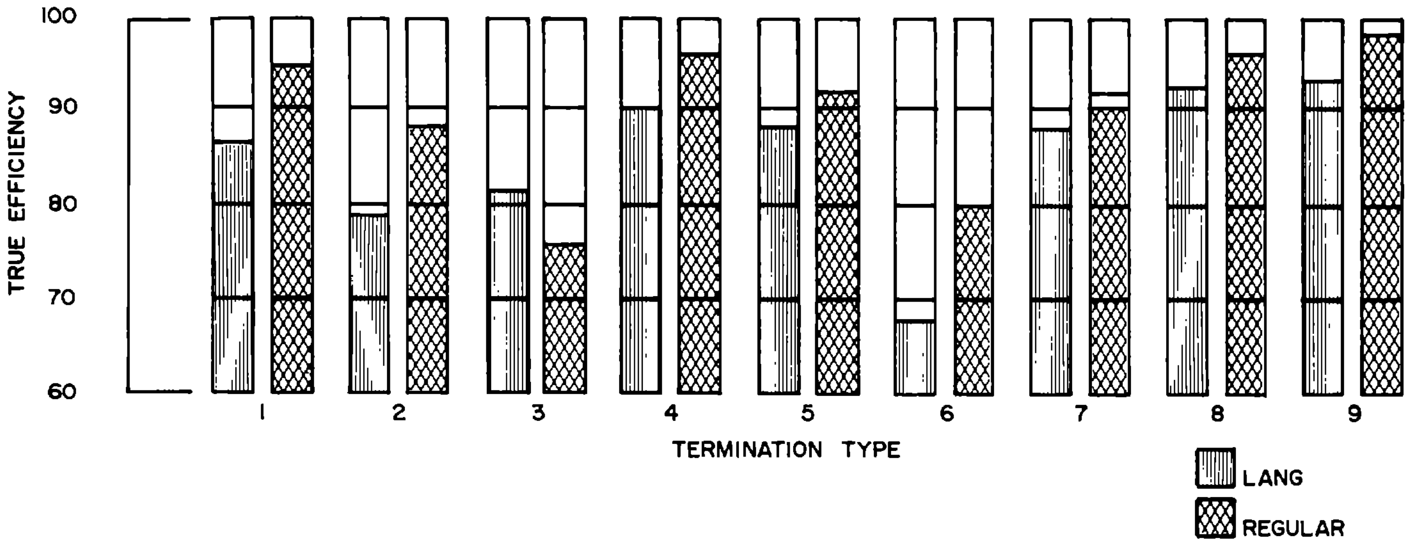


Figure 18 Bar Graph of TE for Lang and Regular Construction at 25 mm (1 in.) diameter.

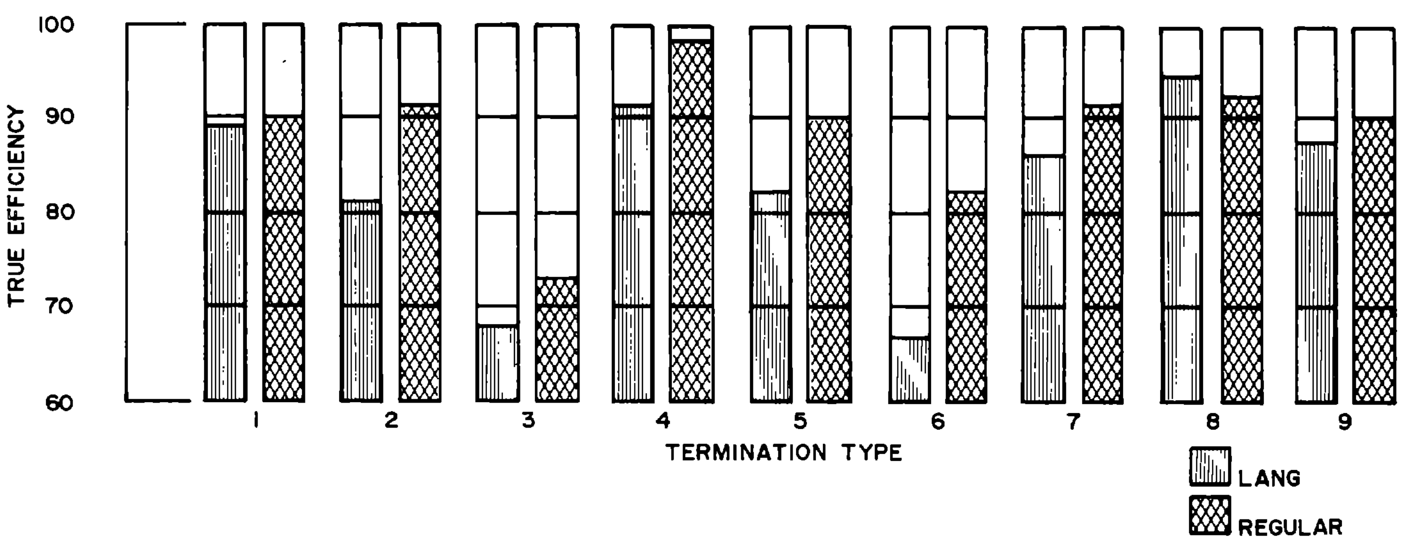


Figure 19 Bar Graph of TE for Lang and Regular Construction at 38 mm (1½ in.) diameter.

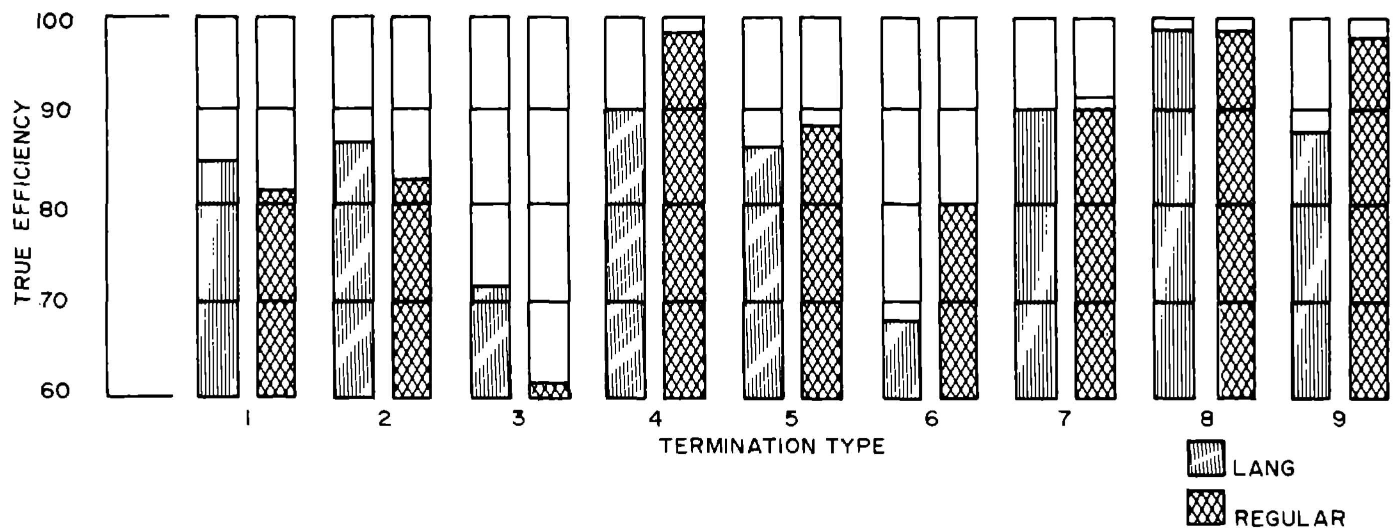


Figure 20 Bar Graph of TE for Lang and Regular Construction at 51 mm (2 in.) diameter.

5. At the 51 mm (2 in.) diameter, Lang construction yielded a higher TE value for the Wedge Socket. Regular construction yielded higher TE values for the Swaged Socket, Thimble Splice with Four Tucks, and Epoxy Resin Poured Socket. The other five WRTs performed about the same with either construction.

In summary, the preceding analysis has identified Regular Construction as the one yielding the higher TE values for the greatest number of WRTs. The Thimble Splice with Four Tucks alone attained higher TE values with Regular construction for all five diameters. The next most consistent performance with Regular construction was the Swaged Socket in the four larger diameters.

The data of Table 18 can also be used to examine the effect that accounted for fifteen percent of the variation in TE, the two-way interaction of WRT Type and Rope Diameter. Again, the WRT Types are assigned the numbers shown in Table 18. The data are plotted separately for each of the two constructions, but represent the mean value averaged over rope class. Figure 21, presents under Lang construction, WRT Types 1 thru 5, all showing the characteristic drop in TE values at the 19 mm (3/4 in.) diameter, except for the Wedge Socket. These five WRTs are within a TE spread of five points of each other at the 19 mm (3/4 in.) diameter. A twelve point spread contains WRT Types 1, 2, 4 and 5 for the remaining three diameters. The Wedge Socket has a thirteen point drop at the 38 mm (1½ in.) and barely rises above a TE of 70% at the 51 mm (2 in.) diameter. It should be recalled that this drop is partially attributed to the cracked socket failures experienced by the Wedge Socket at these two diameters. In Figure 22, under Regular construction, WRT Types 1 and 2 do not exhibit the drop in TE value at the 19 mm (3/4 in.) diameter, while WRT Types 3, 4, and 5 do. In this plot the Wedge Socket is again below the other WRTs with a mean value of 61% at the 51 mm (2 in.) diameter.

Returning to the Lang construction, WRT Types 4 thru 9 are plotted in Figure 23. WRT Type 4, Swaged Socket, is repeated to provide a reference line since it had the highest TE values at four of the five diameters in the previous two figures. At the 13 mm (½ in.) diameter the five WRTs are spread over a TE band of twenty-six points. The Thimble Splice with Four Tucks, WRT Type 6 is the lowest, even lower than the Wedge Socket, and remains so for all diameters. After reaching the 25 mm (1 in.) diameter the other WRTs remain relatively high and approximately within ten TE points of each other. The Zinc Poured Socket yielded the highest TE values at the larger diameters. The Regular construction data for WRT Types 4 thru 9 are plotted in Figure 24 with the Closed Swaged Socket again repeated for reference. The Thimble Splice with Four Tucks is again the lowest of this group, but is higher than the Wedge Socket. After reaching the 25 mm (1 in.) diameter the other WRTs again remain relatively close together for the remaining two diameters.

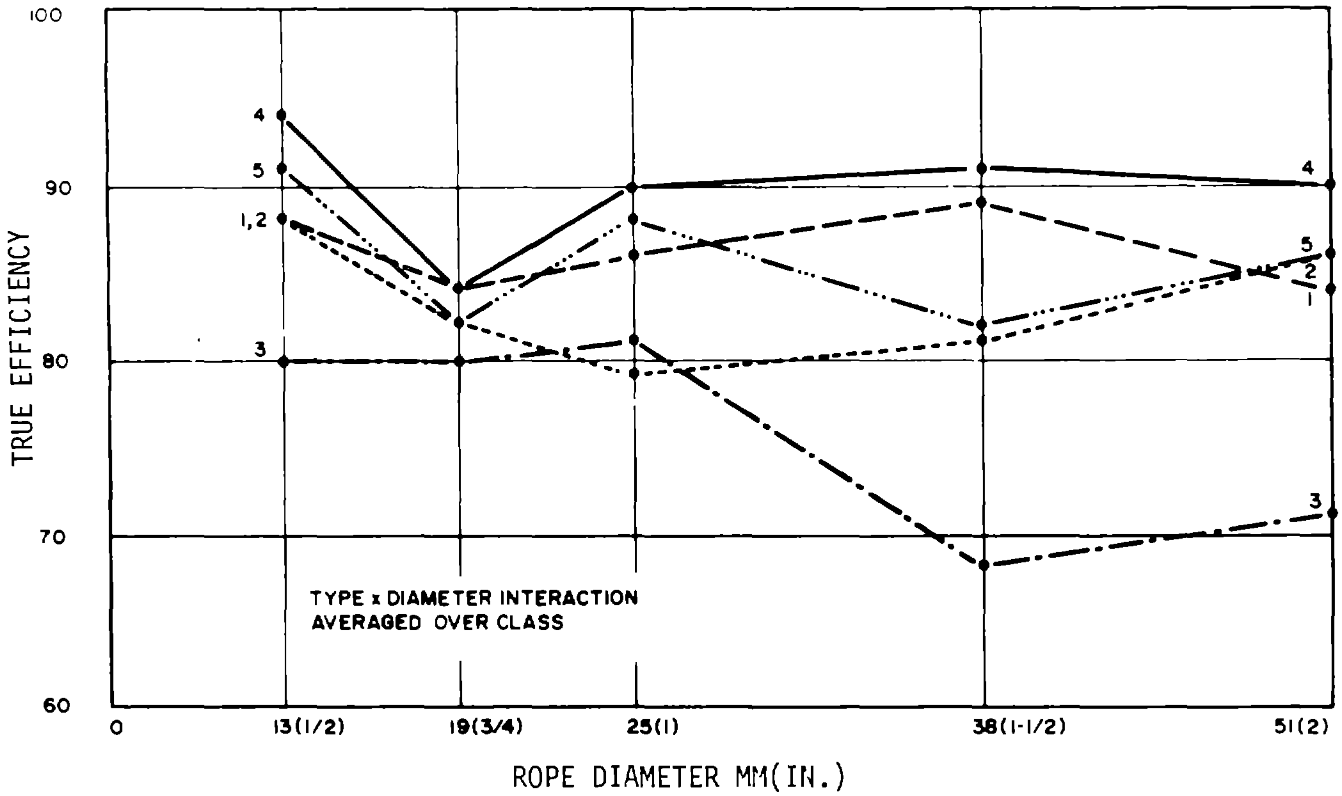


Figure 21 TE for Lang Construction on WRT Types 1,2,3,4, and 5.

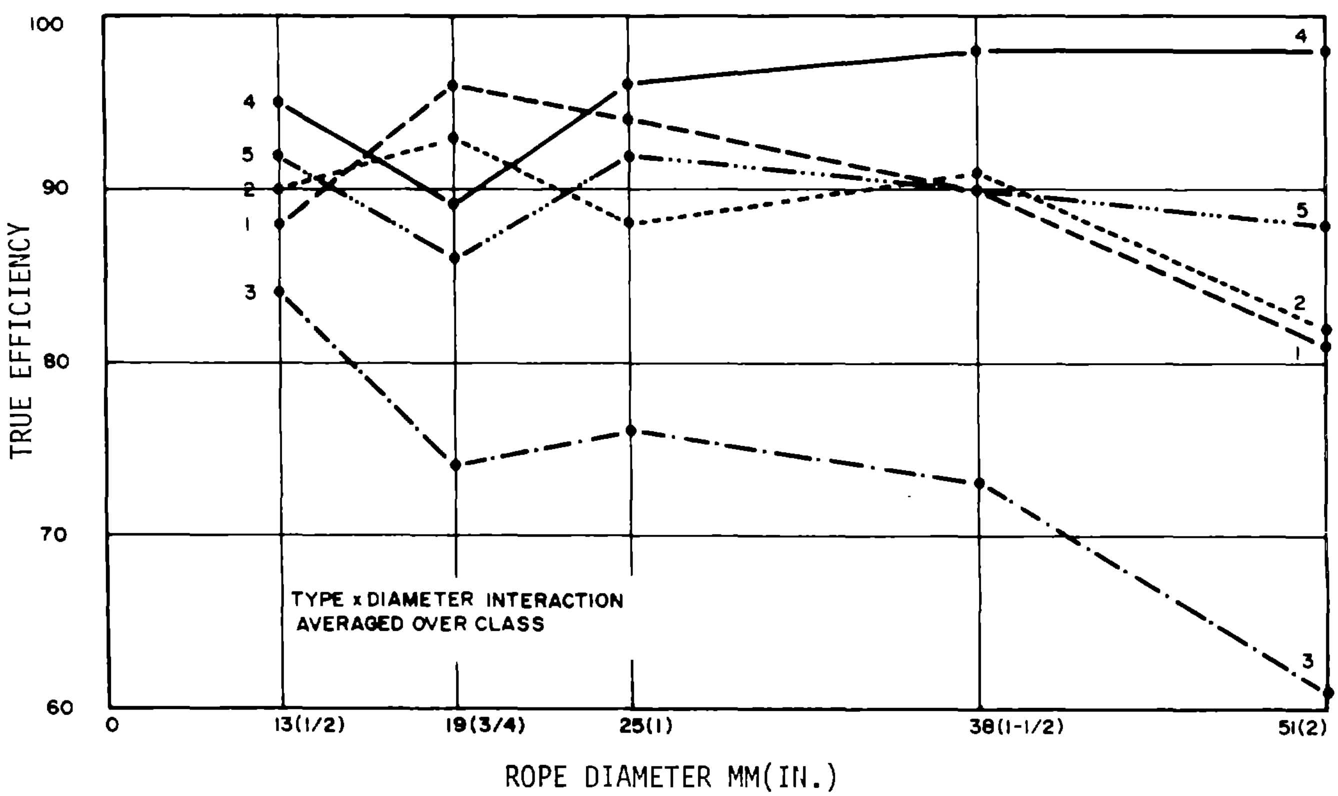


Figure 22 TE for Regular Construction on WRT Types 1,2,3,4, and 5.

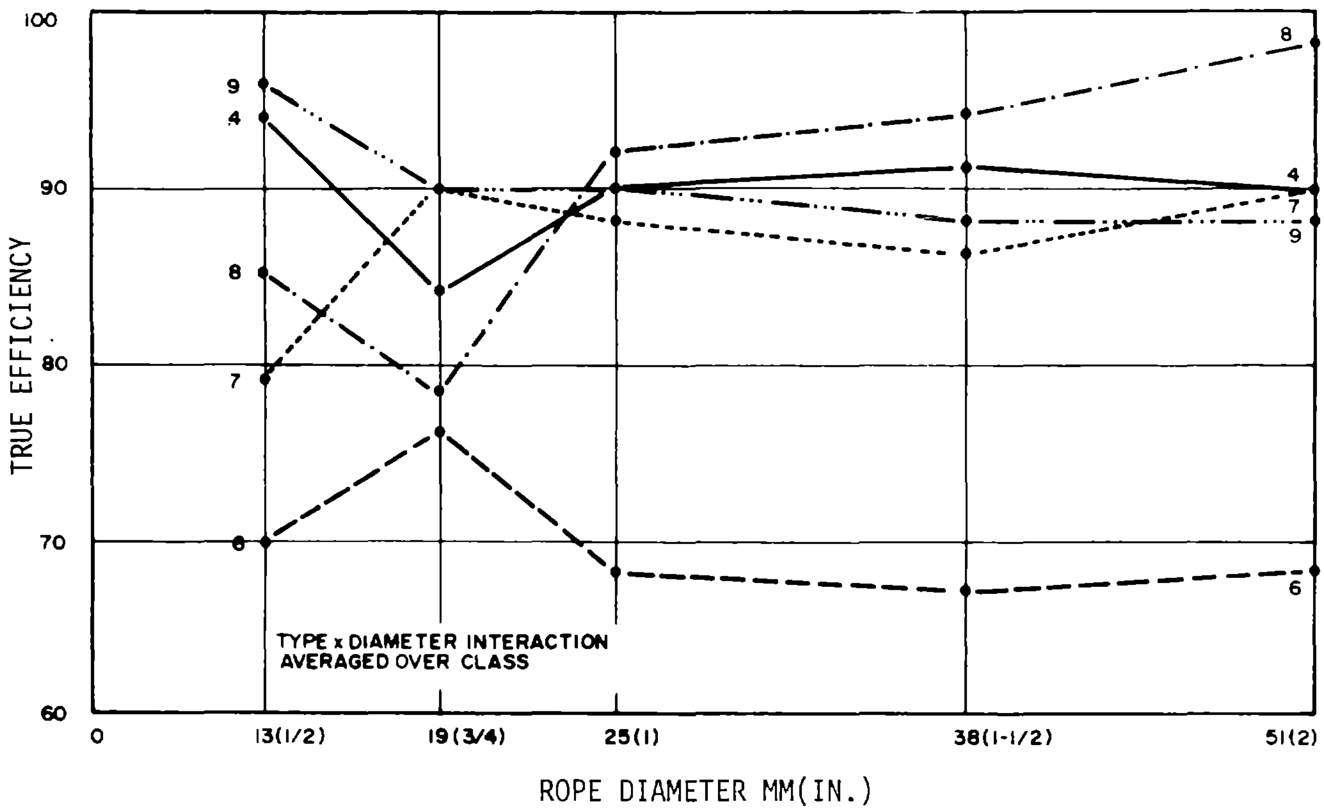


Figure 23 TE for Lang Construction on WRT Types 4,6,7,8, and 9.

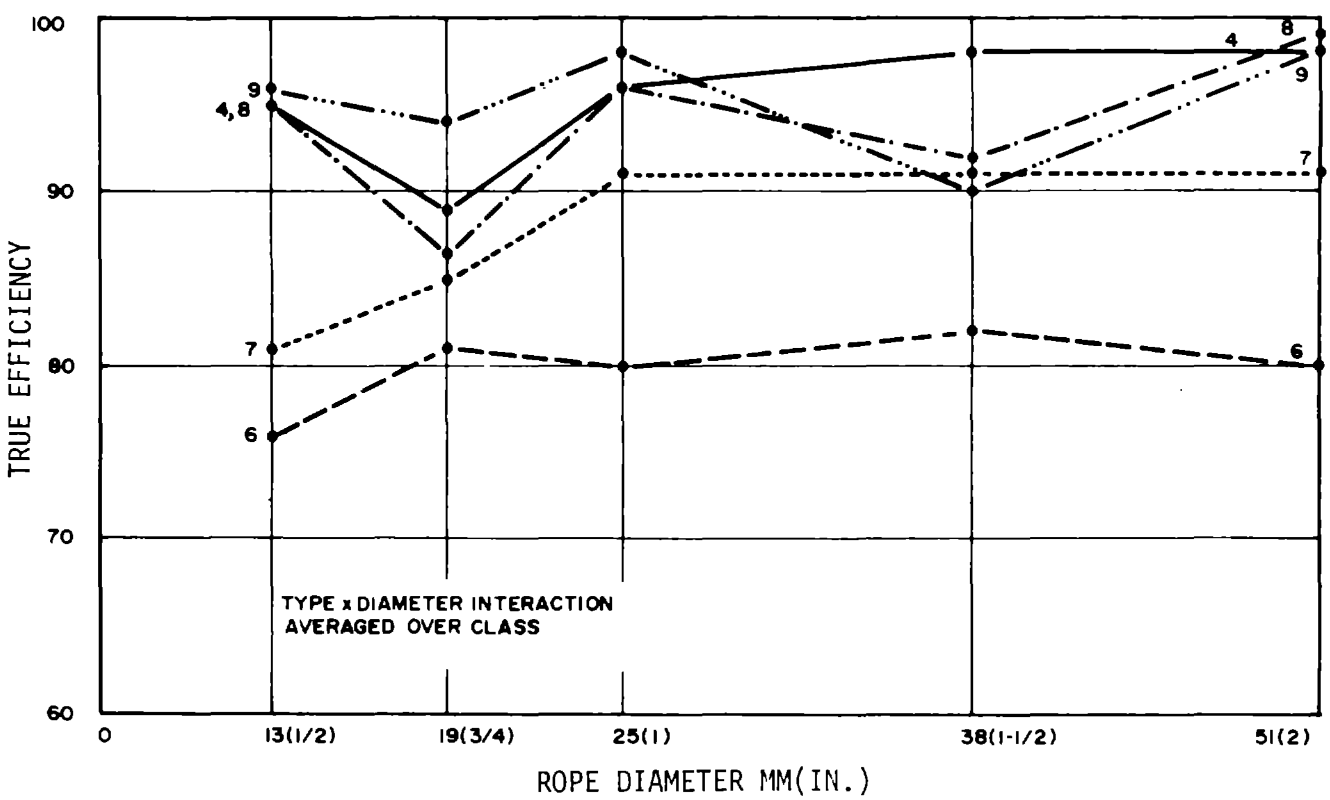


Figure 24 TE for Regular Construction on WRT Types 4,6,7,8, and 9.

As a convenience to those who may wish to compare the WRTs without considering the rope construction, Table 18 also contains the mean TE value combining the Lang and Regular construction data. However, the effect of construction has been sufficiently demonstrated to possibly make such an overall comparison misleading.

The analysis and discussion has so far been directed at the interaction effects, but will now turn to the four main effects which together accounted for thirty-two percent of the variation in TE. The fact that there were statistically significant interaction effects means that the variation produced by the main effects or their respective categories or levels, are not independent. That is, one must study the main effects as they interact with each other since the observed variation in TE is not completely the result of independent action by a particular level of any main effect. For example, it is insufficient to state that increasing diameter reduced the TE value. As discussed in the previous paragraphs one must also state for what particular WRT Type, Rope Construction, and Rope Class this effect was observed. Nevertheless, it is possible to examine the pattern of main effects by assuming a linear additive model of the main effects. Although such a model will not predict accurately each data point measured, it is possible that the conclusions drawn from the model would be essentially those drawn from a study of the main effects including the interaction effects. The linear model and its associated conclusions will be developed in the next section. Therefore, the conclusions one might draw from the measured data will be given here now and later used as a means of evaluating the accuracy of the linear model.

4.1.2 Conclusions Based on the ANOVA

1. All factors considered had a significant effect, but not independent of each other.

2. The Lang construction rope in the 6x19 class should not be used in WRTs relying on a pressed sleeve, nor in the Thimble Splice with Four Tucks and U-Bolt Clip with Thimble.

3. The 19 mm (3/4 in.) ropes exhibited low TE values as a whole, but in particular for the Lang 6x19 and Regular 6x37 constructions.

4. The Zinc Poured Socket and Epoxy Resin Poured Socket were least affected by the interaction of rope class and diameter.

5. Neither class of ropes yielded consistently higher TE values for any of the WRTs.

6. Regular construction rope yielded TE values greater than or nearly equal to those of Lang construction for at least seven of the WRTs in four of the five diameters. This difference was less noticeable at the 51 mm (2 in.) diameter.

7. The Swaged Socket yielded the highest and most consistent TE values for all diameters, except the 19 mm (3/4 in.) with either construction.

8. With Lang construction the Zinc Poured Socket has TE values above the Swaged Socket for diameters of 25 mm (1 in.) and higher.

9. With Regular construction the Epoxy Resin Poured Socket had TE values above or equal to the Swaged Socket for all but the 38 mm (1½ in.) diameter.

10. The Thimble Splice with Four Tucks yielded the lowest TE values of all with Lang construction.

11. The Wedge Socket yielded the lowest TE values with the Regular construction, except at the 13 mm (½ in.) diameter.

12. With Lang construction, a spread of ten TE points at the 51 mm (2 in.) diameter contains WRT Types 1, 2, 4, 5, 7, 8, and 9.

13. With Regular construction, a twenty point band of TE at the 51 mm (2 in.) diameter contains WRT Types 1, 2, 4, 5, 6, 7, 8, and 9.

4.1.3 Multiple Classification Analysis

To study the pattern of the main effects on TE one can use the Multiple Classification Analysis (MCA) produced by the ANOVA. The MCA presented in Table 19 assumes a linear model for TE of the form:

TE = Grand Mean + Type Deviation + Diameter Deviation + Construction Deviation + Class Deviation

As the above equation shows, the model does not consider the interaction effects, thus the MCA is especially useful when interaction effects are not significant. As previously mentioned the MCA's accuracy can be checked by comparing the conclusions drawn from the ANOVA with those drawn from the MCA. In Table 19 the Grand Mean value for TE is given as 84.76% while the deviation from the Grand Mean produced by each level or category of the four independent variables is listed under the column "Deviation." The "Variable + Category" column lists the nine WRT Types by numbers as most recently defined in Table 18. This column also lists the five rope diameters, two rope constructions, and two rope classes. The "N" column simply lists the number of data points used in computing the deviation value for each category. The proportion of variation in TE explained by each variable is listed under the "eta^2" column, and as previously shown in Table 15, WRT Type accounts for 24 percent of the variation, Rope Diameter for 3 percent, Rope Construction for 4 percent, and Rope Class for 1 percent. Because these four variables are orthogonal to each other, i.e. the same number of cases in each cell of a cross classification, the proportionate variation of all four variables is additive. Therefore the four variables jointly explain 32 percent of the variation in TE.

The deviation computed by the MCA were used to identify those categories within each variable that contributed to or detracted from high TE values. For WRT Types the Swaged Socket is shown to be the best while last place is shared by the Wedge Socket and Thimble Splice with Four Tucks. The 25 mm (1 in.) diameter gives the highest TE values while the 38 mm (1½ in.) gives the lowest TE values. Regular construction is shown to be better than Lang, and the 6x37 class is shown to be better than the 6x19 class.

TABLE 19 MULTIPLE CLASSIFICATION ANALYSIS OF TRUE EFFICIENCY

GRAND MEAN = 84.76

VARIABLE + CATEGORY	N	DEVIATION	eta^2
TYPE			
1	60	3.45	.24
2	60	1.23	
3	60	-9.91	
4	60	7.58	
5	60	2.59	
6	60	-9.87	
7	60	- .61	
8	60	2.66	
9	60	2.88	
DIAM			
1 13 mm	108	1.64	.03
2 19 mm	108	- .50	
3 25 mm	108	2.66	
4 38 mm	108	-3.33	
5 51 mm	108	- .47	
CONSTR			
1 Lang	270	-2.35	.04
2 Regular	270	2.35	
CLASS			
1 6x19	270	-1.01	.008
2 6x37	370	1.01	

N: Number of data points used to compute the deviation value.

DEVIATION: Difference between Grand Mean and mean value for each category of each variable.

eta^2: Proportion of Variation in TE attributed to each variable.

The deviation values provided by the MCA table can also be used to compute the Expected True Efficiency (ETE) for any combination of WRT Type, Rope Diameter, Rope Construction, and Rope Class used in this experiment. Because of the orthogonal property of the four variables, one can express ETE as:

ETE = 84.76 + WRT Type(i) + Dia.(j) + Construction(k) + Class(m)

where: i = 1, 2, 3, 4, 5, 6, 7, 8, 9 WRT Types
j = 1, 2, 3, 4, 5 Rope Diameters
k = 1, 2 Rope Construction
m = 1, 2 Rope Class

For example, the ETE for a WRT using a Flemish Loop with Steel Sleeve (Type No. 2), a 38 mm (1½ in.) diameter rope of Lang construction, and 6x19 class rope would be as follows:

ETE = 84.76 + (1.23) = (-3.33) + (-2.35) + (-1.01)

ETE = 79.3 or 79% of TBL

This value for TE computed by the linear model is 5 points above the corresponding mean TE value of 74% computed from the measured data, resulting in a positive six percent error for the model. The model predicts that the highest TE value of 98% is to be expected from a Swaged Socket pressed on 25 mm (1 in.) diameter rope of Regular construction and 6x37 class. This high value compares well with the mean TE of 96% for the specified combination and gives only a positive two percent error for the model. The highest mean TE value actually reached was 100% by the Epoxy Resin Poured Socket, both with a Lang 6x19 rope at the 13 mm (½ in.) diameter and a Regular 6x19 rope at the 51 mm (2 in.) diameter. The model predicts that the lowest TE value of 68% is to be expected from a Wedge Socket attached to a 38 mm (1½ in.) diameter rope of Lang construction and 6x19 class. This low value also compares well with the mean TE of 64% for the specified combination and gives a positive six percent error for the model. Other comparisons that can be made result in both positive and negative errors for the model, and although most errors are less than ten percent, there is an extreme negative error of sixteen percent for the Epoxy Resin Poured Socket with a 13 mm (½ in.), Lang 6x19 rope and a positive error of seventeen percent for the Zinc Poured Socket with a 19 mm (3/4 in.) Lang 6x37 rope.

The ETE values for all possible combinations used in this study are presented in Table 20. The ETE values and the MCA table itself can be used to evaluate the usefulness of the linear model by testing each of the conclusions based on the ANOVA with this data. The first conclusion is of course not applicable. The second conclusion is in agreement with the model that shows Lang 6x19 rope to be less desirable than the other choices. The model agrees with only part of the third conclusion, identifying the 19 mm (3/4 in.) diameter rope as producing a negative deviation. The fourth conclusion is not addressed by the model. The fifth conclusion is only in slight disagreement with the model that attributed a 2 percent difference between the rope classes. The sixth conclusion is in agreement with the model that attributed a 4.7 percent advantage to Regular construction. The model agrees with the seventh conclusion, but disregards the exception at the 19 mm (3/4 in.) diameter. The eighth and ninth conclusions find no support from the model. The model agrees with the tenth and eleventh conclusions, but does not differentiate between the Thimble Splice with Four Tucks and the Wedge Socket. The model does not address the twelfth or thirteenth conclusions.

In general it is observed that the linear model would agree with the conclusions drawn from the ANOVA. The model however, is found to be lacking in its ability to discriminate or permit other than general conclusions. Such a finding is in agreement with the fact that the main effects on which the model is based accounted for only thirty-two percent of the variation in TE. The forty-four percent of the variation in TE attributed to interaction effects was not considered by the model.

TABLE 20 EXPECTED TRUE EFFICIENCY OF WIRE ROPE TERMINATIONS

Wire Rope			Termination Type[a]								
Diameter	Construction	Class	1	2	3	4	5	6	7	8	9
13 mm (½ in.)	Lang	6x19	86	84	73	91	86	73	82	86	86
		6x37	88	86	75	93	88	75	84	88	88
	Regular	6x19	91	89	78	95	90	78	87	90	91
		6x37	93	91	80	97	92	80	89	92	93
19 mm (3/4 in.)	Lang	6x19	84	82	71	88	83	71	80	84	84
		6x37	86	84	73	90	86	73	82	86	86
	Regular	6x19	89	87	76	93	88	76	85	88	88
		6x37	91	89	78	95	90	78	87	90	90
25 mm (1 in.)	Lang	6x19	88	85	74	92	87	74	83	87	87
		6x37	90	87	76	94	89	76	85	89	89
	Regular	6x19	92	90	79	96	91	79	88	91	92
		6x37	94	92	81	98	93	81	90	93	94
38 mm (1½ in.)	Lang	6x19	82	79	68	86	81	68	77	81	81
		6x37	84	81	70	88	83	70	79	83	83
	Regular	6x19	86	84	73	90	85	73	82	85	86
		6x37	88	86	75	92	87	75	84	87	88
51 mm (2 in.)	Lang	6x19	84	82	71	89	84	71	80	84	84
		6x37	86	84	73	91	86	73	82	86	86
	Regular	6x19	89	87	76	93	88	76	85	88	89
		6x37	91	89	78	95	90	78	87	90	91

[a] WIRE ROPE TERMINATIONS

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

4.2 Service Life of WRTs

4.2.1 Analysis of Standard Specimen Data

The Service Life (SL) of the WRTs expressed as the logarithim to the base 10 of the cycles to failure can be shown as a function of rope diameter for four of the five diameters tested. As discussed earlier a load range of 35% was used for the 13 mm (½ in.) and 19 mm (3/4 in.) diameters, and a load range of 25% was used for the 25 mm (1 in.) and 38 mm (1½ in.) diameters. Therefore, it is valid to compare the SL of the WRTs at each of these two pairs of diameter values.

In Figure 25 the SL values with Regular construction of WRT Types 1, 4, and 5 are shown to decrease as the diameter increases from the 13 mm (½ in.) to the 19 mm (3/4 in.) diameter. WRT Type 9 shows an increase which is unrelated to the size effect since the mean SL value at the 13 mm (½ in.) diameter includes two cracked socket failures. At the 25 mm (1 in.) to 38 mm (1½ in.) diameter increase WRT Types 1, 4, and 9 show a decrease in SL. The lower SL mean value of WRT Type 5 at the 25 mm (1 in.) diameter are the result of three early failures from cracked aluminum sleeves. The low SL values for WRT Type 9 are the result of cracked sockets.

WRT Types 2, 3, 6, 7 and 8 are displayed in Figure 26. The SL values of WRT Types 2, 3, and 6 decrease as the diameter increases from the 13 mm (½ in.) to the 19 mm (3/4 in.) diameter while WRT Type 8 remains constant. At the 25 mm (1 in.) to 38 mm (1½ in.) diameter increase, WRT Type 3 is the only one to decrease in its SL values and even this decrease is relatively small. The increase in SL of WRT Type 2 may be attributed to the ability of the larger wires in the 38 mm (1½ in.) diameter rope to withstand the bending about the load pin better than the wires in the 25 mm (1 in.) diameter rope. Like WRT Type 3, WRT Type 6 shows a change which is relatively small and considered to be within the data spread expected in fatigue tests.

WRT Type 7 shows an increase in SL values in the two sets of diameter increases. It is possible this may be related to a difference in the local stress produced by the U-Bolt Clip torque. If the stress is proportional to the torque and the CBL of a rope is proportional to the rope's capacity to resist the stress, then the ratio of torque to CBL could be used to compute a relative stress for each rope. Although this is speculation, it turns out that these ratios, shown below, would support this logic.

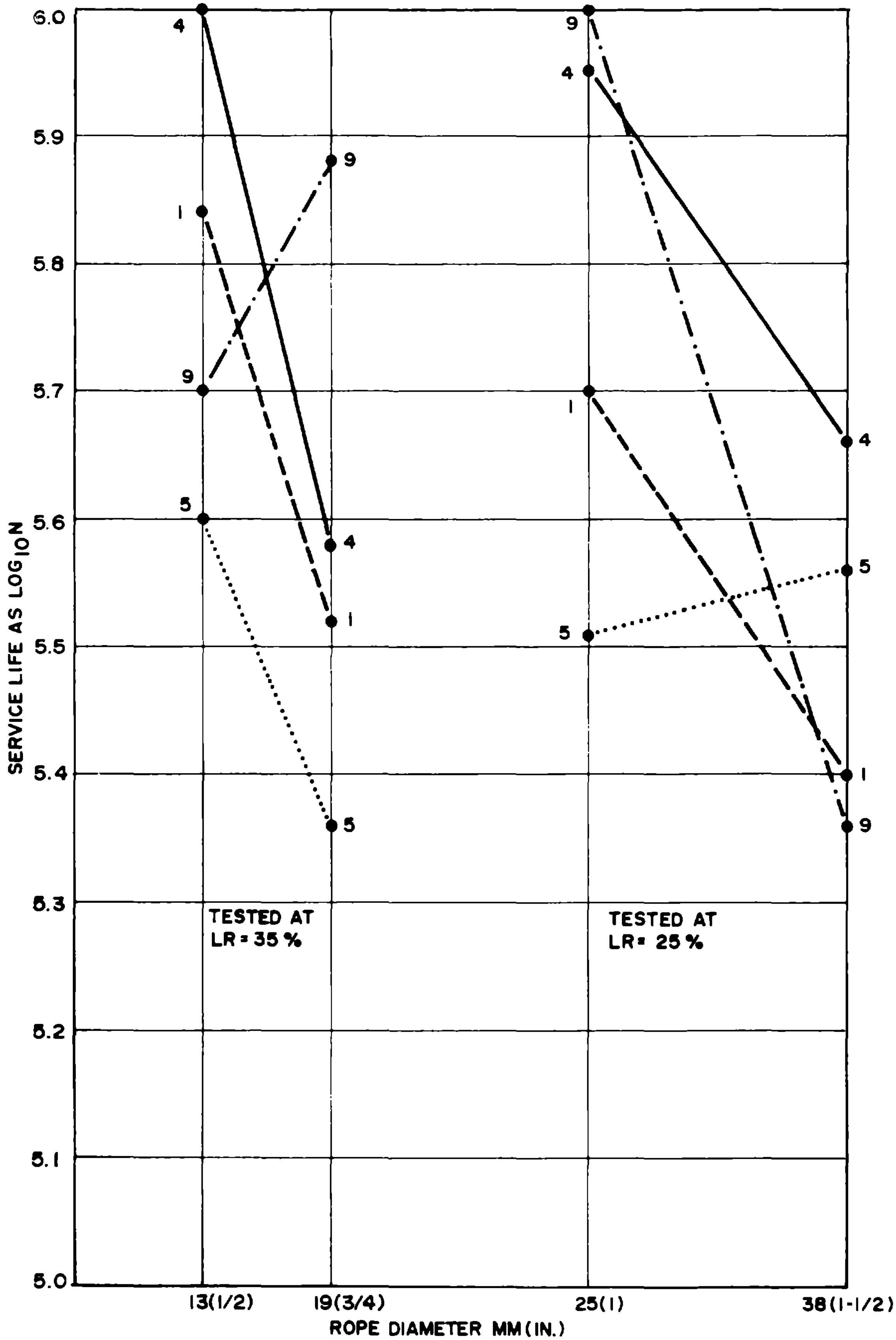


Figure 25 SL for Regular Construction on WRT Types 1,4,5, and 9.

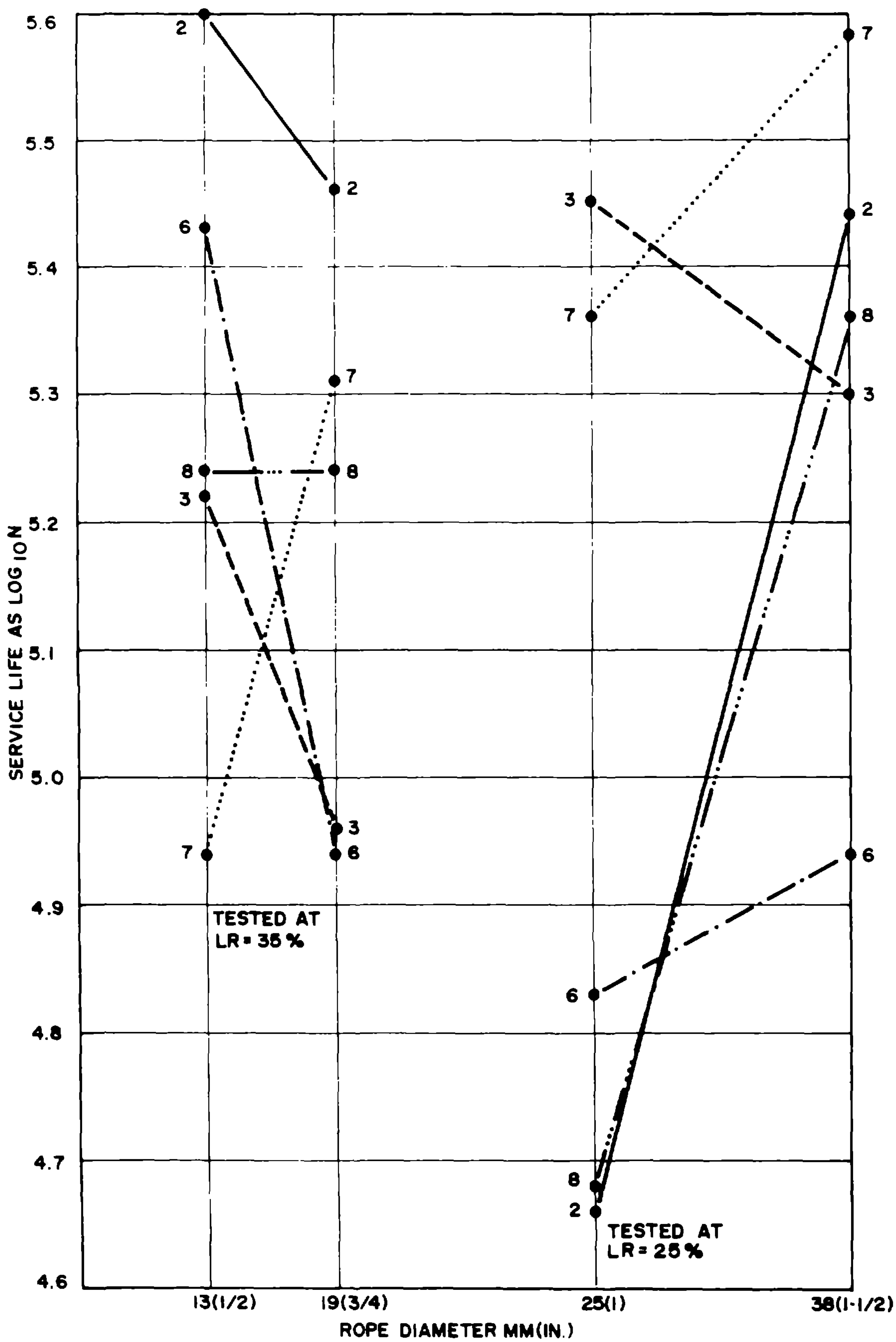


Figure 26   SL for Regular Construction on WRT Types 2,3,6,7, and 8.

Diameter	Torque	CBL (Kg)	Torque/CBL
13 mm (½ in.)	88.4 joules	10,432	.0085
19 mm (3/4 in.)	176.8 joules	23,224	.0076
25 mm (1 in.)	306 joules	40,732	.0075
38 mm (1½ in.)	489.6 joules	89,720	.0054

As the torque to CBL ratios show, a higher relative local stress exists at the 13 mm (½ in.) than at the 19 mm (3/4 in.) diameter. The same is true for the 25 mm (1 in.) and 38 mm (1½ in.) diameters. Therefore one might speculate that although the same load range was applied to each of the two pairs of diameters; 13 mm (½ in.) and 19 mm (3/4 in.) and 25 mm (1 in.) and 38 mm (1½ in.), the local stress field was higher at the smaller diameter of each pair due to the torque of the U-Bolt Clip. Thus the lower Service Life at the smaller diameters.

The large increase in the SL values of WRT Type 8 must be attributed to the increase in rope diameter. The four specimens involved were tested at the same frequency, on the same machine and failed in the same characteristic mode of broken wires at the base of the socket.

The SL data plots of Regular construction show that increasing rope diameter results in decreasing SL values for WRT Types 1, 3, 4 and 6. For WRT Types 2, 7, and 8 an increase in rope diameter results in an increase in SL values. The results for WRT Type 7 may not be caused by the independent effect of rope diameter, but the result of rope diameter combined with the torque values used to tighten the U-Bolt Clips. Cracked sleeves in WRT Type 5 and cracked sockets in WRT Type 9 did not permit demonstration of any rope diameter effect on these two WRTs.

The single SL values obtained with Lang construction are plotted in Figures 27 and 28. The pattern for WRT Types 2, 4, 5, and 7 are exactly as with Regular construction. For WRT Types 1, 7, 8, and 9 the pattern is the same for at least one set of diameters considered. Thus, there appears to be no effect on SL values from rope construction.

4.2.2 Residual Load Capacity of Fatigue Specimen

Fifty-three specimens of standard assembly were salvaged after fatigue testing and pull tested to determine the Residual Load Capacity (RLC). The other seventy-two standard assembly fatigue specimens were not tested for RLC because of a complete rope separation, hardware failure, or logistics.

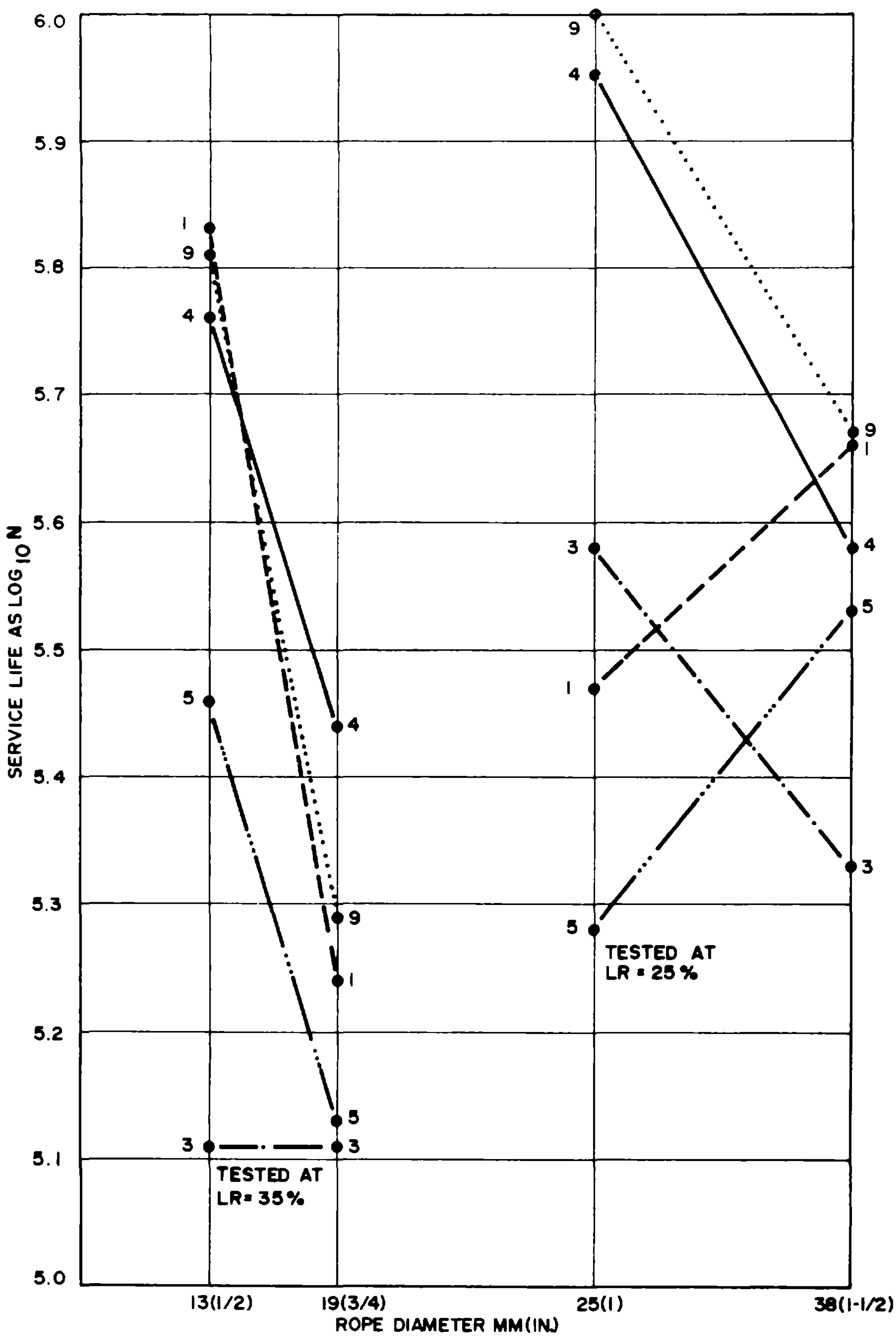


Figure 27 SL for Lang Construction on WRT Types 1,3,4,5, and 9.

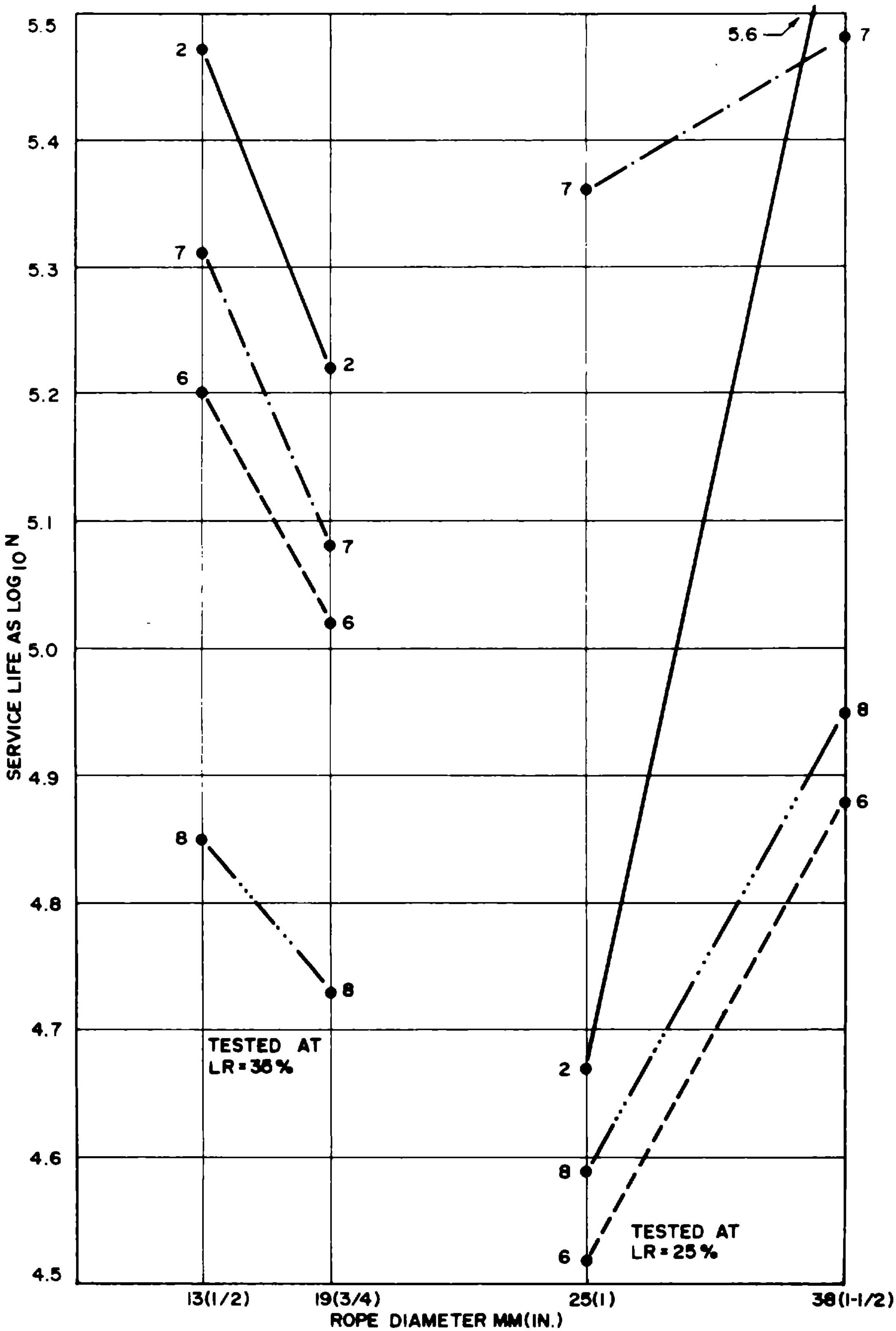


Figure 28 SL for Lang Construction on WRT Types 2,6,7, and 8.

The fifty-three fatigue specimens had satisfied the failure criteria of one or more broken strands or twenty broken wires. The failure description found in Appendix D identifies the specimens by termination type and identification number. The location of the failure is given and the failure is described in terms of the number of strands broken, the number of broken wires in each of these strands, and a qualitative description of the core. The core was described as "OK" if all core strands appeared intact, and as "All" if all six strands were broken or the core had disintegrated.

The results of the RLC tests are shown in Table 21, with specimens identified by termination type and identification number. For each specimen the table lists the rope diameter, the RLC value as a percent of the Catalog Breaking Load (CBL), and the association between the RLC and the failure description based on a visual inspection. The degree of association is expressed as Good, Fair, and Poor, with a minus sign (-) or a plus sign (+) before a Poor association indicating respectively that the RLC value was below or above what would be expected from the visual inspection.

Of the fifty-three specimens only two had RLC values below the Safe Working Load (SWL), usually set as 20% of CBL. Thus replacing a WRT when it reached the failure criteria used in these tests would provide a substantial margin of safety, assuming the SWL was not exceeded by a dynamic overload. Furthermore, the visual inspection of the rope in general provided a valid report on the rope's condition with over three fourths of the specimens displaying a Good or Fair degree of association between the visual inspection and the resulting RLC value. The ability of a visual inspection to predict the RLC of course varied with the WRT Type. The Flemish Loop with Steel Sleeve & Thimble, Wedge Socket, Epoxy Resin Poured Socket, and Thimble Splice with Four Tucks had no Poor associations at all. The remaining WRTs had two or more Poor associations, and all of these except two had a minus sign, suggesting that substantial damage in these WRTs was not detectable by a visual inspection.

TABLE 21 RESIDUAL LOAD CAPACITY OF STANDARD ASSEMBLY FATIGUE SPECIMENS

Termination Type	I.D. No.	Rope Dia. mm (in.)	Residual Load Capacity (% CBL)	Association With Visual Inspection
Flemish Loop With Steel Sleeve & Thimble	13	13(½)	29	Good
	17	13(½)	44	Good
	18	13(½)	70	Good
	49	19(3/4)	1	Good
	125	25(1)	78	Good
	131	25(1)	78	Good
	211	38(1½)	46	Fair
	212	38(1½)	38	Good
Flemish Loop With Steel Sleeve	1	13(½)	39	-Poor
	5	13(½)	54	Good
	6	13(½)	63	+Poor
	53	19(3/4)	57	Good
	311	19(3/4)	74	+Poor
	63	25(1)	62	Fair
	64	25(1)	61	Good
	146	25(1)	52	Good
	206	38(1½)	50	-Poor
	207	38(1½)	50	-Poor
Wedge Socket	227	13(½)	37	Good
	228	13(½)	28	Good
	231	13(½)	25	Good
	249	25(1)	72	Good
	256	25(1)	67	Fair
Swaged Socket	33	13(½)	37	Fair
	496	38(1½)	29	-Poor
	497	38(1½)	24	-Poor
Turn Back Loop With Aluminum Sleeve & Thimble	173	13(½)	45	Good
	396	13(½)	44	Good
	386	19(3/4)	0	-Poor
	387	19(3/4)	61	Fair
	189	25(1)	64	Good
	190	25(1)	56	-Poor
	194	25(1)	56	-Poor
Thimble Splice with Four Tucks	68	13(½)	76	Fair
	69	13(½)	55	Good
	77	13(½)	68	Fair
	84	19(3/4)	32	Good
	85	19(3/4)	56	Fair
	89	19(3/4)	30	Good
	90	25(1)	53	Good
U-Bolt Clip With Thimble	216	13(½)	43	Fair
	217	13(½)	47	Good
	441	38(1½)	50	-Poor
	442	38(1½)	50	-Poor
Zinc Poured Socket	352	13(½)	37	Good
	353	13(½)	56	Good
	354	13(½)	35	-Poor
	340	19(3/4)	53	Good
	324	25(1)	96	Good
	325	25(1)	39	-Poor
	329	25(1)	44	-Poo4
Epoxy Resin Poured Socket	1016	25(1)	89	Good
	1021	25(1)	78	Fair

4.3 Sensitivity to Poor Workmanship

The static and dynamic performance of a WRT, described in this report as the True Efficiency and Service Life is based on a correctly assembled WRT. Should lack of materials, time or skill become involved in the assembly of a WRT, the performance may be degraded. For each of the standard assembly procedures presented in Appendix B there are many points where an incorrect step could occur. Of these, two were selected and identified as Modified Procedure No. 1 (Mod. 1) and Modified Procedure No. 2 (Mod. 2). Both modified procedures for each WRT are presented in Appendix B.

The sensitivity of a WRT to poor workmanship is generally defined as the vulnerability of the assembly procedure to errors by an unskilled worker. The more complex the procedure in terms of sequence of steps, critical measurements, or control of assembly processes, the more likely is the possibility that an error will be made. A short and simple assembly procedure is less likely to be misunderstood or incorrectly followed. Of the nine WRTs evaluated, none was completely "fool proof." That is, each has an assembly procedure which is susceptible to human and machine error or both. Another aspect considered here is one that is related to the sensitivity to poor workmanship and is described as the quality or characteristic of a WRT that will prevent an improperly assembled one from getting into service. Such a characteristic could be that an improperly assembled WRT would be easily identified by an inspector. Another one might be that when improperly assembled the WRT breaks or falls apart, rendering it useless. Thus in classifying a WRT as being very sensitive or insensitive to poor workmanship two aspects of the assembly procedure will be considered: (1) the vulnerability of a WRT to errors, and (2) the likelihood that an improperly assembled WRT will get into service. The preferred WRT would be the one invulnerable to error and also very unlikely to get into service even if improperly assembled. The WRT which might cause damage to men and materials is the one with a subtle, but critical defect.

Two Mod. 1 and two Mod. 2 specimens were prepared for rope diameters of 13 mm (½ in.), 25 mm (1 in.), and 51 mm (2 in.) using the 6x19 Regular rope construction. One such specimen was then pull tested while the other was fatigue tested. The test results in the form of True Efficiency (TE) and Service Life (SL) are shown in Tables 22 and 23 respectively along with the TE and SL values for specimens prepared in the standard manner. The results are discussed below for each WRT and a certain amount of familiarity with these WRTs is assumed. The reader may profit by reading Appendix B before going on to the next sections.

TABLE 22 TRUE EFFICIENCY OF STANDARD AND MODIFIED TERMINATIONS

Wire Rope Dia. mm (in.)	13 (½)				25 (1)				51 (2)			
Assembly Procedure	Stnd x	Stnd $\bar{x}$	Mod 1	Mod 2	Stnd x	Stnd $\bar{x}$	Mod 1	Mod 2	Stnd x	Stnd $\bar{x}$	Mod 1	Mod 2
Flemish Loop With Steel Sleeve & Thimble	88 88 90	89	86	82	94 94 94	94	83	84	70 75 79	75	75	16
Flemish Loop With Steel Sleeve	90 91 93	91	88	84	87 88 88	88	85	35	79 80 85	81	36	7
Wedge Socket	79 86 88	84	69	85	77 77 84	79	74	84	57 58 64	60	60	57
Swaged Socket	95 98 98	97	98	97	91 99 99	96	99	60	97 94 97	97	94	92
Turn Back Loop With Aluminum Sleeve & Thimble	91 93 94	93	87	92	90 92 94	92	92	94	78 90 92	87	76	91
Thimble Splice With Four Tucks	76 77 79	77	73	78	76 83 85	81	70	85	63 77 84	75	45	70
U-Bolt Clip With Thimble	79 83 84	82	80	80	93 95 96	95	92	97	59 77 93	76	85	77
Zinc Poured Socket	60 88 96	81	84	83	97 97 98	97	99	100	98 99 99	99	98	99
Epoxy Resin Poured Socket	84 98 100	94	0	0	99 99 99	99	57	82	80 99 100	93	26	95

TABLE 23 SERVICE LIFE OF STANDARD AND MODIFIED TERMINATIONS[(a)]

Wire Rope Dia. mm (in.)	13 (½)			25 (1)			51 (2)		
Assembly Procedure	Stnd	Mod 1	Mod 2	Stnd	Mod 1	Mod 2	Stnd	Mod 1	Mod 2
Flemish Loop With Steel Sleeve & Thimble	603 817	382	.70	482 536	611	0	162 201	0	0
Flemish Loop With Steel Sleeve	293 538	222	0	42 49	12	0	27 29	0	0
Wedge Socket	142 189	78	43	245 327	74	356	138 190	34	93
Swaged Socket	10^6 10^6	600	10^6	900 900	900	429	457 549	702	341
Turn Back Loop With Aluminum Sleeve & Thimble	342 480	396	346	204 509	112	229	106 141	126	28
Thimble Splice With Four Tucks	214 337	451	78	40 114	17	79	43 46	0	39
U-Bolt Clip With Thimble	85 91	109	143	196 267	168	251	223 231	163	209
Zinc Poured Socket	163 183	134	138	42 56	37	42	26 52	36	50
Epoxy Resin Poured Socket	252 10^6	287	149	10^6 10^6	296	110	203 304	0	568

(a) Service Life of Regular 6x19 specimens expressed as the number of cycles to failure x 10^3, except for run out values of 1 million cycles (10^6).

4.3.1 Flemish Loop with Steel Sleeve and Thimble

The Mod. 1 procedure differed from the standard only in the second stage pressing. After pressing was complete in the first set of dies, the Mod. 1 steel sleeves were pressed only twice, rotating 90° between presses. The standard procedure required several presses rotating 45° between each press. For the 13 mm (½ in.) size rope, the 86% TE is only 3 points below the mean 89% value for the standard and the failure mode was identical, with strands and core breaking inside the sleeve. For the 25 mm (1 in.) rope there was an 11 point difference in TE, but no difference in failure mode with breaks inside the sleeve. The Mod. 1 TE value equaled the TE value for the standard 51 mm (2 in.) specimen. Therefore, as measured by the TE, the Mod. 1 procedure did not change the performance of this WRT. As measured by the SL, the performance of the Mod. 1, 13 mm (½ in.) specimen was below the standard value range and was just above the higher SL value of the two 25 mm (1 in.) specimens, and yielded an SL of zero for the 51 mm (2 in.) diameter. The failures for the 13 mm (½ in.) size were in the pressed sleeve for both the standard and Mod. 1 specimens. For the 25 mm (1 in.) standard specimens the failure was also in the sleeve, but the Mod. 1 specimen failed in the top of the loop. In the 51 mm (2 in.) Mod. 1 specimen, the rope slipped in the pressed sleeve during dynamic testing although it would hold the maximum dynamic load under static conditions.

The Mod. 2 procedure eliminated the pressed steel sleeve completely and used wire seizing to keep the rolled-in splice from unlaying. The TE values for the 13 mm (½ in.) and 25 mm (1 in.) size Mod. 2 specimens were only 6 points and 10 points below the standard mean values, respectively; failing by slippage of the rolled-in splice and breaking of a strand and of the core. The 59 point drop in the TE for the 51 mm (2 in.) specimen reflects a failure due entirely to slippage. Dynamic loading of the Mod. 2 specimens resulted in a slippage failure for all three sizes.

An incorrectly pressed sleeve on the Flemish Loop Steel Sleeve and Thimble can be detected by proper inspection with a Go Gage, but might get past a Proof Test in smaller diameter ropes. A wire seizing should never be relied upon to hold a rolled-in splice, and being a very obvious error makes it unlikely that such a WRT would get into service. The slippage might be more easily detected in the field if the rope above the sleeve were painted flush to the sleeve. The appearance of unpainted rope at this location during a routine field inspection might warn of a defective WRT.

4.3.2 Flemish Loop with Steel Sleeve

The Mod. 1 and Mod. 2 assembly procedures were the same as for the Flemish Loop with Steel Sleeve and Thimble. Once again for the two rope diameters, 13 mm (½ in.) and 25 mm (1 in.) the TE for the Mod. 1 and Mod. 2 dropped below that for the standard. For Mod. 1 the TE was 3 points and 7 points below the standard mean value for the two smaller diameters. For the 51 mm (2 in.) diameter there was a 45 point drop in the TE. The large difference in Mod. 1 TE values at this diameter between the two types of Flemish Loops might be attributed to the thimble support. The failure mode of the standard and Mod. 1 specimens was the same in the 13 mm (½ in.) and 25 mm (1 in.) size rope, breaking of strands and core in or adjacent to the steel sleeve. In the 51 mm (2 in.) rope the standard specimen failed at the steel sleeve, but the Mod. 1 specimen failed by slippage. The Mod. 1 SL values also dropped from the standard specimens; 20 points in the 13 mm (½ in.) size, and 3 points in the 25 mm (1 in.) size. In the 51 mm (2 in.) size the SL was zero, failing by slippage.

The Mod. 2 TE dropped 7 points for the 13 mm (½ in.) size just as had the Mod. 2 Flemish Loop with Steel Sleeve and Thimble. For the 25 mm (1 in.) size and the 51 mm (2 in.) size the TE dropped 53 points and 74 points respectively, much larger changes which could be attributed to the absence of the thimble. As before, failure of the Mod. 2 specimen was by slippage. The SL for Mod. 2 were all zero, reflecting the slippage failure under dynamic loading. The benefits of a thimble were not as easy to identify in the standard TE as they were in the standard SL data. But, in the Mod. 2 TE data the thimble appears to exert some control in the amount of load a defective termination can support. This speculation should be considered as a caution, since the thimble would increase the likelihood of a defective WRT entering service.

4.3.3 Wedge Socket

Of the nine WRTs evaluated the Wedge Socket would appear to be the least sensitive to poor workmanship from both aspects discussed earlier. The assembly procedure is simple, so less vulnerable to errors, and the types of errors it permits reduce the likelihood of it getting into service. The dead part of the rope can be looped incorrectly toward the lugs (load pin linkage) or away from the lugs. The wedge can be put in correctly or not at all, in which case the rope will pull out at very low loads. The Mod. 1 procedure was to turn the rope loop toward the lugs, a rather obvious error. The TE value dropped 15 points below the mean for the 13 mm (½ in.) rope and 5 points below the mean for the 25 mm (1 in.) rope.

There was no change for the 51 mm (2 in.) rope. The pull test failure of both the standard and Mod. 1 specimens was at the base of the socket where the wedge presses on the rope. The Mod. 1 SL values were from one-half to one-third of the standard mean values, demonstrating an interaction effect between the Mod. 1 assembly and dynamic loading, an effect not obvious from the static load data.

The Mod. 2 assembly procedure was based on field observations of attaching a U-Bolt Clip to the live and dead parts of the rope as a means of keeping the wedge in position at those times when the rope should suddenly go slack. Such a step was not given in any wire rope catalogs and was identified as an error in a technical manual on rigging (12). The TE data for the three rope diameters used shows the Mod. 2 values to exceed or very nearly equal the standard values. The failure of the Mod. 2 specimens was rope breakage at the U-Bolt Clip rather than at the base of the socket. The SL values for the Mod. 2 specimens are: 74% lower for the 13 mm (½ in.) rope, 20% higher for the 25 mm (1 in.) rope and 42% lower for the 51 mm (2 in.) rope. In dynamic testing failure for the standard and Mod. 2 specimens occurred at the base of the socket and so was unrelated to the U-Bolt Clip. This limited data, both the TE and SL, place into question whether attaching a U-Bolt Clip is an error. Under static loading the Mod. 2 performance was equal or better than standard and under dynamic loading the Mod. 2 failures were unrelated to the U-Bolt Clip.

The publisher of the technical manual on rigging cited above was queried on this point. In response they stated that attaching the U-Bolt Clip to both the live and dead parts of the rope introduced the possibility that the saddle would be placed on the dead part. The U-Bolt might then reduce the efficiency of the termination. This concern is shared by the major U-Bolt Clip manufacturer cited earlier who is of the opinion that the crushing effect of the U-Bolt will reduce the fatigue life of the rope. This particular modified assembly was not tested so there is no data to support or contradict this opinion. A second reason given by the rigging manual publisher for their recommendation was the possibility that an improperly seated wedge would later allow the live rope to pull tight and so change the angle of the saddle base plane to the plane of the base of the Wedge Socket. Whether this would affect the TE or SL values is a question yet to be answered by testing.

4.3.4 Swaged Sockets

The Swaged Socket is almost completely machine assembled so errors can occur only during two phases of the assembly. The first is the placing of the rope into the hollow shank of the socket and the second is in the pressing operation. The Mod. 1 procedure was to insert the rope end one rope diameter less than full depth. As expressed by the three TE values, an error of that magnitude had no effect and the failure modes were all the same, rope breakage at the base of the pressed socket. The insertion error had no effect on the SL values, yielding fatigue runout values of nearly one million cycles.

The Mod. 2 procedure was a shortened pressing operation, requiring only two presses with a 90° rotation in between. The TE value acknowledged this error only for the 25 mm (1 in.) specimen where failure was caused by the rope pulling out of one socket. The SL values only detected the Mod. 2 error for the 25 mm (1 in.) rope also. Here failure was a gage length break of several strands.

The Swaged Socket is vulnerable to errors and there appears to be a high likelihood of a defective unit entering service. This would be the case for the Mod. 1 error because once pressed there is no inspection procedure that can detect whether or not the rope was inserted to the very bottom of the shank. Arguing against this view however, is the knowledge that only skilled workers are entrusted with the operation of a hydraulic press. Therefore, the higher skill level of the press operator gives assurance that the rope would be fully seated before the dies closed down on the shank. The same skill level also guards against pressing errors, although these errors could be detected by the Go Gage inspection.

4.3.5 Turn Back Loop with Aluminum Sleeve and Thimble

This WRT is also one that is rather simple to assemble and vulnerable to errors during the pressing operation. Forming of the turn back loop around the thimble can only be done one way. The length of rope extending on the dead part can vary, but is easily adjusted when the sleeve is slipped onto the two rope parts and forced against the bottom of the loop. For this reason the two modified procedures had to do with the pressing operation where only two presses with one 90° rotation were used in Mod. 1 and no lubricant was used in Mod. 2. As with the Swaged Socket, the Mod. 1 error showed up only in one TE value, that for the 51 mm (2 in.) rope. The failure mode for that particular specimen was a splitting of the aluminum sleeve and pull out of the rope. This in itself was not unusual since several of the standard assembly specimens had also failed in this manner. The more frequent failure mode was rope breakage at or in the pressed sleeve. The SL data for the Mod. 1 specimen exhibited a one third reduction for the 25 mm (1 in.) rope, the result of a split sleeve failure.

In Mod. 2, the absence of any lubricant to facilitate the cold flow of the aluminum was unnoticed, at least in the static loading. The TE values for all three Mod. 2 specimens were nearly equal or higher than the mean TE value for the standard specimens. The Mod. 2 SL values were below the mean value for the standard specimens, but within the range of standard values shown.

4.3.6 Thimble Splice with Four Tucks

Assembly of a Thimble Splice is a completely handmade operation which requires a skilled and experienced worker. It is therefore vulnerable to errors, but because it is easy to inspect visually, there is small likelihood of a defective unit getting into service. The pattern of interweaving strands makes an error in splicing easy to detect by a trained inspector. The number of hand tucks can also be counted easily, so it is unlikely that a splice with less than the required number of tucks will get past an inspector.

The Mod. 1 procedure assembled the first tuck in the standard manner, then completed the next three tucks for strand no. 1 by rotating the spike and laying strand no. 1 under strand A. Next strand no. 2 had its remaining three tucks layed in under strand B, and so on for the remaining strand sets 3/C, 4/D, 5/E and 6/F. In the standard procedure, each of the six numbered strands are used to make a complete tuck before going on to the next tuck. The Mod. 1 procedure could only be done on the 13 mm (½ in.) and 25 mm (1 in.) rope due to the stiffness of the 51 mm (2 in.) rope. For the 51 mm (2 in.) rope specimen the Mod. 1 procedure was to make an error in the fourth tuck by placing both strand no. 3 and no. 4 under strand C.

The resulting TE values for the Mod. 1 specimens were lower than for the standard specimens. For the 13 mm (½ in.) rope it was 4 points below the mean values, for the 25 mm (1 in.) rope it was 11 points below the mean value, and for the 51 mm (2 in.) rope, it was 30 points below the mean value. This definite trend could be attributed to the increasing wire size which would accentuate any irregularity in the splice pattern.

The Mod. 1 irregularity appears not to have had a great influence on the SL values since this WRT had such a short fatigue life. For the 13 mm (½ in.) rope the Mod. 1 SL value was actually higher than the standard mean value by 17 points while for the 25 mm (1 in.) rope the Mod. 1 SL value was 6 points under the standard mean SL value. For the 51 mm (2 in.) rope the SL value was zero. The failure mode was the same in the standard and Mod. 1 specimens, broken wires and strands in the splice area, except for the slippage failure of the Mod. 1 specimen in the 51 mm (2 in.) rope. The Mod. 1 variation for the fourth tuck was more critical to the splice than the errors introduced in the 13 mm (½ in.) and 25 mm (1 in.) specimens.

The Mod. 2 procedure was to make only three tucks in the splice. From the TE values for all three rope diameters one would conclude that three tucks are sufficient for developing the full strength of the WRT. The Mod. 2 SL data for the 13 mm (½ in.) rope reflects slipping during the initial testing and a resulting early failure. For the 25 mm (1 in.) rope the Mod. 2 SL value was below the standard mean value, but as the magnitude of the SL values show, the splice itself creates so much wear and bending stress that the effect of a modified procedure is negligible. The 51 mm (2 in.) SL value supports the previous comment. The failure mode for Mod. 2 specimens was similar to Mod. 1 and standard specimens, with broken wires and strands in the splice area.

As discussed earlier, an assembly error on the Thimble Splice WRT is very possible, but rather unlikely to be missed by an inspector. The Mod. 1 and Mod. 2 procedures respectively represent a splicing error and a shortened splice error. These types of errors do not seem to yeild a performance that is much worse than that to be expected from a correctly assembled Thimble Splice.

4.3.7 U-Bolt Clip with Thimble

Although this WRT is assembled by hand and requires only the use of a torque wrench, the procedure is vulnerable to errors, and unless checked with a torque wrench, an improperly made termination can get into service. The Mod. 1 procedure was to alternate the saddle position of adjacent clips from the long (live) part of the rope to the short (dead) part of the rope. When tightened, the U-Bolt Clips cause the rope to bend back and forth. The Mod. 1 TE values for the three rope diameters was nearly equal to the mean of the standard specimens, and the strands broke at the last clip, the one furthest from the thimble, for all specimens. Since the saddle of the clip at this particular location was always on the live part of the rope, the failure at this clip suggests that the gripping forces of the other clips merely prevent slipping. The orientation of the saddle for the other clips with respect to the saddle of the clip furthest from the thimble did not affect the load distribution at the failure site.

These results were brought to the attention of the major U-Bolt Clip manufacturer cited earlier and in their response they expressed the opinion that the U-Bolt of the last clip should not be on the live part of the rope. Therefore, they simply recommend that all saddles be placed on the live part of the rope.

The SL data for Mod. 1 specimens supports the above discussion on the TE values. Once again the Mod. 1 values were nearly equal to the standard and the failures for all specimens occurred at the clip furthest from the thimble.

The Mod. 2 procedure required the assembly person not to look at the dial of the torque wrench while tightening the nuts and to estimate the required torque. The resulting error averaged 15% below the 88 joules (65 ft. lbs.) for the 13 mm (½ in.) specimen, 3% below the 306 joules (225 ft. lbs.) for the 25 mm (1 in.) specimen, and 17% below the 490 joules (750 ft. lbs.) for the 51 mm (2 in.) specimen. The Mod. 2 TE values were again very close to the standard values and the failure as before took place at the clip furthest from the thimble. The SL values for the Mod. 2 specimens were actually above the standard and the failure site was as in the pull tests.

These results on Mod. 2 suggest that there is a margin of safety between the torque value specified by the manufacturer and the torque value required to prevent slipping. With the apparent inability of an experienced mechanic to judge the specified torque, and rather settle on a lower value, perhaps a higher than necessary torque specification is justified for field applications where there are no torque wrenches, or at least no calibrated torque wrenches.

4.3.8 Zinc Poured Socket

There were several steps in the assembly of the WRT where an error could occur, both in the rope cleaning procedure and in the zinc pouring procedure. Many such errors would not be detectable by post assembly inspection, making it likely that an incorrectly prepared termination could get in the field. Since ultrasonic cleaning is now being used for removing the lubricant from the broomed end, this cleaning technique was incorporated into the modified procedures.

In Mod. 1 ultrasonic cleaning was used to remove the lubricant from the broom rather than the standard or traditional method of brushing the lubricant out while soaking the broom in a solvent. The other steps involving acid etching and neutralizing remained the same. To avoid any confusion it is repeated here that a zinc flux rinse was not used as a final step in preparing the standard or modified specimens. The TE values for the Mod. 1 specimens equaled or exceeded the standard TE values, giving support to the use of ultrasonic cleaning of the rope broom. The SL data, as was the case for the Thimble Splice with Four Tucks, simply reflects a short fatigue life where the Mod. 1 procedure had no effect.

The Mod. 2 procedure used ultrasonic cleaning as the only step to prepare the rope broom for socketing, eliminating the acid etching and neutralizing steps. The high TE values obtained for Mod. 2 suggest there is little difference between the bond formed by molten zinc and etched steel wires and molten zinc and steel wires cleaned in an ultrasonic bath. As with Mod. 1, the SL values simply reflect a short fatigue life where the Mod. 2 effect, even if valid, was not detectable.

Although the TE values were relatively high for the standard, Mod. 1 and Mod. 2 specimens, the failures did not always occur in the gage area. Furthermore, failures usually involved the core and some strands. The recommended assembly procedure, using a zinc flux rinse after etching, not only yielded high TE values, but the failures were in the gage area and usually involved the core plus all six strands. This indicates a more uniform bond between the molten zinc and all the steel wires in the broom.

4.3.9 Epoxy Resin Poured Socket

Although the standard assembly for this new WRT is similar to that for the Zinc Poured Socket, the differences are substantial enough to affect the sensitivity to poor workmanship. The Mod. 1 procedure required that only the last one third of the rope end be cleaned of lubricant. The Mod. 2 procedure did not allow time for the resin to flow to the bottom of the socket and displace the air. Intentionally the resin was poured quickly to trap air in the socket and thus create air voids in the cured resin.

The Mod. 1 and 2 TE values of zero for the 13 mm (½ in.) diameter specimens are the result of the rope pulling out of the socket. The presence of lubricant and air prevented a good bond from forming. The Mod. 1 TE value of 57% for the 25 mm (1 in.) rope was the result of the socket itself cracking and not a failure of the rope or of the epoxy resin bond with the rope. The Mod. 2 TE value of 82% was due to the breaking of two strands inside the socket. For the 51 mm (2 in.) rope the Mod. 1 TE value of 26% is again the result of the rope pulling out of the socket, while the Mod. 2 value of 95% is due to the breaking of two strands at one socket.

The SL data itself does not permit evaluating the Mod. 1 and Mod. 2 procedures. Several sockets broke at very short fatigue lives before any detrimental effects of the modified procedures could be detected. The Mod. 1 SL failure for the 13 mm (½ in.) rope was due entirely to a broken socket. The Mod. 2 specimen for the 13 mm (½ in.) rope failed as a result of the effects of the air voids which caused the rope to slip 5 cm (2 in.) when the initial load was applied. Even though the termination reset itself, failure occurred in the rope section which had slipped out of the socket. The SL values for Mod. 1 and Mod. 2 on the 25 mm (1 in.) rope are due completely to broken sockets. The SL value for the 51 mm (2 in.) Mod. 1 specimen is zero as a result of the rope pulling out of the socket. For the Mod. 2 specimen failure occurred in the gage area of the rope, suggesting that air voids are less likely to form in the sockets with a larger volume.

4.4 Field Use of Test Data

The purpose of this project was to determine the operational limits of WRTs so that their use in the mining industry would contribute to safe working conditions and high productivity. The initial phase of the project identified the WRTs in use and the operating conditions surrounding their use. The applications of WRTs in the mining industry are numerous as indicated earlier in the discussion of the mine site visits. A representative list is shown below of many of the applications of WRTs described in terms of the purpose to which the WRT is used or in terms of the machinery of which the WRT is a part.

<u>Surface Mining</u>

Dragline Hoist	Driller Hoist
Dragline Rope	Shovel Boom Hoist
Boom Support	Shovel Bucket Hoist
Sled Haul Line	Shovel Hoist
Hand Rail	Shovel Crowd & Retract
Boom Hoist	Boom Suspension

<u>Underground Mining</u>

Conveyor Roller Support	Haulage Ropes
Brake Car Hoist	Car Unloader
Shaft Hoist	Elevator Hoist
Balance Ropes	

<u>General Mining</u>

Car Retarder	Railroad Car Haulage Rope
Slings	Aerial Tramways

Associated with each application is the normal working load, usually called the Safe Working Load, which is 1/4, 1/5, or less of the CBL of the rope involved. In each application the load magnitude varies with time as dictated by the machine, the machine operator, and the local terrain. These variations in load were observed and found not to exceed one cycle per minute. Impact loads and high static loads occur even less frequently. The TE measure of WRT performance corresponds to static load conditions, while the SL performance measure corresponds to dynamic load conditions. Besides the load spectrum described above, the WRT is affected by other operating conditions at the mine site. Listed below are some known operating conditions, no doubt others exist.

1. Wear and abuse of rope end and WRT.
2. Corrosiveness of working environment.
3. How often the rope end is cut off and reterminated.
4. Inspection frequency and detail.
5. Skill of WRT assembler.
6. Local practice concerning assembly of a WRT.

Items 4, 5, and 6 above are associated with a WRT's sensitivity to poor workmanship.

The selection of a WRT for a particular mining application should therefore consider three of the information sets produced by this study. These three sets are:

1. Relative TE of a WRT.
2. Relative SL of a WRT.
3. Relative sensitivity of a WRT to poor workmanship.

The information sets can be reduced to a very easily used form by simply ranking the WRTs with respect to each of these three characteristics from highest to lowest. The rank of a WRT with respect to TE and SL is shown in Table 24 and Table 25 respectively for each of the five diameters considered. The rank of a WRT with respect to its sensitivity to poor workmanship is shown in Table 26 for assembly conditions. The ranking under "With Skilled Workers or Inspection" column reflects a WRT's ability to carry into the field a subtle, but critical defect, one caused by even a skilled worker which is difficult to detect by an inspector. The ranking "With Unskilled Workers and No Inspection" column reflects the simplicity of a WRT's assembly procedure and the sensitivity of the WRT to an error.

The process for selecting a WRT should follow a procedure similar to the steps suggested below.

1. Decide if the load condition is primarily a static one or a dynamic one.
2. If the load is static, then select, under the closest rope diameter, the top three WRTs as ranked with respect to TE in Table 24.
3. If the load is dynamic, then select, under the closest rope diameter, the top three WRTs as ranked with respect to SL in Table 25.
4. If the top three WRTs were selected on the basis of TE, retain the two WRTs with the highest rank based on SL.
5. If the top three WRTs were selected on the basis of SL, retain the two WRTs with the highest rank based on TE.

TABLE 24 RANK ORDER OF TERMINATIONS[a]
WITH RESPECT TO TRUE EFFICIENCY

	Rope Diameter mm (in.)				
Rank	13 (½)	19 (3/4)	25 (1)	38 (1½)	51 (2)
I	9	9	9	4	8
II	4	1	8	8	4
III	5,8	2,7	4	1	9
IV	2	4	1,5,7	7,9	7
V	1	5	2	2,5	5
VI	3	8	3	6	2
VII	7	6	6	3	1
VIII	6	3	-	-	6
IX	-	-	-	-	3

[a] WIRE ROPE TERMINATIONS

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

TABLE 25 RANK ORDER OF TERMINATIONS[a] WITH RESPECT TO SERVICE LIFE

Rank	Rope Diameter mm (in.) 13 (½)	19 (3/4)	25 (1)	38 (1½)	51 (2)
I	4	9	4,9	4	4
II	1	4	1	7	9
III	9	1	5	5	7
IV	2	2	3	2	1
V	5	5	7	1	3
VI	6	7	6	8,9	5
VII	8	8	8	3	6
VIII	3	3	2	6	8
IX	7	6	-	-	2

[a] WIRE ROPE TERMINATIONS

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

TABLE 26 TERMINATIONS RANKED IN ORDER OF INCREASING SENSITIVITY TO POOR WORKMANSHIP[a]

Rank	With Skilled Workers or Inspection	With Unskilled Workers and No Inspection
I	7	3
II	8	4
III	4	7
IV	5	1
V	9	2
VI	6	5
VII	3	6
VIII	1	9
IX	2	8

[a] WIRE ROPE TERMINATIONS

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

6. Decide which of the two assembly conditions identified in Table 26 exists at the mine site.
7. Of the two WRTs remaining in the initial selection, eliminate the WRT with the lowest rank based on sensitivity to poor workmanship using Table 26.
8. The Candidate WRT should then be evaluated for compatibility with other operating conditions such as availability of tools.
9. If the Candidate WRT is acceptable it is designated the WRT to use.
10. If the Candidate WRT is rejected, then return to step 2 or 3, ignoring the initial Candidate, and repeat the procedure.

The following is an example of the above selection procedure for a Boom Suspension system with a 25 mm (1 in.) rope.

1. Load is primarily static.
2. Select WRT Types 9, 8, and 4.
3. N/A
4. Retain WRT Types 4 and 9.
5. N/A
6. Skilled Workers or Inspection are available.
7. Eliminate WRT Type 9.
8. WRT Type 4, the Candidate WRT is compatible with other operating conditions.
9. WRT Type 4, Swaged Socket, is the designated one to use.

Suppose that in the above example it was found that there were no Swaged Sockets available in stock. One would then return to Step 2 in the selection procedure to find a new WRT.

2. Select WRTs Types 9, 8, 1, 5, and 7.
3. N/A
4. Retain WRT Types 9 and 1.
5. N/A
6. Skilled Workers or Inspection still available.
7. Eliminate WRT Type 1.
8. WRT Type 9, the Candidate WRT is compatible with other operating conditions.
9. WRT Type 9, the Epoxy Resin Poured Socket is the designated one to use.

Besides providing useful information to help select a WRT for different mining applications, the test data can also be useful for inspection and replacement of WRTs. The inspection of a WRT can be more complete if specific features indicating the initiation of failure are known. The failure modes identified earlier under the pull and fatigue tests provide such information. The failure modes described in Sections 3.1.2 and 3.2.2 and the listings in Tables 9 and 12 can be used to identify both the location of most failures and the features associated with such failures. These are presented in Table 27 for inspection purposes.

The SL data on WRTs can also be used as a guide for retirement of axially loaded wire rope on which the WRTs are used. The rationale here is that the SL of a WRT is some percentage of the rope's Service Life. The True Service Life (TSL) of each diameter rope tested can be estimated by those specimens reaching the run out value of one million cycles, by gage length failures, or the maximum number of cycles attained by a specimen representing a particular rope, even if this was a termination associated failure. Dividing the SL of a WRT by the TSL of the rope yields a quantity termed Service Life Efficiency (SLE) which is expressed as a percentage. The mean of the two SL values of Regular 6x19 rope for each WRT will be used to compute the SLE. Therefore the TSL of the Regular 6x19 rope at each of the five diameters tested will be used in the denominator of the equation:

$$SLE = \frac{\text{SL of WRT}}{\text{TSL of Rope}} \times 100$$

The multiples of SLE in 100 is equivalent to the number of times the WRT is replaced during the life of the rope. When this number R of WRT replacements is reached, the wire rope is to be retired. The TSL of each rope and the SLE of each WRT at the five diameters tested are shown in Table 28. Also shown is the replacement number R at which the rope is to be retired. As shown in the footnotes three of the TSL values are run out values of one million cycles, one is a termination associated failure, and one is a gage length failure. This table can serve as a guide to wire rope retirement, but could certainly benefit from additional research under axial loading. TSL data on ropes for bending over sheaves loading would permit expanding this guide to include the retirement of rope which normally fails from bending stresses.

TABLE 27 LOCATION AND FEATURES OF COMMON WRT FAILURES

Termination Type	Failure Location	Characteristic Features
Flemish Loop with Steel Sleeve & Thimble	Base of Steel Sleeve	Broken wires
Flemish Loop with Steel Sleeve	Crown of Loop	Broken wires
Wedge Socket	Base of Socket	Broken wires on live rope
Swaged Socket	Base of socket & body of rope	Broken wires
Turn Back Loop with Aluminum Sleeve & Thimble	Sleeve body Base of Sleeve	Cracks Broken wires
Thimble Splice with Four Tucks	Entire length of splice	Broken Wires
U-Bolt Clip with Thimble	Clip closest to main rope	Broken wires on live rope
Zinc Poured Socket	Base of socket	Broken wires
Epoxy Resin Poured Socket	Socket body Body of rope	Cracks Broken wires

TABLE 28 WIRE ROPE RETIREMENT CRITERIA BASED ON FREQUENCY OF WRT REPLACEMENT

Wire Rope Diameter	TSL x 10^3 [b]		Termination Type [a] 1	2	3	4	5	6	7	8	9
13 mm	1,000 [e]	SLE [c]	71	42	16	100	41	28	8	17	62
(½ in.)		R [d]	1	2	6	1	2	3	12	5	1
19 mm	1,000 [e]	SLE	34	28	9	40	22	9	20	18	80
(3/4 in.)		R	2	2	11	2	4	11	5	5	1
25 mm	1,000 [e]	SLE	54	4	28	100	36	8	24	5	100
(1 in.)		R	1	25	3	1	2	12	2	20	1
38 mm	446 [f]	SLE	57	60	44	100	78	20	82	50	49
(1½ in.)		R	1	1	2	1	1	5	1	2	2
51 mm	702 [g]	SLE	26	4	24	72	18	6	32	6	36
(2 in.)		R	3	25	4	1	5	15	3	16	2

(a) WIRE ROPE TERMINATIONS

1 Flemish Loop with Steel Sleeve & Thimble
2 Flemish Loop with Steel Sleeve
3 Wedge Socket
4 Swaged Socket
5 Turn Back Loop with Aluminum Sleeve & Thimble
6 Thimble Splice with Four Tucks
7 U-Bolt Clip with Thimble
8 Zinc Poured Socket
9 Epoxy Resin Poured Socket

(b) TSL: True Service Life of rope estimated by maximum number of cycles sustained by any specimen at a specified load.

(c) SLE: Service Life Efficiency is percent of TSL sustained by WRT.

(d) R: Number of times a WRT is replaced during the TSL of a rope in Axial loading. The rope is retired when the time arrives for the Rth replacement of a WRT.

(e) Run out value.

(f) Termination associated failure.

To use this rope retirement guide one would first determine that axial loading was the primary form of loading on the rope and that bending loads did not contribute significantly to the rope's failure. The table would be entered at the rope diameter closest to the rope being evaluated and the R value for the WRT of interest would be identified. If R was greater than the number of times the WRT had been replaced then the rope could continue in service unless other considerations dictated otherwise. If R was equal to or less than the number of times the WRT had been replaced, then the rope should be retired from service.

So that the origin of the R values will be known at some future time, the TSL and SLE values have also been presented in the table even though they are not used in the actual determination of rope retirement. The R value can be made a more accurate guide with better estimates of TSL and SLE. Such improvements in these estimates could come from additional laboratory test data or from field data.

5.0 CONCLUSIONS

5.1 Conclusions Pertaining to True Efficiency

5.1.1 The maximum True Efficiency (TE) of a WRT is affected by the interaction effects of WRT Type, Rope Diameter, Rope Construction, and Rope Class.

5.1.2 A simple linear model can predict with acceptable error the TE of a WRT.

5.1.3 The failure modes exhibited by a WRT in a pull test are usually the failure modes exhibited from a fatigue test, but not always.

5.1.4 The effect of rope construction on a WRT's performance is more important in a static load condition than in a dynamic load condition.

5.1.5 With some anticipated improvements in hardware fabrication, it will soon be possible for the mine operator to hand assemble in the field a WRT with a TE of 100% and very long Service Life.

5.1.6 Epoxy and polyester resins are suitable replacements for molten zinc when used with the appropriate socket. The polyester resin can develop a TE of 100% with the RR-S-550 socket. The epoxy resin must be used in sockets with a longer body to develop a TE of 100% and long Service Life.

5.2 Conclusions Pertaining to Service Life

5.2.1 Of the nine WRTs evaluated, the Swaged Socket gave the longest Service Life (SL) more consistently than any other.

5.2.2 Of the hand assembled WRTs, the Epoxy Resin Poured Socket gave the longest SL. The long tapered body of the socket was attributed for the long SL.

5.2.3 Molten zinc at 510 C (950 F) did not change the mechanical properties of steel wires. The short SL of Zinc Poured Sockets is attributed to the short body of the socket. The effect of opening the rope into the "broom" configuration was not separated.

5.2.4 The SL of a WRT is primarily dependent of the WRT Type, and rope construction has a negligible effect.

5.2.5 In general, SL decreases as rope diameter increases.

5.2.6 The benefits of the thimble became apparent in the fatigue test results.

5.3 Conclusions Pertaining to Poor Workmanship

5.3.1 There are no WRTs which are completely "fool proof." Mining personnel cannot be expected to correctly assemble WRTs without some training.

5.3.2 A proof test will not always detect an incorrectly assembled WRT. The effect of some modified assembly procedures became apparent only in the fatigue tests.

5.3.3 The availability of the required materials and tools at a field site would contribute to better field assembled WRTs.

5.4 Conclusions Pertaining to Field Applications

5.4.1 Whenever possible mine operators should order wire rope with the required WRT attached at the wire rope manufacturer's facility.

5.4.2 Replacement practice of a WRT depends on the application. Where state and or federal laws do not specify an interval for cutting the rope end and replacing the WRT, the machine operator or maintenance foreman decide when to replace the WRT.

5.4.3 The selection of a WRT for a particular application should begin by deciding if the principal manner of loading is static or dynamic.

5.4.4 The Service Life of a WRT can be expressed as a percentage of the wire rope's Service Life. This relationship can then be used to relate the replacement frequency of a WRT to the timely retirement of the wire rope.

6.0 RECOMMENDATIONS

6.1 Recommendations on WRT Usage

6.1.1 When it is desired to optimize the True Efficiency of a WRT, the selection of rope diameter, construction, and class should be considered carefully to avoid detrimental interaction effects. Use of the simple linear model described in this report may be accurate enough for most applications.

6.1.2 The selection of a WRT to optimize Service Life need not consider rope class nor rope construction. The WRT Type with the longest SL, that is compatible with other operating considerations should be selected.

6.1.3 The failure modes of each WRT are consistent enough that they can be used to improve the field inspection of a WRT by identifying both the location and characteristic of the failure mode suspected.

6.1.4 The replacement frequency of WRTs can be related to a wire rope's Service Life and so used as a retirement criteria for the wire rope.

6.2 Recommendations on Further Research

6.2.1 The same torque applied to all clips on a U-Bolt Clip WRT result in failure of the rope at the clip furthest from the thimble or loop. If the torque decreased in value from the clip furthest from the thimble or loop the True Efficiency (TE) and the Service Life (SL) of this WRT might be increased.

6.2.2 The effect of attaching the U-Bolt to the live part of a rope on TE and SL should be investigated. Such information would show the seriousness of committing a reversal error on this WRT. The information would also resolve the question as to whether or not a U-Bolt Clip should be connected to both the live and dead parts of a rope on a Wedge Socket WRT.

6.2.3 The operational limits of polyester resin, as a substitute for zinc and epoxy resin, ought to be investigated. This would give the mining industry another choice for field assembled WRTs.

6.2.4 The possible improvement in TE and SL of using a steel sleeve in the Turn Back Loop with Metal Sleeve & Thimble rather than an aluminum sleeve should be determined. The characteristic split sleeve failure with aluminum was responsible for specimen failures that showed no sign of wire rope failures.

6.2.5 The use of ten broken wires as a WRT replacement criteria was recommended for field inspections. The residual load capacity and impact load capacity remaining in a WRT which exhibits this much rope damage ought to be determined.

GLOSSARY

BASKET (SOCKET) The conical bore of a socket into which the end of the rope is inserted and secured with zinc or some other binding material.

BREAKING LOAD (1) Ultimate or Actual: The load required to pull a wire, strand, or rope to destruction. (2) Aggregate: The sum of the individual breaking loads of all wires in a strand or rope. (3) Catalog: The minimum breaking load of a rope or strand guaranteed by the manufacturer.

BRIGHT WIRE Wire made of iron or carbon-steel and not galvanized, aluminized, or otherwise coated.

BROOMING The unlaying and straightening of strands and wires in the end of a wire rope, usually in preparation for socketing with zinc.

CASTLOK SOCKET A commercially available termination using a long tapered basket and epoxy resin to attach the wire rope to the socket.

CLIP (U-BOLT CLIP) A strand or rope fitting comprised of a malleable iron or forged steel saddle piece (grooved to suit rope lay) and a U-bolt by which the clip is held to two parallel ropes. Primarily used to anchor the dead end of a rope to the live side to form a loop.

CLOSED SOCKET A socket in which the basket and the curved bail are connected.

CONSTRUCTION Term used to describe the design of a rope, covering the number of strands, number and arrangement of the wires in the strands, direction and type of lay, grade of wire material, and type of core.

CORE The axial member of a wire rope about which the strands are laid. It may consist of wire strand, wire rope, synthetic or natural fiber, or solid plastic.

DEAD END (OR PART OF A ROPE) Portion of an operating rope which carries no load. Often refers to the nonactive part of a rope protruding from a loop termination.

DESIGN FACTOR   The ratio of the catalog breaking load to the maximum load during operation. Standards are often set by statutory bodies for minimum design factors. Also known as FACTOR OF SAFETY--See SAFE WORKING LOAD (SWL).

DROSS   Impurities that rise to the surface of molten zinc.

EYE SPLICE   A loop formed in the end of a rope by tucking the strand ends under or around the strands of the live part of the rope. A thimble is often used in the loop.

FACTOR OF SAFETY   See DESIGN FACTOR

FILLER WIRES   Small auxiliary wires in a strand for spacing and positioning of other wires.

FLEMISH EYE   A type of eye loop made by separating the rope end into two groups of strands and then relaying the strands to form a loop. Used with and without a thimble in the loop, but always with a tapered sleeve swaged around the dead and live parts of the rope.

GALVANIZED ROPES, STRANDS, AND WIRES   Ropes, strands, and wires in which the individual wires are coated with zinc.

GRADES: ROPE   Classification of wire rope according to wire breaking strength per unit area. In order of increasing strength the various rope grades are "iron", "traction", "mild plow steel", "plow steel", "improved plow steel", and "extra improved plow steel".

IMPROVED PLOW STEEL   Next to highest grade of wire rope (IPS).

INDEPENDENT WIRE-ROPE CORE (IWRC)   The supporting center of a wire rope, which is itself a smaller diameter wire rope.

LANG-LAY ROPE   Rope in which the direction of lay of the wires in the strands is the same as the direction of lay of the strands in the rope. Sometimes called ALBERT'S LAY.

LAY   The helical shape that the strands take in the rope. Only lay length is the distance required for a strand to make one turn around the rope. Lay may be right hand (the same as the threads of a right hand screw), or left hand. If the wires of the strands and the strands of the rope are both of the same lay, the construction is called Lang Lay. If the two lays are opposite, the construction is called Regular Lay.

LIVE (PORTION OF A ROPE) The portion of an operating rope which carries the load. Usually applied to a rope that is not cut at the termination, but passes through it, leaving an unloaded (dead) rope section.

LONG SPLICE A splice which joins two ropes end-to-end and which involves about twice the rope length of a short splice.

LOOP SPLICE An eye splice without a thimble.

MARLINE SPIKE A pointed metal spike, used to separate strands of rope in splicing

MOLLY HOGAN See FLEMISH EYE

OPEN SOCKET Wire-rope fitting with two integral lugs through which a pin connection is made to the load or anchorage.

PITCH (1) Length of Lay: The distance parallel to the axis of the rope (or strand) in which a strand (or wire) makes one complete helical revolution about the core (or center). (2) The spacing of grooves on a drum.

POLYPROPYLENE FIBER CORE A plastic core made of many polypropylene filaments.

POURED SOCKET An end-fitting attached to a rope by pouring molten zinc into a cavity around broomed-out rope wires, and allowing the zinc to solidify.

PREFORMED WIRE ROPE (Form Set) A wire rope in which the strands and wires receive a final helical shape before closing that matches the lay and set of the finished rope.

PRESSED SLEEVE AND THIMBLE A termination made by forming a wire loop around a thimble and then swaging a metal sleeve around the live and dead parts of the rope.

PROOF-LOADING (Proof Testing) Preliminary loading of a rope to the maximum expected working load to test the load bearing capability of the rope and associated equipment. This proof load can sometimes be twice the Safe Working Load.

RATED CAPACITY The Safe Working Load of a rope or termination. Usually less than or equal to 1/5 the Catalog Breaking Load of the rope involved.

REEVING The threading of a wire rope through a block, sheave, or other parts of a wire-rope system.

REGULAR-LAY ROPE A rope in which the lay of the wires in the strand is opposite the lay of the strand in the rope.

RESIDUAL LOAD CAPACITY The load sustained by a rope after use.

RESIN SOCKET An end fitting attached to a rope by pouring an epoxy or polyester resin into a cavity around the opened end of a rope, and allowing the resin to cure.

RIGHT LAY The direction of a strand or wire helix corresponding to that of a right-hand screw thread.

SADDLE That part of a U-Bolt Clip that bears against the live side of the rope. Grooved to fit the external surface of the rope, it is fastened to the U-bolt with nuts. Also called a bridge.

SAFE WORKING LOAD The maximum load on the rope during operation. SWL equals the Catalog Breaking Load divided by the Design Factor or Factor of Safety.

SEALE STRAND CONSTRUCTION A strand with uniformly sized wires laid parallel with the same number of uniformly sized but smaller wires in the inner layer(s).

SEIZE To bind a rope or strand securely with annealed wire. Also, to secure by wire two parallel portions of rope.

SEIZING (1) The annealed wire used to seize a rope. (2) The completed wire wrapping itself.

SHORT SPLICE A splice used for attaching two rope ends together. See SPLICING.

SLEEVE A type of swage fitting usually employed in the formation of a loop or eye in the end of a wire rope.

SOCKET A wire rope termination fitting, one end of which has a long axial cavity to receive the end of the wire rope. The socket may then be squeezed down onto the wire rope (swaged socket) or may be filled with molten metal (poured socket), or synthetic resin (epoxy, polyester).

SPELTER SOCKET See POURED SOCKET.

SPLICING Interweaving a rope end into a rope section or another rope end to form a loop termination (EYE SPLICE) or a longer or circular rope (ENDLESS SPLICING).

STRAND CORE A wire strand used as the core of a rope. Sometimes called a WIRE STRAND CORE (WSC).

SWAGE FITTING A tubular steel or alloy fitting sized to accommodate one or more parts of rope or strand. The fitting is applied by squeezing it onto the rope, usually in a swaging press.

SWAGING The pressing process used to apply a swage fitting.

TERMINATION Any device or process applied to the end of a wire rope.

THIMBLE A grooved ring (usually teardrop-shaped) used to fit in a loop of a rope as protection from chafing and provide support for the rope in the loop.

THIMBLE SPLICE A termination made by forming a wire rope loop around a thimble and then splicing (4 or 5 hand tucks) the dead end into the live part of the rope.

TUCK In splicing, the passage of a strand from a rope into or through another section of rope.

U-BOLT CLIP A clip consisting of a U-bolt and a saddle or bridge which is fastened to the bolt with nuts.

VALLEY The crevice between strands or between wires in a wire rope.

WEDGE SOCKET Wire-rope fitting in which the rope is secured with a wedge inside the socket.

WIRE Single continuous length of metal drawn from a rod. May be "round" in cross section or "shaped" into ovals, triangles, helices, etc.

WIRE ROPE A number of wire strands laid helically about an axial core.

WIRE-STRAND CORE See STRAND CORE.

WORKING LOAD The load that a rope is designed to carry in a particular service. See SAFE WORKING LOAD (SWL).

ZINC SOCKET (Poured Socket) Wire-rope end fitting having a conical basket into which the broomed end of the rope is secured with zinc. May be either open or closed.

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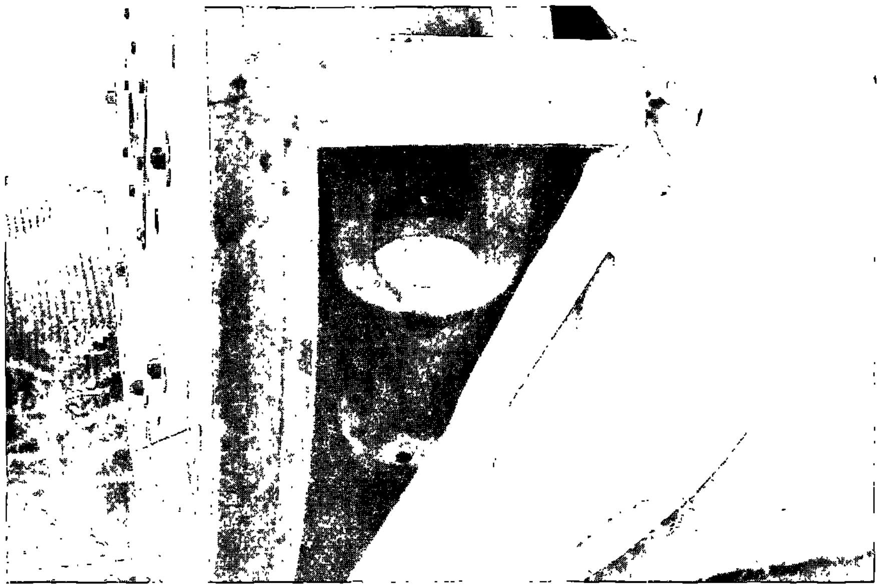
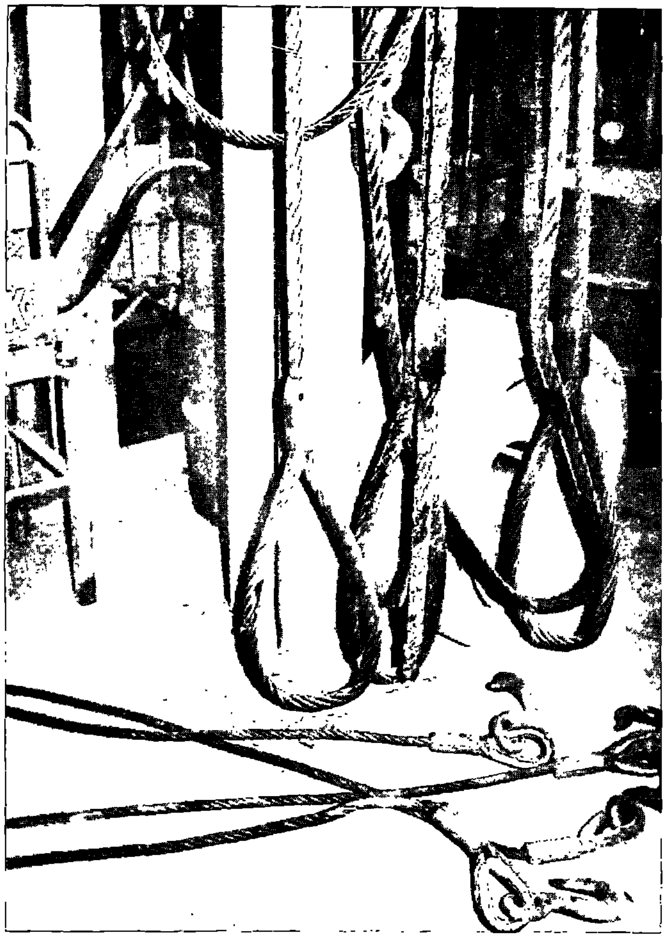
APPENDIX A

WIRE ROPE TERMINATIONS USED IN THE MINE FIELDS



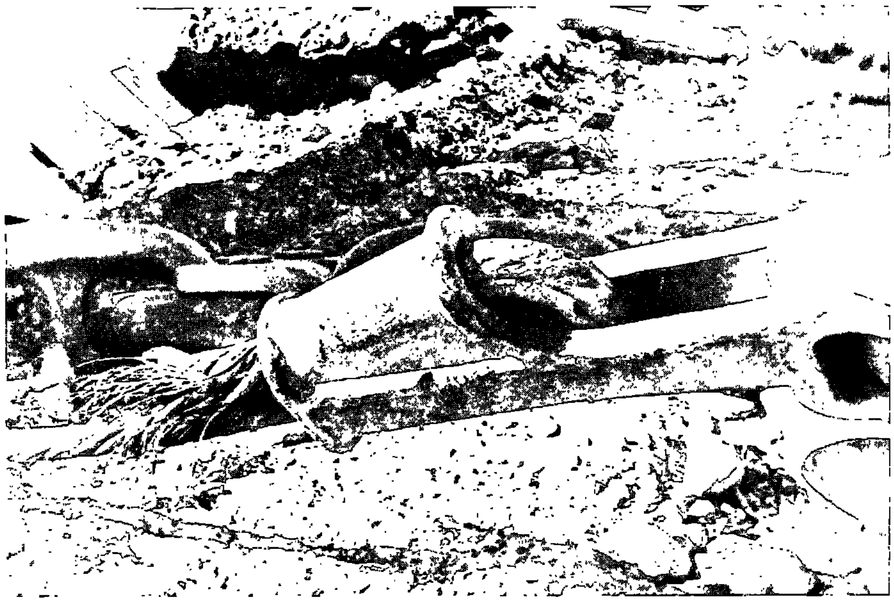
Wire rope reel as delivered with Open Zinc Poured Socket attached to one end of rope.

Wire rope reel as delivered with Turn Back Loop with Sleeves attached to one end of rope.



Flemish Loop with Steel Sleeve and Turn Back Loop with Aluminum Sleeve & Thimble used as slings.

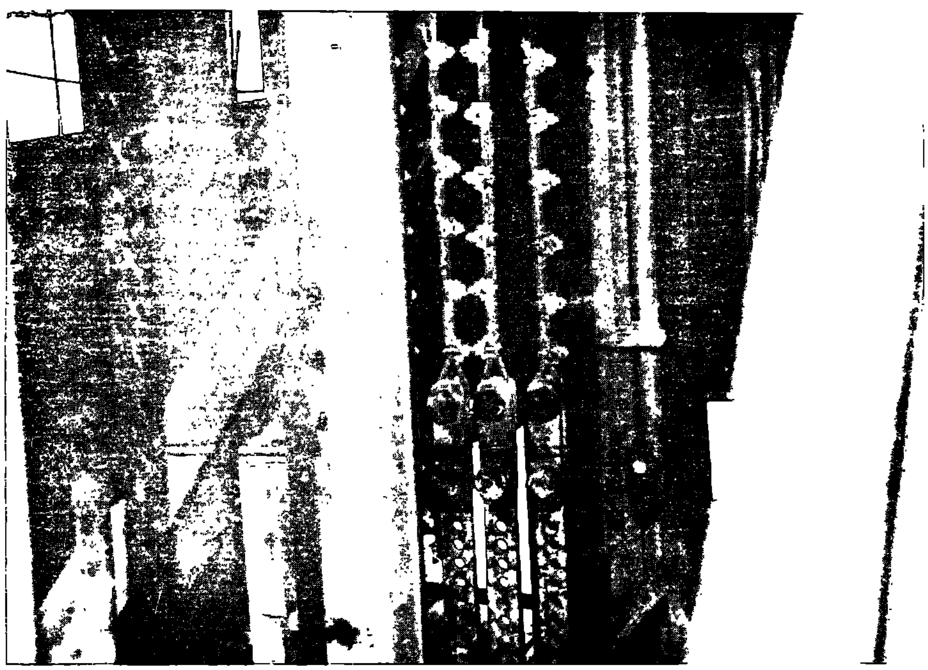
Wedge Sockets on hoist rope of Dragline Machine.



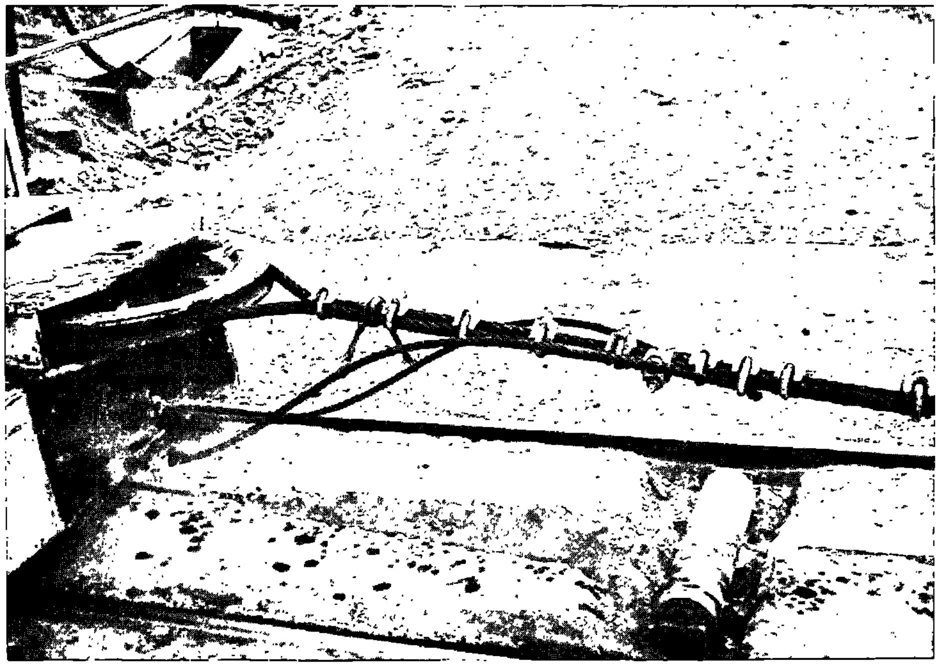
Wedge Sockets on drag rope
of Dragline Machine.

Splice Loop on boom hoist
rope of Shovel Machine.

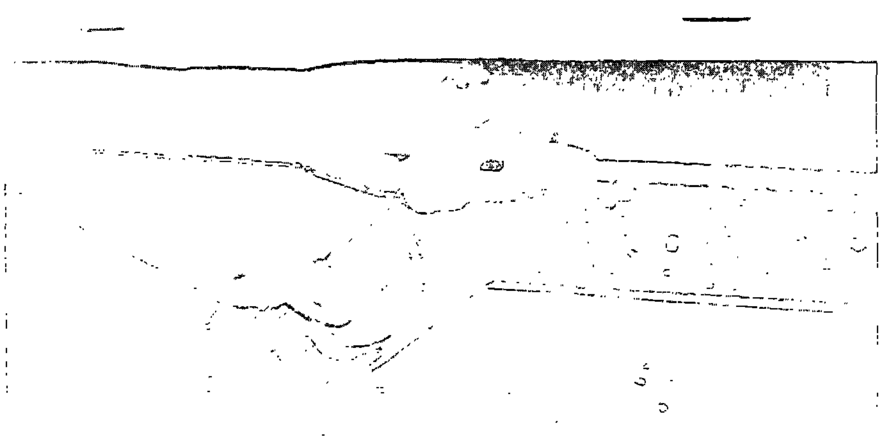
U-Bolt Clips on sled haulage ropes.



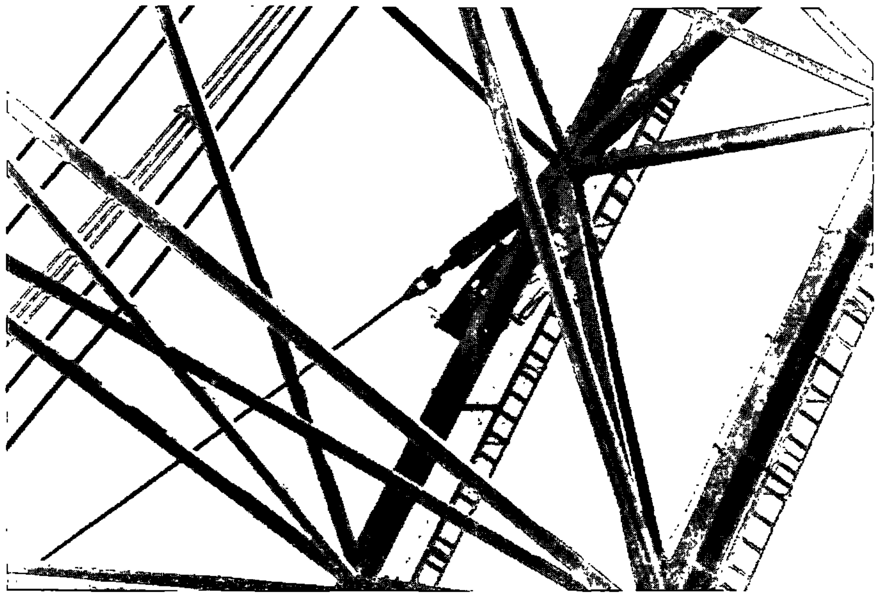
U-Bolt Clips on shaft hoist ropes.



U-Bolt Clips on Man Trip
Car of Slope Hoist ropes.



Zinc Poured Sockets on
train Car Retarder rope.



Zinc Poured Socket on
support rope of surface
mining machine.

APPENDIX B

STANDARD AND MODIFIED PROCEDURES FOR THE ASSEMBLY OF WRT SPECIMEN

GENERAL TERMINATION PROCEDURE

Seizing Wire Rope

1. Prior to cutting wire rope, seize the rope on each side of the cut mark with at least eight turns of the correct diameter (see table below) annealed iron seizing wire. At least three seizings should be placed on each side of the cut mark, approximately one rope diameter apart.

2. Lang lay wire rope with Independent Wire Rope Core (IWRC) should get one additional seizing on each side of cut mark.

3. Two inch diameter wire rope must be seized using a serving bar to get adequate tension. In this case each sizing should be about 30 turns.

Rope Diameter	Seizing Wire Diameter	Number of Seizings
½"	.035	3
3/4"	.063	3
1"	.092	4
1½"	.092	4
2"	.120	5

General Hand Tools required for Splicing

1. 12" Marline Spike
2. 16" Marline Spike
3. 14" Nippers
4. 2 lb. Blacksmiths (or ballpeen) hammer
5. Knife

Cutting of Wire Rope

An abrasive cut-off wheel is recommended for cutting wire rope since this makes a clean cut, does not bend individual wires and eliminates the need for welding the end together and then dressing the edges of the wire rope end.

PREPARATION OF FLEMISH LOOP WITH THIMBLE STEEL SLEEVE & THIMBLE AND FLEMISH LOOP WITH STEEL SLEEVE

NOTE: Also known as "Flemish Eye," "Molly Hogan," or "Rolled in Eye Splice".

1. Slide the sleeve to be pressed later onto the rope. Seize the rope at a distance from the end equal to the length of loop desired, plus a length equal to the ten rope diameters.

2. Separate the rope into two equal sections with one section containing the wire rope core. For a six strand wire rope there will be three strands in one section and three strands plus the core in the other section.

3. Bend the two rope sections toward each other and pass one section under the other. After the loop is formed place the thimble inside the loop when required by twisting the loop open and then resetting.

4. Adjust the contact point for the size loop desired and then permit the two sections to interlock at the top or crown of the loop.

5. Lay the strand sections back into the rope grooves, alternating from one section to the other until the two sections project past the bottom or throat of the loop.

6. To complete the loop, roll the two sections into the main rope then slide the sleeve up to the bottom of the loop.

7. Place the rope in the swaging dies and press the sleeve following the procedure for swaged sockets.

MODIFIED PROCEDURE No. 1; Swage sleeve in second set of dies (second stage) only two times, rotating 90° between swages.

MODIFIED PROCEDURE No. 2: Replace the sleeve with a wire seizing.

PREPARATION OF A WEDGE SOCKET

1. Seize end of wire rope with one long seizing or two short seizings.

2. Insert and seat the wedge in the socket. Mark a line with chalk on the side of the wedge, next to the top of the socket.

3. Place socket in upright position (pin horizontal) and reeve rope through socket and turn back away from ears of socket in large, easy to handle loop.

4. The dead end of rope should then be passed through the socket and allowed to extend from the socket base a distance of at least one rope lay. Insert the wedge.

5. Secure ears of socket to a sturdy support and carefully take a strain on the live end of the rope. Pull wedge and rope loop into position tight enough to hold wedge in place during handling.

6. Increase load gradually until chalk line on wedge is next to top of socket.

MODIFIED PROCEDURE No. 1: Reeve rope through socket and turn <u>toward</u> ears of socket.

MODIFIED PROCEDURE No. 2: Relax load and place U-bolt clip over dead end and secure with saddle on live part of rope. Torque the U-bolt nuts as follows:

Diameter	Torque in Ft. Lbs.
1/2"	65
3/4"	130
1"	225
1½"	360
2"	750

PREPARATION OF CLOSED SWAGED SOCKET

1. Cut the rope to the desired length. Using an acetylene torch, burn the end of the rope to weld all of the wires and strands together. If the rope is preformed, this step may not be necessary. Dress down the end of the rope so that it will slip easily into the cavity and mark this distance on the end of the rope to insure that rope is inserted to bottom of swage socket. Insert the rope end all the way into the cavity of the swage socket.

2. Apply lubricant to both die blocks to facilitate cold flow of socket metal.

3. Press termination in hydraulic press using the correct size die blocks closing the dies one-half (one-fourth or one-third for large sockets) the distance at initial contact with the socket. Rotate the socket and rope 45 degrees after each swaging.

4. Press the termination again, closing the dies one-half (one-fourth or one-third for large sockets) the distance at initial contact with the socket. Rotate the socket and rope 45 degrees.

5. Repeat Step 4 until the dies bottom out, i.e., close completely.

6. Large sockets should be pressed progressively, starting at the tapered end, before rotating.

MODIFIED PROCEDURE No. 1: Set the wire rope into the swage fitting approximately one rope diameter less than full depth.

MODIFIED PROCEDURE No. 2: Press fitting only twice in hydraulic press rotating 90 degrees between swages.

PREPARATION OF TURN BACK LOOP WITH ALUMINUM SLEEVE

1. Mark the rope with chalk where the center of the thimble location is to be and measure the turn back length of rope required from the first mark and mark again for cutting. The turn back length of rope is the distance halfway around the thimble plus the length of the sleeve plus three rope diameters. Seize on each side of the cut mark with eight turns of correct size iron seizing wire and cut on mark.

2. Cut the end of the wire rope with an abrasive wheel and place rope in splicer's vise. Remove seizing and slip the sleeve over the end of the rope and down the rope past the location of the loop.

3. Form the loop around the thimble.

4. Slide the sleeve back to the loop and slip the short end of the rope through the sleeve. Drive it home securely.

5. Remove from splicer's vise and press the sleeve using well lubricated die blocks in a hydraulic press using the correct size blocks for the wire rope diameter and rotating the sleeve 45 degrees after each press. For each press, close the dies one-half the distance at initial contact with the socket.

MODIFIED PROCEDURE No. 1: Press sleeve only two times, rotating 90 degrees between presses.

MODIFIED PROCEDURE No. 2: Use no lubricant while pressing sleeve.

PREPARATION OF THIMBLE SPLICE WITH FOUR TUCKS

1. Bend the wire rope around a matching size heavy duty thimble at the location desired. Hold in splicer's vise. If a regular vise is used, securely bind the rope to the thimble with seizing wire. The turn back length of the dead end of the wire rope, not including the length of rope required to pass around the thimble, should be as follows:

Rope diameter - inches	Turn-back length - feet
½"	1½'
3/4"	2'
1"	3'
1½"	4'
2"	5'

2. Seize dead end of the wire rope on each side of cut mark with eight turns of annealed iron seizing wire of correct diameter. Cut off excess wire rope between seizings.

3. Remove seizing from Short Rope (dead end) and untwist the strands all the way back to the thimble. The end of each strand is either burnt (welded together) with an acetylene torch or seized with seizing wire.

4. Strands on the Long Rope (live end) are lettered A through F and the strands of the Short Rope are numbered 1 through 6. Strand 1 is adjacent to and directly opposite strand C at the point of the thimble.

5. Open the Long Rope for the first forming tuck by passing a marline spike between strand C and strand D; through the center of the rope, three strands on each side of the marline spike, strands C, B, and A below the spike, strands D, E, and F above the spike.

6. Rotate the marline spike to the right so that it moves between the strands and away from the vise, about one quarter turn. Form the first forming tuck by passing strand 1 from the Short Rope around the Long Rope and through the hole created by the marline spike, and between it and the vise. Pull strand 1 tight and rotate marline spike back with the lay of the rope towards the vise. The spike carries strand 1 with it. Seat strand 1 as tightly as possible and remove the spike. Cut off Short Rope core as short as possible.

7. Insert the marline spike between strands A and B of the Long Rope and out between strand C and D. Rotate the spike a quarter turn with the lay and wrap strand 2 from the Short Rope around the Long Rope and back through the opening caused by the spike and pull tight. Rotate the spike back with the lay towards the thimble pulling strand 2 tight, and seat strand 2. Strand 2 now enters the Long Rope in the same location as strand 1 but is tucked under only two strands of Long Rope (B and C).

8. Insert the marline spike under strand C of the Long Rope, rotate ¼ turn with the lay and wrap strand 3 from the Short Rope around the Long Rope and back through the opening made by the spike and on the thimble side of spike. Pull strand 3 tight and rotate spike back with the lay towards the thimble seating strand 3. This completes the forming tucks.

9. Insert marline spike under strand D, rotate one quarter turn with the lay and tuck strand 4 under strand D, pull tight and seat by rotating the spike back towards the thimble so that it rests above strand 3 between strands C and D.

10. Insert marline spike under strand E, rotate one quarter turn with the lay, and tuck strand 5 under strand E, pull tight and rotate spike back towards thimble seating strand 5 so that it is above strand 4 between strands D and E.

11. Insert marline spike under strand F, rotate one quarter turn with the lay and tuck strand 6 under strand F, pull tight, and rotate spike back towards the thimble seating strand 6 above strand 5 and between strand E and F. This completes the first set of tucks for all strands.

12. The second set of tucks for the six strands are put into the splice in a manner similar to that of the first set of tucks, starting with strand number 1. The marline spike is inserted under strand A, rotated a quarter turn with the lay, and strand 1 is brought around the Long Rope and tucked under strand A through the opening made by the spike, and between the spike and the vise. Pull tight and rotate spike back with the lay, seating strand 1 above strand 6 so that it lies between strand F and strand A.

13. Repeat the procedure of 12 above for strand 2 tucked under strand B, strand 3 under strand C, strand 4 under strand D, strand 5 under strand E, and strand 6 under strand F. This completes the second set of tucks.

14. Repeat 12 and 13 above twice more in succession to form the third and fourth sets of tucks.

15. Now the thimble splice is complete. Any irregularities in the shape of the splice can be smoothed out by tapping the splice with a 2-pound blacksmith's hammer against a solid flat surface.

16. Cut off excess length of the protruding strands with large nippers.

17. The splice is seized with the correct size iron seizing wire. Pass the marline spike under two strands of the Long Rope approximately one rope diameter away from the end of the thimble splice. Pass the short end of the seizing wire through the rope and curve or spiral it between strands to the thimble and make fast. Pull seizing wire tight and with seizing tool or marline spike wrap (against the lay) tightly until the ends of the cut strands are well covered or if desired all the way to the thimble. Twist the two ends together to secure the seizing, but cut off excess seizing wire and tuck the twisted ends down between the rope strands.

MODIFIED PROCEDURE No. 1: When the first set of tucks is complete, make tucks 2, 3, and 4 for strand 2 under strand B, until four tucks are complete for all six strands.

MODIFIED PROCEDURE No. 2: Make splice with only three tucks.

PREPARATION OF U-BOLT CLIPS WITH THIMBLE

1. Seize the end of the wire rope and slide a loosely assembled U-Bolt Clip onto the rope.

2. Measure and chalk mark the specified turn back length given in the table below. This length is measured from the bottom of the loop or thimble.

3. Turn back the wire rope, bending it around the thimble, and slide the end of the rope through the U-Bolt Clip.

4. Position the live (long) part of the rope in the saddle (base) of the clip and the dead (short) part of the rope in the U-Bolt part of the clip.

5. Slightly tighten the nuts and position the rope end beyond the clip base a distance equal to the width of the base. Tighten nuts evenly to torque values given in the table below.

6. Position the second U-Bolt Clip up against the bottom of the loop. Tighten nuts, but do not torque them.

7. Position additional clips, as given in the table below, at locations equally spaced between the first and second clips. Tighten all nuts, but do not torque them.

8. To remove any slack and equalize tension in both parts of the rope, pull the long part of the rope while restraining the loop.

9. Tighten all nuts evenly on all clips to the torque values given in the table below.

10. Apply the initial load and retighten nuts to the required torque values. (This step will be performed at the pull test and fatigue test facilities.)

MODIFIED PROCEDURE No. 1: Alternate the position of the clip saddles of the live (long) and dead (short) part of the rope.

MODIFIED PROCEDURE No. 2: Tighten all nuts until they feel "tight enough" without looking at the dial on the torque wrench. When the mechanic is satisfied the nut is tight enough, he should look at the dial and record the value. Do not loosen or tighten the nuts after this. During the pull and fatigue tests the nuts will be torqued only to the value recorded by the mechanic. These modified procedure specimen should be assembled after all other U-Bolt Clip specimen have been prepared so that the mechanic will have learned to feel the correct tightness of the nuts.

TABLE FOR PREPARING U-BOLT CLIP TERMINATIONS

Rope Dia. in Inches	Minimum No. of Clips	Rope Turn-Back in Inches	Required Torque in Foot Pounds
1/4	2	4 3/4	15
5/16	2	5 1/4	30
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
1	5	26	225
1 1/8	6	34	225
1 1/4	6	37	360
1 3/8	7	44	360
1 1/2	7	48	360
1 5/8	7	51	430
1 3/4	7	53	590
2	8	70	750

PREPARATION OF ZINC POURED SOCKET

1. Start heating zinc to 510 degrees Centigrade (950 Fahrenheit). Use only "high grade" zinc per A.S.T.M. Specification B-6-58. Do not use babbitt or other anti-friction metal.

2. Securely seize and serve wire rope with soft wire ties on both sides of cutting point and also at distances from the end of the rope equal to one length of the socket basket (first seizing) and two lengths of the socket basket (second seizing).

3. After cutting off the rope, slide the socket on, then place the rope in a vise, remove the end seizing and open up the rope. Spread the strands out to the first seizing. A core of fiber or synthetic material and any other non-metallic material must be cut off as close to the first seizing as possible. Do not cut off the independent wire rope core (IWRC) or wire strand core (WSC). Untwist the wires in each strand and in the metallic core, spreading them out to form a "brush" or "broom". A wire straightening tool may be necessary for large diameter wire ropes.

4. Holding the broom end of the rope in a horizontal position, clean all the wires to the first seizing with benzene, high flash naphtha or trichloroethane. Shake off any excess and wipe dry. See supplemental instructions if using ultrasonic cleaning bath.

5. Dip the wire broom for three quarters of its length into a bath composed of one-half commercial muriatic acid and one-half water. Remove the broom from the bath after 30 seconds or one minute; when the wires have turned a dull, gray steel color. The acid bath must be kept clean by skimming off lubricant from previous dipping. Keep wire broom pointing down until the excess acid has been shaken off or wiped dry.

6. Next dip the wire broom into a bath of boiling water to which has been added a small amount of soda. Remove the rope and shake dry. Steps 5 and 6 do not apply to galvanized wire rope.

7. Slide the socket to the end of the rope until it rests on the first seizing and then clamp the rope in a vise.

8. Check that the ends of the broom wires are even with the top of the socket basket. If they are not, slide the socket down the rope. Shorten or lengthen the broom by adding or removing wire to the first seizing. Slide the socket back up around the wire broom.

9. Align the socket with the axis of the rope and place fire clay, putty or asbestos wicking around the bottom of the socket. Work this sealer into the space between the strand valleys and the inside surface of the socket basket.

10. Heat the socket to about 94 degrees Centigrade (200 F) by holding the flame of a portable torch to the socket for five minutes.

11. Skim off any dross which may have accumulated on the surface of the zinc bath. Pour molten zinc at 510 C (950 F) into the socket basket until the zinc is even with the top of the basket.

12. After the zinc has congealed with a depression in the center of the upper layer, plunge the socket into cold water for one minute.

13. Remove the sealer as well as the first and second seizing. Apply some lubricant to the rope adjacent to the base of the socket.

MODIFIED PROCEDURE No. 1: In step 4 use Ultrasonic cleaning bath rather than solvent and brush. Continue with steps 5 & 6.

MODIFIED PROCEDURE No. 2: In step 4 use Ultrasonic cleaning bath rather than solvent and brush. Delete steps 5 & 6, the acid bath and neutralizing bath.

Supplementary Instructions for Use of Ultrasonic Cleaner:

1. Fill the ultrasonic cleaner tank with enough solvent so the wire broom will be immersed to the first seizing. With the wire broom immersed in the solvent turn on the cleaner and when action starts, set timer from two to five minutes. The time can be determined by experience and depends on how much lubricant and dirt must be removed.
2. After the first cleaning period, inspect the wire broom for cleanliness. Places between the wires may hold large accumulations of dirt, and these may be helped along with a clean brush.
3. Repeat cleaning process until wire broom is uniformly clean in appearance. Two to four cleanings will be required.

PREPARATION OF EPOXY RESIN POURED SOCKET

1. Check the storage temperature of the epoxy resin kit and, if necessary, place the epoxy resin kit in a warm area to raise its temperature to 22 C (72 F).

2. Chalk mark the rope at a distance from the end equal to the length of the socket basket.

3. Slide the socket onto the rope.

4. Seize the rope just below the chalk mark and then mount the rope in a vise, gripping it just below the seizing.

5. Separate the strands down to the seizing and cut out any fiber core down to the seizing.

6. Separate the strands of an IWRC core for 1/3 of its length.

7. Unlay the IWRC strands to just over 1/3 of their length to form the "coke bottle" shape.

8. Unlay the rope strands to just over 1/3 of their length to form the "coke bottle" shape. Exercise care with 6x37 Lang ropes which tend to unlay more than desired.

9. Apply heat from top to bottom of unlayed rope to melt any heavy lubricant. The lubricant should congeal at the seizing.

10. Remove the rope from the vise and stir the rope end briskly in Varsol or some other grease solvent and use a brush to help remove lubricant.

11. Rinse the rope end in trichloroethane and let dry.

12. Slide the socket up to the seizing and grip rope in a vise at a point beyond the socket. Remove the seizing.

13. Pull the socket onto the rope end, twisting the socket in the lay direction. When properly seated the wire ends should be flush with the inside top edge of the basket.

14. Suspend the socket vertically at a comfortable working height and secure rope to prevent movement in relation to socket.

15. Place the duct seal putty at the joint of the socket base and rope and below for a length of twice the rope diameter. Press the putty firmly into the strand valleys and against the base of the socket. Then using a cloth or paper, squeeze the putty tight around the rope.

16. Apply heat to socket to warm it and remove any moisture. If the working room or area temperature is below 22 C (72 F) heat the socket until it is hot to the touch. If the socket becomes too hot to even touch then let it cool down before pouring epoxy resin mixture.

17. Prepare the epoxy resin by mixing the base (Part A) and hardner (Part B). For the epoxy kits packaged in plastic bags, remove the separator and squeeze the base into the hardner and knead the contents for two (2) minutes so that both parts are thoroughly mixed.

18. For epoxy kits packaged in cans, stir the resin base alone before adding the hardner. Stir for two (2) minutes so that both parts are thoroughly mixed.

19. Check the temperature of the socket and reheat if necessary.

20. Pour the epoxy resin into the basket along the inside edges. This allows the resin to flow to the bottom and avoids trapping air inside the basket. Air voids must be avoided.

21. For epoxy resin kits packaged in cans, the mixture should be transferred to a clean paper cup (not a styrofoam cup) to facilitate pouring.

22. Fill basket half-full then wait one minute before pouring the remaining mixture to cover the wire ends.

23. Observe the top surface of the resin for two minutes. Only pin head size air bubbles should appear. The presence of any air bubbles as big as a pencil eraser should be reported to supervisory personnel since such bubbles indicate the possible presence of air voids which can produce a weak termination.

24. Allow the termination to remain in the suspended position for two (2) hours before removing the seal putty and moving the termination.

MODIFIED PROCEDURE No. 1: Delete Steps 9, 10, and 11. Only remove the grease from the top 1/3 of the "coke bottle" by stirring that part of the unlayed rope in Varsol. Do not use a brush and do not rinse in trichloroethane.

MODIFIED PROCEDURE No. 2: Delete Steps 16, 19, 20, 22 and 23. Pour the epoxy resin mixture right into the center of the basket. Do not wait for the resin to flow to the bottom, but pour the entire contents in at one time until the wire ends are covered. Do not, however, allow the resin to overflow the basket as it is being poured.

APPENDIX C

IDENTIFICATION OF MATERIAL SOURCES[a]

Item	Source
Wire rope	Bethlehem Steel Corp.
Epoxy Resin Poured Socket	CASTLOK, Loos & Co.
Epoxy Resin	Loos & Co.
Polyester Resin	SOCKETFAST, Philadelphia Resins Corp.
Trichloroethane Solvent	Dow Chemical Corp.
Thimbles, heavy duty	The Crosby Group
Steel Sleeves	The Crosby Group
Aluminum Sleeves	The Crosby Group
Closed Swaged Sockets	The Crosby Group
Wedge Sockets; ½, 3/4, 1 inch	The Crosby Group
Zinc Poured Sockets, RR-S-550	The Crosby Group
U-Bolt Clips	The Crosby Group
Wedge Socket; 1½, 2 inch	Lowery Brothers
Zinc Ammonium Chloride	E.I. DuPont

[a] Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

APPENDIX D

FAILURE DESCRIPTION OF SALVAGED FATIGUE SPECIMEN

FAILURE DESCRIPTION OF SALVAGED FATIGUE SPECIMENS

I.D. No.	Location of Failure	Broken Strands	Broken Wires	Condition of Core
	Flemish Loop with Steel Sleeve & Thimble			
13	Base of Sleeve	1,2,3	All	All
17	One Sleeve	1,2	All	
	Other Sleeve	3	All	All
18	Base of Sleeve	1,2	All	
	Gage Area	3	1	
49	Base of Sleeve	1,2,3,4	All	All
		5	9	
		6	4	
125	Crown & Base of Loop	1crn	4	OK
	Thimbles Cracked	2bs	10	
131	Crown & Base of Loop	1crn	15	OK
		2bs	9	
211	Base of Sleeve	1	15	OK
	Thimbles Cracked	2	14	
212	Base of Sleeve	1	All	Three
	Thimbles Cracked	2	All	strands
	Flemish Loop with Steel Sleeve			
1	Base of One Sleeve	1	All	OK
		2	1	
5	Crown of Loop	1,2,3	All	All
		4	6	
6	One Loop Crown	1,2,3	All	All
	Other Loop Crown	1,3	9	
		2	6	
53	Crown of Loop	1,2,3	All	All
		4	6	
311	Crown of Loop	1,2,3	All	All
63	Crown of Loop	1	All	Four
		2	All	Strands
		3	All	
64	Crown of Loop	1	All	Three
		2	All	Strands
146	Crown of Loop	1	8	OK
		2	8	
		3	9	
		4	10	
206	Crown of Loop One End	1	6	OK
	Crown of Loop Other End	2	2	

FAILURE DESCRIPTION OF SALVAGED FATIGUE SPECIMENS (cont.)

I.D. No.	Location of Failure	Broken Strands	Broken Wires	Condition of Core
		Wedge Socket		
227	Base of Wedge	1,2	All	All
		3	3	
		4	2	
		5	2	
		6	1	
228	Base of One Socket	1,2	All	All
	Base of Other Socket	3	All	
		4	8	
231	Base of Wedge	1,2,3	All	All
		4	10	
249	Base of Wedge	1	All	One Strand
256	Base of Wedge	1	22	Two Strands
		Closed Swaged Socket		
33	Base of Socket	1,2	All	All
		3	8	
496	Base of Socket	1	9	Two
		2	9	Strands
		3	2	
497	Base of Socket	1	All	All
		2	9	
	Turn Back Loop with Aluminum Sleeve & Thimble			
173	Cracked Sleeve & Thimble	1,2,3	All	All
396	At Cracked Sleeve	1,2,3	All	All
386	One End	1,2	All	All
	Other End	3	All	
		4	13	
387	Cracked Sleeve & Thimble	1	1	OK
189	Base of Pressed Sleeve	1	All	Two Strands
	One Cracked Sleeve			
190	Base of Pressed Sleeve	1	6	OK
	One Cracked Sleeve			
194	Base of Pressed Sleeve	1	9	OK

FAILURE DESCRIPTION OF SALVAGED FATIGUE SPECIMENS (cont.)

I.D. No.	Location of Failure	Broken Strands	Broken Wires	Condition of Core
		Thimble Splice with Four Tucks		
68	First Tuck	1	All	OK
		2,5	20	
		3	17	
		4,6	5	
69	First Tuck	1,2	All	OK
		3	21	
		4,5	10	
		6	8	
77	First Tuck	1	12	OK
		2	4	
		3	8	
		4	6	
84	First Tuck	1,2,3,4	All	OK
85	First Tuck	1,2,3,4	All	OK
89	Last Tuck	1,2,3	All	All
		4	4	
90	Top of One Splice	1	All	OK
		2	22	
		3	9	
		4	8	
		5	2	
		U-Bolt Clip with Thimble		
216	First Clip	1,2	All	All
		3	15	
217	First Clip	1,2,3	All	All
441	First U-Bolt Clip	1	All	Two Strands
442	First U-Bolt Clip	1	All	Two Strands
		2	3	
		3	1	

FAILURE DESCRIPTION OF SALVAGED FATIGUE SPECIMENS (cont.)

I.D. No.	Location of Failure	Broken Strands	Broken Wires	Condition of Core
		Zinc Poured Socket		
352	Base of Socket	1,2,3	All	All
		4,5,6	15 ea.	
353	½" From Base of Socket	1,2	All	All
		3	10	
354	Base of Socket	1	All	All
		2	23	
		3	5	
340	Base of Socket	1	All	All
		2,3	20	
324	Base of Socket	1	9	OK
		2	8	
		3	4	
325	Base of Socket	1	9	OK
		2	8	
		3	2	
329	Base of Socket	1	5	OK
		2	6	
		3	4	
		4	3	
		Epoxy Resin Poured Socket		
1016	N/A	None	None	OK
1021	N/A	None	None	OK