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STATISTICAL ANALYSIS OF WIRE ROPE

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Battelle, Columbus Laboratories

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16. Abstract. Laboratory and field data for wire ropes typical of constructions used in underground mine hoisting were obtained, screened, encoded and analyzed statistically. The statistical analysis of data for hoist ropes retired from service showed that rope remaining strength (or, conversely, strength loss) can be predicted with good accuracy if several nondestructive measures of rope damage are assessed. Found to be most important was the outer-wire corrosion rating, the electromagnetic (EM) nondestructive-inspection technique used for predicting strength loss, and the rope diameter reduction. Signs of rope deterioration such as broken wires or damage were also important indicators of strength loss. Based on the results of this investigation, a number of recommendations are presented that promise to yield better rope inspection and retirement criteria which will in turn lead to improved safety and efficiency in underground mine-hoist systems.		14.	
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FOREWORD

This report was prepared by Battelle, Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201, under USBM Contract Number J0215012. It was administered under the technical direction of the Spokane Research Center with Mr. Grant Anderson acting as Technical Project Officer. Mr. Larry Rock was the contract administrator for the Bureau of Mines. This report is a summary of work completed as a part of this contract during the period December 16, 1980 to February 16, 1983.

This report contains data and information inputs from domestic and foreign sources representing the academic and technical scientific communities, suppliers to the mining industry, mine operators and their engineering and maintenance personnel, and the mining safety regulatory agencies.

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INTRODUCTION AND SUMMARY

Laboratory and field data for wire ropes were solicited from sources throughout the world, with special emphasis placed on vertical shaft, underground mine-hoist rope constructions and operating conditions. Data obtained as a result of this solicitation were screened, and selected data were encoded in standardized formats for each of four data types.

The four data types included (1) comprehensive post-retirement field rope examinations (Ontario's Special Rope Tests), (2) routine, hoist rope conveyance-end cutoff test results from field ropes, (3) laboratory axial fatigue data and (4) laboratory bend-over-sheave fatigue data. In excess of 2,650 field rope test records and 5,400 laboratory test records were encoded. Each field rope test record involved the documentation of up to 75 different independent and dependent variables, while each laboratory test record involved the documentation of up to 35 separate variables.

A preliminary analysis was completed for each of the four basic data groups to identify outliers and to discern the statistical distribution of key variables. Based on the preliminary analysis, a statistical analysis plan was developed, reviewed and implemented. The major focus of the statistical analysis was the Ontario Special Rope Test data base, since it represents the most comprehensive field rope data base ever assembled, and it offered a unique opportunity for gaining an improved understanding of what factors most significantly influence hoist rope remaining strength and service life.

The statistical analysis of field data clearly showed that hoist rope remaining strength can be predicted with good accuracy if several nondestructive measures of rope damage are properly identified. Found to be most important was the outer wire corrosion rating, the electromagnetic (EM) nondestructive-inspection technique used for predicting strength loss, and the rope diameter reduction. Signs of physical deterioration such as broken wires or damage were also important indicators of strength loss.

The analysis showed service life to be somewhat less predictable than is strength loss in terms of the available independent variables. This is probably due to the inconsistent causes for retirement of the hoist ropes used as the data base for the current study (e.g. time, mine shut down, rope "damage"). However, despite the inconsistent causes for retirement, there were a number of factors that were found to relate to long service life with low strength loss. The most important factors were found to be high drum/sheave-to-rope diameter (D/d) ratios, high wire strength and short lubrication intervals.

Based on the results of this investigation, a number of specific recommendations are presented that promise to yield better rope inspection and retirement criteria which will in turn lead to improved safety and efficiency in underground mine-hoist systems.

SUBJECT INVENTIONS

No patentable inventions were made during this project.

CONCLUSIONS

Based on the results of the statistical analysis of the Ontario Special Rope Test data, it is concluded that hoist rope remaining strength is the most important and predictable dependent variable. Service life in terms of time or hoisting cycles is less predictable, at least in terms of the independent variables which were monitored and controlled on the Special Rope Test samples. Remaining strength values can be correlated most completely with the following independent variables, in order of importance:

- (1) Elongation (during tensile testing) of used rope test samples
- (2) Corrosion rating of used rope outer wires
- (3) Torsion test values of used rope outer wires
- (4) Electromagnetic (EM)-predicted strength loss
- (5) Rope appearance (e.g. worn, broken wires, "damaged")
- (6) Diameter reduction
- (7) Lubrication rating of the used rope core
- (8) Rope usage (e.g. drum hoist, friction hoist, friction tail)

Of these eight factors, outer wire corrosion rating, EM-predicted strength loss, rope appearance and diameter reduction are the only practical non-destructive inspection measures that could be employed to evaluate the retirement of an underground mine hoist rope. Therefore, it is concluded that the most important nondestructive inspection procedures would involve periodic

- (1) Assessments of outer wire corrosion damage in a rope
- (2) Electromagnetic (EM) inspection of the entire rope
- (3) Visual inspections to identify worn areas and broken wires, but principally sites of rope damage
- (4) Rope diameter reduction measurements.

Indeed, if the above factors are known, there is evidence based on blind predictions of remaining strength for the Special Rope Test data that the degraded rope sections can be identified with greater than 90% accuracy.

There are a number of factors that tend to promote long service life with low losses in rope strength. The most important of these factors have been shown to be:

- (1) High D/d ratios
- (2) High wire strength
- (3) Short lubrication intervals

The results also suggest that the following conditions are undesirable in terms of shortened rope life and increased rope strength losses:

- (1) Low initial core lubrication
- (2) More than three rope layers on the drum.

It has been shown that the most likely site for rope degradation is the lower one-half of the rope where corrosive conditions would appear to be the most severe. Measures of mine corrosivity (e.g., mine water pH, upcast ventilation, humidity) were not linked clearly with rope strength loss or service life, but this is probably more a reflection on the lack of such data in most of the data base than it is a reliable statement that these factors are unimportant.

It is not possible to make a definitive statement regarding the importance of rope cutoffs. It is clear that the cutoff program does not ensure integrity of the whole rope and that the large majority of rope cutoffs show almost no strength loss. There is some reason to believe, based on the results of this study, that a mandatory cutoff program would be no more effective than an elective cutoff program combined with careful visual and nondestructive inspection of the rope near the conveyance.

Finally, it is concluded that the laboratory axial- and bend-over-sheave fatigue data base accumulated in this program is useful for (1) making approximate calculations of expected rope service life and (2) tradeoff analyses on the effect of potential operating and/or rope construction changes.

RECOMMENDATIONS

The U.S. Bureau of Mines should consider the following actions based on the results of this study:

- Begin a comprehensive field rope evaluation program which would include periodic in-service inspections of hoist ropes and destructive examinations of retired rope sections thought to be degraded in strength. All operating conditions and rope variables should be identified, in addition to the nondestructive inspection data which are collected. The ultimate goal should be the development of a new set of nondestructive retirement criteria that is highly reliable for the detection of significant rope degradation.

Specific elements of the above effort should include:

- Further development of the Ontario corrosion rating system such that the resulting technique methodology would be more objective, better "automated" and can be more easily applied in the field.
- The determination of pre-installation baseline data for field ropes to define at a minimum
 - rope breaking strength
 - outer wire breaking strength
 - core lubrication %
 - initial rope diameter under load.

- The requirement that hoisting cycles to be logged for each rope and that explicit reasons for rope removal be given in all cases.
- The development of a reliable and rapid method for in-service rope diameter measurement.
- The ongoing and careful assessment of current and emerging EM device capabilities in terms of detecting broken wires and corrosion.
- A rope cutoff program based not on fixed time intervals but on the observation of signs and rope damage near the conveyance.

In addition, laboratory work should be initiated to

- Characterize bend-over-sheave and axial fatigue characteristics for locked-coil ropes.
- Develop a better corrosion inhibition system, through improved lubricants/lubrication techniques and/or wire coatings.

Analysis work should be oriented towards

- The statistical assessment of newly acquired nondestructive and destructive test data to properly evaluate their reliability and to develop improved rope retirement criteria.
- A cumulative damage analysis of wire rope that provides reliable estimates of field rope service performance including the combined effects of fatigue, corrosion and wear.

BACKGROUND

Both productivity and safety in underground mines could be improved if mine-hoist rope life and reliability could be predicted more accurately. As a result, hoist-rope failure processes and their effects on rope life and remaining strength need to be quantified and related in such a way that improved retirement criteria can be developed. This is true whether the failure is incipient or actual and whether the failure mode is by corrosion, wear, fatigue or a combination of these factors. Logically, the Bureau of Mines is concerned about the safety of the ropes in shaft-hoist systems. Heretofore, there has not been available a comprehensive statistical analysis methodology that could be applied to the problem. Therefore, the program reported on here was initiated to provide such a methodology. This document, which represents the Final Report on the program, summarizes the development of the methodology and provides examples of its utility in determining, insofar as available data will allow, the major operational and environmental influences on rope life and strength, their quantitative values and their relative importance. In addition, recommendations are made for needed research and development pertinent to the generation of improved retirement criteria for hoist ropes.

MINE-HOIST CHARACTERISTICS

Underground mining operations currently employ wire rope for a large variety of purposes. Generally, however, wire rope for underground mining is used in two primary applications--hoisting and nonhoisting. Battelle completed a study for the Bureau of Mines in 1971 (1) which described the various requirements on wire rope for hoisting and non-hoisting applications.

In context with that study and in line with terminology used here, hoisting applies to systems used to transport men, materials, and/or products between the earth's surface and underground working levels either through vertical or inclined shafts. Nonhoisting ropes are categorized by their exclusion from the hoisting definition on the basis of function; e.g., slings, track ropes, scraper and slusher ropes. Nonhoisting ropes were not considered in this program.

The following paragraphs describe two primary hoisting applications, vertical shafts and slope shafts. Mine elevators also involve vertical-shaft hoisting systems; however, the requirements and service performance of these systems are sufficiently different from man/materials carrying shaft hoists that they were omitted from consideration in this program.

Vertical-Shaft Hoists

Vertical-shaft hoisting systems are commonly used for intermediate to deep mine operations. In the United States, this depth range has been from about 500 feet to 3,000 or 4,000 feet. Deeper mines up to 5,000 to 8,000 feet and greater are relatively few and new in the U.S.; such mines are represented by the Homestake gold mines in South Dakota and the Coeur d'Alene silver mines in Idaho. In some mines outside the United States, (especially those in South Africa), depths greater than 7,000 feet are already relatively common. (2,3)

Shaft hoists are made in two basic designs: (1) drum hoists or "winders" and (2) friction or "Koepe" hoists. Drum hoists have been used most extensively in the United States but friction hoists are increasing in popularity. The distinctive features and the related wire rope requirements are discussed in the following two sections. The latest specifications for wire ropes used in mines appear in ANSI M11.1-1980 (4).

Drum Hoists

Vertical-shaft drum hoisting systems commonly operate on a counter-balance hoisting principle. In this type of system, two ropes are used simultaneously, one of them is wound onto the drum from the top and one is wrapped on from the bottom. Each rope is attached at the end away from the drum to a skip or conveyance (each of approximately equal weight), although one conveyance may actually be a counterweight for the other active conveyance. Also, two drums are sometimes used with a safety clutch system between drums so that one conveyance can be moved relative to the position of the other. A variety of noncylindrical drum shapes are sometimes used for balancing of the hoisting system, but they are not of particular importance in this discussion.

Regardless of the specific drum design in a vertical-shaft hoisting system, the wire ropes used are generally terminated at the drum and at the conveyance or counterweight.

A variety of wire-rope constructions and sizes are used on vertical-shaft drum hoists (1). The large percentage of those ropes, however, are 6 x 19 Seale and 6 x 25 filler wire constructions with internally lubricated fiber cores in diameter ranges from 3/4 inch to 2-1/4 inch. Both Lang-lay and regular-lay are used with no apparent preference for one over the other--except for shafts where the conveyance is relatively free to spin; in those cases, regular-lay rope is specified. Medium-to high-strength wire materials are normally used. Mines outside the U.S. have employed a variety of other rope constructions including flattened-strand and locked-coil designs with considerable success, but only the flattened-strand constructions are used extensively in the U.S. at the present time.

Friction Hoists

Friction (or Koepe) hoisting systems operate on the basis of a frictional driving force which develops between the rope (or ropes) and a driving wheel. Two or more ropes are normally used in parallel. The ropes are not terminated on the drive wheel as they are on a drum hoist; they simply pass over it. Therefore, the presence of lubricants in the contact area between the drum and the rope can alter the performance of the hoist to a significant degree. The end of the ropes which pass over the drive wheel are always counterweighted and the counterweight and conveyance are connected by a "tail" rope to form a continuous loop of rope. Such an arrangement allows balancing of rope tensions onto and off of the drive wheel regardless of the vertical position of the conveyance.

The wire-rope constructions used for friction hoists may be the same as those used on drum hoists but are often different because the friction hoist requires a higher real area of contact between the rope and the wheel to achieve maximum frictional driving force. Therefore, locked-coil ropes from 3/4-inch to 2-1/4-inch diameter are sometimes used, as are 6 x 27 and 6 x 30 flattened-strand, Lang-lay, fiber-core ropes. There also is a tendency towards use of higher strength wire materials in these ropes to reduce the inherent rope weight problem.

The tail ropes (sometimes called balance ropes) used in friction hoisting systems are generally made in 18 x 7, 8 x 19, or 34 x 7 nonrotating, regular-lay, fiber-core constructions. They are not of primary interest in this program, however, since they do not directly support the conveyance or counterweight. Even so, tail ropes can fail precipitously; precisely because they do not support a conveyance or counterweight, they receive less attention and maintenance and, thus far, they have not been subject to rigorous retirement inspections.

Slope-Shaft Hoists

Slope shafts are usually constructed for production from relatively shallow mines of less than 400 or 500 feet. Slope-shaft hoisting systems

are generally drum hoist devices and most are plain, cylindrical drums with helical grooving.

The wire ropes used in slope-hoist systems are often relatively coarse wire constructions to accommodate the considerable abrasion normally encountered. A 6 x 19 fiber-core, regular-lay rope is the construction used most often, while 6 x 21 fiber-core, regular-lay rope is used in the majority of the remaining systems. A flattened-strand rope such as a 6 x 27 would probably work reasonably well under such conditions, although it is apparently not used extensively for this application in the United States.

Wire Rope Characteristics

Overall, the large majority of wire ropes used in vertical shafts in the United States are still round-strand or flattened-strand constructions with fiber cores; only a limited number of friction hoist systems are using locked- and half-locked coil ropes. As more deep mines come into operation in the United States, there will probably be an increase in the use of locked-coil ropes because of fewer rope rotation problems and the size advantages of friction hoists when deepening a shaft requires placing a hoist downshaft.

Failure/Retirement Criteria for Hoist Ropes

When a rope is operated on a shaft hoist, it experiences a combination of environmental and mechanical factors that eventually lead to rope degradation and replacement. Of course, if replacement does not occur soon enough, a single high load in the rope can cause failure. The environmental aspects of the problem must be addressed also; the effect of lubricants in preventing corrosion in hoist ropes was investigated by Battelle in a recent program (5). Chemical corrosion and/or fretting corrosion has been found to "lock" wires and strands in place--vastly increasing the stresses in particular wires when the rope is bent. Also, corrosion fatigue has been indicted as a common mode of failure in a significant number of hoist ropes. Therefore, the corrosivity of the shaft environment, (e.g., contact with acid mine water, etc) must be included as a significant input variable in the analysis of field rope failures and in the development of improved retirement criteria. If lubrication practices and the lubricant itself are effective, few ropes fail by corrosion despite the environment. However, the effects of corrosion remain very difficult to quantify and there are few laboratory test data in corrosive media.

In contrast with the effects of corrosion, mechanical effects on wire rope life are more tractable. Stresses that induce fatigue in a wire rope are introduced through axial loads on the rope and through bending forces on the rope over drums and sheaves. The combination of these forces leads to internal and external wire wear, and under certain conditions, plastic deformation of the wires in the rope.

The problem of fatigue in wire rope is usually separated into two modes--axial fatigue and bending fatigue. Wear is not normally addressed directly, it is generally considered a by-product of the axial or bending fatigue experienced by the rope. Shaft-hoist ropes are subjected to axial load fluctuations and bending over sheaves and drums; therefore, realistic statistical analyses of hoist rope failure must address the synergistic effects between axial and bending forces.

Considerable laboratory testing has been done on each of these problems separately. In regard to bend-over-sheave fatigue, a number of basic facts are known. For one, the sheave-to-rope diameter ratio (D/d) exerts a strong influence on the life of a wire rope and the mode of failure. At any given load, and with similar operating conditions, the service life of a wire rope will increase with increasing D/d values. Most wire rope catalogs discuss the effect of sheave size in terms of "relative service life" (RSL) for various D/d ratios. A typical curve from one of these sources is shown in Figure 1 (6).

Obviously, the service life of a wire rope under normal operating conditions also depends strongly on the load that it carries. A plot of cycles-to-failure versus load for a typical wire rope is shown in Figure 2 (7). Another plot covering a much wider range of loads and D/d ratios is shown in Figure 3 (8). The curve shapes are said to be typical of those to be expected for all types of wire ropes. Figure 3 also illustrates another important point. While rope life is nearly always inversely proportional to load, this dependency can vary greatly depending on the load range. Note that in Figure 3, at the higher loads, the life decreases rapidly with only a small increase in load.

Several investigators have attempted to correlate the effect of combinations of load, D/d ratio, and other parameters such as rope construction, with rope life as measured in laboratory fatigue tests (9). No universally accurate technique has yet been found that can be applied to all results. One problem that makes correlation difficult resides in the uncontrolled and machine-induced effects characteristic of different fatigue-machine configurations and operating conditions. Another is the lack of a commonly agreed-upon definition of rope failure. Many investigators use the complete parting of at least one strand as the failure point, but others use a different criterion, sometimes unspecified.

Nevertheless, such correlations can be useful, especially in the absence of any other rational method for predicting rope life. The one discussed here, the Drucker-Tachau factor (10) has been found reasonably accurate for normal loads and D/d ratios, so long as other factors, such as groove shape, sheave material, etc, are constant.

Figure 4 is a plot of the Drucker-Tachau bearing-pressure-ratio factor (B) versus cycles to failure for 6 x 37 class wire rope. In this figure, the results of a series of experiments completed at Battelle in 1974 (7) are contrasted with the original curve published by Drucker and Tachau for 6 x 37 fiber-core rope. Their data were primarily derived from a

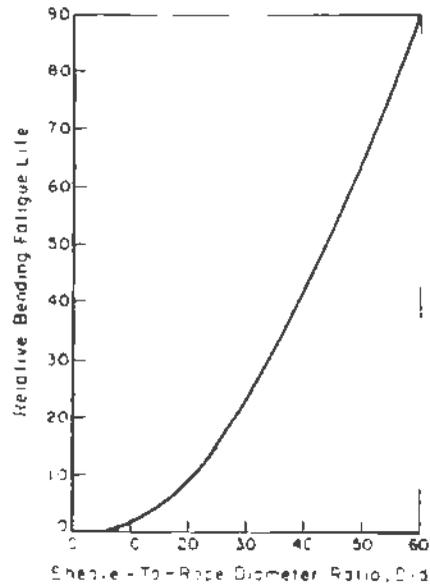


FIGURE 1. Effects on rope life of rope construction and D/d.

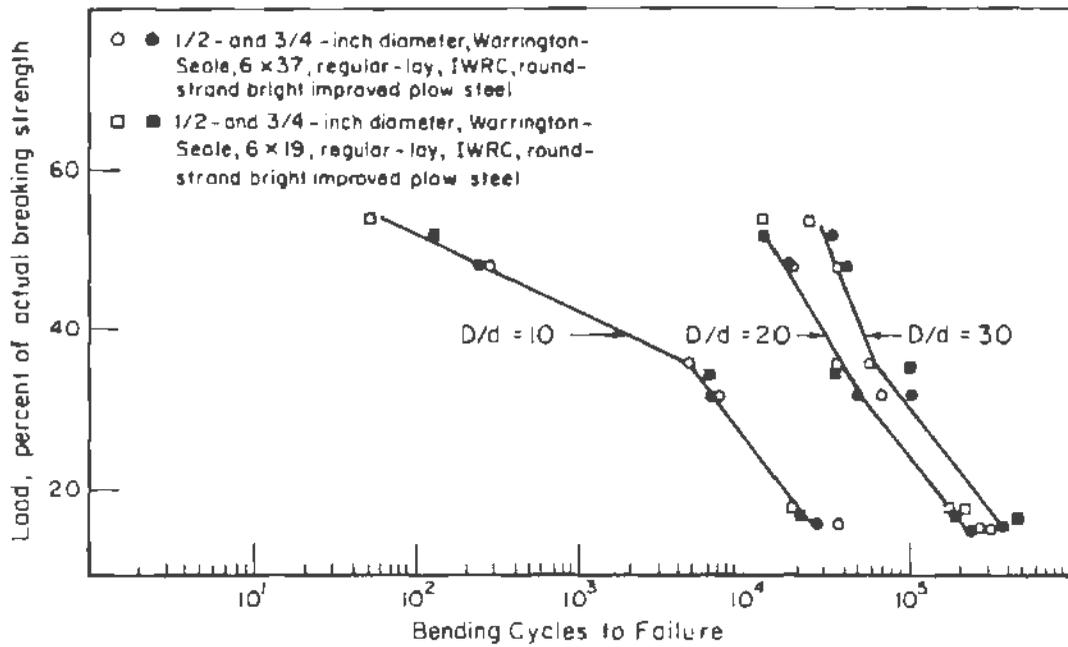


FIGURE 2. Bending-fatigue data for small-diameter IWRC ropes.

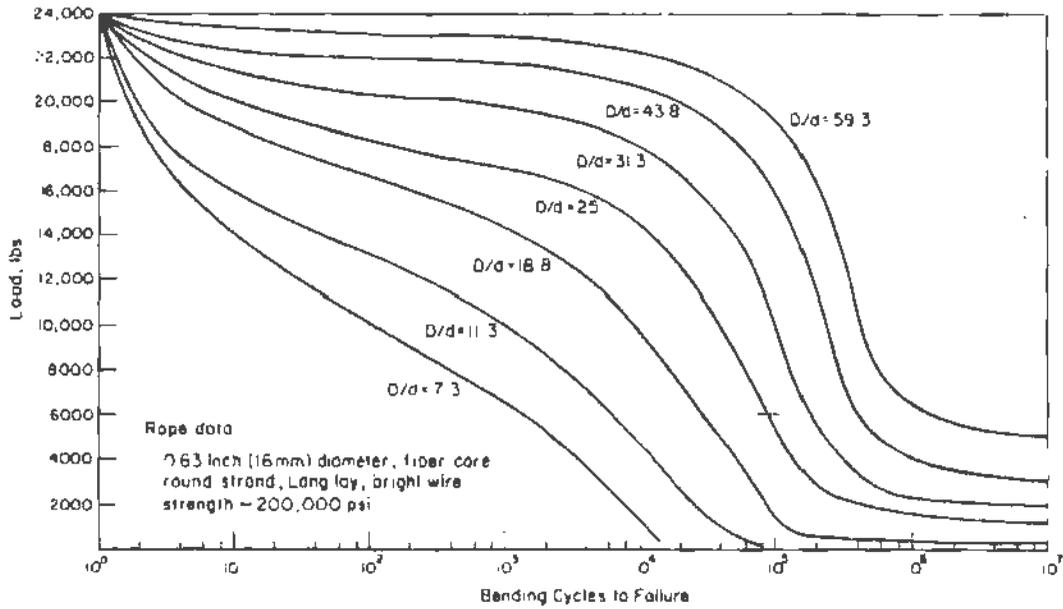


FIGURE 3. Bending-fatigue data for a wide range of loads and D/d ratios.

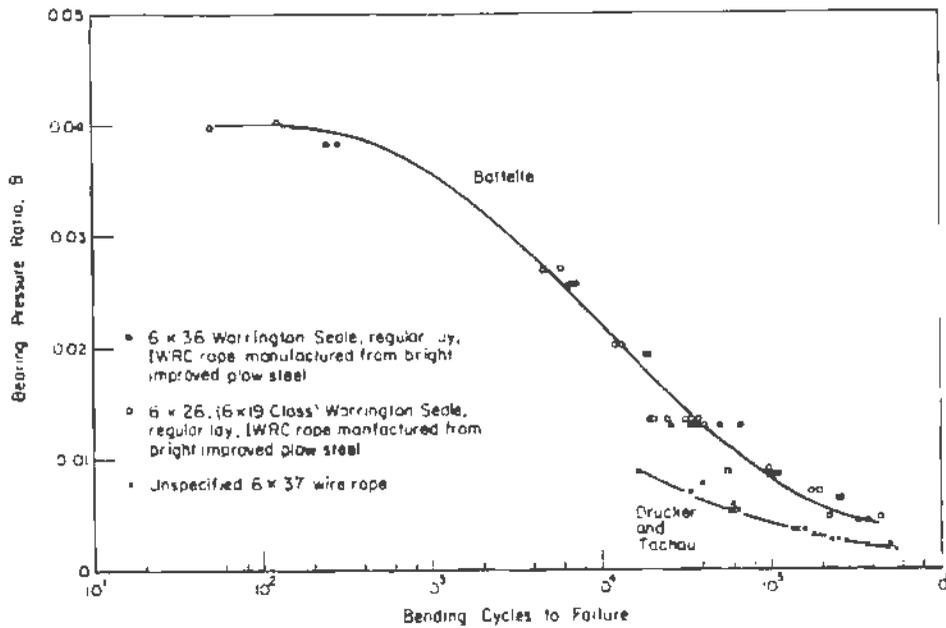


FIGURE 4. Comparison of bending-fatigue data on the basis of bearing pressure ratio.

series of experiments conducted by Scoble in England and Woernle in Germany from about 1927 to 1935 (11-14). The difference is probably due to a combination of improvements in wire rope and to different experimental techniques.

One drawback that "8", the bearing-pressure-ratio factor, has is that it does not accurately accommodate the fatigue characteristics of the wire material. The wire (or rope) ultimate strength is used in the parameter and this indicates nothing about the material's actual resistance to fatigue cycling. Some wire materials are more resistant to tri-axial fatigue than others, even though they may have similar ultimate strengths.

Laboratory studies have also been done on a range of other variables that affect bend-over-sheave fatigue life. They will not be discussed here as they were reviewed in a recent article by one of the authors (15).

A more limited amount of experimental research has been done on the axial-fatigue characteristics of wire rope. Some of the effects noted in bending fatigue of wire rope are also significant in axial fatigue. The conditions that are normally simulated in axial-fatigue tests are substantially different, however, than are those considered in bending-fatigue experiments. Under constant-amplitude cyclic loading of a wire rope, several load cycle characteristics must be considered, the maximum load, the mean load, and the load range. Of these, the load range has been shown to have the most effect on fatigue life (16, 17). The primary damage factors under variable-amplitude axial load fatigue are more complex and less clearly understood.

All of the influences mentioned above were considered in the current program to select variables and/or derive parameters for use as variables in the statistical analysis.

RESEARCH PROCEDURES AND RESULTS

The program was conducted in two phases: Phase I - Data Reporting and Analysis Plan Development and Phase II - Data Analysis. Phase I was subdivided into four tasks and Phase II into two tasks. In Phase I these tasks were: Task (1) collection of laboratory and field data, Task (2) data assessment, Task (3) development of a statistical analysis plan and Task (4) preliminary data analysis. The Phase II tasks were Task (5) refined statistical analysis and Task (6) assessment of rope performance trends and operating parameters.

Task 1. Collection of Laboratory and Field Data and Task 2. Data Assessment

Laboratory and field data for wire ropes were collected from throughout the world to provide an adequate data base for analysis. Results from about 6,000 pertinent laboratory rope tests and about 6,000 pertinent field rope tests were acquired in Task 1 and they were subsequently identified as promising in Task 2 for applicability and comprehensiveness. The details of the data acquisition, assessment, and examples of such data

will not be repeated here. However, data that were selected for analysis will be delivered to the Bureau on magnetic tape with this report.

Task 3. Development of Statistical Analysis Plan

A statistical analysis plan was generated and formulated specifically to evaluate the data acquired and assessed for usefulness in Tasks 1 and 2 of the program. The analysis plan was constructed to lead to high-confidence correlations between the major dependent variables (rope life and remaining strength) and the important independent variables. The plan included: (1) a description of the methods to be used for separating the data into groups (which were largely to be studied independently), (2) a preview of the results which were to be obtained from analyzing each group, and (3) a survey of the methods which were to be used to analyze the data.

Task 4. Preliminary Data Analysis

In Tasks 1 and 2 of this program, a large collection of laboratory and field data were obtained and encoded for analysis. These data fell into four primary data groups. They include two types of data for field ropes; these are (1) "Special Rope Tests"* on retired hoist ropes and

* Data are from "Special Rope Tests", Mining Health and Safety Branch, Ministry of Labour, Ontario, Canada.

(2) Routine Rope Tests** on hoist ropes in service. Also included are

**Data are from "Routine Rope Tests", Provinces of Ontario, Manitoba and Newfoundland, Canada.

two types of data from laboratory rope tests: (1) axial fatigue tests and (2) bend-over-sheave fatigue tests.

The preliminary statistical analysis on each group of data was handled separately. Because the available correlative information and operating conditions varied between data groups, the kinds of questions which could be addressed differed from group to group.

Task 5. Refined Statistical Analysis and Task 6. Assessment of Rope Performance Trends and Operating Parameters

The discussion concerning the statistical analysis of the data which follows is divided into four major sections. The first section provides a description of the primary wire rope data groups that were considered. The second section includes a summary of analysis activities on the Ontario Special Rope Test data for retired ropes from the field. The third section focuses on the analysis of data for the Routine Rope Tests (on conveyance-end cutoffs) demanded by Canadian mining regulations, while the last section is devoted to analyses completed on the axial and bend-over-sheave laboratory fatigue data. In each section, pertinent performance trends

and the influence of operating parameters on rope strength and life are presented.

Primary Wire Rope Data Groups

As mentioned earlier the wire rope data included in this analysis were from the field and from the laboratory. As shown in Table 1, the field data consisted of "Special Rope Tests" from Ontario and "Routine Rope Tests" from Ontario and the Provinces of Newfoundland and Manitoba.

The Special Rope Tests represent comprehensive tests on retired hoist ropes. Each retired rope had been sectioned in from 2 to 30 different locations to characterize and destructively evaluate the condition of the overall rope. There are 359 ropes represented in the current Special Rope Test data base. Over 5,500 individual tests were completed on these ropes. The detailed data from 1,670 of these rope tests were selected for this analysis. Data from the maximum- and minimum-strength sites were recorded for all 359 ropes, while data for 952 other sites displaying at least 5% strength loss were also included.

The Special Rope Test data came from 67 different mining companies and 96 different mines. As shown in Table 2, the distribution of ropes was quite widespread, with an average of less than 6 ropes per mine for the most-represented 7 companies. In most cases, the ropes from a given mine were from several different compartments. The most ropes recorded from a single compartment of a single mine over the 35-year Special Rope Test history is 4. This fact precluded a hoped-for analysis of the variability in rope performance for nominally identical operating and environmental conditions.

In comparison, the Routine Rope Test data represent periodic tests on sections cut from the conveyance end of hoist ropes. Each rope is cut off at regular intervals (usually 6 months) and the results of the test may dictate rope removal. There are 1,010 ropes represented in the present Routine Rope Test data base. Over 2,950 cutoff tests were completed on these ropes, indicating an average of almost 3 cutoffs/rope during the service life of these ropes. Over 3,800 nondestructive tests were completed on this same collection of ropes. All of the destructive and nondestructive inspection data recorded for the last cutoff before rope retirement were selected for analysis. Previous satisfactory breaking-strength and nondestructive inspection test results were not encoded.

The Routine Rope Test data came from 57 different mining companies and 113 different mines. Approximately, one third of the companies and mines represented in the Routine Rope Test data base were also represented in the Special Rope Test data base. As shown in Table 3, the distribution of ropes comprising the Routine Rope Test data base was also quite widespread, with an average of less than 14 ropes per mine for the 6 most-represented companies.

TABLE 1. PRIMARY WIRE ROPE DATA GROUPS

General Category	Specific Category	Description	Major Sources
Field	Special	Detailed examinations of retired service ropes, including multiple breaking strength tests and wire evaluations.	Ontario
	Routine	Periodic in-service examinations based on breaking strength tests of cutoffs and NDI tests on the complete rope.	Ontario Newfoundland Manitoba
Laboratory	Axial	Constant-amplitude cyclic load fatigue tests.	Bethlehem Steel Company (5)* U.S. Steel (1) Univ. of Pittsburgh (1) Catholic University (2)
	Bend-Over-Sheave	Constant-load bending fatigue tests.	U.S. Navy (20) University of Alabama (2) Southwest Research (1) Battelle (5) OIPEEC (4) ACCO (1)

*Number of Separate References.

TABLE 2. SPECIAL ROPE TEST DATA SOURCES

Company No.	No. of Mines	No. of Ropes	% of Total
6	7	68	18.9
18	9	36	10.0
5	3	16	4.5
15	4	15	4.2
27	1	11	3.1
32	3	11	3.1
29	<u>1</u>	<u>10</u>	<u>2.8</u>
	29	167	46.6%

TABLE 3. ROUTINE ROPE TEST DATA SOURCES

Company No.	No. of Mines	No. of Ropes	% of Total
6	13	165	16.3
65	2	77	7.6
18	9	72	7.1
32	5	65	6.4
--*	4	48	4.8
61	<u>3</u>	<u>42</u>	<u>4.2</u>
	36	469	46.4%

*Not represented in Special Rope Test data base.

The laboratory axial fatigue tests included in the present study were restricted to constant amplitude, cyclic tension tests on wire rope and strand. A total of 778 axial fatigue tests are represented in the data base. Of this number, 128 experiments involved dual failure criteria, so that a total of 906 axial fatigue test results are included.

The laboratory bend-over-sheave fatigue tests included in the present study were restricted to constant-load experiments on wire ropes whose construction represents some potential application in mine hoisting. A total of 4,003 bend-over-sheave fatigue tests are represented in the data base. Of this number, 505 experiments involved dual failure criteria, so that a total of 4,508 bend-over-sheave fatigue test results are included in the data collection.

Analyses completed on each of the four major categories of data are reviewed in the following sections. The Special Rope Test data, which is the most important data collection in terms of its direct bearing on hoist-rope performance, is addressed first, and in the most detail. The Routine Rope Test data analysis results are presented next, followed by a review of selected analyses completed on the laboratory data collections.

ANALYSIS OF SPECIAL ROPE TEST DATA BASE

The Special Rope Test analysis centered around two major questions.

- (1) What operating conditions promote long service life with the least loss in rope strength?
- (2) What measurable, nondestructive quantities are meaningful indicators of remaining rope strength?

The first question has received the most attention in previous analyses. As Table 4 summarizes, there have been two serious attempts to review these data in the past few years. The work done by Benson is summarized in a recently published Bureau of Mines Report (18). The primary focus of this study was on the accuracy of the electromagnetic (EM) nondestructive*

*NDI methods for rope inspection entered in the Ontario Special Rope Test and Routine Rope Test data records are carried out with an electro magnetic (EM) test device that scans the rope to indicate areas of "loss of strength".

strength estimates that were recorded just prior to retirement for about half of the Special Ropes. Similarly, the work of Aimone (19) has also centered on the accuracy of the EM nondestructive inspection results. The current study is much more broad-based than either of the previous investigations. This study includes almost three times the number of records for significantly degraded rope samples as were included in Benson's analysis, and almost eight times the number of records examined in Aimone's analysis. All of the variables directly measured in the Ontario

TABLE 4. SUMMARY OF PREVIOUS ANALYSES OF ONTARIO DATA

Analysis by Midwest Research Institute (David Benson)

- 336 hoist records examined (from 1947-1974)
- Examined only maximum and minimum strength test sections
- Performed selected F and T tests
 - Discriminant analyses
 - Correlation analyses
- Did not perform
 - Regression analyses
 - AID analyses
- Focused primarily on accuracy of electromagnetic (EM) NDI strength estimates

Analysis by Heath and Sherwood (Peter Aimone)

- 132 hoist rope records examined (from 1961-1980)
 - Examined only minimum strength test sections
 - Focused only on accuracy of EM test strength estimates
 - Performed no computer analyses
-

Special Rope Tests (over 60 in number) have been assessed to determine their relative importance to rope strength and service life. In addition to the directly measured variables, more than 25 derived variables were also assessed. The current study also included an examination of the influence of specific mining company practices on rope performance.

Several advanced statistical analysis packages were used in analyzing the Special Rope Test collection. Specifically, the AID program was used to highlight important variables and interactions between variables, while the SPSS package was used to complete a stepwise discriminant analysis of the data and to develop trial predictions of rope strength and service life. Both of these analysis packages are reviewed in more detail at the pertinent location in the analysis summary which follows.

Identification and Preliminary Assessment of Dependent and Independent Variables

There are several direct and derived variables that can be considered as dependent variables in terms of hoist rope performance. Certainly, rope remaining strength is the key dependent variable, since it is the integrity of the rope upon which the overall hoisting system safety depends. Besides remaining strength, however, the service life of the rope, either in terms of hoisting cycles or time is also an important dependent variable. All three dependent variables were examined in the analyses described in the balance of this report.

There are a large number of independent variables that can influence the dependent variables described above. More than 60 direct independent variables were encoded from the original Special Rope Test records. Appendix A provides a detailed breakdown of the direct variables and their descriptions. Examples of some of these direct independent variables are tonnage hoisted, rope speed, mine water pH, corrosion rating and core lubrication percentage.

In addition to the direct variables, more than 25 other variables were derived from available information. For example, hoisting cycles were computed by dividing the tonnage hoisted by the live load, rope diameter reduction was determined by comparing new and used rope diameters, and minimum dynamic design factors were calculated by the appropriate combination of various factors such as acceleration time, maximum skip/cage velocity, live and dead load and rope weight. Other commonly considered factors, such as bearing pressure ratio and wire strength were also estimated from available information. The important derived variables used in the AID analyses are specifically defined later in this report.

In order to characterize and validate the overall collection of independent and dependent variables, each variable was examined individually. The distribution of values for each variable was examined so that outliers might be examined for correctness.

One of the first important tasks was the identification of the distribution of remaining strength values. Figure 5 shows the cumulative distribution of remaining strength values from the majority of rope samples

in the overall Special Rope collection. Several important factors are apparent. First, there is a large number of significantly degraded ropes in the collection. Roughly 10% of the samples show over 15% strength loss, while more than 2% of the samples (roughly 100 cases) show over 30% strength loss. Second, the percentage of cases showing little or no strength loss is quite high (greater than 70%).

These two factors taken together simply illustrate the importance of the present study. There are some sections of hoist ropes in service that are severely degraded; therefore, there must be criteria developed that will ensure the identification of these rope sections and the retirement of the rope before catastrophic failure occurs. At the same time, most hoist ropes see little strength loss after extensive service and there is the significant possibility that a number of ropes are retired well before they would have to be simply because the retirement criteria (the signs of rope strength loss) are not precisely defined. It was an expectation going into this study that specific criteria could be defined which would relate with high confidence to rope strength loss.

The distribution of service times and operating cycles were also examined, as shown in Figure 6. Note that service times tend to be log-normally distributed and range from roughly $\frac{1}{2}$ -year to 6 or 7 years, with an average of about 2 years. Service cycles also tend to be log-normally distributed (except for the extreme upper tail), with values ranging from roughly 20,000 cycles to over 500,000 cycles, and they show an average of about 50,000 cycles. Certainly all three dependent variables showed wide ranging, clearly definable variability, which was an encouraging sign in terms of the likelihood of success of any subsequent statistical analysis. The problems associated with sorting out the factors which cause rope strength loss or reduce rope life were not taken lightly, however, since it was readily apparent, as shown in Figures 7 and 8 that there was no clearly discernable relationship between strength loss and hoisting cycles (as one would expect in a well-controlled laboratory test program).

In the preliminary assessment of the various independent variables it was possible not only to identify encoding errors, but it was also possible to identify some very interesting and potentially significant distributions of measured and observed rope and system variables. For example, the distribution of outer wire torsion values (on used rope wire samples), shown in Figure 9, revealed a fairly large variability ranging from 1 to over 50, suggesting substantial damage to at least some of the wires taken from retired ropes. Similarly, the distribution of elongation results for new and retired rope samples showed a significant effect of service (Figure 10). The distribution of retired rope diameters relative to new rope diameters showed substantial diameter reductions (of greater than 3%) for over 50% of the significantly degraded rope samples (Figure 11).

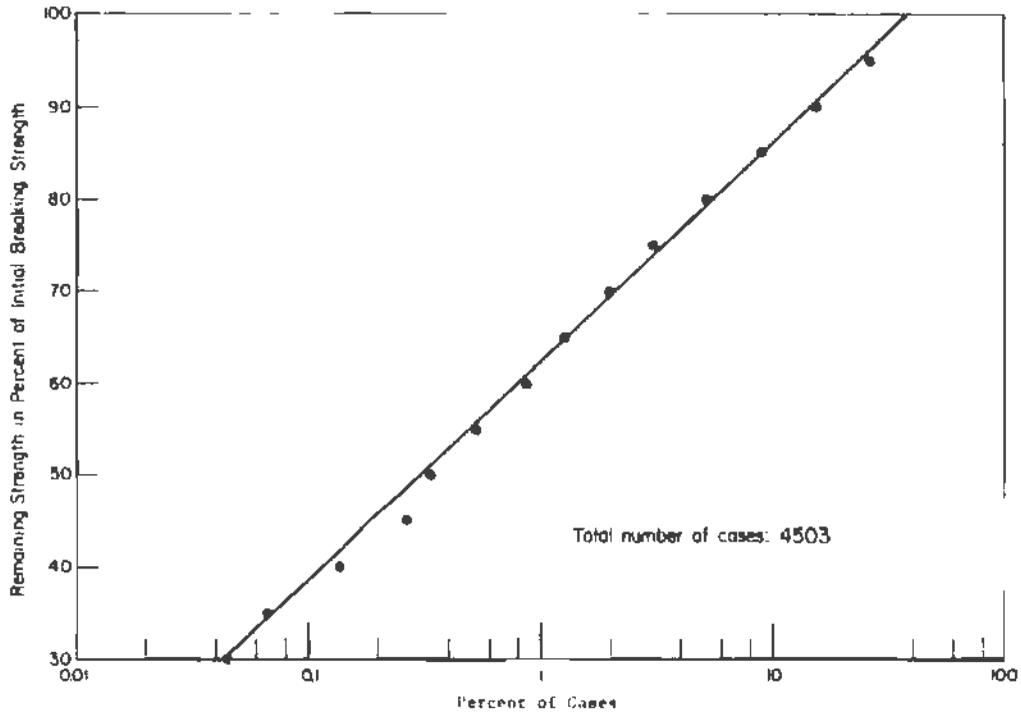


FIGURE 5. Remaining strength as a percentage of initial breaking strength based on the collection of 4503 Ontario Special Rope Tests.

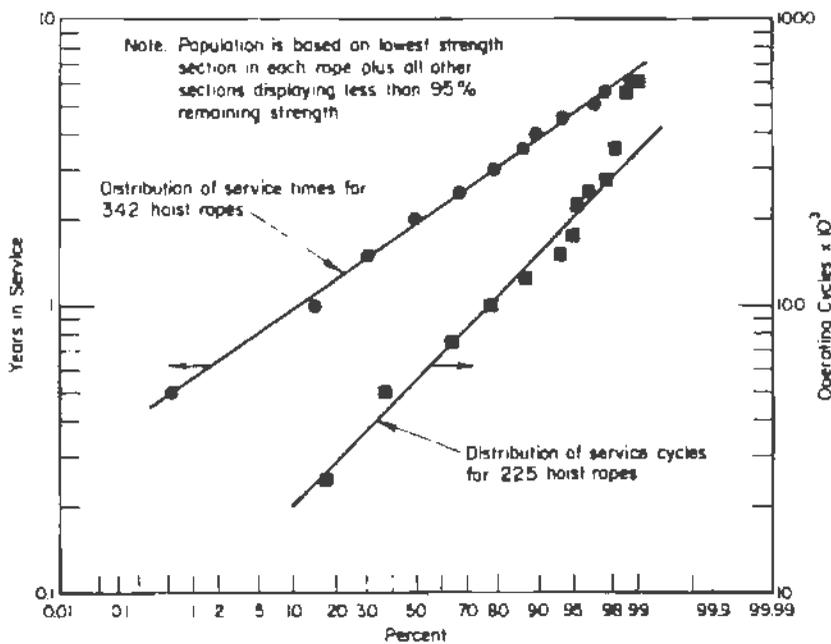


FIGURE 6. Distribution of service times and operating cycles reported in Ontario Special Rope Test data.

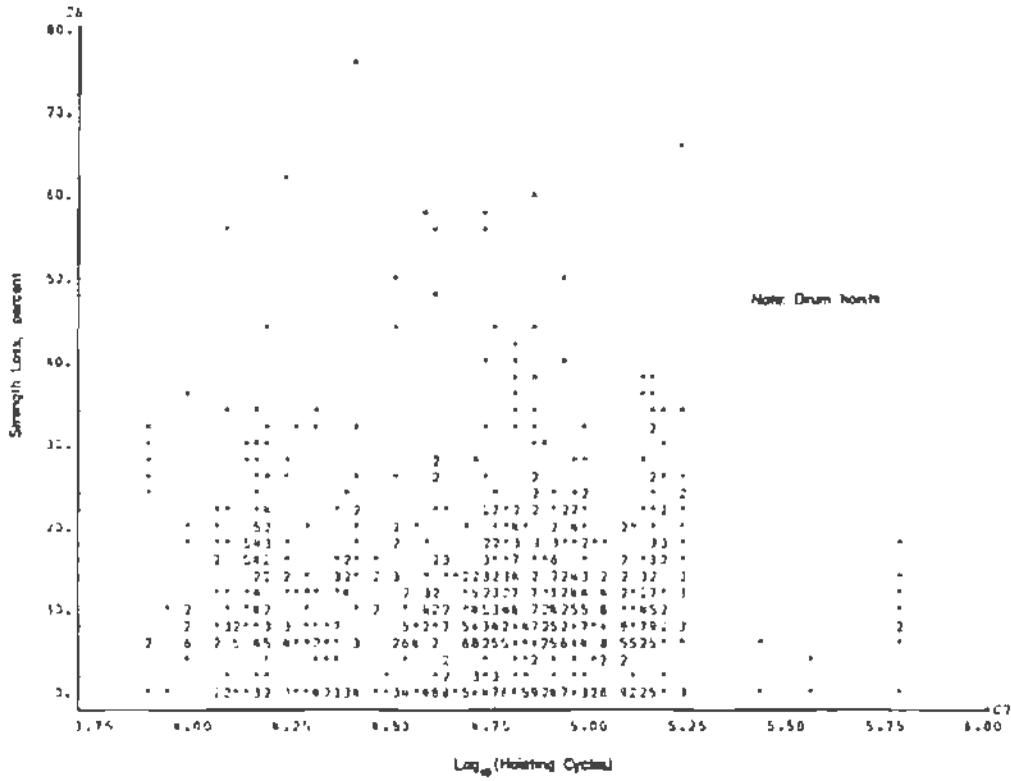


FIGURE 7. Rope strength loss as a function of hoisting cycles for drum-hoist systems reported in Ontario Special Rope Tests.

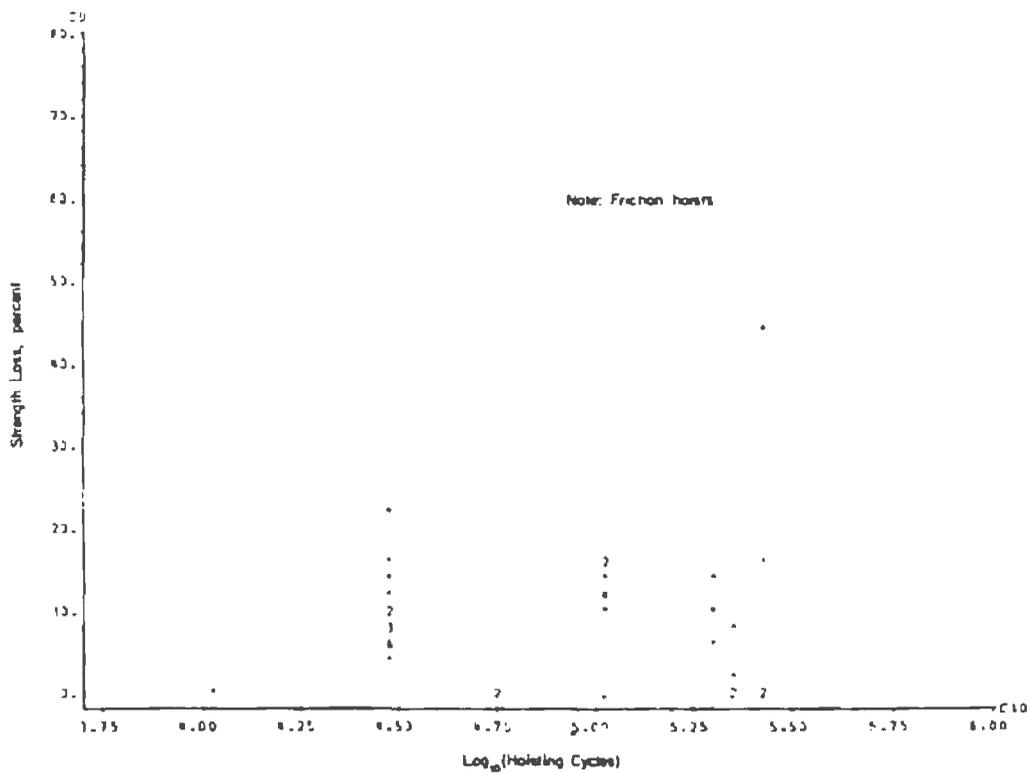


FIGURE 8. Rope strength loss as a function of hoisting cycles for friction-hoist systems reported in Ontario Special Rope Tests.

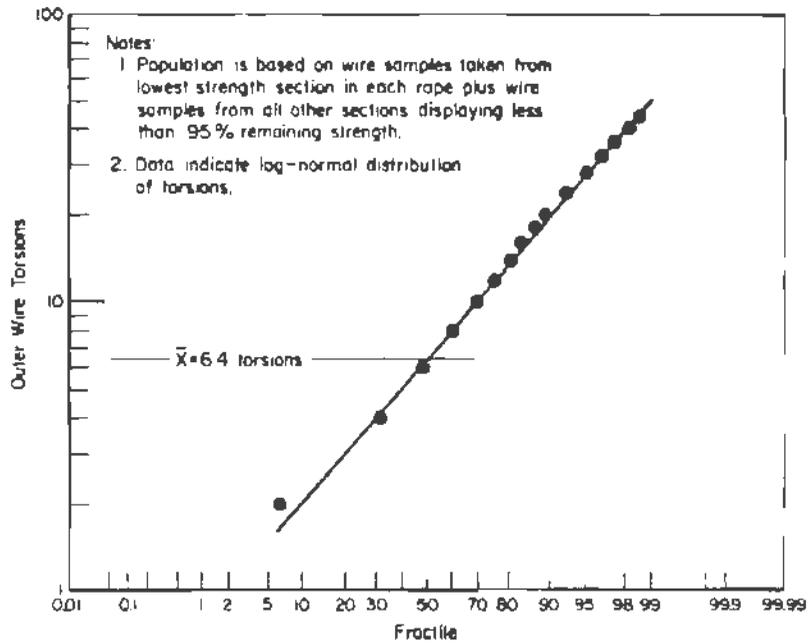


FIGURE 9. Distribution of outer wire torsion values from 1236 Ontario Special Rope Test samples.

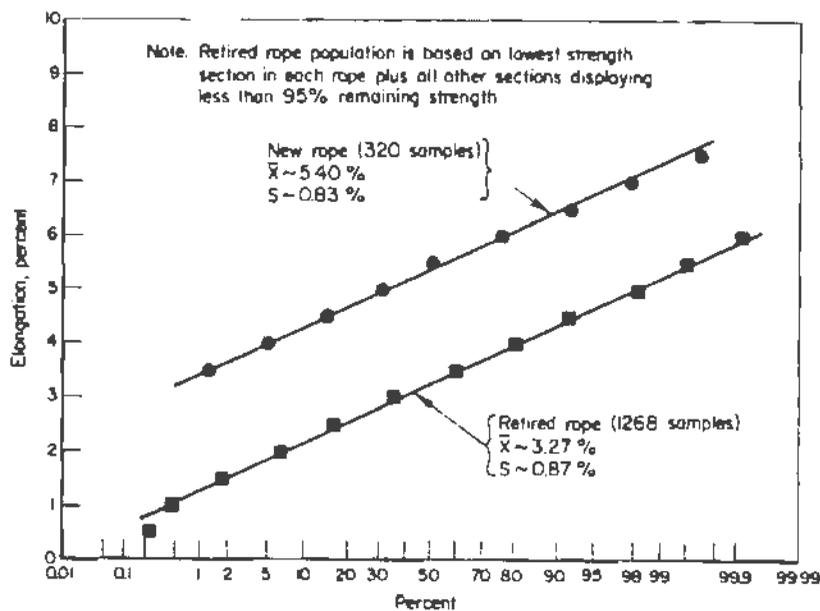


FIGURE 10. Distribution of elongation results for the new and retired Ontario Special Rope Test samples.

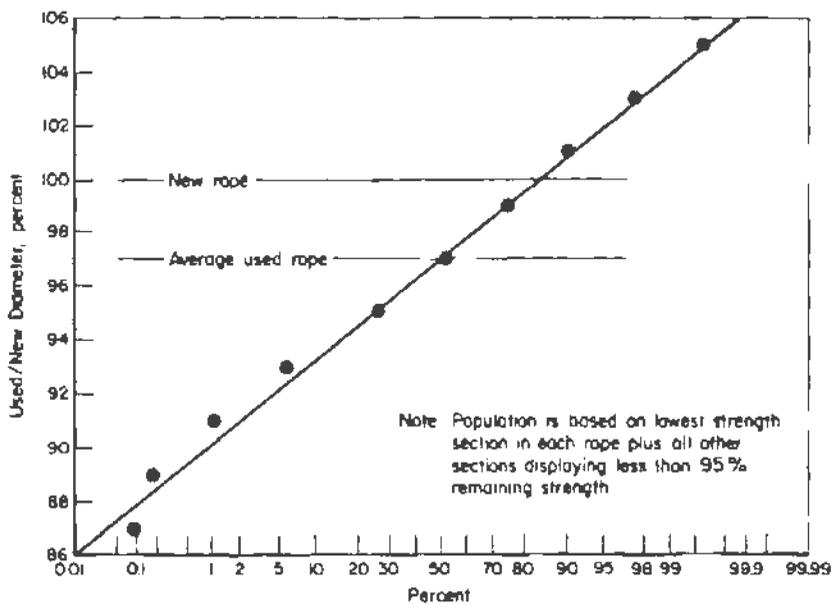


FIGURE 11. Distribution of retired rope diameters relative to new rope diameter reported in Ontario Special Rope Tests.

An examination of some of the hoisting system variables was also quite revealing. For example, Figure 12 shows a histogram of mine shaft depths in the Special Rope Test data collection. Although Ontario now has vertical-shaft mines as deep as 8,000 ft, the data for Special Rope Tests treated in this program for vertical shafts, ranged from less than 500 feet to nearly 5,000 feet, with mines roughly 3,000 feet deep being most common. Some of the small number of slope shafts represented in the collection of Special Ropes were quite long--7,500 to 8,500 feet. Very long or deep shafts such as those represented in this collection, highlight the importance of rope strength and weight in satisfactory operation. Figure 13 further highlights the importance of rope weight in these hoist systems. This figure presents load factors for drum-hoist systems, considering first, live loads only, then live plus dead loads, and finally live plus dead loads combined with maximum suspended rope loads. Live loads taken by themselves are quite low in most cases, requiring (on the average) only about 6% of the rope's initial strength to support. Live and dead loads combined are substantially more significant, since they require about 14% of the rope's initial strength to support, on the average, with some cases going as high as 22 to 24 percent. This relates to a rope design (safety) factor of only slightly greater than 4. When rope loads are added to the total conveyance loads, the safety factors are further reduced, with about one half of the cases showing safety factors of less than 5, and about 10% of the cases showing safety factors of less than 4.

After the various dependent and independent variables were examined individually, some preliminary analyses were completed to identify important variable interactions and to facilitate the detailed analyses which would follow. One very important issue to clarify was the exact makeup of the population in terms of rope construction and type of service. Initially, the rope constructions were categorized according to the exact designation on the Special Rope Test records. More than 80 rope constructions resulted as shown in Table A-5 of Appendix A. Many of these rope constructions were virtually identical and, after several iterations, all of the rope constructions were reduced to five basic categories as shown in Table 5. When rope construction was viewed in conjunction with the type of service, some interesting observations could be made (most of which tended to support previously suspected trends). The predominance of drum-hoist systems was quite clear; and in these systems, 6 x 19 classification round strand and 6 x 37 classification flattened strand ropes were used in most cases (and with virtually equal frequency). In about 6% of the drum-hoist systems, locked-coil ropes were used, while in about 3% of the drum-hoist systems, 8-strand or other rotation-resistant constructions were used. Of the 27 friction-hoist systems represented in the Special Rope data collection, most were used with locked-coil ropes, and most of the rest were used with flattened-strand ropes. Only eight tail or balance ropes from friction hoist systems were included in the Special Rope collection. All but one of these was the standard (for this service) rotation-resistant type construction. An assortment of rope constructions were represented in the small (nine ropes) collection of slope-shaft hoist systems.

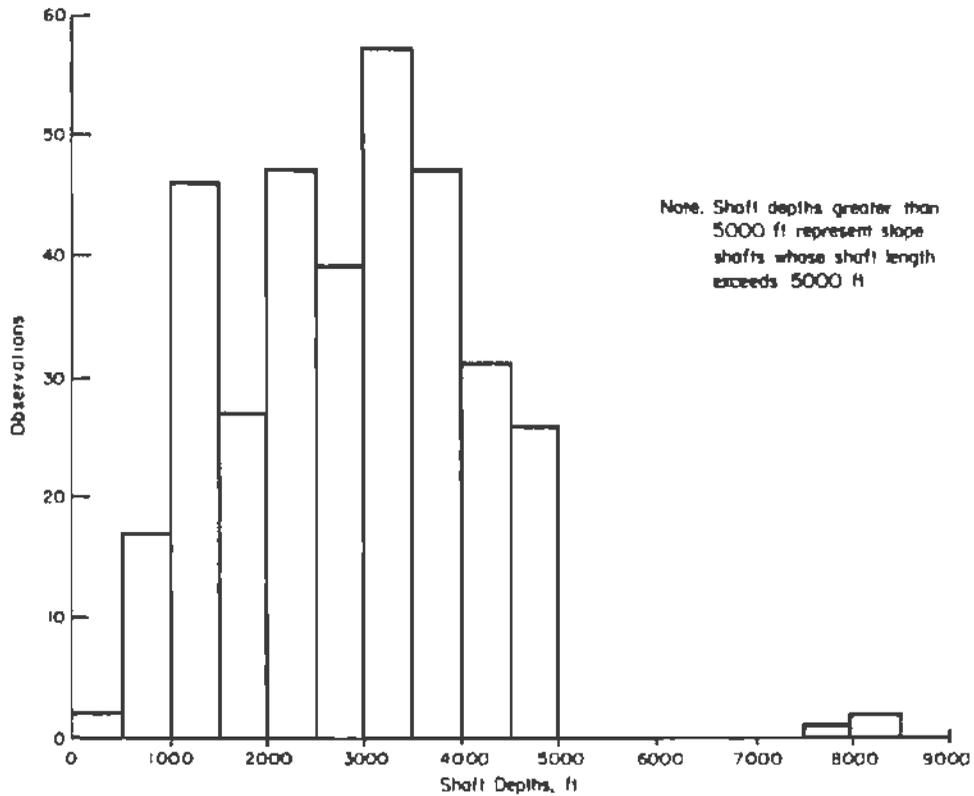


FIGURE 12. Distribution of shaft depths based on 342 Ontario Special Rope Tests

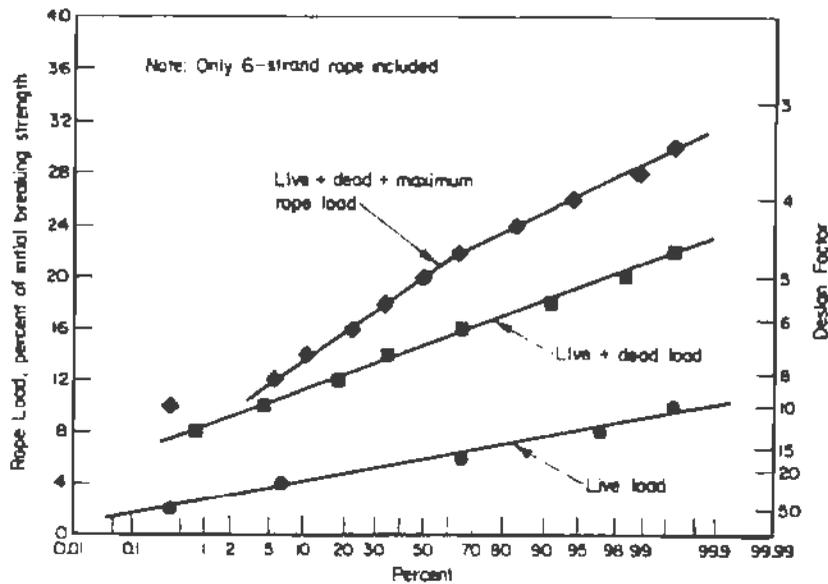


FIGURE 13. Load factors for drum hoists, based on 264 Ontario Special Rope Test records.

TABLE 5. BREAKDOWN OF ONTARIO SPECIAL ROPE TEST DATA BY ROPE CONSTRUCTION AND TYPE OF SERVICE

ROPE CATEGORY	ROPE CONSTRUCTION	TYPE OF SERVICE			
		DRUM HOIST	FRICTION HOIST HEAD	FRICTION HOIST TAIL	SLOPE HOIST
I	6 X 27, 30 FLATTENED STRAND	143	8	0	3
II	6 X 17, 19, 21, 25 ROUND STRAND	144	1	0	2
III	6 X 7 ROUND STRAND	0	0	1	3
IV	LOCKED COIL	18	17	0	0
V	8, 12, 18, 34 STRAND ROTATION RESISTANT	<u>10</u>	<u>1</u>	<u>7</u>	<u>1</u>
		315	27	8	9

Another interesting combination of variables is shown in Figure 14. Approximate service cycles per day are plotted versus years of service for the hoist systems represented in the Ontario Special Rope Test data. Note that diagonal lines plotted on the log-log plot represent lines of constant operating cycles per day. The approximate distribution of data, (as derived from Figure 6), shows that most mines operate at from 50 to 200 operating cycles per day.

A normalized distribution of lowest breaking strength sites is shown in Figure 15. Note that all of the various length ropes have been normalized to a 100% length and the site of greatest damage (strength loss) has been similarly normalized. A large percentage of ropes (15%) showed the most damage near the drum attachment while slightly over half that number showed the most damage near the conveyance attachment. Away from the rope ends, the largest majority of ropes (58%) showed the most rope damage in the lower half of the rope. Less than one third that percentage (18%) showed the most rope damage in the upper half of the rope. This result was quite surprising in that the highest rope loads and stresses that would produce bend-over-sheave or axial fatigue damage are induced in the top half of the rope. This result tended to suggest early in the statistical analysis program, that bending fatigue was not the most important factor in rope degradation. Other factors, such as corrosion, which would tend to be more pronounced at the lower end of the rope, appear to dominate the rope failure process.

Preliminary analysis of corrosion rating did show it to be quite important. Figure 16 shows the cumulative distributions of remaining-strength values for the populations defined only by outer-wire corrosion rating. (See Appendix A for a definition of what specific corrosion ratings mean--regardless, the higher the number, the more severe the condition.) Corrosion ratings of 1, 2, or 3 showed remaining strength distributions that are almost identical. Corrosion ratings of 4, 5, and 6, however, showed successively lower distributions of remaining strength. These results provided clear evidence of the importance of corrosion as an indicator of rope remaining strength.

In contrast to outer-wire corrosion rating, outer-wire lubrication rating was found to be only weakly linked with rope strength loss. Lubrication ratings of 1 through 3 (denoting successively poorer lubrication levels) were indistinguishable in terms of their effect on remaining strength, as shown in Figure 17. Only when a lubrication rating of 4 (denoting a dry condition) was identified, was there a modest increase in the percentage of severely degraded rope samples.

After completion of the review of dependent and independent variables and a preliminary assessment of key variables, it was possible to move into a more sophisticated statistical analysis of the Special Rope Test data.

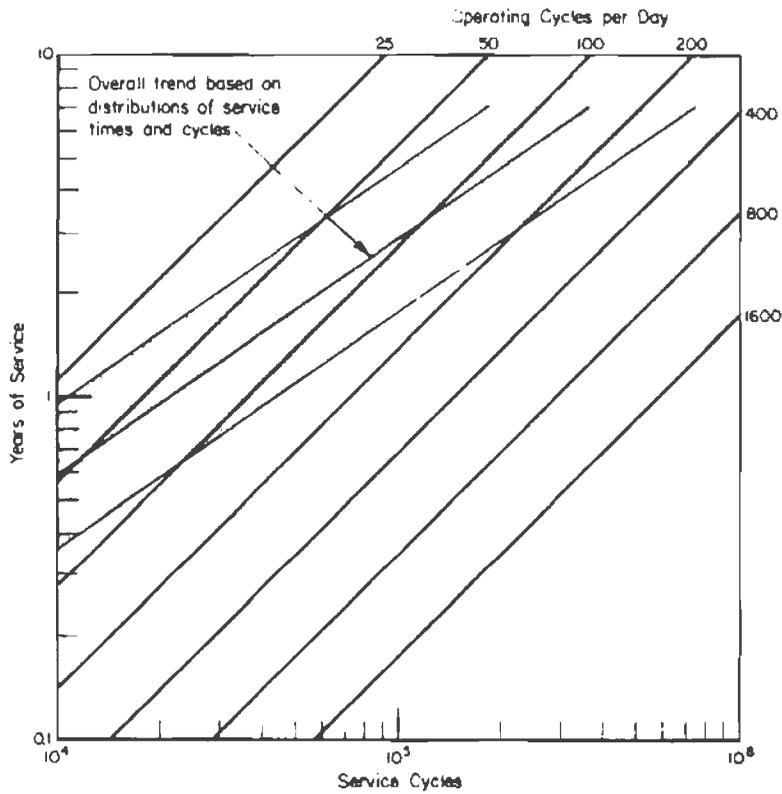


FIGURE 14. Approximate service cycles per day for hoisting systems represented in Ontario Special Rope Test data.

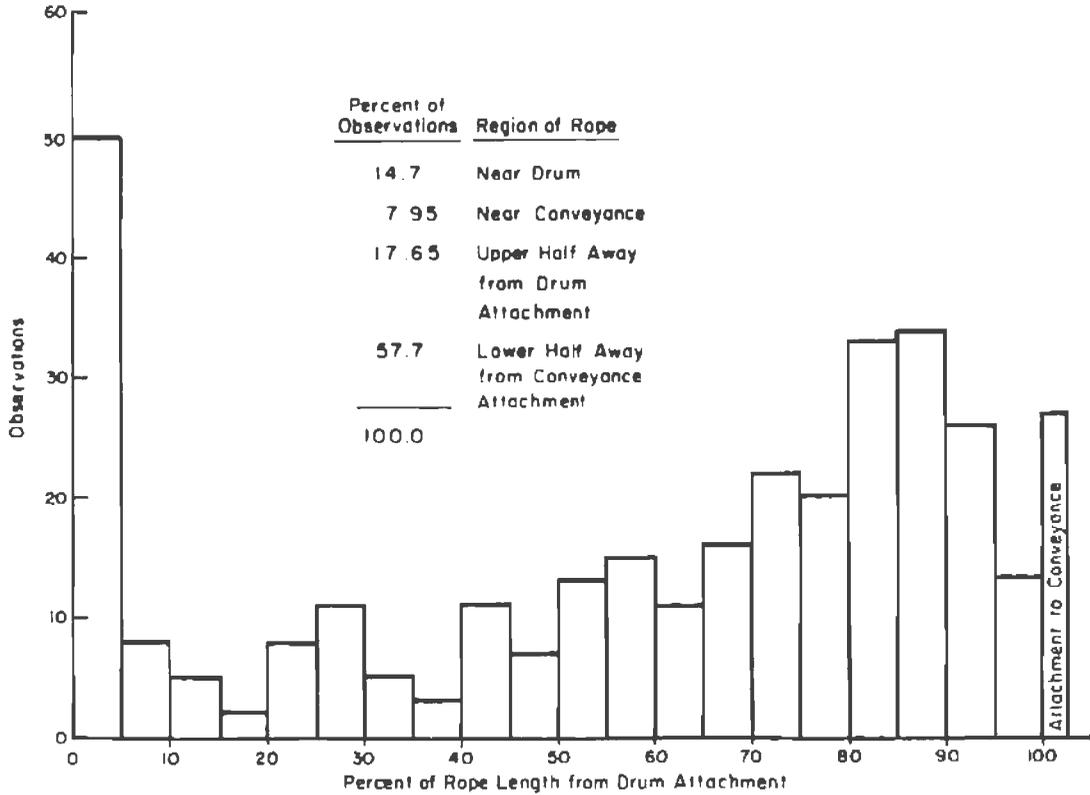


FIGURE 15. Distribution of lowest breaking strength points in 340 Ontario Special Rope Tests.

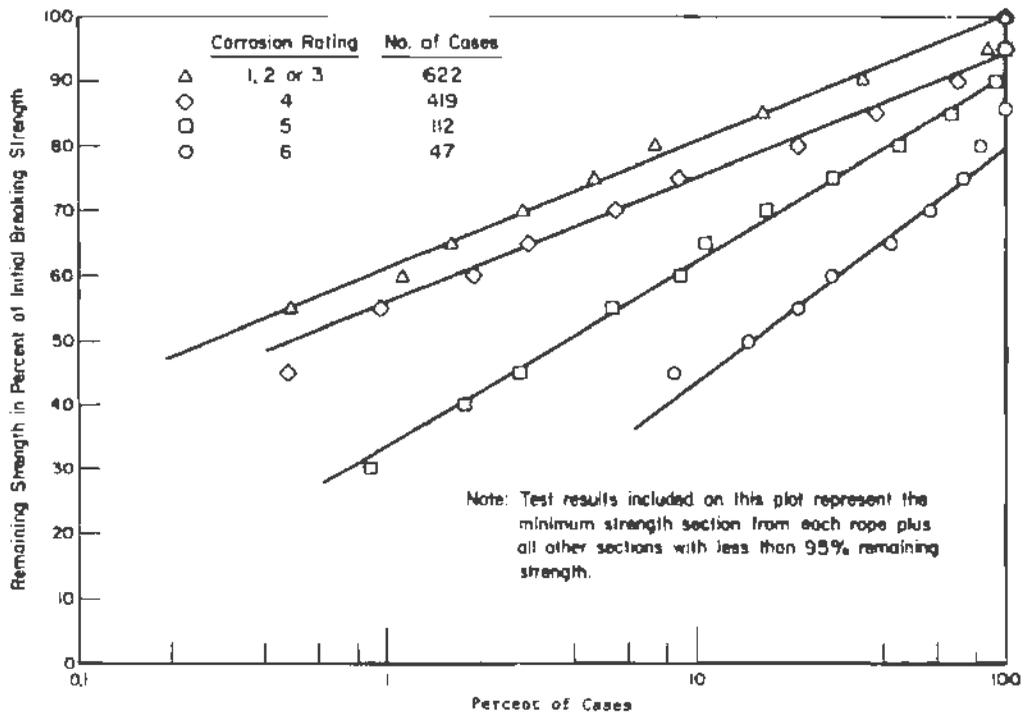


FIGURE 16. Remaining strength associated with a specific corrosion rating as indicated in Ontario Special Rope Test data.

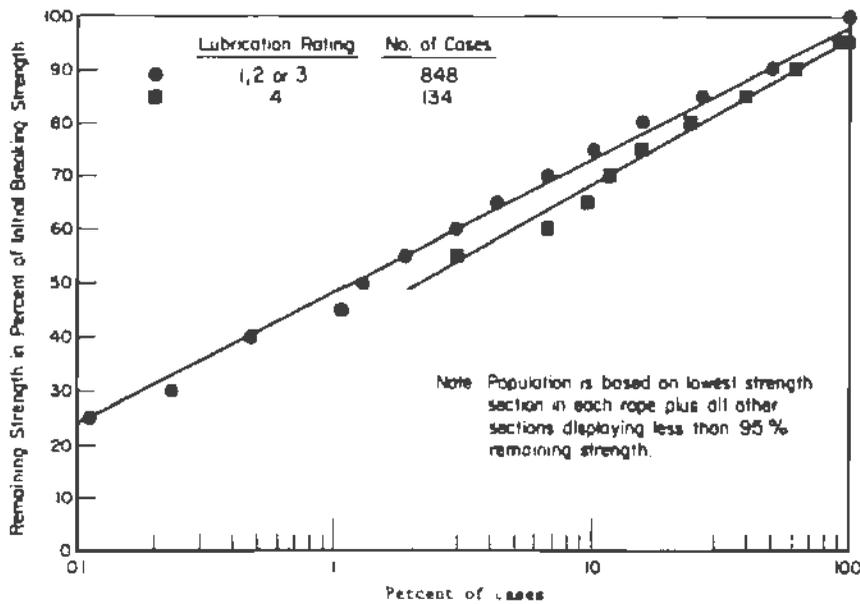


FIGURE 17. Remaining strength associated with a specific lubrication rating as indicated in Ontario Special Rope Test data.

AID Analysis

AID stands for Automatic Interaction Detector. It is a powerful statistical analysis program designed to automatically search out the most important independent variables and interactions between variables. The program generates a graphical display of the analysis results in terms of a hierarchical tree. The structure of the tree allows visual identification of the statistically main effects and interactions (20).

The list of variables used in the AID analysis was quite extensive, as shown in Table 6. This collection of 41 variables was developed from the list of approximately 90 direct and derived variables considered in earlier phases of the program. Note that many of the AID variables were derived variables which essentially represent from 2 to 5 direct variables. No adequately defined independent variables thought to be of any possible significance were excluded from the initial AID analyses. The AID variables fell into four primary categories as follows:

- (1) System-Related Physical Parameters
- (2) Rope-Related Physical Parameters
- (3) Destructive Measures of Rope Degradation
- (4) Observable Nondestructive Measures of Rope Degradation.

The system- and rope-related physical parameters are identified in Table 7 while the destructive and nondestructive measures of rope degradation are shown in Table 8.

The first AID analyses were completed using remaining strength, or more specifically, strength loss as the dependent variable. The result of this analysis is shown in Figure 18. Note that from the initial population of strength losses (approximately 13% average), elongation of the tensile specimen for the retired rope was found to be the most important variable in terms of explaining the overall variability in the data collection. Secondary to this, corrosion rating was found to be of greatest importance. The two subpopulations created by the corrosion rating split were each split further on used rope elongation. Note here that the same variable can be split a number of times if subpopulations are successively better defined by this variable than by other variables. The final split shown in Figure 18 is a split on rope diameter reduction. These graphical results are more precisely defined in Table 9. Note that in each case the splits that are made are intuitively satisfying. The low elongation results are associated with high strength loss, as are the high corrosion rating and the greatest losses in rope diameter.

These trends are seen even more clearly in Figures 19 through 21, where strength loss is plotted as a function of used rope elongation, corrosion rating and rope diameter reduction, respectively. The mean values of the subgroups of each independent variable are plotted along with ± 1 standard deviation variability bands to illustrate the degree of scatter within each subgroup.

TABLE 6. LIST OF VARIABLES USED IN AID ANALYSIS OF
SPECIAL ROPE TEST DATA BASE

Variable Number	Identification	Variable	Definition or Computation Methods
1	Mine Record Number		
2	Diameter Reduction, Percent of Original		$[V38/V2] \cdot 100^*$
3	Rope Type	1 2 3 4 5	Flattened Strand 6 x 19 Class Round Strand 6 x 7 Class Round Strand Locked Coil Rotation Resistant
4	Rope Usage	1 2 3	Drum Hoist Friction Drive Friction Tail/Balance
5	Length of Service, Days		V5
6	Hoisting Cycles		$[V6 \cdot 2000]/V7$
7	Minimum Dynamic Design Factor (Bottom of Shaft, Loaded)		$V27/[V7 \cdot 1000 + V8] \cdot (1 + \text{Skip Acceleration}) + V61 \cdot \text{Rope Weight}$
8	Lubricant	1 2 3 4 5 6 7 8 9 10	2 4 5 7 10 14 16 21 28 68
9	Lubricant Application Method	1 2 3 4	Continuous Drip Spray Hand Brush Box Gland
10	Lubricant Application Interval, Days		V12

*See Appendix A for Variable List.

TABLE 6. (Continued)

Variable Number	Identification	Variable	Definition or Computation Methods
11	Sheave to Rope Diameter Ratio, D/d		$(V14 + V15)/2 \cdot V2$ for Drum Hoist
12	Rope Layers on Drum		V16
13	Chairs	1 2	Yes No or unspecified
14	Shaft Ventilation	1 2	Upcast Downcast
15	Environment	1 2 3	Wet Dry Humid
16	Mine Water pH		V23
17	Loading Operation	1 2 3 4 5 6	One Loading Pocket Three Loading Pockets Two Loading Pockets Loading Pockets at 1900 ft and 3000 ft Two Loading Pockets Plus Car Loading at Lower Levels Twenty Operating Levels
18	Reason for Removal	1 2 3 4 5	EM Results, Old Variable, 25, Nos. 1,2,5 and 8 Broken Wires, Old Variable 25, No. 3 Time, Old Variable 25, No. 4 Too Short, Old Variable 25, No. 6 Damage, Old Variable 25, Nos. 7,9 and 0
19	Initial Outer Wire Torsions		V30
20	Initial Core Lubrication, percent		V31
21	Maximum Skip/Cage Acceleration, ft/sec ²		$V9/(60 \cdot V17)$

TABLE 6. (Continued)

Variable Number	Identification	Variable	Definition or Computation Methods
22	Estimated Wire Strength, psi		$W = V27/(V2)^2$ $W = 2.86$ for flattened strand $= 3.15$ for round strand and rotation resistant $= 1.73$ for locked coil
23	Estimated Bearing Pressure Ratio		$2 \cdot V27/(X \cdot Y \cdot V15 \cdot V2)$ $X =$ Minimum Dynamic Design Factor $Y =$ Estimated Wire Strength
24	Strength Loss, percent of IBS		$100 - (V33/V27) \cdot 100$
25	Predicted Strength Loss, percent of IBS		$100 - V35$
26	Used Rope Elongation, percent		$(V36/V40) \cdot 100$
27	Lubricant in Core after Retirement, percent		V58
28	Increase in Lay Length to Rope Diameter Ratio, percent		$(V59/V60 - 1) \cdot 100$
29	Rope Appearance	1 2 3	Worn Broken Wires Damaged
30	Lubrication Rating, Outer Wires	1 2 3 4	Good Fair Poor Dry
31	Lubrication Character, Outer Wires	1 2 3 4 5 6	Caked Viscous Gummy Dry Gummy, Viscous Gummy, Caked
32	Lubrication Rating, Core		same as 30

TABLE 6. (Continued)

Variable Number	Identification	Variable	Definition or Computation Methods
33	Lubrication Character, Core		same as 31
34	Corrosion Rating, Outer Wires	0	No corrosion
		1	Very slight corrosion
		2	Corrosion scale established
		3	Wire completely scale covered
		4	Surface completely corroded
		5	Same as 4 with loss of cross section
		6	Very severe corrosion
35	Outer Wire Torsions		V55
36	Length of Rope from Drum		(V70/V61)·100
37	Broken Wires		V71
38	Galvanized wire	1	Yes
		2	No
39	Company/Mine Identification	1	5-1
		2	6-1
		3	6-2
		4	6-3
		5	14-1
		6	15-2
		7	18-2
		8	27-1
		9	29-1
		10	32-1
		11	39-1
40	Test Date, year		V81
41	Shaft Type	1	Vertical
		2	Slope

TABLE 7. SYSTEM- AND ROPE-RELATED PHYSICAL PARAMETERS

System Related	Rope Related
Rope Usage	Rope Type
Minimum Dynamic Design Factor	Lubricant Type
Maximum Skip/Cage Acceleration	Initial Outer Wire Torsions
Lubricant Application Method	Initial Core Lubrication
Lubrication Interval	Wire Strength (estimated)
D/d	Galvanizing
Rope Layers on Drum	
Chairs	
Shaft Ventilation and Conditions	
Environment	
Mine Water pH	

TABLE 8. DESTRUCTIVE AND NONDESTRUCTIVE MEASURES OF ROPE DEGRADATION

Destructive Measure	Observable Nondestructive Measures
Actual Breaking Strength	Diameter Reduction
Used Rope Elongation	Length of Service
Core Lubricant Percentage	Hoisting Cycles Along with Bearing Pressure Ratio
Lubrication Rating & Character, Interior Wires & Rope Core	Predicted Strength Loss by EM Test
Outer Wire Torsions	Lay Length/Rope Diameter Ratio Increase
	Rope Appearance
	Lubrication Rating, Outer Wires
	Corrosion Rating, Outer Wires
	Broken Wires

TABLE 9. AID ANALYSIS SUMMARY FOR ROPE STRENGTH LOSS
MIN., MAX., AND < 95 PERCENT REMAINING STRENGTH SITES

Group Split	Subgroup	Variable	Variable Magnitude	Strength Loss, %	N
1	2	Elongation	0 - 2%	39.77	71
	3		> 2%	11.90	1192
3	4	Corrosion	Rating 0-3	8.96	652
	5		Rating 4-6	15.45	540
5	6	Elongation	2.0 - 2.9%	20.28	173
	7		3.0 - 5.9%	13.17	367
4	8	Elongation	2.0 - 2.9%	13.43	130
	9		3.0 - 6.9%	7.85	522
7	10	Rope Diameter, % of Original	< 92%	20.20	74
	11		> 92%	11.39	293
9	12	Rope Diameter, % of Original	< 93%	11.64	104
	13		> 93%	6.90	419

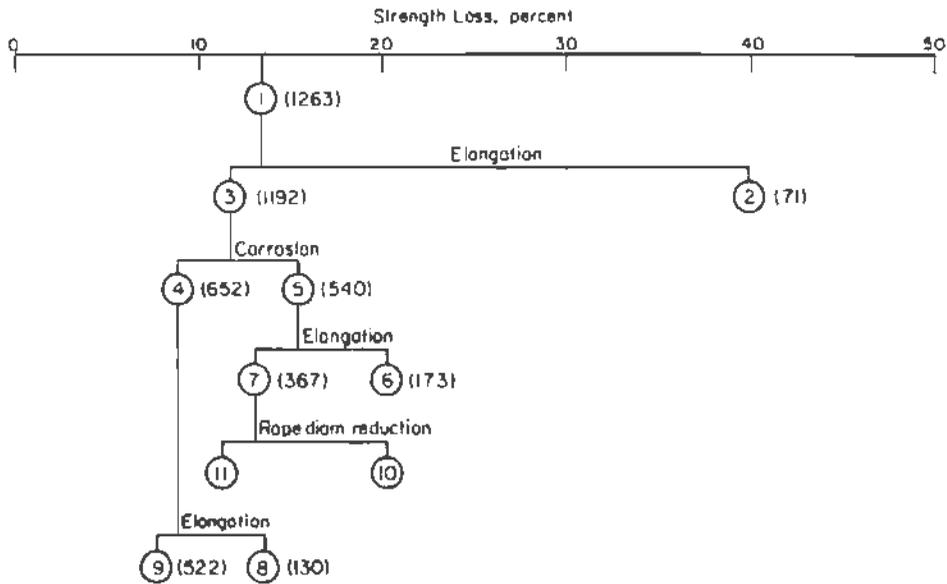


FIGURE 18. AID tree for rope strength loss. All variables included, min, max, and $\pm 95\%$ remaining strength sites included.

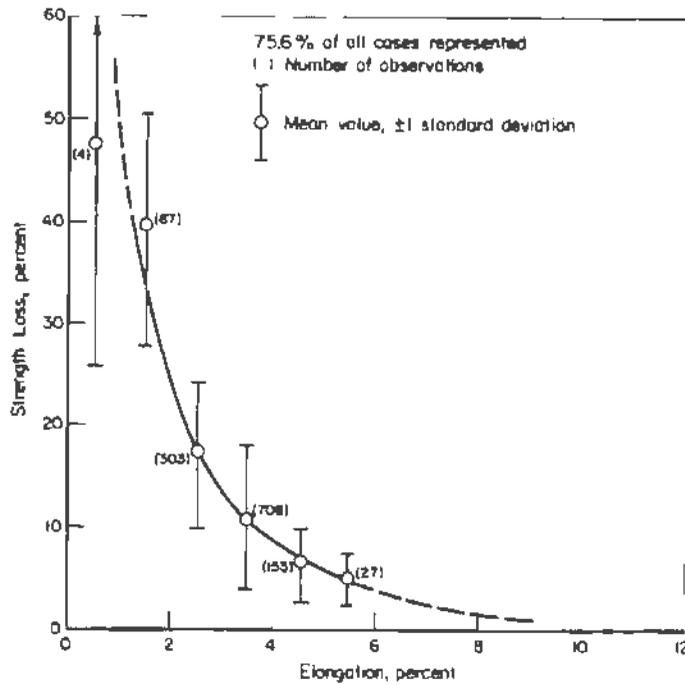


FIGURE 19. Rope strength loss as a function of rope elongation for retired ropes.

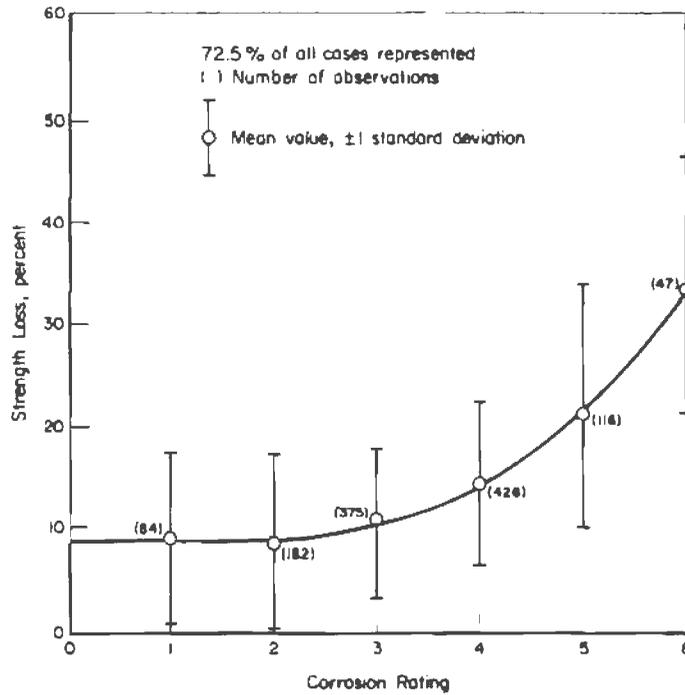


FIGURE 20. Rope strength loss as a function of outer-wire corrosion rating for retired ropes.

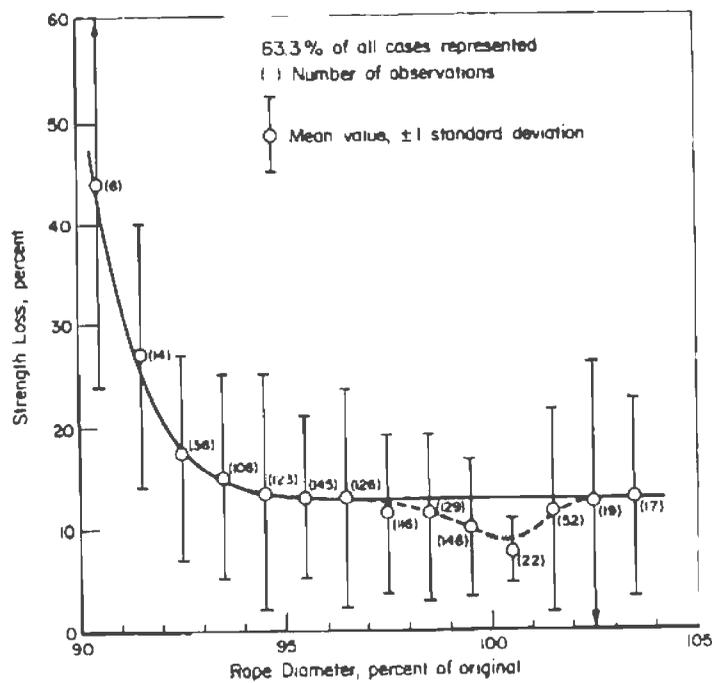


FIGURE 21. Rope strength loss as a function of diameter reduction for retired ropes.

Several independent variables were noticeable in their absence from the AID tree shown earlier in Figure 18. EM-predicted strength loss was the most surprising omission. Despite the presence of the EM nondestructive inspection data base in the current Special Rope data collection, the AID analysis showed at least three other variables to be more closely linked with actual strength loss than was the EM prediction of strength loss. A plot of predicted versus actual strength loss shown in Figure 22, illustrates part of the reason for the relatively poor correlation. First of all, the variability is fairly high and secondly the trends are not particularly consistent between predicted and actual strength loss. It should be noted here, in fairness to current wire rope EM devices, that most of the EM data available for this analysis is more than 15 years old, and it probably reflects the initially poor fidelity of the early model of the device and the vicissitudes of a new and emerging technology. Perhaps a similar study done on more recently inspected and tested ropes would show a much stronger correlation.

Another somewhat surprising result was that distance from the drum did not show itself to be significant. The results previously displayed in Figure 15 seemed to suggest that this variable might be significant. However, the trends shown in Figure 23, illustrate why this variable was not a good predictor of strength loss. Figure 23 may seem inconsistent with the trends shown in Figure 15, but it really is not. If the number of cases are noted within each cell, it is obvious that there were far more sections of rope in the "conveyance" half of the collection of mine hoist ropes that displayed significant strength losses than there were in the "drum" half. Figure 24 shows this trend.

As a second trial case, the AID analysis was rerun, with remaining strength retained as the dependent variable, but all destructive measures of rope degradation (such as used rope elongation) were removed. The results of this analysis are shown in Figure 25. Corrosion rating of the exterior wires appeared as the primary variable in explaining rope strength loss. Rope appearance and rope type were two new independent variables that rose (relatively speaking) in importance, after all destructive measures of rope degradation were removed. Table 10 presents in tabular form the results shown in Figure 25. Again, all results seem reasonable. In the case of rope appearance, the rather general descriptors "worn" or "damaged" showed lower average strength losses than did those ropes with 6 or more broken wires. Rope categories 3 and 5 showed higher strength losses than did the other constructions. This result was not too surprising since almost all Category 3 and 5 ropes were used either as tail/balance ropes or slope-hoist ropes.

Strength loss with respect to some other dependent variables will now be discussed. Even though some of these variables did not show themselves to be particularly good predictors of remaining strength, they do display some underlying relationship with strength loss that are worth noting. For example, an examination of remaining strength as a function of exterior wire lubrication rating shows, as in Figure 26, that there is a modest tendency toward lower strength as the outer wires are more poorly lubricated. This trend is probably a secondary result of the fact that poorly lubricated ropes tend to develop more severe corrosion problems, which can (as shown earlier) greatly reduce rope strength. Interestingly, the correlation between strength loss and the lubrication rating

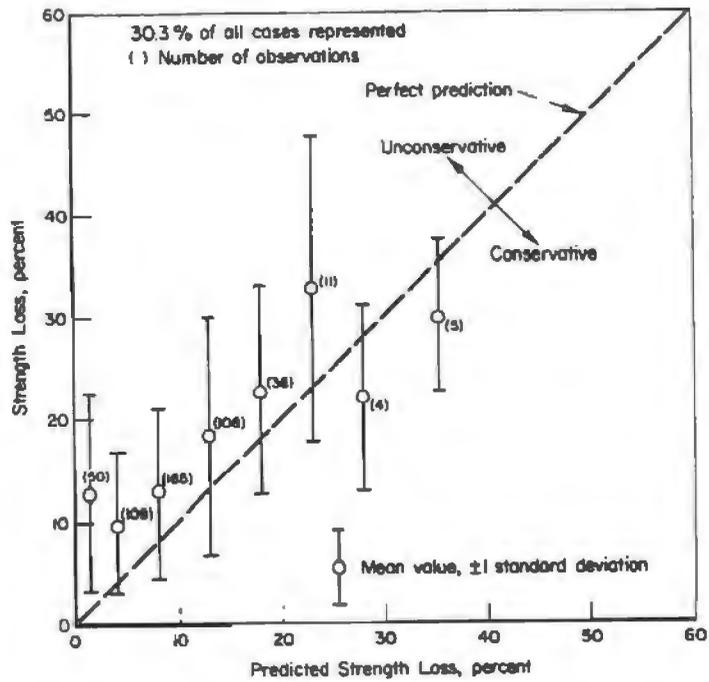


FIGURE 22. Rope strength loss as a function of NDI-predicted strength loss.

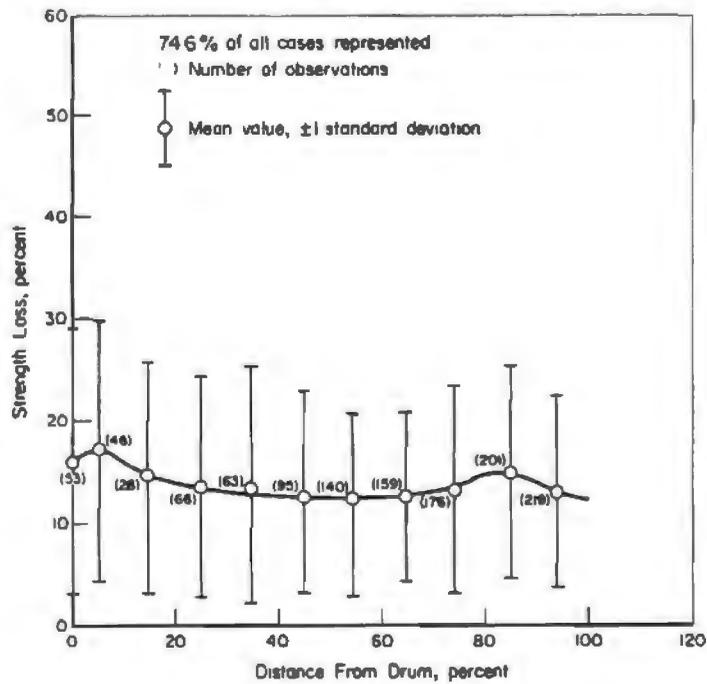


FIGURE 23. Rope strength loss as a function of distance from the drum.

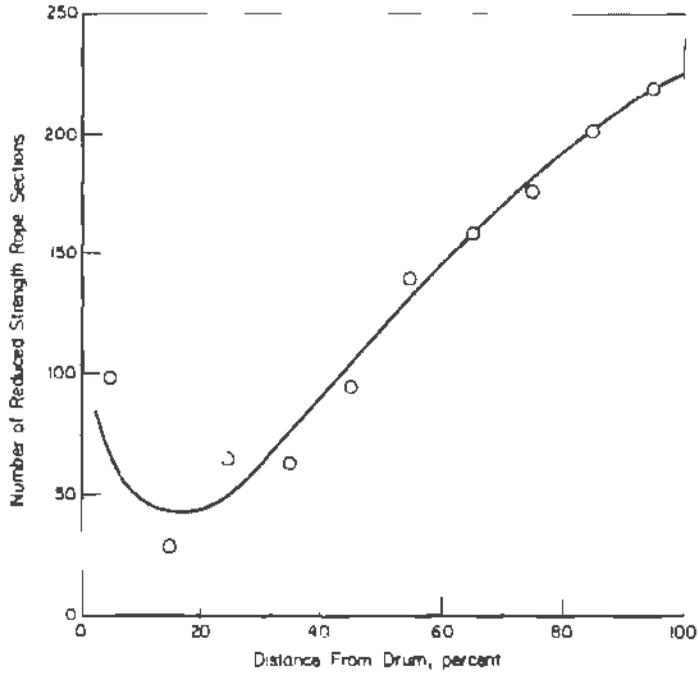


FIGURE 24. Number of reduced strength rope sections as a function of distance from the drum.

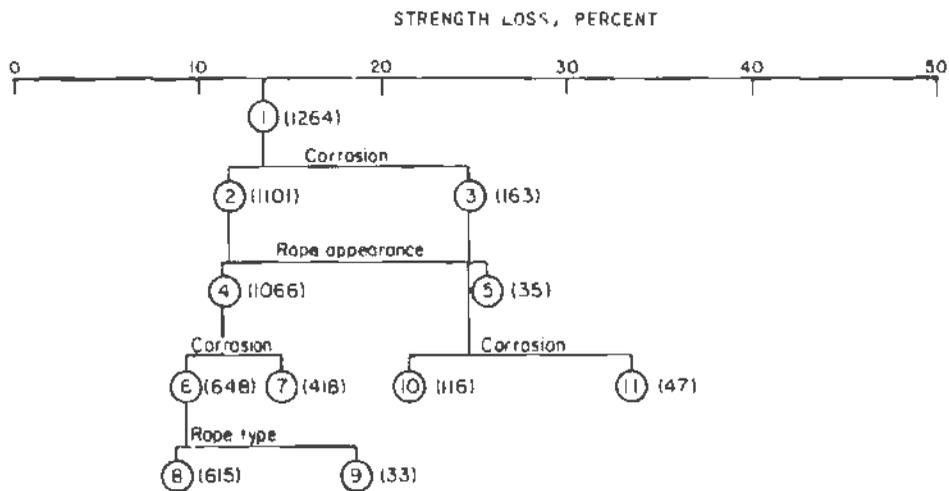


FIGURE 25. AID tree for rope strength loss, destructive variables removed, min, max, and ≤ 95 remaining strength sites included.

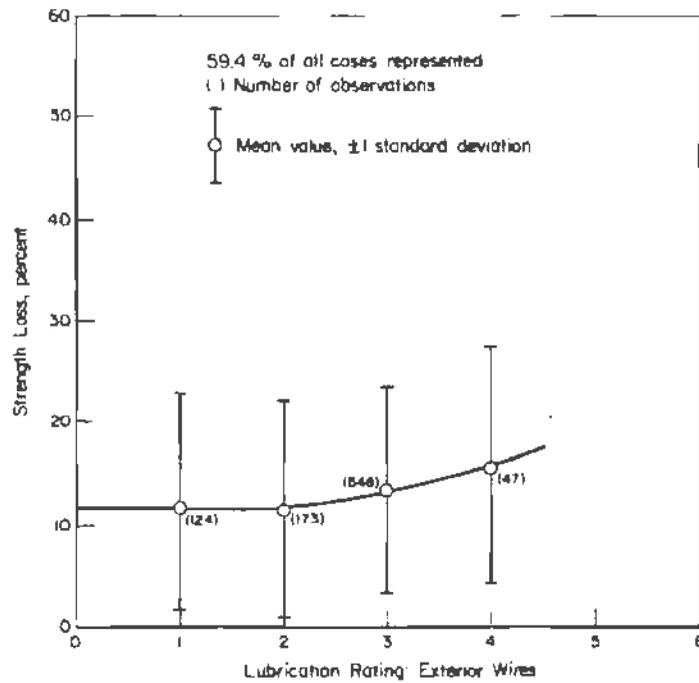


FIGURE 26. Rope strength loss as a function of exterior wire lubrication rating.

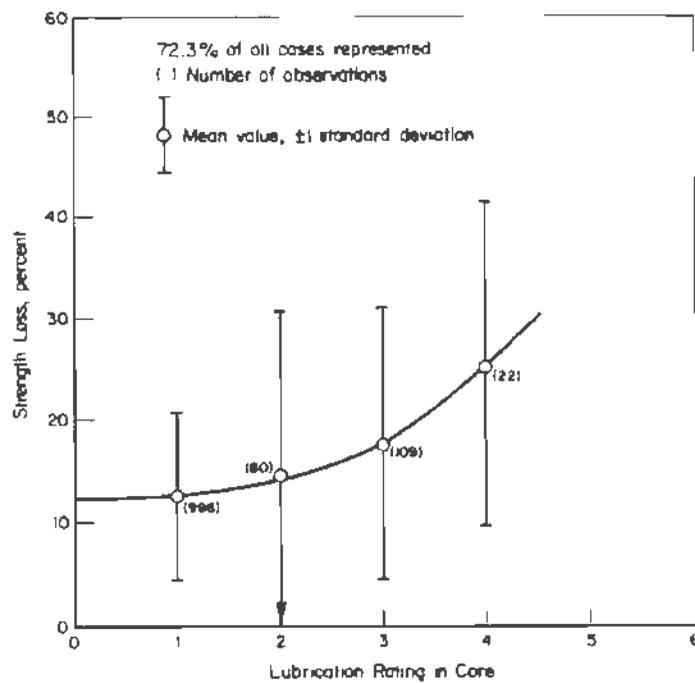


FIGURE 27. Rope strength loss as a function of core lubrication rating.

TABLE 10. AID ANALYSIS SUMMARY FOR ROPE STRENGTH LOSS
 MIN., MAX., AND \pm 95 % REMAINING STRENGTH SITES,
 DESTRUCTIVE TEST VARIABLES OMITTED

Group Split	Subgroup	Variable	Variable Magnitude	Strength Loss, %	N
1	2	Corrosion	Rating 0-4	11.76	1101
	3		Rating 5,6	24.91	163
2	4	Rope Appearance	Worn or damaged	11.32	1066
	5		Broken Wires	25.37	35
4	6	Corrosion	Ratings 0-3	9.36	648
	7		Rating 4	14.35	418
6	8	Rope Type	Categories 1,2,4	8.87	615
	9		Categories 3,5	18.52	33
3	10	Corrosion	Rating 5	21.42	116
	11		Rating 6	33.53	47
7	12	Rope Diameter, Reduction	< 92%	20.18	73
	13		> 92%	13.12	345

of the core is stronger, as shown in Figure 27. This result seems to suggest that the likelihood of significant damage to the rope is greater when the core is dry than when only the outer wires show a lubricant deficiency. This makes sense if indeed the core can no longer support the strands when it becomes dry and friable and/or the core acts as a reservoir of lubricant for the entire rope; thus, when the core of the rope is dry, the balance of the rope is almost surely dry of lubricant as well.

Another interesting relationship is the one between broken wires and remaining strength. Figure 28 shows the general trends that were observed. Unfortunately, the number of cases where a significant number of broken wires was reported was small, with only 38 samples out of 1,670 having more than 4 broken wires reported. Even among those cases, the variability is great, so that it is impossible to establish a clear link between the number of wire breaks and strength loss. There is a probable explanation for the relatively poor correlation. The problem would seem to be that broken wires are not identified as to what type they were or where they came from in the 62-inch-long test piece--they could be cover wires or filler wires, and they could come from only a single strand in a very short length, or they could be widely dispersed throughout the rope sample. Filler wire breaks or widely dispersed cover wire breaks might well produce a negligible strength loss, while 3 or 4 closely associated cover wire breaks in a single strand could lead to a significant strength loss.

A modest influence on strength loss was also identified with increasing rope layers on the drum, as shown in Figure 29. It is not clear whether this trend is caused by increasing rope damage due to crushing or cross-over damage, or whether it is due to the fact that drum systems having greater than 3 layers are used in slope shafts (where abrasion of the rope is the predominate mode of failure) while drums involving only one or two rope layers are used in vertical shafts where corrosion is probably the predominate mode of failure.

Another factor originally thought to be a likely correlate with strength loss that did not show a strong relationship, was the change in the ratio of rope lay length to rope diameter. The trend of rope strength loss as a function of this parameter is shown in Figure 30. There appears to be a modest increase in strength loss with increasing values of this parameter but the increase is almost certainly not significant.

After completing the AID analyses involving strength loss as the dependent variable, two similar AID analyses were completed with hoisting cycles treated as the dependent variable. The first of these analyses was completed including all 41 variables. Only maximum and minimum remaining strength sites were included in the analysis since hoisting cycles obviously did not differ for the various different sections of rope tested from each retired hoist rope. The results of this analysis are shown in Figure 31. Note that the overall population of service lives displayed

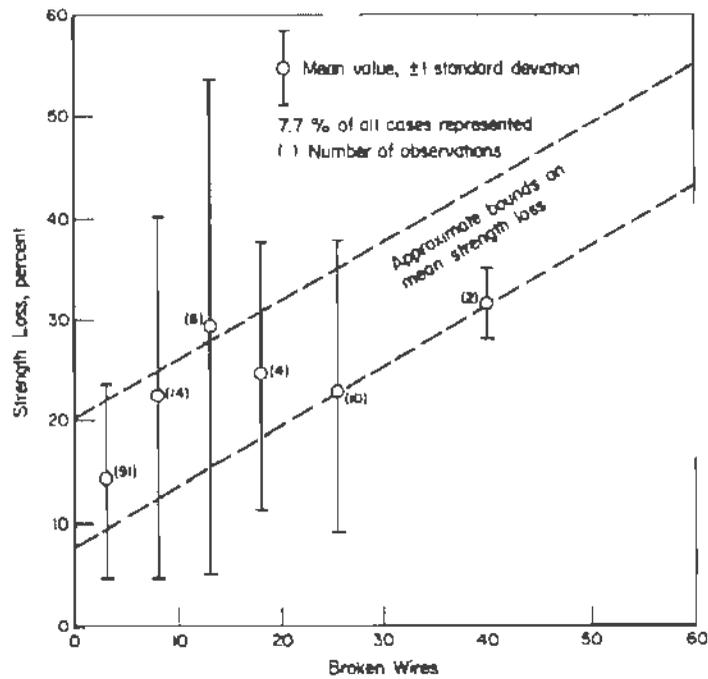


FIGURE 28. Rope strength loss as a function of the number of broken wires in a 60-inch test piece.

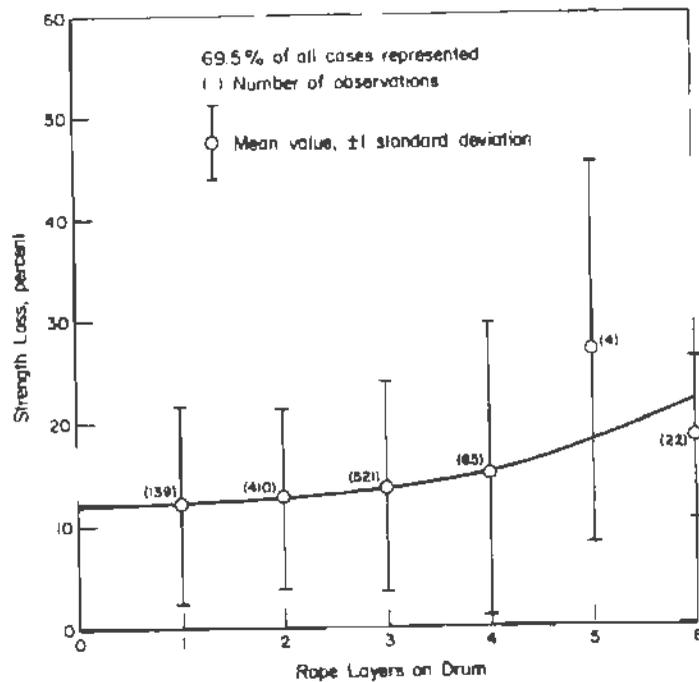


FIGURE 29. Rope strength loss as a function of rope layers on the drum.

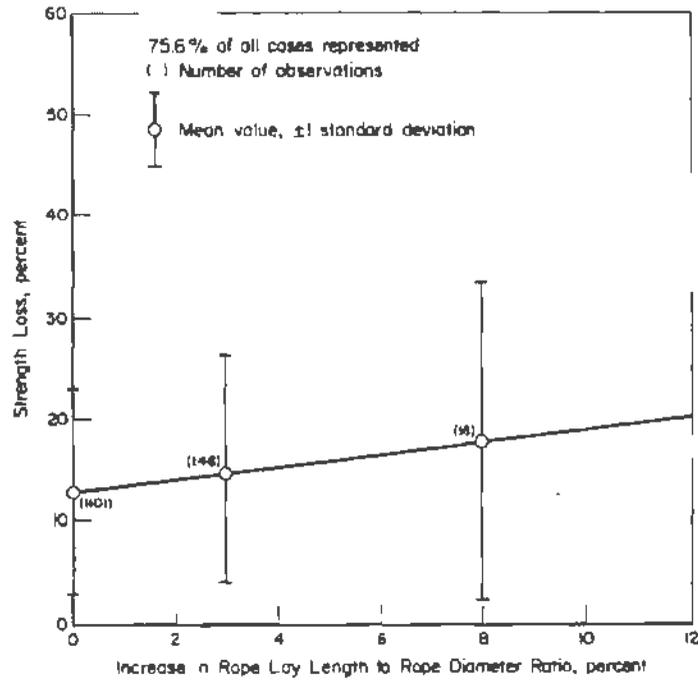


FIGURE 30. Rope strength loss as a function of the increase in the ratio of rope lay length to rope diameter.

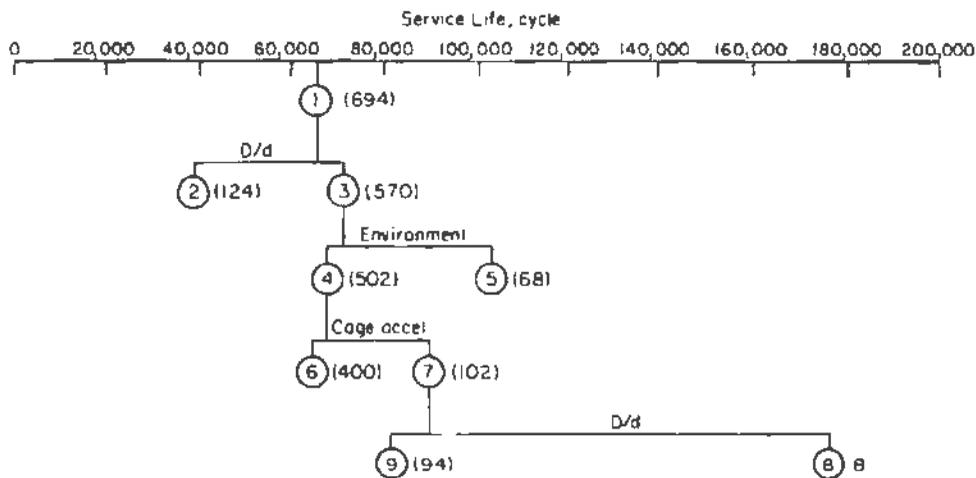


FIGURE 31. AID tree for rope service life, all variables included, maximum and minimum strength sites only.

an average of approximately 65,000 hoisting cycles. The primary variable that was isolated was the drum/sheave*-to-rope diameter (D/d) ratio.

* For these analyses, the diameters of the drum and headsheave were averaged.

Secondary to D/d, a split on service life was made based on differences in environment and skip/cage acceleration. Unfortunately, as shown in Table 11, only the split made based on D/d resulted in logical service life subpopulations.

The split made on environment is somewhat puzzling. A humid environment would seem to promote rapid rope degradation and short service lives, but the opposite trend is indicated. Perhaps in environments known to be hostile the ropes are treated with greater caution in terms of more effective lubrication and, therefore, tend to last longer. An intermediate skip/cage acceleration rate of 2 to 3 ft/sec² is indicated by the analysis to be conducive to long rope life although there is no obvious reason why this should be the case.

The extent of the D/d correlation is shown in Figure 32. Note that even this correlation is not strongly defined. The general trend, as would be expected, is toward longer life with larger D/d's, but there is high variability and some notable (and unexplained) exceptions to these trends.

The average trends in hoisting cycles do not vary with corrosion rating as shown in Figure 33. This result simply suggests that corrosion ratings ranging from 1 to 6 can be found in hoist ropes, regardless of the prior history in terms of operating cycles.

The average trends in hoisting cycles do show a modest correlation with the lubrication rating of the core and exterior wires as shown in Figure 34. The conclusion would seem to be that ropes used for extended periods of time tend to become depleted of lubricant.

The link between initial core lubrication and hoist rope service life is shown in Figure 35. Note that very low initial core lubrication percentages tend to be linked with short rope service lives, which supports the common belief that a well lubricated core is conducive to long rope life.

There is also a significant correlation between hoisting cycles and rope layers on the drum, as shown in Figure 36. Not surprisingly, the single-layer drum systems are related to longest rope life while the multiple-layer drum systems tend to produce shorter lives with increasing numbers of rope layers.

TABLE 11. AID ANALYSIS SUMMARY FOR ROPE SERVICE LIFE,
MIN. AND MAX. REMAINING STRENGTH SITES ONLY

Group Split	Subgroup	Variable	Variable Magnitude	Service Life	N
1	2	D/d	< 70	39,035	570
	3		> 70	71,377	124
3	4	Environment	Wet or Dry	67,077	502
	5		Humid	103,129	68
4	7	Max Cage/Skip Acceleration	2.1-3.0 ft/sec ²	90,531	102
	6		≤2.0,>3.0 ft/sec ²	61,096	400
7	8	D/d	70 - 74	178,370	8
	9		> 75	83,055	94

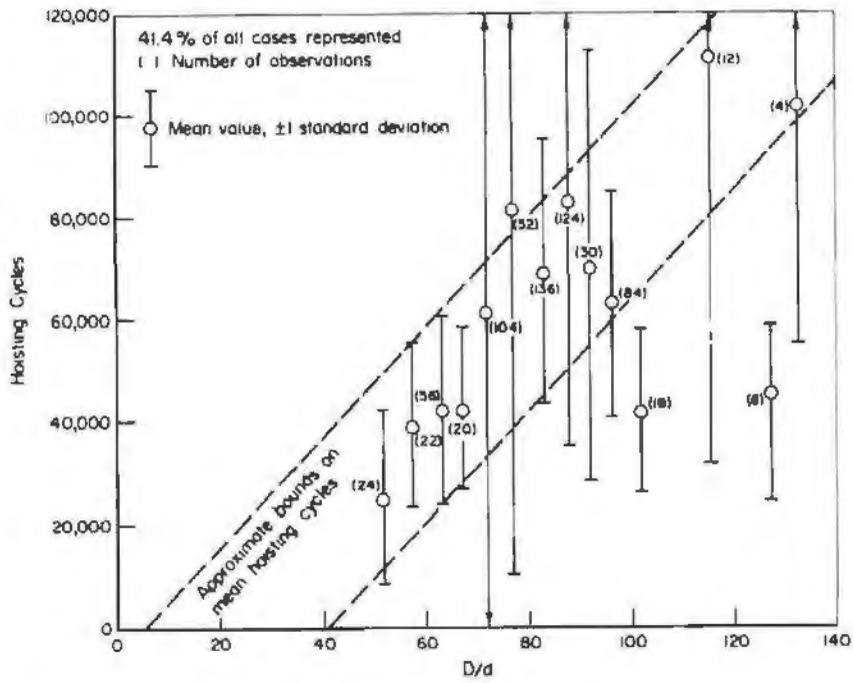


FIGURE 32. Hoisting cycles as a function of drum-to-rope diameter ratio.

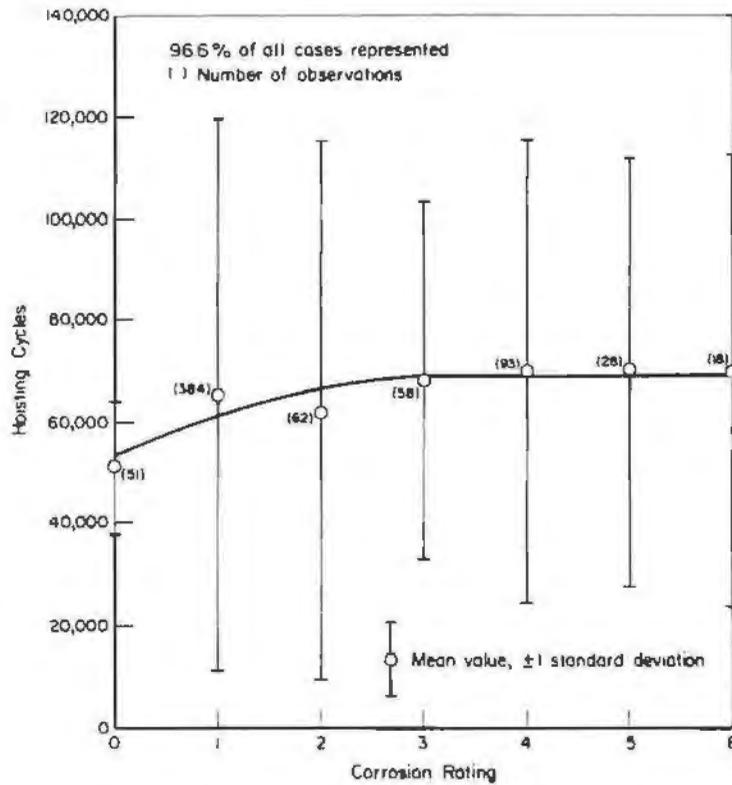


FIGURE 33. Hoisting cycles as a function of corrosion rating.

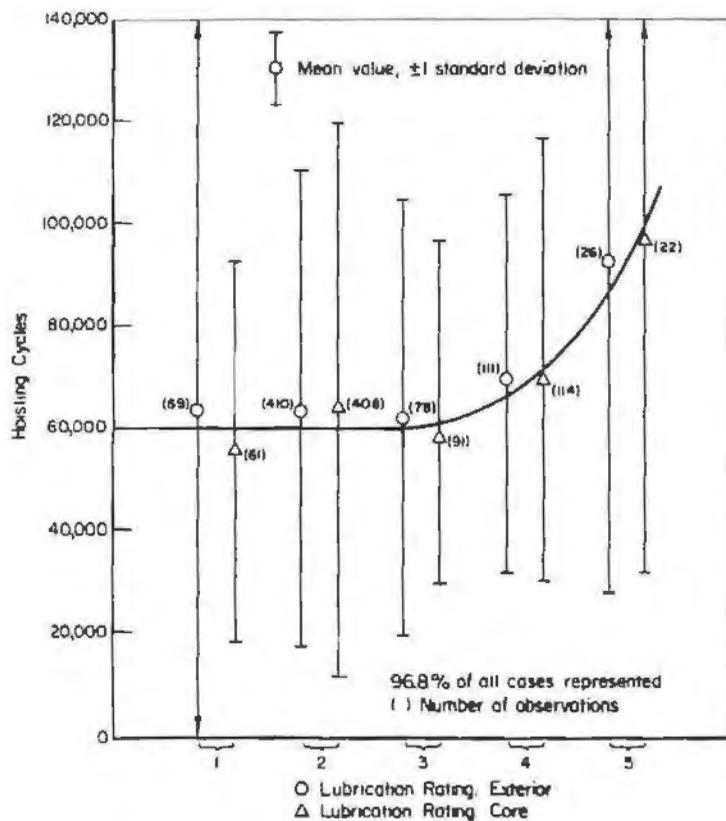


FIGURE 34. Hoisting cycles as a function of lubrication rating for the core and for exterior wires.

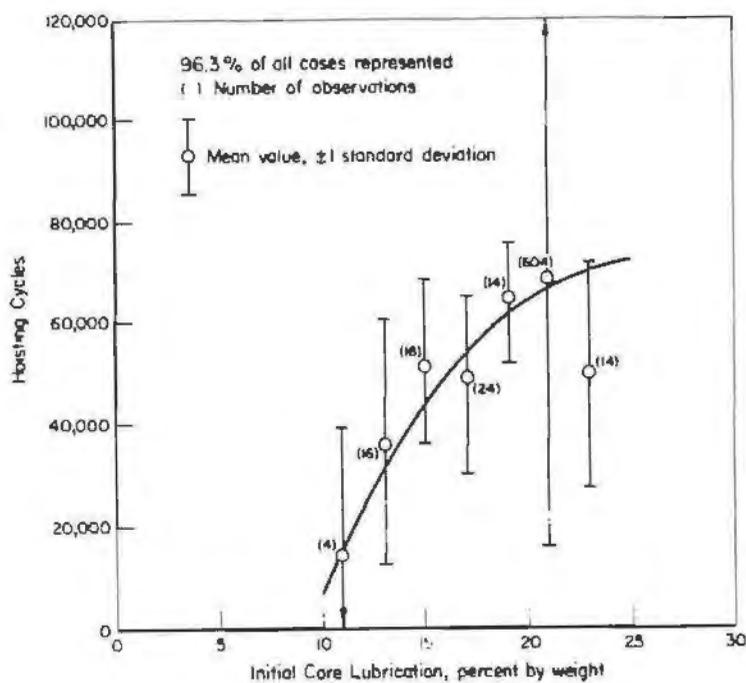


FIGURE 35. Hoisting cycles as a function of initial core lubrication.

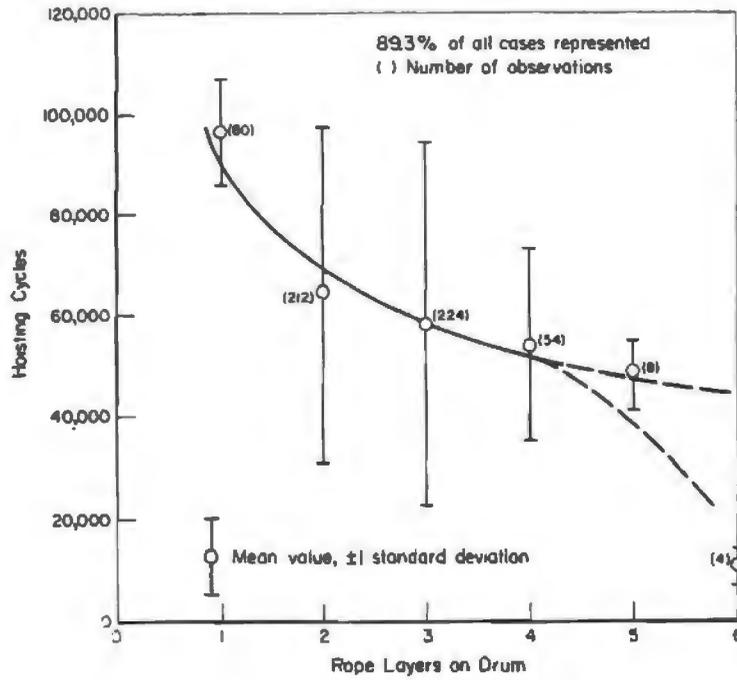


FIGURE 36. Hoisting cycles as a function of rope layers on the drum.

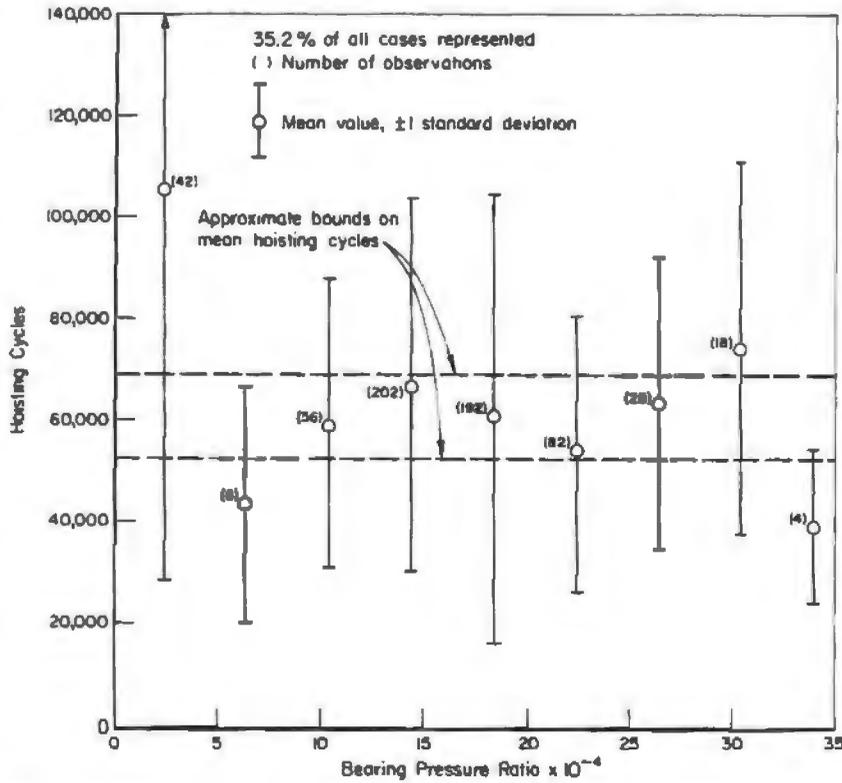


FIGURE 37. Hoisting cycles as a function of bearing pressure ratio.

Two factors which were expected to be linked directly with hoisting cycles, but were not, are bearing pressure ratio and rope strength loss. As shown in Figure 37, there was no consistent trend to support the commonly held belief that high bearing pressure ratios produce short rope lives, which is further support for the already noted observation that bending fatigue seems to be a secondary degradation factor in the ropes represented in the Ontario Special Rope Tests. With regard to strength loss, a similar lack of correlation with hoisting cycles was found as shown in Figure 38. Of course, in a well controlled laboratory system, rope strength loss is very strongly linked with bending cycles over a sheave. The fact that it is not for these hoist ropes is undoubtedly linked to the previous observation regarding bearing pressure ratio.

Several additional AID analyses were completed that are worthy of some mention. One analysis again involved rope hoisting cycles as a dependent variable, but the primary destructive variables were removed and only the minimum remaining strength sites were included in the analysis. The results, as shown in Figure 39, are somewhat similar to the previous run with the same dependent variable (Figure 31), except that several new relationships emerged that were previously hidden. The detailed results are shown in Table 12. Completely uncorroded ropes (where outer wire corrosion rating was equal to zero) did show longer service lives, which suggests that any corrosion, if allowed to develop, will lead to less-than-optimum rope life. Significant rope diameter reductions were found to be linked with long rope lives which tend to confirm the logical conclusion that rope diameter reduction would increase with greater rope usage.

Length of service (in days) was shown to be a subtle correlate with hoisting cycles, as shown in Figure 40. There is no clear pattern between these variables, although there is a tendency for most ropes to be used at such a modest rate that the average use rate based on the Special Rope Test data indicate that hoist ropes accumulate hoisting cycles at a rate of only 20 to 25 cycles/day.

The above result suggested that an AID analysis involving the length of service in days as the dependent variable would be of interest. Such an analysis was completed, and the results are graphically displayed in Figure 41. Some previously unidentified variables surfaced in this analysis. Rope type, company and mine identification, bearing pressure ratio, broken wires and lubrication interval all were found to be related to length of service. As Table 13 illustrates, Categories 3 and 4 ropes produced the longest service in terms of time on the hoist. The Category 3 ropes are largely slope-shaft ropes and Category 4 are largely friction-hoist ropes. Most of the slope hoists operate for relatively few hoisting cycles per day, while the friction-hoist ropes generally operate at very high design factors.

No clearly discernable reasons could be found to explain the shorter average lengths of service in Mine Nos. 1, 6, 8, and 9. No two of these mines are properties of the same company. The bearing-pressure-ratio

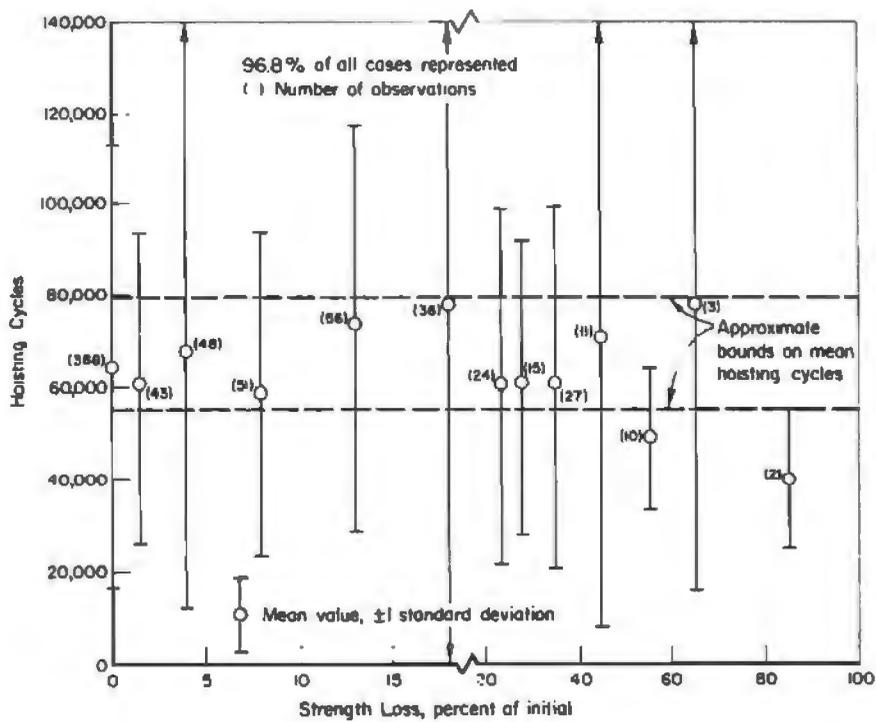


FIGURE 38. Hoisting cycles as a function of rope strength loss.

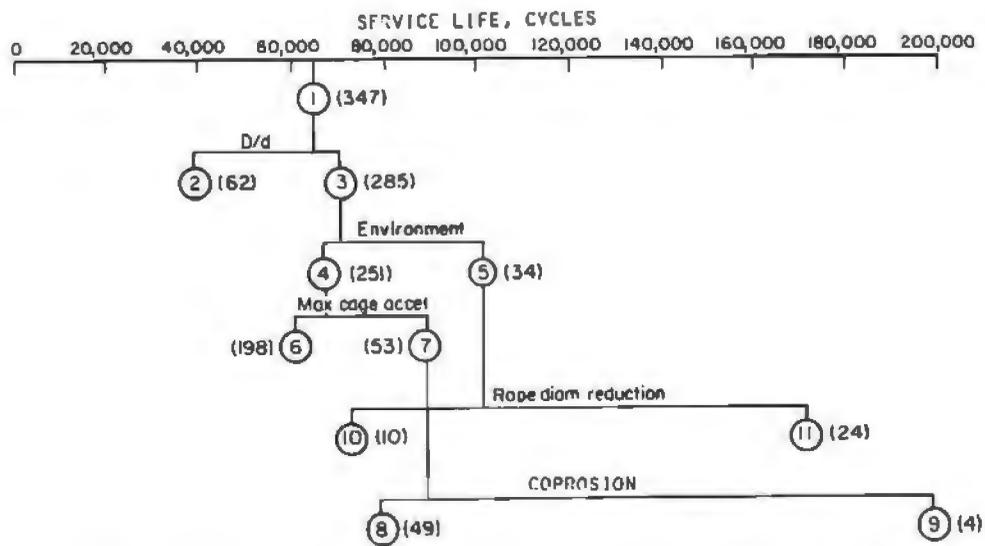


FIGURE 39. AID tree for rope service life, minimum remaining strength sites only, primary destructive variables removed.

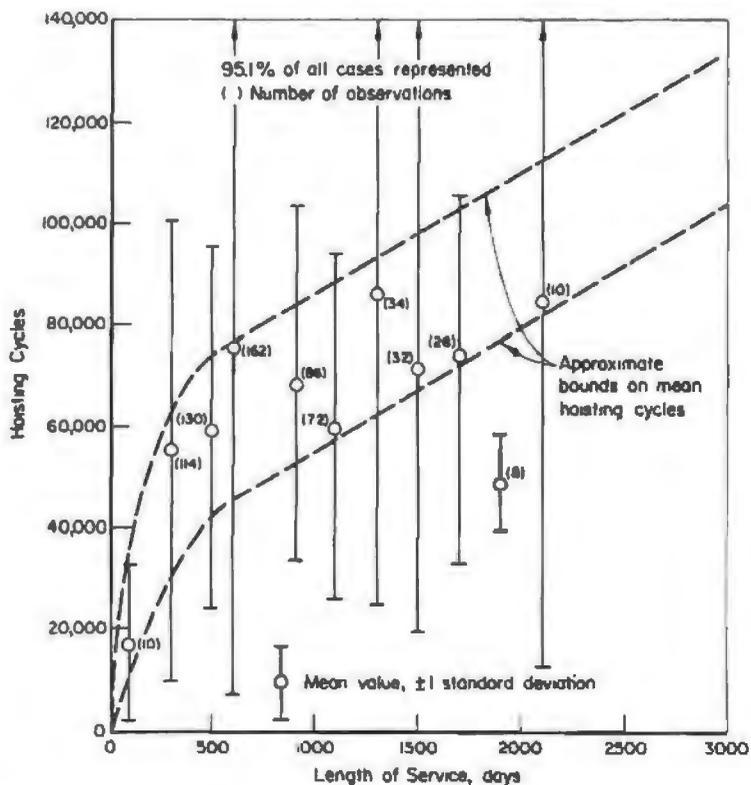


FIGURE 40. Hoisting cycles as a function of length of service.

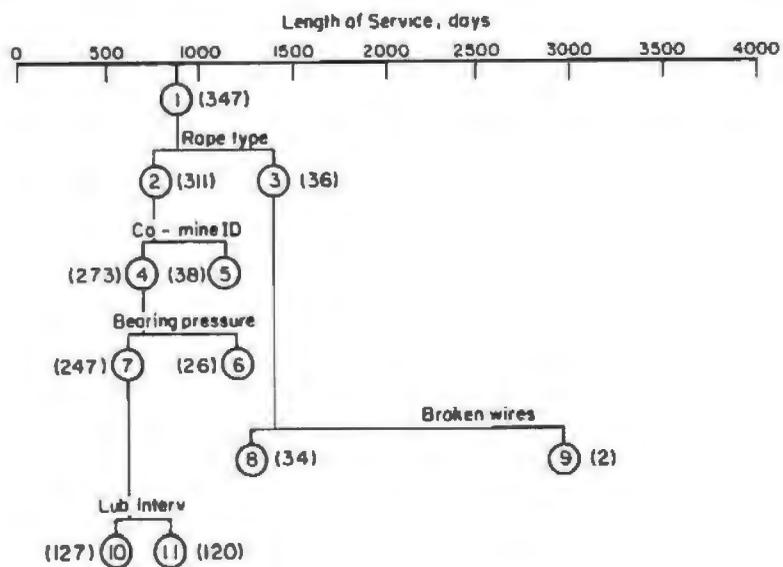


FIGURE 41. AID tree for length of service, minimum strength sites only, destructive variables removed.

TABLE 12. AID ANALYSIS SUMMARY FOR ROPE SERVICE LIFE,
MINIMUM REMAINING STRENGTH SITES ONLY

Group Split	Subgroup	Variable	Variable Magnitude	Service Life	N
1	2	D/d	< 70	39,035	62
	3		> 70	71,378	285
3	4	Environment	Wet or Dry	67,077	251
	5		Humid	103,129	34
4	6	Max Cage/Skip Acceleration	$\leq 2.0\text{-ft/sec}^2$	61,274	198
	7		$> 2.0\text{ ft/sec}^2$	88,756	53
7	8	Corrosion	Ratings 1-6	79,931	49
	9		Rating 0	196,858	4
5	10	Rope Diameter, percent of original	$\leq 95\%$	171,946	10
	11		$> 95\%$	74,455	24

TABLE 13. AID ANALYSIS SUMMARY FOR LENGTH OF SERVICE,
MINIMUM REMAINING STRENGTH SITES ONLY

Group Split	Subgroup	Variable	Variable Magnitude	Length of Service	N
1	2	Rope Type	Categories 1,2,5	760	311
	3		Categories 3,4	1,438	36
2	4	Mine ID	Mine Nos. 1,6, 8,9	710	273
	5		Mine Nos. 2-5, 7,10,11	1,114	38
4	6	Bearing Pressure Ratio	0-.0004	1,160	26
	7		> .0004	663	247
3	8	Broken Wires	0-5	1,296	34
	9		6-10	2,863	2
7	10	Lubrication Interval	< 15, > 35 Days	569	127
	11		15-35 Days	763	120

result was in the expected direction--longer service lives for lower bearing pressure ratios--although this result cannot be viewed too positively in light of the poor correlation between hoisting cycles and bearing pressure ratio. The broken wire result, although in the direction one would expect, is insignificant because of the small sample size. Lubrication interval again shows a modest improvement in rope service performance for intermediate intervals of about 2 weeks to 1 month.

One final AID analysis was done in an attempt to combine the strength-loss and hoisting-cycle dependent variables into a single dependent variable. This variable was defined as the Fatigue Damage Fraction, and it was computed as follows:

$$\text{Fatigue Damage Fraction} = \frac{\text{Hoisting Cycles}}{N_f}$$

where N_f = predicted bend-over-sheave fatigue life to one wire failure, based on the computed bearing pressure ratio for the field rope and laboratory bend-over-sheave fatigue data.

Specifically, N_f was computed as

$$N_f = 300(\text{BPR})^{-1.0}.$$

Note that the bearing pressure ratio which was used was based on the minimum dynamic design factor or maximum rope load. Also, the definition of rope failure was a very conservative one--one-wire failure; therefore, relatively high computed fatigue damage fractions were anticipated, since a number of field ropes do experience more than one wire break before retirement.

Using the above-described definition for the Fatigue Damage Fraction, an AID analysis was completed. All independent variables were considered in the analysis, except bearing pressure ratio and hoisting cycles, since they were used to compute the dependent variable. Only minimum strength sites were included. The results are presented in Table 14.

The primary independent variable that emerged as significant in the analysis was minimum dynamic design factor. High design factors were related with low damage fractions and vice versa, which is as expected. Outer wire torsions were also seen to be logically linked with the damage fraction, with low torsions being related to high damage fractions. Two splits on lubricant were then made. Unfortunately, no clearly defined categories (i.e., classification of lubricants as to physical/chemical types) for lubricants were identifiable as inferior or superior, since the lubricant numbers showing high or low damage fractions were not consistent. Test data and predicted strength loss entered as lower-importance-level variables, with the more recently installed ropes and larger predicted strength losses showing higher damage fractions.

TABLE 14. AID ANALYSIS SUMMARY FOR DAMAGE FRACTION,
MINIMUM STRENGTH SITES ONLY

Group Split	Subgroup	Variable	Variable Magnitude	Fatigue Damage Fraction	N
1	2	Minimum Dynamic Design Factor	< 5	.828	166
	3		> 5	.486	146
2	4	Outer Wire Torsions	> 8	.668	61
	5		< 8	.923	105
3	6	Lubricant	Nos. 4,8,9,11	.400	109
	7		Nos. 1-3, 5-7	.739	37
5	8	Lubricant	Nos. 1-4, 6,7, 10,11	.881	97
	9		Nos. 5,8,9	1.44	8
8	10	Date	Before 1968	.860	95
	11		1968,70	1.83	2
10	12	EM-Predicted Strength Loss	< 15%	.81	82
	13		> 15%	1.15	13

The overall test results of the AID analyses completed on the Ontario Special Rope Test data base are summarized in Table 15. Remaining strength was found to be the most predictable and important dependent variable, although some useful correlations with hoisting cycles, service life and their combination (damage fraction) were also established.

The results just summarized were based on the AID tree. Another useful interpretation of the AID analysis for remaining strength (or, conversely, strength loss) was also made. From the analysis results developed prior to the first AID split on strength loss, (see Appendix D), it was possible to look at the relative importance of each independent variable acting on the total population (considering no interactions). Table 16 shows the relative importance of each independent variable in terms of the BSS/TSS ratio*. A high BSS/TSS ratio for a specific

*BSS/TSS = Between groups sum of squares/total sum of squares.

variable indicates that a high percentage of the variability in strength loss was explained by splitting the total population into two trial groups according to that variable. Note that the BSS/TSS ratios ranged from almost 0.40 down to about 0.002, which indicated that some independent variables were closely linked to strength loss, while others were almost unrelated. The ten independent variables most strongly related to strength loss are presented in Table 17. Most of the variables listed are ones which the AID tree highlighted as being important. One significant exception is used rope outer wire torsions. It is interesting that this variable shows up so strongly here, while it never even appeared in the higher branches of the AID tree, previously shown in Figure 18. This result seems to have occurred because outer wire torsions were so closely linked with outer wire corrosion rating that corrosion rating, which was a slightly stronger variable, effectively "hid" outer wire torsions from exposure in the higher branches of the AID tree. This result tends to support the contention that the torsion test is primarily an indication of wire surface quality and that corroded wires have poor surface quality and, therefore, low torsions.

Discriminant Analysis

The Ontario Special Rope Test data were also evaluated using a discriminant analysis. The discriminant analysis was in some ways similar to the AID analysis, in that it sorted out the primary independent variables. The discriminant analysis differed from the AID analysis in that it was used specifically to identify the independent variables which would best classify the Special Rope Test data into distinct groups based on strength loss, hoisting cycles and other important combinations of the dependent variables that were selected for the analysis.

The discriminant analysis package which was used is a part of the Statistical Package for the Social Sciences (SPSS) (21).

TABLE 15. AID ANALYSIS SUMMARY

Degree of Correlation	Remaining Strength	Hoisting Cycles	Damage Fraction
Most Strongly	Elongation, Used Rope (during tensile test on retired rope section)	D/d (Sheave/drum-to-rope diameter ratio) Rope Layers on Drum	Dynamic Design Factor Outer Wire Torsions
	Corrosion Rating, Exterior Wires	Initial Core Lubrication	
	Diameter Reduction		
	EM-Predicted Strength Loss		
Moderately	Lubrication Rating, Strands and Core, Used Rope	Corrosion Rating, Exterior	Lubricant
	Broken Wires	Lubrication Rating, Strands and Core, Used Rope	EM-Predicted Strength Loss
	Rope Layers on Drum		
	Lay Length Increase		
Weakly		Strength Loss, Actual and EM-Predicted	
		Length of Service	
		Bearing Pressure Ratio	

TABLE 16. RELATIVE INFLUENCE OF VARIABLES ON REMAINING STRENGTH IN AID ANALYSIS

Variable No.	Variable Name	BSS/TSS ^(a)	Relative Ranking ^(b)
1	Diameter Reduction	.0516	6
2	Length of Service	.0137	18
3	Lubricant	.0124	20
4	Lubricant Application	.0181	15
5	Lubrication Interval	.0102	24
6	D/d	.0168	17
7	Rope Layers on Drum	.0079	29
8	Chairs	.0022	35
9	Shaft Condition	.0058	32
10	Shaft Ventilation	.0080	28
11	Environment	.0079	30
12	Mine Water pH	.0021	37
13	New Rope Outer Wire Torsion	.0312	13
14	New Rope Core Lubrication	.0045	33
15	Maximum Cage Acceleration	.0080	27
16	Wire Strength	.0180	16
17	Bearing Pressure Ratio	.0329	11
18	Hoisting Cycles	.0087	26
19	EM-Predicted Strength Loss	.0861	4
20	Elongation	.3908	1
21	Used Rope Core Lubrication	.0109	22
22	Increase in Lay Length Ratio	.0071	31
23	Rope Appearance	.0535	5
24	Lubrication Rating - Exterior	.0109	23
25	Lubrication Char. - Exterior	.0116	21
26	Lubrication Rating - Core	.0445	7
27	Lubrication Char. - Core	.0336	10
28	Corrosion	.1933	2
29	Used Rope Outer Wire Torsions	.1912	3
30	Length From Drum	.0134	19
31	Broken Wires	.0292	14
32	Galv. Wire	.0021	36
33	Co./Mine ID	.0371	9
34	Date	.0095	25
35	Rope Usage	.0394	8
36	Rope Type	.0320	12
37	Min. Dyn. Des. Factor	.0029	34
38	Strength Loss	-	-

(a) Between group sum of squares/total sum of squares

(b) Based on maximum BSS/TSS, which identifies the fraction of variability in strength loss explained by splitting the population according to a specific independent variable.

TABLE 17. PRIMARY VARIABLES INFLUENCING STRENGTH LOSS IN AID ANALYSIS

Ranking	Variable Number	Variable Name	Strongest Split	
			High Strength Loss	Low Strength Loss
1	20	Elongation	$\leq 2\%$	$> 2\%$
2	28	Corrosion Rating*	5,6	≤ 4
3	29	Used Rope Outer Wire Torsions	≤ 2	> 2
4	19	EM-Predicted* Strength Loss	$> 10\%$	$\leq 10\%$
5	23	Rope Appearance*	Broken Wires, Damaged	Worn
6	1	Diameter* Reduction	$\leq 94\%$	$> 94\%$
7	26	Lub. Rating of Core	3,4	1,2
8	35	Rope Usage*	Slope	Drum, Friction
9	33	Co./Mine ID*	5,6,8-10	1-4,7,11
10	27	Lub. Character of Core	1,3,6	2,5

* Nondestructive Test Procedures

The discriminant analysis procedure which was used involved a step-wise selection of the linearly related independent variables. In each case, the first variable selected was the single variable most influential in defining distinct subgroups of the dependent variables. Then, with the first variable incorporated into the analysis, the second most influential variable was chosen. This procedure was automatically continued until it was found that no remaining independent variables could add significantly to the discrimination between the dependent variable subgroups.

The first dependent variable subgroups that were examined were defined as follows:

Group 1 = >30% strength loss
Group 2 = <10% strength loss.

Obviously, it would be desirable to know, based on nondestructive measures, whether a hoist rope was in Category 1 or 2. If the rope were in Category 1 and went undetected, it could lead to a catastrophic rope failure. On the other hand, if a rope that really was a Category 2 rope, was not identified as such, it might well be retired prematurely.

As already inferred, the focus of the analysis was on the selection of nondestructive indicators of rope degradation that would best predict high and low rope strength losses. Table 18 lists the independent variables considered in the discriminant analysis for remaining strength. Note that nearly all of the variables listed are ones shown to be of some importance in the AID analysis.

The results of the discriminant analysis are shown in Table 19. Five discriminating variables were found to be significant. The discriminating equation was, therefore, defined as follows

$$X = A_0 + A_1V_1 + A_2V_2 + A_3V_3 + A_4V_4 + A_5V_5.$$

If the discriminant score exceeded 1.54, then Group 1 was predicted if the score was less than 1.54, Group 2 was predicted. Corrosion rating was found to be the single most important discriminating variable, with higher ratings leading to a substantially higher discriminant score and a stronger Group 1 prediction.

Rope appearance was found to be second in importance as a discriminating variable. Recall here that a Rope Appearance Value of 1 means that the rope is worn, 2 means broken wires (> 5), and 3 means damaged. Again, higher ratings produce a higher discriminant score and a stronger Group 1 prediction. Rope diameter reduction was found to be third in importance. In this case, higher rope diameter ratios (less reduction) led to lower discriminant scores and a stronger Group 2 prediction. Rope layers on the drum and EM-predicted strength loss were the fourth and fifth most important variables. Both of these factors were positively related to a Group 1 prediction, i.e. higher values led to a stronger Group 1 prediction. The standard coefficients for EM-predicted strength loss and for rope layers on the drum was fairly small though, suggesting a modest contribution to the discrimination capability.

TABLE 18. INDEPENDENT VARIABLES CONSIDERED IN DISCRIMINANT ANALYSIS FOR REMAINING STRENGTH

1. Corrosion Rating, Exterior Wires	7. Rope Layers on Drum
2. EM-Predicted Strength Loss	8. Rope Diameter Reduction
3. Rope Appearance	9. Hoisting Cycles
4. Lubrication Rating Outer Wires	10. Length of Service
5. Broken Wires	11. Relative Distance from the Drum
6. Outer Wire Torsions	12. Increase in Lay Length/Diameter

TABLE 19. DISCRIMINANT ANALYSIS FOR REMAINING STRENGTH

Variable Number	Description	Discriminant Standardized	Coefficients Unstandardized
V1	Corrosion Rating	.905	A0 = 5.757
V2	Rope Appearance	.405	A1 = .963
V3	Rope Diameter Reduction	-.270	A2 = 1.602
V4	Rope Layers on Drum	.226	A3 = -.109
V5	EM-Predicted Strength Loss	.216	A4 = .292
			A5 = .0395
$X = A0 + A1 \cdot V1 + A2 \cdot V2 + A3 \cdot V3 + A4 \cdot V4 + A5 \cdot V5$			
If $X > 1.54$, > 30% Strength Loss is Predicted < 1.54, < 10% Strength Loss is Predicted			

As a test of the quality of the discriminating equation which was developed, a trial run was completed on the Special Rope Test data base. Of the 1,670 possible cases in the data base, only 497 had values for all the desired discriminating variables. Of the 497 values, 28 fell into Group 1 and 233 fell into Group 2, as shown in Table 20. Using the discriminating equation, 24 of the 28 Group 1 cases were correctly classified while 222 of the 233 Group 2 cases were correctly classified for an overall classification accuracy of about 94%. This result was very significant, because it said that better than 90% of the Special Rope Test specimens included in this analysis could have been sorted into Groups 1 and 2, before any destructive testing was carried out, provided adequate nondestructive test procedures were available and used to quantify the corrosion rating, rope appearance, rope diameter reduction and EM-predicted strength loss.

A similar discriminant analysis was performed using hoisting cycles as the dependent variable. The subgroups to be discriminated were defined as follows:

- Group 1 = <40,000 hoisting cycles
- Group 2 = >120,000 hoisting cycles.

In this case, the independent variables considered for the analysis were restricted to nondestructive variables, and even more specifically, to hoist system and rope description variables alone. The list of variables considered is given in Table 21.

The results of the stepwise discriminant analysis are shown in Table 22. Only three discriminating variables were found to be significant in this case. The drum/sheave-to-rope-diameter ratio, D/d, was found to yield the single most important discriminating score and a stronger Group 2 prediction. Initial wire strength was found to be second in importance as a discriminating variable. In this case, wire strength was estimated from rope breaking strength, diameter and construction information since such information was not directly reported. Higher wire strength values led to a higher discriminant score and a stronger Group 2 prediction. Lubrication interval was found to be third in importance (and only of marginal significance). In this case, longer lubrication intervals led to lower discriminant scores and a stronger Group 1 prediction.

To test the quality of the discriminating equation which was developed, a trial run was completed on the Special Rope Test data base. The results are shown in Table 23. Of the 1,670 possible cases in the data base, 1,108 had values for all of the desired discriminating variables. Of the 1,108 cases, 344 fell into Group 1 while 149 fell into Group 2 (the remaining 615 cases fell intermediate to these limits). Of the 344 Group 1 cases, only 209 were correctly classified, while all 149 Group 2 cases were correctly classified, for an overall classification accuracy of 73%. This result is not so impressive as was the prediction percentage determined in the analysis using remaining strength as the dependent variable, although the prediction accuracy for the long-life ropes was even

TABLE 20. PREDICTION OF REMAINING STRENGTH

Number of Samples in Test Population - 497

Actual Group	No. of Cases	Predicted Group	
		1	2
1	28	24 (86%)	4 (14%)
2	233	11 (5%)	222 (95%)

Overall Percentage of Cases Correctly Classified - 94%

TABLE 21. INDEPENDENT VARIABLES CONSIDERED IN DISCRIMINANT ANALYSIS FOR HOISTING CYCLES

1. D/d	9. Rope Category or Type
2. Lubrication Interval	10. Length of Service
3. Initial Wire Strength	11. Rope Lubricant
4. Rope Layers on Drum	12. Lubricant Application Method
5. Bearing Pressure Ratio	13. Initial Outer Wire Torsions
6. Environment	14. Shaft Ventilation
7. Minimum Dynamic Design Factor	15. Initial Core Lubrication
8. Type of Service or Rope Usage	16. Mine Water pH

TABLE 22. DISCRIMINANT ANALYSIS FOR HOISTING CYCLES

Variable Number	Description	Discriminant Coefficients	
		Standardized	Unstandardized
V1	D/d	11.53	A0 = -1976.
V2	Initial Wire Strength	11.46	A1 = 25.80
V3	Lubrication Interval	-2.04	A2 = 0.000883
			A3 = -.162
$x = A0 + A1 \cdot V1 + A2 \cdot V2 + A3 \cdot V3$			
If $x < 256.7$, < 40,000 Cycles is Predicted > 256.7, > 120,000 Cycles is Predicted			

TABLE 23. PREDICTION OF HOISTING CYCLE LIFE

Number of Samples in Test Population - 1108

Actual Group	No. of Cases	Predicted Group	
		1	2
1	344	209 (61%)	145 (39%)
2	149	0 (0%)	149 (100%)

Overall Percentage of Cases Correctly Classified - 73%

better than that for the best remaining-strength categorization. The relatively poor prediction accuracy for the short-life ropes may be related to the fact that a significant number of ropes were retired for reasons not covered by the discriminating variables (e.g. time on the hoist, mine shut down, rope damage)--many of which are not contained in the Special Rope Test data base.

A final discriminant analysis was performed using a combination of hoisting cycles and strength loss as dependent variables. The subgroups to be discriminated were defined as follows:

Group 1 = >30% strength loss
and <40,000 hoisting cycles.

Group 2 = <10% strength loss
and >120,000 hoisting cycles.

Both groups of independent variables considered separately in the first analyses were considered jointly for the final analysis.

The results of the stepwise discriminant analysis are shown in Table 24. Eight discriminating variables were found to be significant in this case. The drum/sheave-to-rope diameter ratio (D/d) was found to be most important discriminating variable, with higher D/d values leading to a lower discriminant score and a stronger Group 2 prediction. EM-predicted strength loss was found to be second in importance as a discriminating variable. As expected, high EM-predicted strength losses led to a higher discriminant score and a stronger Group 1 prediction. Of the remaining 6 discriminating variables, all behaved as expected except two of them--initial wire strength and corrosion rating. These variables pushed the discriminant score in a direction opposite to that which would be expected, with high wire strength leading to a Group 1 prediction (contrary to the second discriminant analysis) and high corrosion ratings leading to a Group 2 prediction (contrary to the first discriminant analysis). This kind of reversal in impact of specific variables can happen in a discriminant analysis, depending on the more important variables that precede it in the stepwise discriminant equation.

Despite some of the unsuspected signs of several coefficients in the discriminant equation, the results were very impressive, as shown in Table 25. Out of 45 cases that actually fell into Groups 1 or 2, 100% were correctly classified.

In summary, the discriminant analysis showed that high or low remaining strength in a specific section of hoist ropes can be predicted with over a 90% chance of success if the corrosion rating, rope appearance, rope diameter reduction, rope layers on the drum and EM-predicted strength loss are known. The quality of this prediction is not substantially reduced even if an EM-predicted strength loss reading is not available.

TABLE 24. DISCRIMINANT ANALYSIS FOR REMAINING STRENGTH/HOISTING CYCLES

Variable Number	Description	Discriminant Coefficients	
		Standardized	Unstandardized
			A0 = 14.06
V1	D/d	-1.85	A1 = -0.333
V2	Predicted Strength Loss	.934	A2 = 0.080
V3	Initial Wire Strength	.364	A3 = 0.0000225
V4	Rope Category or Type	.927	A4 = 2.10
V5	Rope Appearance	.501	A5 = 1.44
V6	Corrosion Rating	-.206	A6 = 0.159
V7	Lubrication Interval	.345	A7 = 0.0373
V8	Rope Layers on Drum	.257	A8 = 0.369
$X = A0 + A1 \cdot V1 + A2 \cdot V2 + A3 \cdot V3 + A4 \cdot V4 + A5 \cdot V5 + A6 \cdot V6 + A7 \cdot V7 + A8 \cdot V8$			
If $X > 4.95$, > 30% Strength Loss and < 40,000 Cycles Is Predicted < 4.95, < 10% Strength Loss and > 120,000 Cycles Is Predicted			

TABLE 25. PREDICTION OF REMAINING STRENGTH/HOISTING CYCLE PERFORMANCE

Number of Samples in Test Population - 809			
Actual Group	No. of Cases	Predicted Group	
		1	2
1	9	9 (100%)	0 (0%)
2	36	0 (0%)	36 (100%)
Overall Percentage of Cases Correctly Classified - 100%			

In addition, high- or low-hoisting-cycle lives for a specific rope can be predicted with a greater than 70% chance of success if the D/d, initial wire strength and lubrication interval are known. The long-life conditions are predicted with higher confidence than are the short-life conditions. And finally, predictions based on strength and life simultaneously, are highly confident if the groups are well spaced.

Analysis of Routine Rope Test Data Base

The Routine Rope Test data were initially viewed as a complementary collection of test results that might be used in conjunction with the Special Rope Test data to answer two primary questions:

- (1) Do rope cutoff results offer a worst-case indication of degradation for the balance of the rope?
- (2) Do rope cutoffs reduce the frequency of rope retirement due to rope damage near the conveyance?

Unfortunately, the Routine Test Data are limited in several important ways. First, the Routine Rope Test data base largely does not cover the same time period or mine sites that are covered by the Special Rope Test data. Second, no tonnage hoisted or cycles of operation are reported in the Routine Rope Test data. Third, no subsequent destructive tests were performed on the EM-predicted strength-loss sites in the rope cutoff specimens.

The first limitation of the Routine Rope Test data is highlighted in Table 26, where the chronology of both the Special Rope data and the Routine Rope data is shown. Nearly 85% of the Special Rope Tests were completed before 1965, while over 90% of the Routine Rope Tests in the present data collection were completed after 1965.

Despite the above limitations, however, there were some significant observations which could be made based on the Routine Rope Test data collection. For example, a simple compilation of the reasons for removal of these ropes was quite revealing, as can be seen in Table 27. More than 22% of the ropes were retired because of low EM test results (i.e., indications of greater than 10% strength loss). Over 14% were retired because of broken wires, while almost 12% of the ropes were simply too short after the last cutoff to be useful for further service. In comparison, only 5.7% were retired because of low strength, as determined in the tensile test of the cutoff specimens. This result shows that the cutoff is not normally degraded in strength to any substantial degree, (but this may well be a result of the fact that the cutoff program normally eliminates the critical termination section of rope before damage is significant).

A distribution of remaining strength values for the Routine Rope Test specimens (cutoffs) is shown in Figure 42. This figure shows a bilinear plot of remaining-strength values, which suggests a nonhomogenous population. In fact, the slope is far steeper for the lowest 2% of cases,

TABLE 26. CHRONOLOGY OF SPECIAL ROPE TESTS AND ROUTINE TESTS IN THE PRESENT DATA BASES

Time Period	Special Rope Tests		Routine Rope Tests	
	No.	% of Total	No.	% of Total
Before 1955	130	36	-	-
1955 - 1965	171	48	69	7
1965 - 1970	21	6	89	9
1970 - 1975	15	4	225	22
After 1975	10	3	619	61
No Date Specified	<u>12</u>	<u>3</u>	<u>8</u>	<u>1</u>
	359	100	1010	100

TABLE 27. REASONS FOR REMOVAL OF ROPES CITED IN
THE ROUTINE ROPE TEST DATA

<u>Reason Cited</u>	<u>No. of Cases</u>	<u>Percent of Total</u>
Low EM Test Result	225	22.3
Broken Wires	146	14.5
Shortness	119	11.8
Unfit for Hoisting	101	10.0
Lengthy Service	80	7.9
Low Strength	58	5.7
Waviness, Distortion, Birdcaging	27	2.7
Low Torsions	14	1.4
Damaged	9	0.9
Rope Failure	-	-
Unknown or Unspecified	<u>231</u>	<u>23.1</u>
	1010	100.0

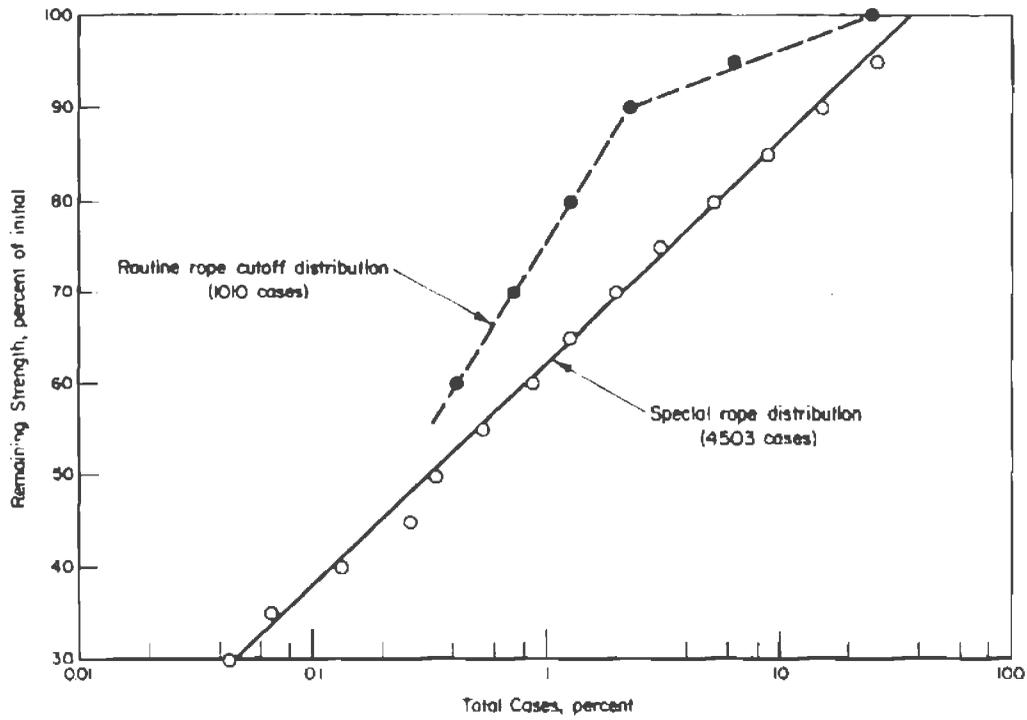


FIGURE 42. Cumulative distribution plot of remaining strength values for the Routine Rope Test data in comparison to the Special Rope Test data.

suggesting that the lower segment is made up primarily of damaged rope samples that might well have been identified through visual inspection.

Outer-wire corrosion ratings and torsion values were available for most of the Routine Rope Test specimens. Figure 43 shows the correlation between average outer-wire corrosion rating and remaining strength. There is a modest correlation ($R = -0.081$) with high corrosion ratings tending to relate to lower remaining strengths. If all readings below 1.0 are ignored, as in Figure 44, the correlation is substantially improved ($R = -0.614$), although still not dramatically. Figure 45 shows the correlation between outer-wire torsions and remaining strength. Again, there is a modest correlation ($R = 0.253$), with low torsions tending to relate to lower remaining strengths. If all readings above 30 are ignored, as in Figure 46, the correlation is somewhat improved ($R = 0.407$).

In summary, the Routine Rope Test data are of limited usefulness in answering the originally posed questions. The current cutoff practice (represented by these test records) does not ensure safe rope operation, nor does it accurately reflect the condition of the overall rope. However, if the rope near the conveyance is damaged or poorly maintained by lack of lubrication, both of which should be discernable with appropriate visual inspection) a cutoff is very helpful. Even so, there is little evidence in the current data base that supports the belief that the conveyance end of the rope is the critical damage site--although available information is probably not adequate to address this question properly. Nevertheless, mandatory cutoff requirements are apt to preclude the corrosion-fatigue failures that would ordinarily occur near the attachment to the conveyance. Thus, cutoffs are believed to result in "referring" failures to other locations in the rope and, depending on the conditions at the failure site, the mode of failure could be different from that characteristic of those that might have occurred if cutoffs had not been made.

Laboratory Rope Analysis

The laboratory data collected in this program were analyzed to determine the extent to which existing laboratory axial-fatigue and bend-over-sheave fatigue data could be used to evaluate the characteristics and service potential of mine-hoist rope constructions. In the review which follows, the axial-fatigue data base is considered first, followed by the bend-over-sheave fatigue data base. In each case, the key variables are discussed, the makeup of the data is reviewed and some sample correlation and regression analyses are presented.

Axial-Fatigue Data

The axial-fatigue data which were collected were encoded in the format described in Appendix C. From Appendix C, a list of variables was constructed for analysis of these data; this list is shown in Table 28. About one-half of the original variable list was retained in its original form, while 5 derived variables were constructed that were known or thought to be of importance. The variables which were omitted were either inadequately defined in the present data base or not pertinent.

CORROSION RATING VS REMAINING STRENGTH
(ALL VALUES)

R = -0.081

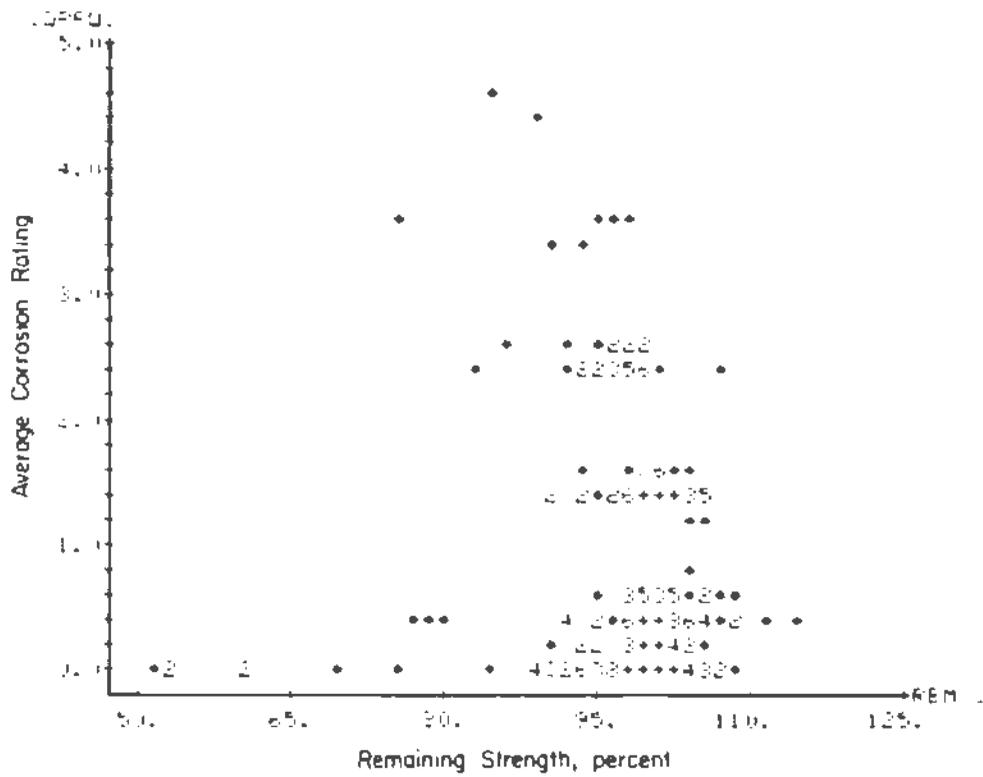


FIGURE 43. Remaining strength versus outer wire corrosion rating.

CORROSION RATING VS REMAINING STRENGTH
(RATINGS > 1.0)

R = -0.614

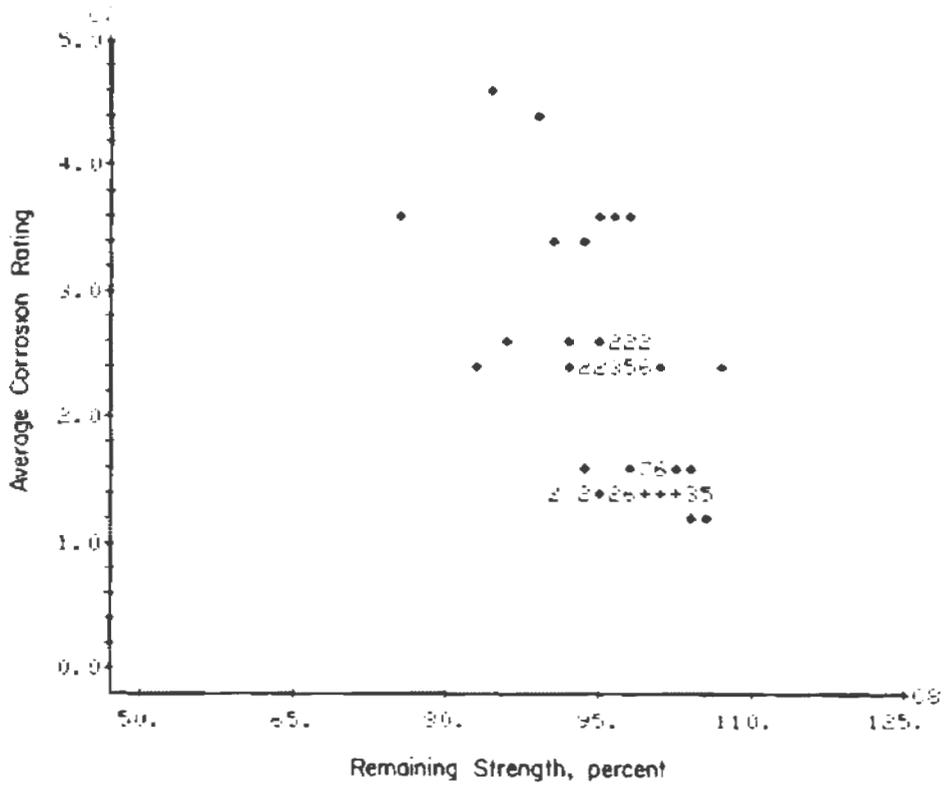


FIGURE 44. Remaining strength versus outer wire corrosion rating (all ratings less than 1.0 excluded).

TABLE 28. LIST OF VARIABLES FOR ANALYSIS OF
LABORATORY AXIAL-FATIGUE DATA ^(a)

Variable No.	Definition	Variable Definition
1	Nominal Rope Diameter, inch	V2
2	Rope Construction	V3
3	Lay Type	V4
4	Wire Material Code	V5
5	Core Type	V6
6	Lubricant Code	V7
7	Rated Breaking Load, kips	V8
8	Actual Breaking Load, kips	V9
9	Number of Exterior Wires/ Strand	V10
10	Data Source Number	V13
11	Environment	V21
12	Termination Type	V22
13	Maximum Load/Rated Breaking Strength	V27/V8
14	Rope Temperature, C	V29
15	Cycling Frequency, cycles/min	V30
16	Fatigue Life, cycles	V32
17	Failure Criteria	V34
18	Strength Loss at Failure Criterion, percent of RBS	$100 - (V35/V8) \cdot 100$
19	Load Range/Rated Breaking Strength	$V27/V8 - 1/V25$
20	Load Ratio	$V8/(V25 \cdot V27)$
21	Equivalent Load/Rated Breaking Strength	$V27 \cdot [1 - \text{Load Ratio}]^{1/2}$ V8

(a) See Appendix C for complete variable list.

The axial-fatigue data which were obtained in this program are summarized in Table 29. The specific data sources are cited in Appendix C. Only three rope constructions are presented; however, more than 900 tests are included--these covering a broad range of rope diameters and fatigue lives.

The data base is broad enough that there are a number of different correlation and regression analyses that can be performed as indicated in Table 30. Several examples of analyses are presented along with the results to illustrate the ways in which the data base can be utilized.

The first example centers on the determination of the best consolidation parameter for axial-fatigue data. There are several possible means for consolidating axial-fatigue data such as maximum load, load range, mean load or some combination of these parameters. If different rope diameters or strength levels are to be considered, then normalized values of the above parameters (where all values would be divided by the rated or actual breaking strength) would be appropriate to consider.

In this case three normalized load parameters were considered and compared. They were defined as follows:

$$(1) \frac{\text{Maximum Load}}{\text{Rated Breaking Strength}}$$

$$(2) \frac{\text{Load Range}}{\text{Rated Breaking Strength}}$$

$$(3) \frac{\text{Load Range } (1 - R)^{\frac{1}{2}}}{\text{Related Breaking Strength}}$$

$$\text{where } R = \frac{\text{Minimum Load}}{\text{Maximum Load}}$$

First, the data were analyzed together using all 906 data points. Figures 47 through 49 show the results of those analyses using Parameters 1, 2, and 3, respectively. Several things are readily apparent in these figures. First of all, in no case does any one of the models consolidate all of the data to any substantial degree--the population is simply too diverse with too many other variables tending to scatter the data. Second, the normalized load range does the best job of minimizing that scatter, as can be seen in the computed R-squared value tabulated below Figure 48. (An R^2 value of 100% indicates a perfect representation of the data, while an R^2 value of 0% indicates no explanation of the data by the model.)

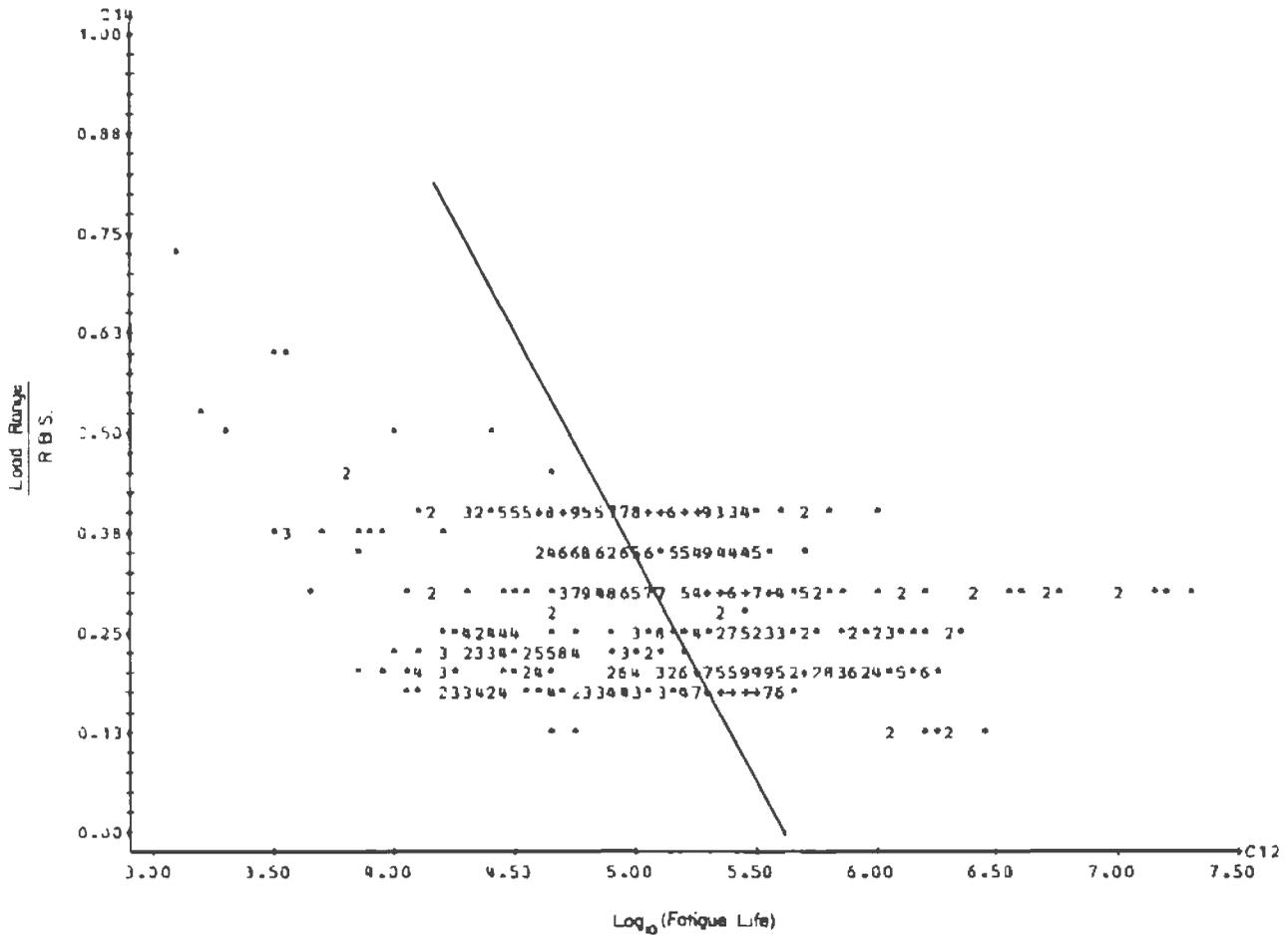
A more critical assessment of the different consolidation parameters was made by selecting several subsets from the overall data collection. In Figures 50 through 52, the same three parameters were evaluated for a collection of 6 x 37, IWRC, regular lay ropes subjected to 2-4 weeks prior exposure in sea water. Note here that the collection of data is

TABLE 29. SUMMARY OF LABORATORY AXIAL-FATIGUE DATA

Data Sources	9
Rope Constructions	3 6 x 25 FW 1 x 19 Strand 6 x 37 WS
Range of Rope Diameters	0.38 in. - 2.69 in.
Range of Fatigue Lives	1000 - 20 million
Test Results	906

TABLE 30. CORRELATION AND REGRESSION ANALYSIS OF AXIAL-FATIGUE DATA

Consolidation of Data
Effects of Construction
Effects of Core Type
Effects of Sea Water Exposure
Effects of Lay Type
Effects of Rope Diameter
Effects of Termination Type
Effects of Lubricant
Effects of Failure Criteria



THE REGRESSION EQUATION IS
 $Y = 5.62 - 1.78 X$

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
I1	C14	-1.7816	0.1999	-8.91

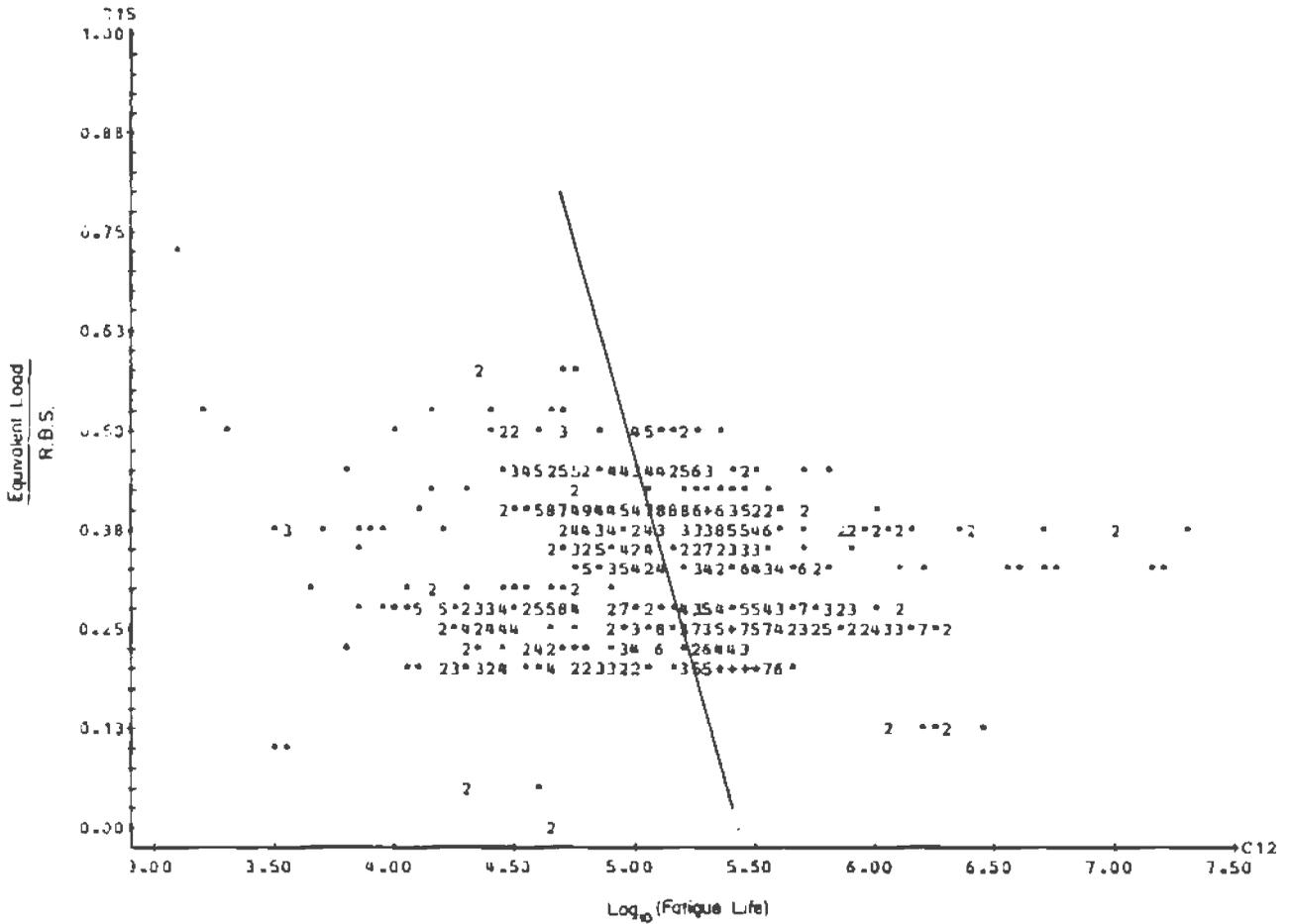
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.5238$
 WITH $(906 - 2) = 904$ DEGREES OF FREEDOM

R-SQUARED = 8.1 PERCENT
 R-SQUARED = 8.3 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS=SS/DF
REGRESSION	1	21.7875	21.7875
RESIDUAL	904	248.0181	0.2744
TOTAL	905	259.8056	

FIGURE 48. Normalized load range, all data.



-- REGR C12 1 C15

THE REGRESSION EQUATION IS
 $Y = 5.32 - 0.926 X1$

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	F-RATIO COEF/S.D.
--		5.41823	0.06574	82.82
X1	C15	-0.9261	0.1981	-4.67

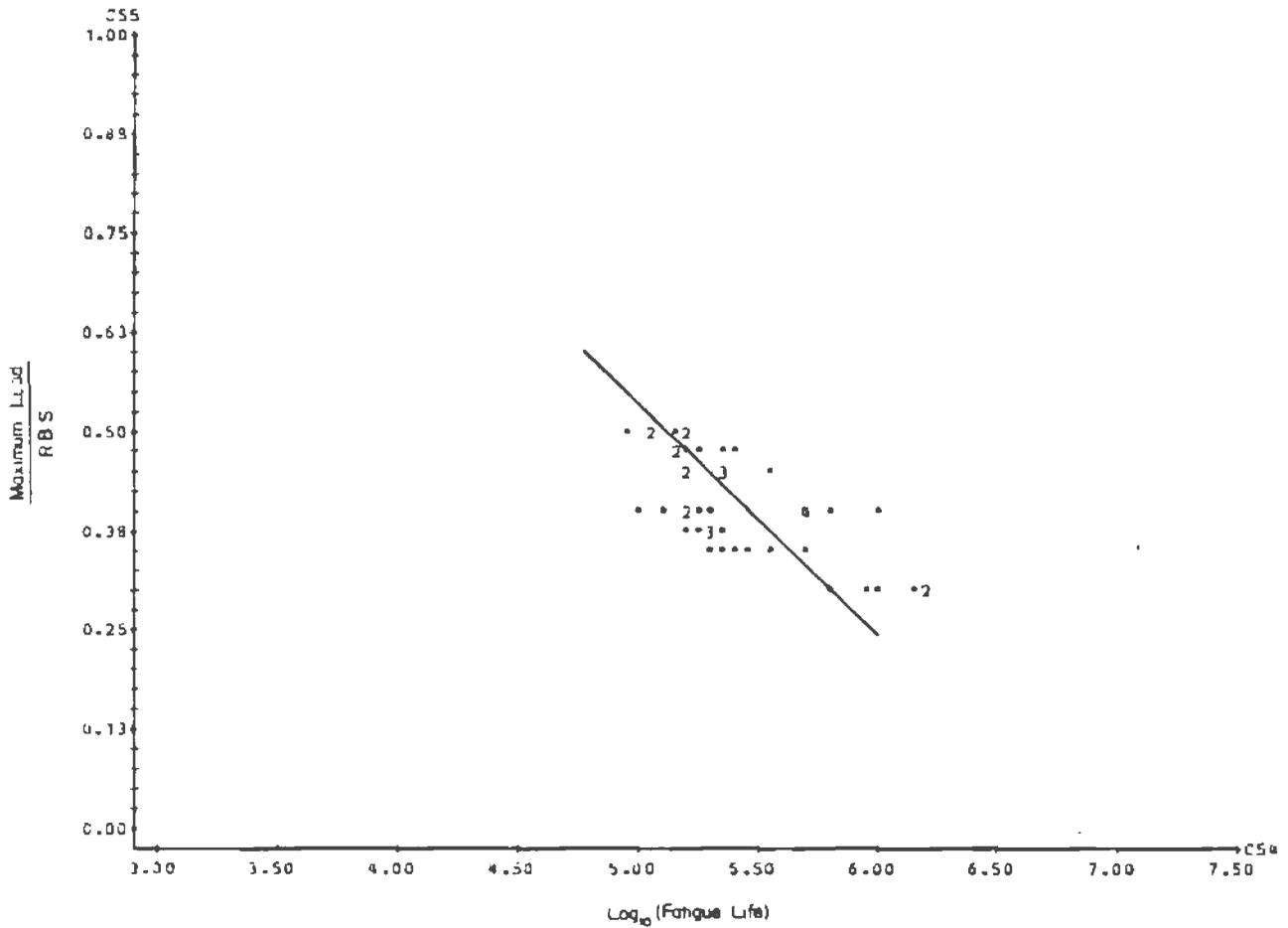
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.5398$
 WITH (906 - 2) = 904 DEGREES OF FREEDOM

R-SQUARED = 2.0 PERCENT
 R-ADJUSTED = 2.3 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DOF TO	DF	SS	MS SS/DF
REGRESSION	1	0.3684	0.3684
RESIDUAL	904	297.4371	0.2914
TOTAL	905	299.8056	

FIGURE 49. Normalized equivalent load, all data.



-- REGR C54 1 C55

THE REGRESSION EQUATION IS
Y = 5.64 - 1.46 X

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO COEF/ST.D.
X1	C55	-1.4598	0.23506	-6.28

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS

S = 0.2391

WITH (48 - 2) = 46 DEGREE OF FREEDOM

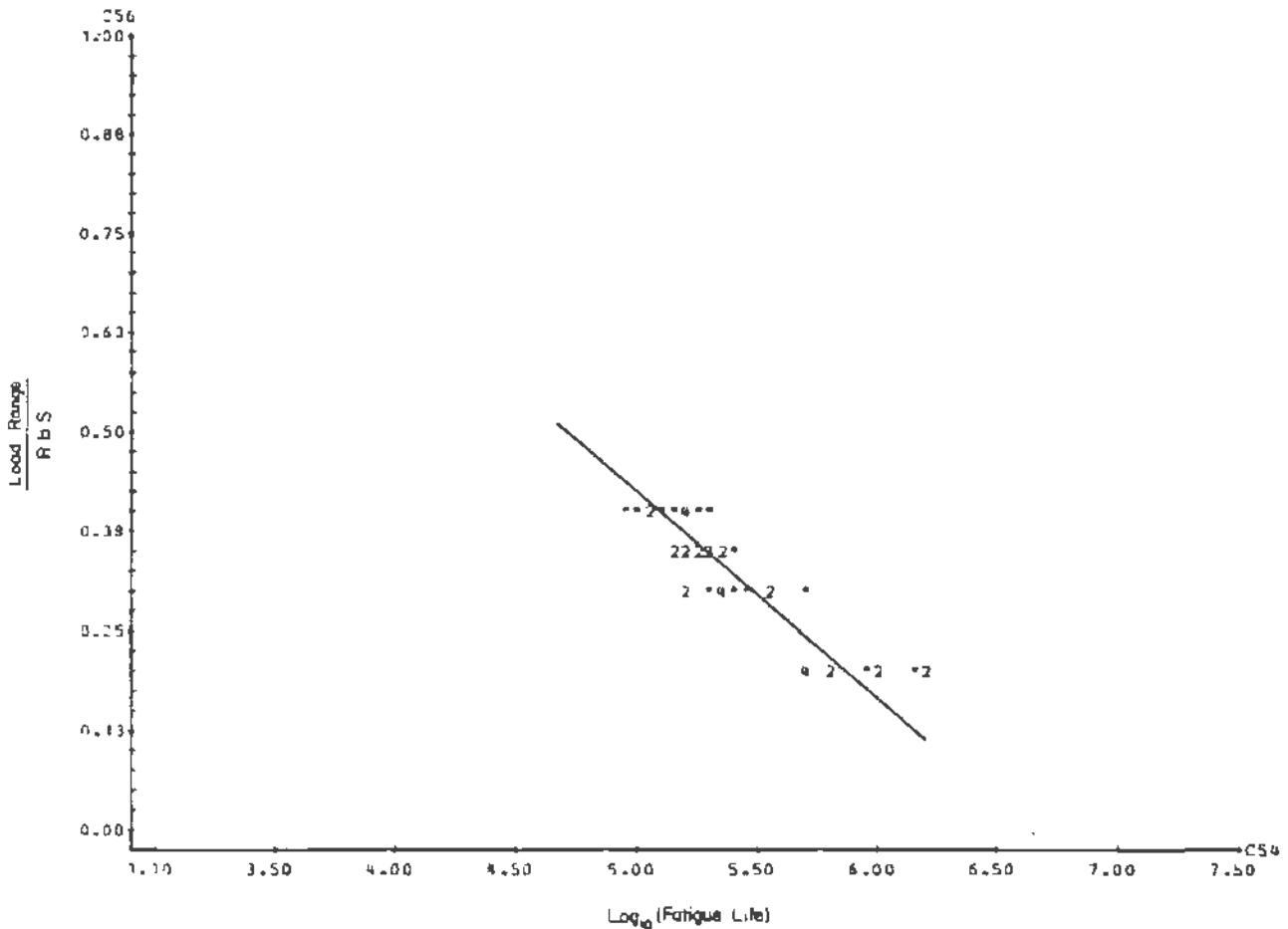
R-SQUARED = 46.2 PERCENT

R-SQUARED = 45.0 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	1	2.26191	2.26191
RESIDUAL	46	2.63523	0.05729
TOTAL	47	4.89714	

FIGURE 50. Normalized maximum load, 6 x 37, IWRC, RL, 2-4 week prior exposure to sea water.



-- BECH C54 1 C56

THE REGRESSION EQUATION IS
 $Y = 6.65 - 1.90 X$

	COLOM	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO COEF/S.D.
--		6.64728	0.09181	72.72
X1	C56	-3.8957	0.2884	-13.70

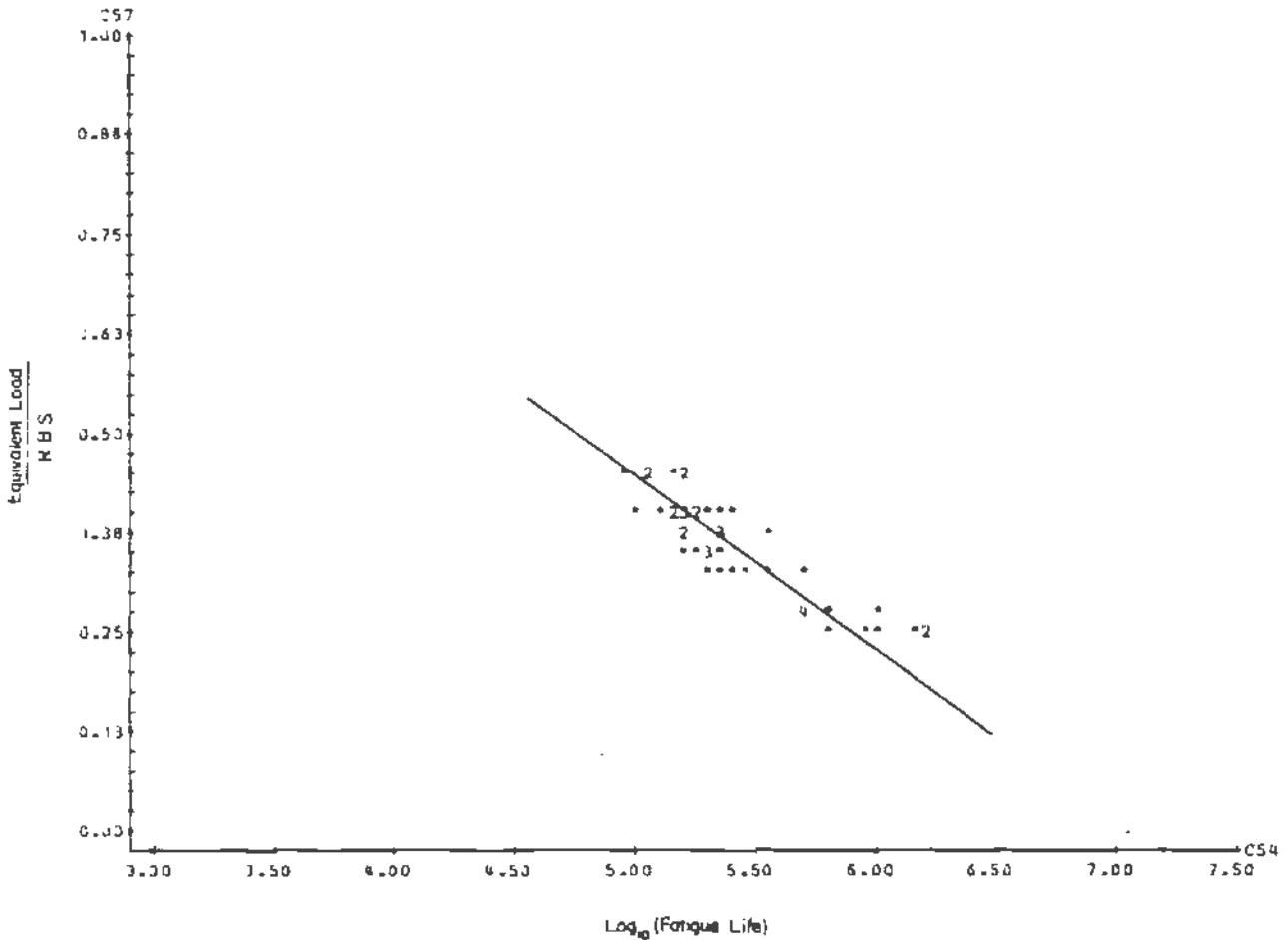
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.1408$
 WITH (48 - 2) = 46 DEGREES OF FREEDOM

R-SQUARED = 80.1 PERCENT
 R-ADJUSTED = 79.9 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS=SS/DF
REGRESSION	1	3.93289	3.93289
RESIDUAL	46	3.06425	0.02096
TOTAL	47	6.67714	

FIGURE 51. Normalized load range, 6 x 37, IWRC, RL, 2-4 week prior exposure to sea water.



-- REGR CS4 1 CS7

THE REGRESSION EQUATION IS
 $Y = 7.05 - 4.57 X$

	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO
1	7.0524	0.1168	60.40
X1	-4.5748	0.3239	-14.13

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.1412$
 WITH (48 - 2) = 46 DEGREES OF FREEDOM

R-SQUARED = 81.3 PERCENT
 R-SQUARED = 80.9 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS=SS/DF
REGRESSION	1	3.97965	3.97965
RESIDUAL	46	0.91749	0.01995
TOTAL	47	4.89714	

FIGURE 52. Normalized equivalent load, 6 x 37, IWRC, RL, 2-4 week prior exposure to sea water.

much less scattered, and that the second and third parameters provide a nearly equal consolidation of the data. An examination of another data collection for 1 x 19 strand is shown in Figures 53 through 55. These results showed convincingly that, under the various conditions of loading that might be encountered, the second parameter, involving a normalized load range, was the most useful consolidating parameter.

A second example of the usefulness of the current axial-fatigue data base centers on the question of rope construction effects. The axial-fatigue resistance of two different IWRC, regular-lay, six-strand ropes was compared with that for a 1 x 19 strand. The data for the 6 x 25 construction are presented in Figure 56. A comparison of this result with the comparable results on the other two construction (previously shown in Figures 51 and 54) revealed that, of the three constructions considered, the 6 x 25 construction shows the lowest fatigue resistance and the 6 x 37 construction shows the highest resistance to fatigue degradation.

A final example focuses on the influence of core type on axial-fatigue resistance. The data base for the 6 x 37, IWRC, regular-lay rope (previously presented in Figure 51) was compared with that for a 6 x 37, fiber-core, regular-lay rope that is shown in Figure 57. It is apparent that the data indicate that the axial-fatigue resistance for the 6 x 37 construction is virtually independent of core type.

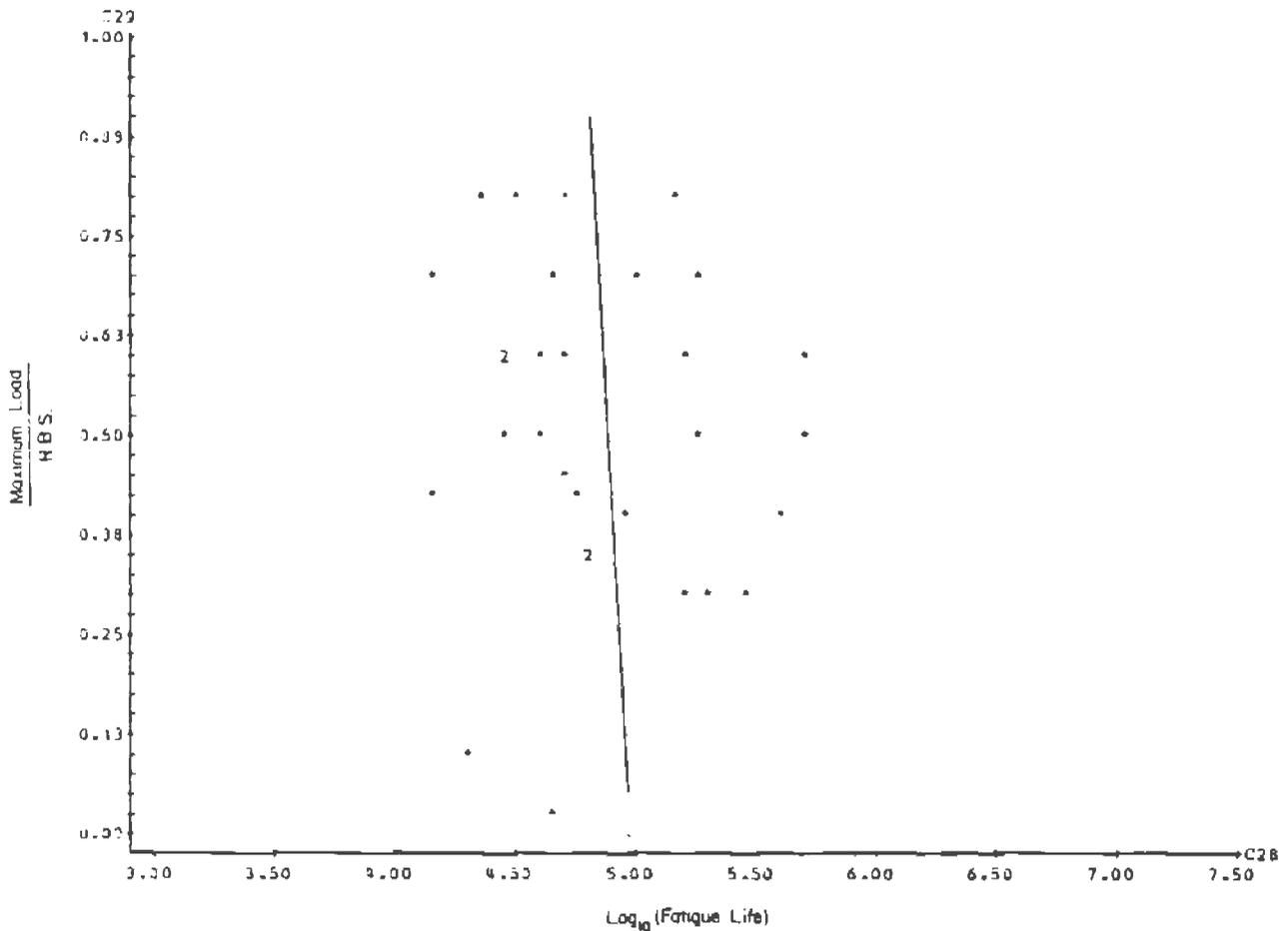
Bend-Over-Sheave Fatigue Data

The bend-over-sheave fatigue data which were collected were encoded in the format described in Appendix C. The list of variables shown in Table 31 was constructed from the complete list in Appendix C for analysis of the bend-over-sheave fatigue data. About two-thirds of the complete list of variables was retained in its original form, while 6 derived variables were constructed that were known or thought to be of importance. The other variables were omitted either because they were inadequately defined or they were not pertinent.

The bend-over-sheave fatigue data which were obtained in this program are summarized in Table 32. A broad range of data sources, rope constructions, rope diameters and fatigue lives are represented.

The bend-over-sheave fatigue data base is even more broad than the axial-fatigue data base. A number of different analyses can be performed as indicated in Table 33. Several examples of analyses are presented along with results to illustrate the ways in which the data base can be utilized.

The first example involves an examination of the influence of core type on bending-fatigue resistance. The commonly used bearing-pressure ratio is used as a consolidating parameter. Figure 58 shows the result for a 6 x 36 WS, fiber-core, regular-lay rope subjected to reverse bending. The comparable result is shown in Figure 59 for a 6 x 36 WS, IWRC, regular-lay rope, also subjected to reverse bending. Note that the bending-fatigue



-- S208 C28 1 C29

THE REGRESSION EQUATION IS:
 $Y = 4.96 - 1.216 X1$

	COLUMN	COEFFICIENT	ST. DEV. OF COEFF.	T-RATIO COEF/S.D.
--		4.9557	0.2261	21.92
X1	C29	-0.2155	0.4107	-0.52

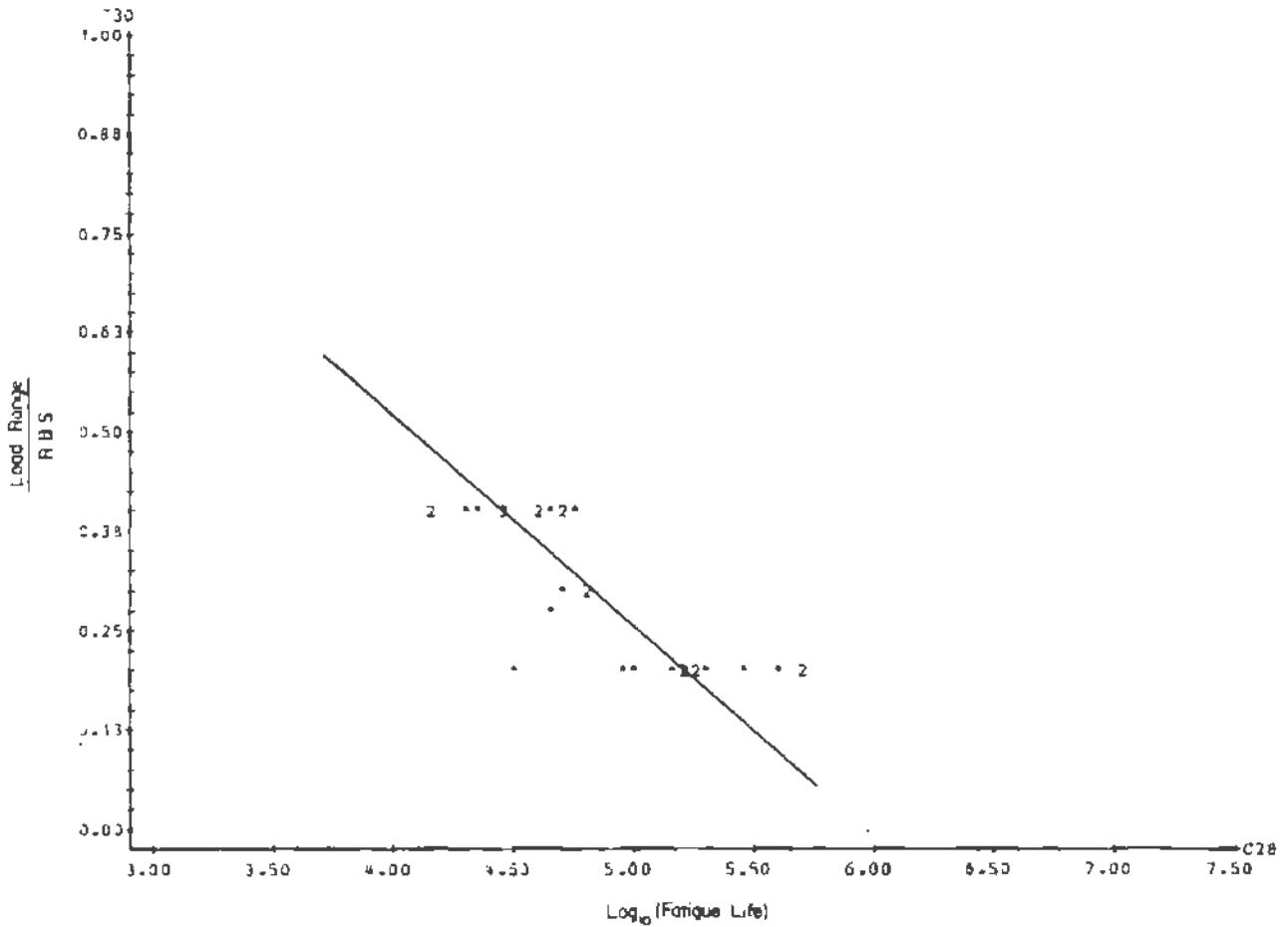
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.4446$
 WITH $(30 - 1) = 28$ DEGREES OF FREEDOM

R-SQUARED = 1.0 PERCENT
 R-SQUARED = 2.6 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS/DF
REGRESSION	1	0.0544	0.0544
RESIDUAL	28	5.5337	0.1976
TOTAL	29	5.5882	

FIGURE 53. Normalized maximum load, 1 x 19 strand.



-- BEGB C28 1 C30

THE REGRESSION EQUATION IS
 $Y = 5.98 - 3.60 X$

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO - COEF/ST.D.
Y1	C30	-3.7953	0.5040	-7.53

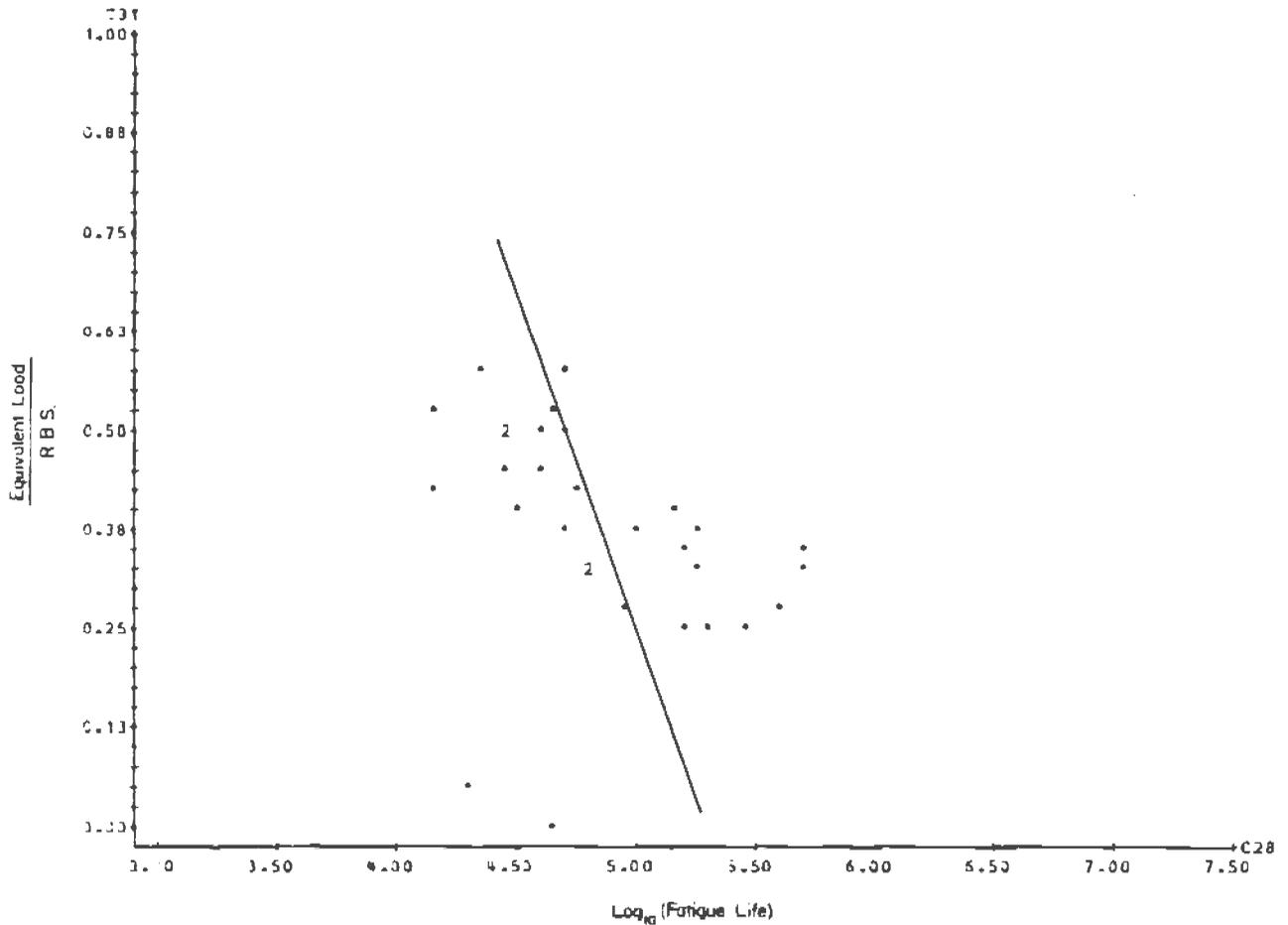
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.2568$
 WITH (30 - 2) = 28 DEGREES OF FREEDOM

R-SQUARED = 67.0 PERCENT
 R-SQUARED = 65.8 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS/DF
REGRESSION	1	1.74134	1.74134
RESIDUAL	29	1.84673	0.06399
TOTAL	29	3.58807	

FIGURE 54. Normalized load range, 1 x 19 strand.



-- BECH C28 1 C31

THE REGRESSION EQUATION IS
 $Y = 5.29 - 1.20 X$

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO COEF/ST.D.
		5.2896	0.2315	22.85
X1	C31	-1.1996	0.5897	-2.03

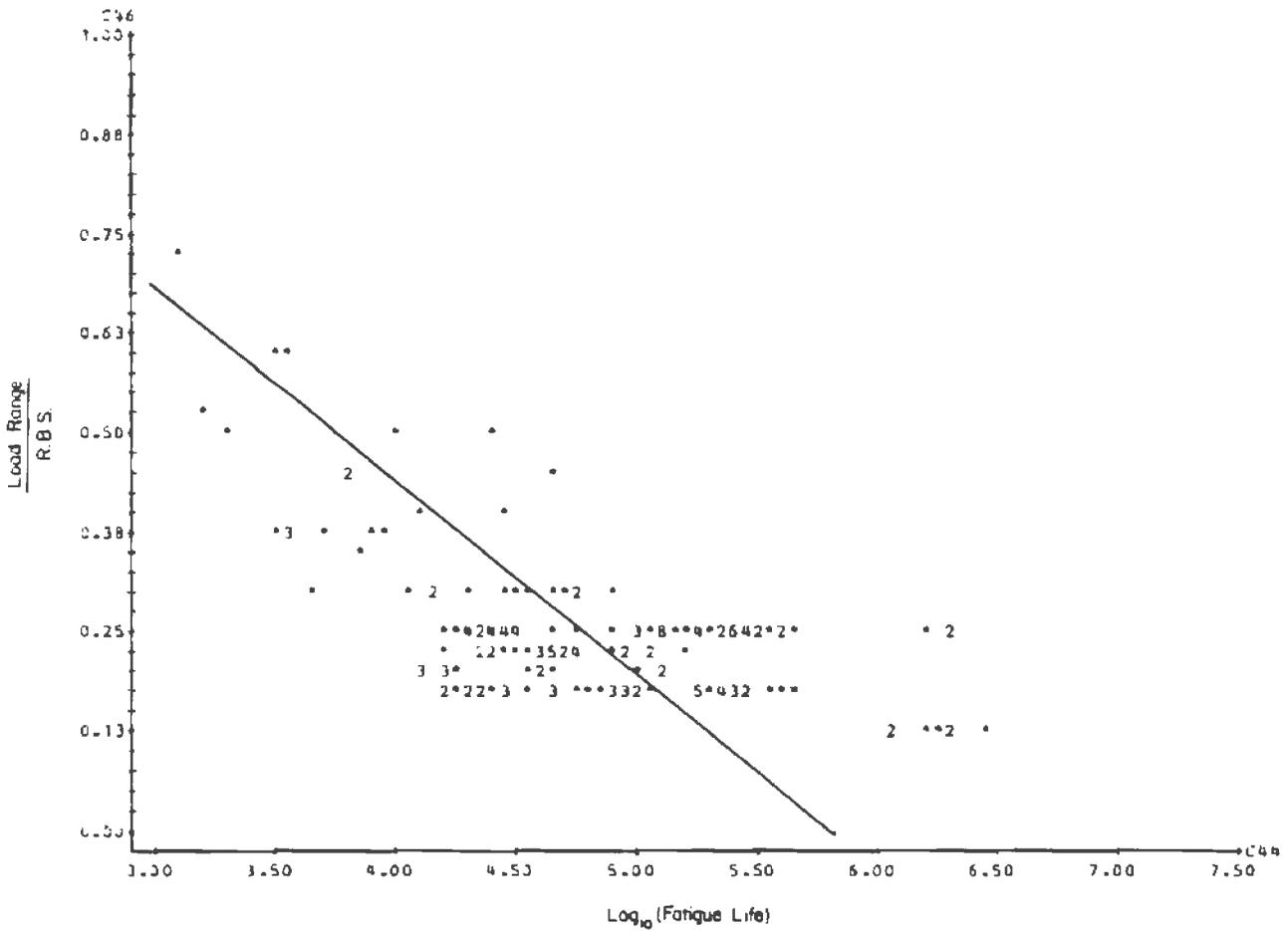
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.8170$
 WITH (30 - 2) = 28 DEGREES OF FREEDOM

R-SQUARED = 12.9 PERCENT
 R-SQUARED = 9.8 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS=SS/DF
REGRESSION	1	0.7196	0.7196
RESIDUAL	28	4.8686	0.1739
TOTAL	29	5.5882	

FIGURE 55. Normalized equivalent load, 1 x 19 strand.



-- HECB C44 1 C46

THE REGRESSION EQUATION IS
 $Y = 5.61 - 4.17 X1$

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/S.D.
		5.9093	0.1127	51.54
X1	C46	-4.1723	0.4318	-9.66

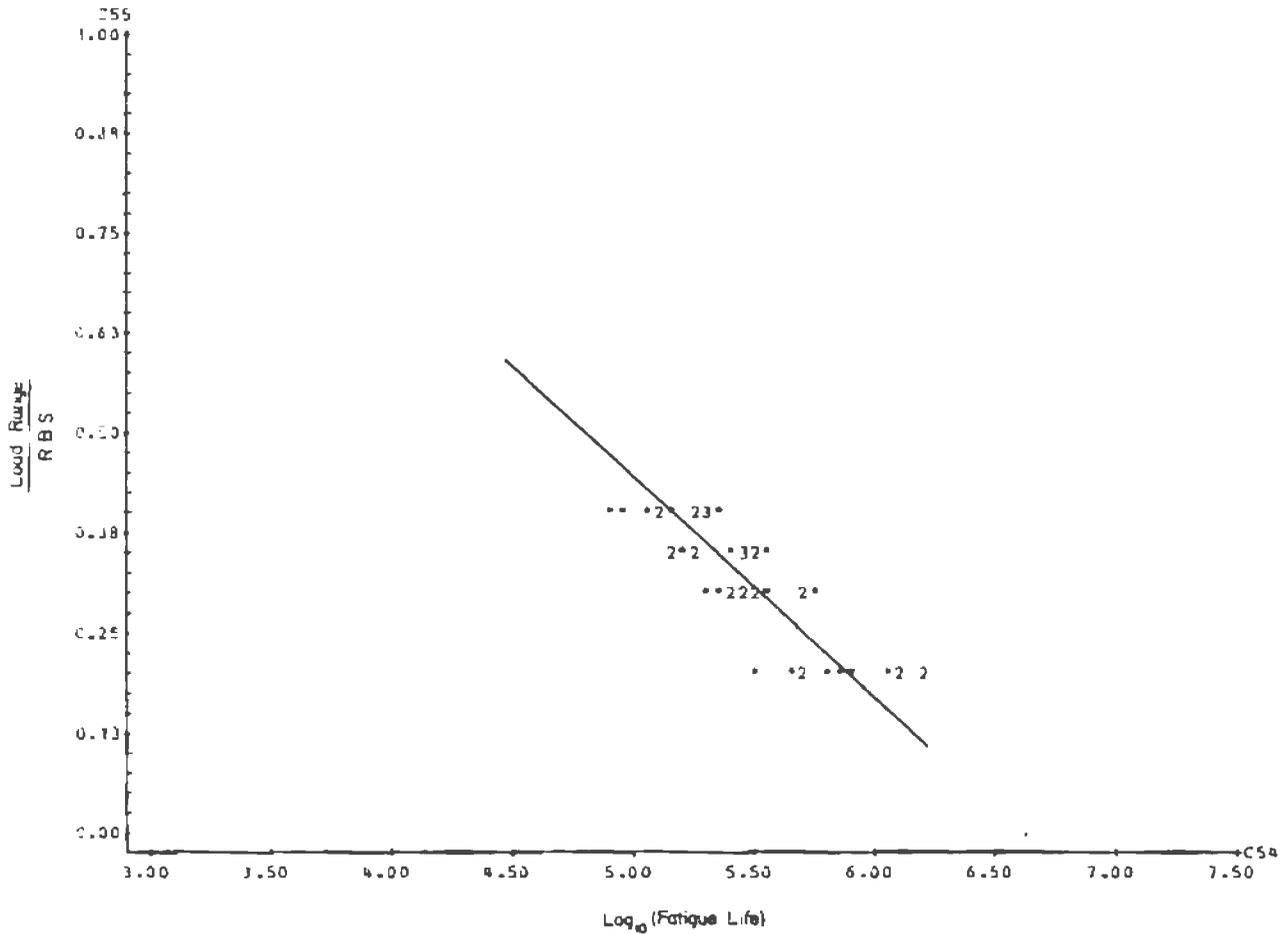
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.5216$
 WITH (190 - 2) = 188 DEGREES OF FREEDOM

R-SQUARED = 33.2 PERCENT
 F-SQUARED = 12.8 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS=SS/DF
REGRESSION	1	25.3926	25.3926
RESIDUAL	188	51.1406	0.2720
TOTAL	189	76.5333	

FIGURE 56. Normalized load range 6 x 25, IWRC, RL.



-- F008 054 1 055

THE REGRESSION EQUATION IS

$$Y = 6.61 - 3.66 X$$

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/ST.D.
--		6.6256	0.1096	52.33
X1	055	-3.6599	0.1255	-11.24

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS

$$S = 0.1657$$

WITH (48 - 2) = 46 DEGREES OF FREEDOM

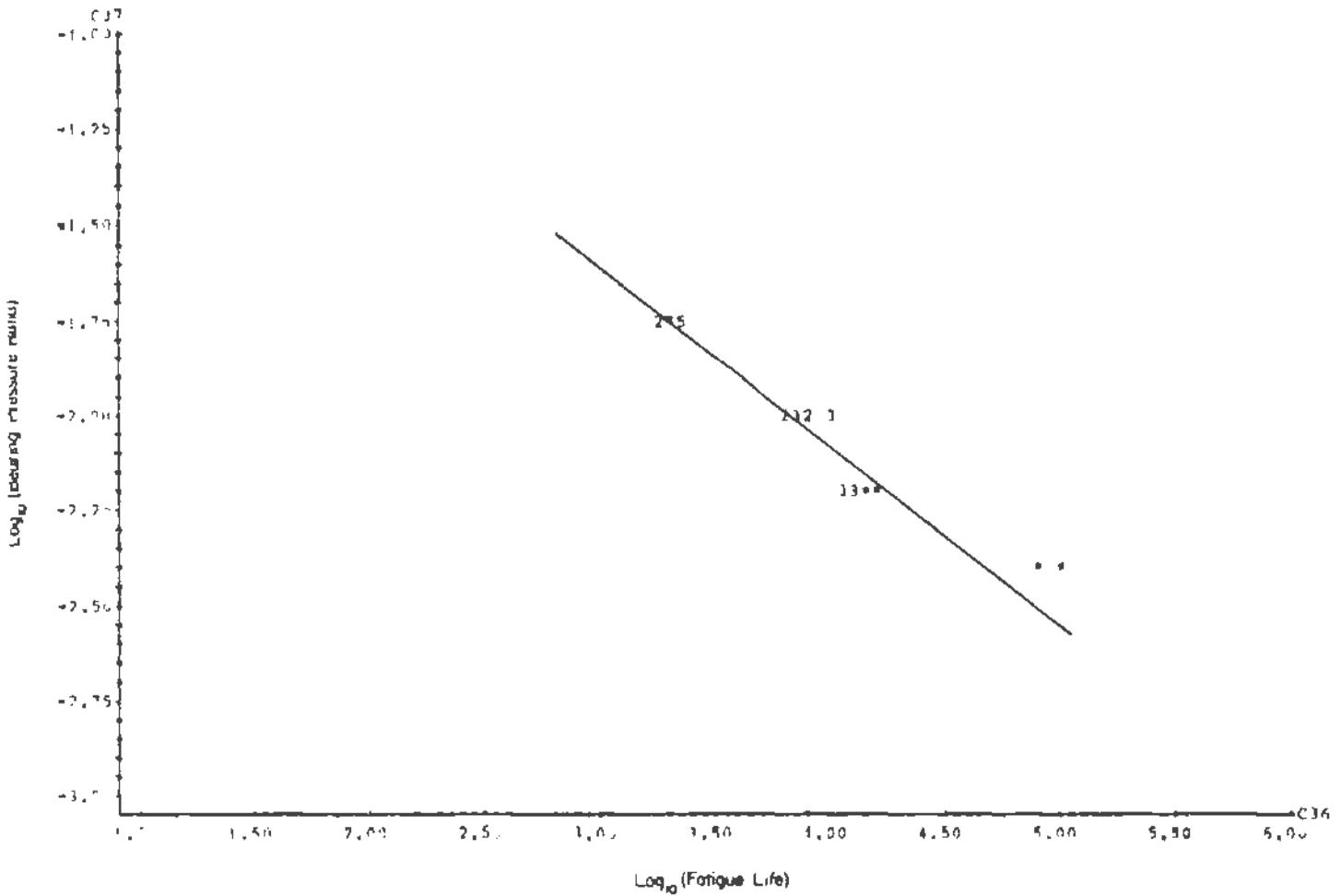
R-SQUARED = 73.3 PERCENT

R-ADJUSTED = 72.7 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

	DFE TO	DF	SS	MS-SS/DF
REGRESSION	1		3.46932	3.46932
RESIDUAL	46		1.26310	0.02746
TOTAL	47		4.73242	

FIGURE 57. Normalized load range, 6 x 37, FC, RL, 2-4 week prior exposure to sea water.



== REGR C16 Y C17

THE REGRESSION EQUATION IS

$$Y = -0.196 - 2.12 X1$$

	COLUMN	COEFFICIENT	ST. EV. OF COEFF.	T-RATIO = COEFF/ST. EV.
	==	-0.1960	0.2590	-1.53
X1	C17	-2.1272	0.1284	-16.53

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS

$$S = 0.1331$$

WITH (26 - 2) = 26 DEGREES OF FREEDOM

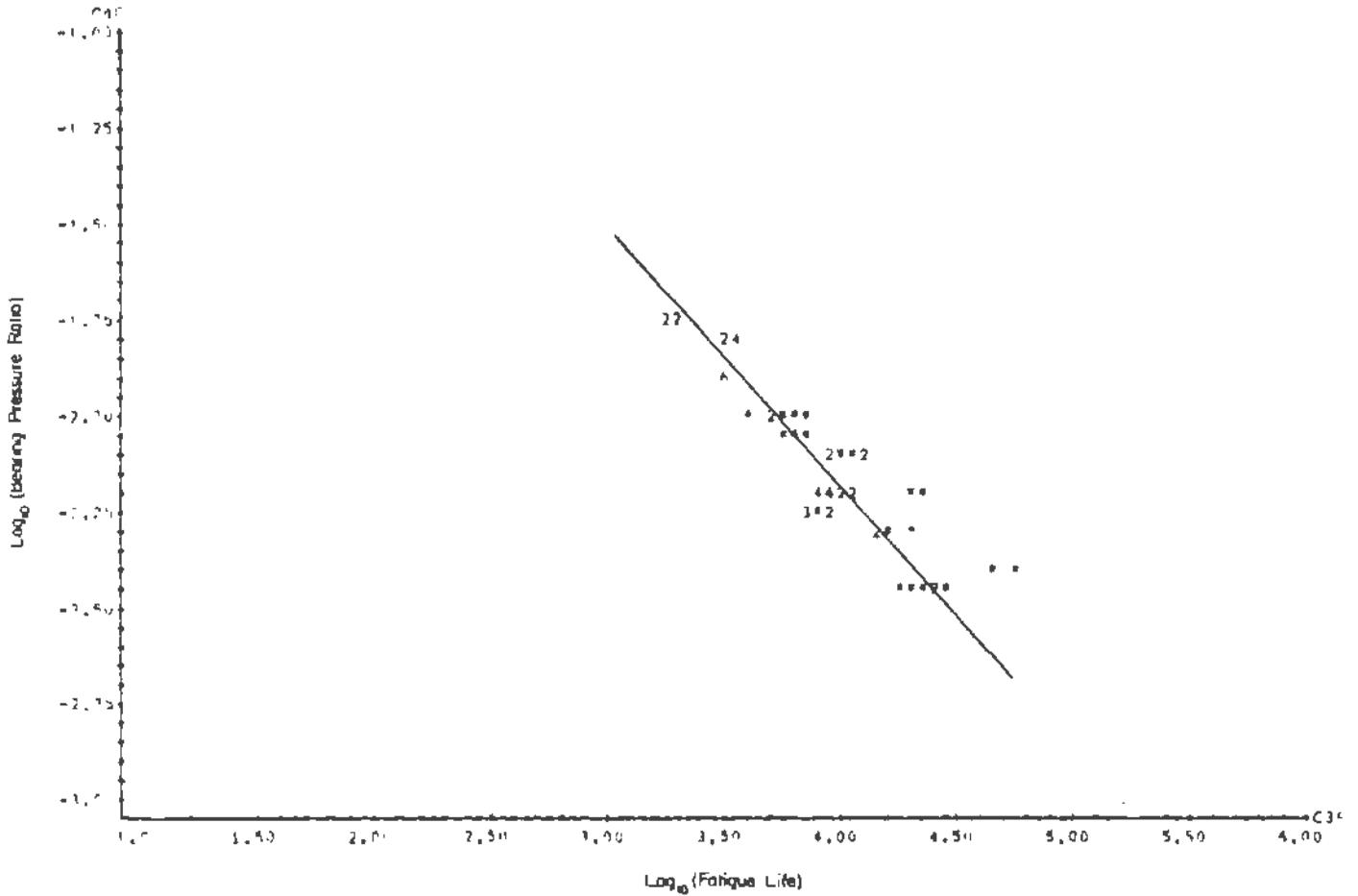
R-SQUARED = 91.1 PERCENT

R-SQUARED = 91.0 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS
REGRESSION	1	3.4336	3.4336
RESIDUAL	24	0.1603	0.01772
TOTAL	25	3.5939	

FIGURE 58. 6 x 36 WS, FC, RL, reverse band.



== REGR C19 1 040

THE REGRESSION EQUATION IS

$$Y = 0.719 - 1.49 X1$$

	COEFFICIENT	ST. DEV. OF COEFF.	T-RATIO = COEFF/ST.D.
X1	-1.49044	.07996	-18.62

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS

$$S = 0.1311$$

WITH (60 - 2) = 58 DEGREES OF FREEDOM

R-SQUARED = 84.5 PERCENT

R-ADJUSTED = 84.2 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
REGRESSION	1	6.6612	6.6612	5.0935
RESIDUAL	58	1.1149	.019214	
TOTAL	59	7.7761		

FIGURE 59. 6 x 36 WS, IWRC, RL, reverse band.

TABLE 31. LIST OF VARIABLES FOR ANALYSIS OF
LABORATORY BEND-OVER-SHEAVE
FATIGUE DATA

Variable No.	Definition	Variable Definition
1	Rope Diameter, Inch	V2
2	Rope Construction	V3
3	Type of Lay	V4
4	Wire Material Code	V5
5	Core Type	V6
6	Lubricant Code	V7
7	Rated Breaking Strength, kips	V8
8	Actual Breaking Strength, kips	V9
9	Average Exterior Wire Strength	V10
10	Number of Exterior Wires/Strand	V11
11	Data Source Number	V13
12	Sheave Groove Radius, inch	V14
13	Sheave Groove Hardness	V17
14	Type of Bend	V20
15	Design Factor	V24
16	D/d	V26
17	Rope Tension, kips	V27
18	Cycling Frequency, cycles/minute	V30
19	Swivels	V31
20	Fatigue Life, Machine cycles	V32
21	Failure Criteria	V34
22	Strength Loss at Failure Criterion, % of RBS	$100 - (V35/V8) \cdot 100$
23	Fatigue Life, Bending Stress Reversals	$V32 \cdot X$
	Where	$V20 \cdot X$
		1 1
		2 2
		3 4
		4 4
		5 6
		6 6
		7 8
		8 10
		9 8
24	Bearing Pressure Ratio	$2 \cdot V27 / (V9 \cdot V26 \cdot V2^2)$
25	Modified Bearing Pressure Ratio	$20 \cdot V27 / (V11 \cdot V9 \cdot V26 \cdot V2^2)$
26	Preformed	0 Preformed
		1 Nonpreformed
27	Rope Categories	1 Flattened Strand
		2 6 x 19 Class Round Strand
		3 6 x 7 Class Round Strand
		4 Locked Coil
		5 8-Strand & Rotation Resistant
		6 6 x 37 Class Round Strand
		7 6 x 61 Class Round Strand
		8 Single Strand

TABLE 32. SUMMARY OF LABORATORY BEND-OVER-SHEAVE FATIGUE DATA

Data Sources	33
Rope Constructions	23
Range of Rope Diameters	0.38 in. - 3.00 in.
Range of Fatigue Lives	2 - 1 million
Test Results	4508

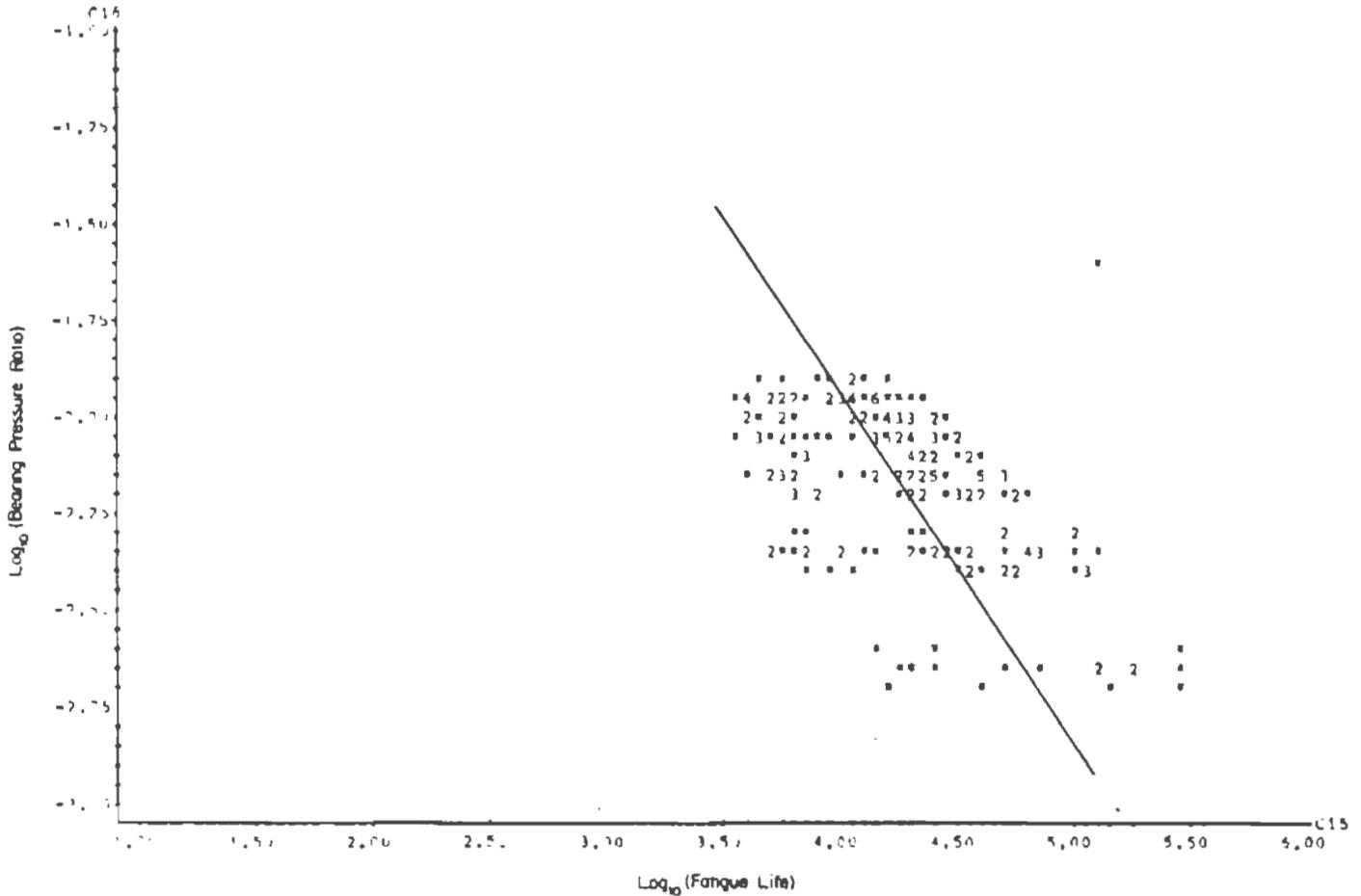
TABLE 33. CORRELATION AND REGRESSION ANALYSES OF BEND-OVER-SHEAVE DATA

Consolidation of Data
Effect of Type of Bend
Effect of Core Type
Effect of Lay Type
Effect of Swivels
Effect of Construction
Effect of Data Source
Effect of Failure Criteria
Effect of Preforming

resistance is comparable at high bearing-pressure ratios, but the fiber-core rope shows superior fatigue resistance at low bearing-pressure ratios. This result is significantly different than that seen for axial fatigue, where core effects were negligible.

A second example centers on an old issue--preforming. It has long been said that preforming provides for superior bending-fatigue resistance. Yet, a large collection of test results for a 6 x 36 WS, fiber-core, regular lay rope subjected to a single bend (see Figures 60 and 61) show only a relatively modest influence of preforming.

Numerous other cases could be examined with both the axial-fatigue and bend-over-sheave fatigue data bases. The cases presented here serve only as examples. Both data bases do contain data for rope constructions currently used in mine-hoist systems. The only significant omission is locked-coil rope--no axial-fatigue or bend-over-sheave fatigue data were found for locked-coil rope. To the extent that axial- and bend-over-sheave fatigue is important to the service life of hoist ropes, these large laboratory data bases will be very useful. Some indications of their applicability can be seen in Figure 62, where average bending stress reversals for the Ontario Special Rope Test data were computed and compared with laboratory data on the basis of bearing-pressure ratio. Certainly, most of the field data fall into the expected range relative to the laboratory data. The only disconcerting factor is that the variation in fatigue performance with decreasing bearing-pressure ratio is negligible in the field ropes and this trend is not well predicted based on laboratory data. This comparison only serves to emphasize the apparent need to consider other factors in addition to fatigue in evaluating the performance of ropes in mine-hoist service.



== REGR C15 I C16

THE REGRESSION EQUATION IS
 $Y = 1.26 + 1.11 X$

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-WALD = COEF/S.D.
==		1.8544	0.2126	7.05
X1	16	-1.1119	0.1116	-9.95

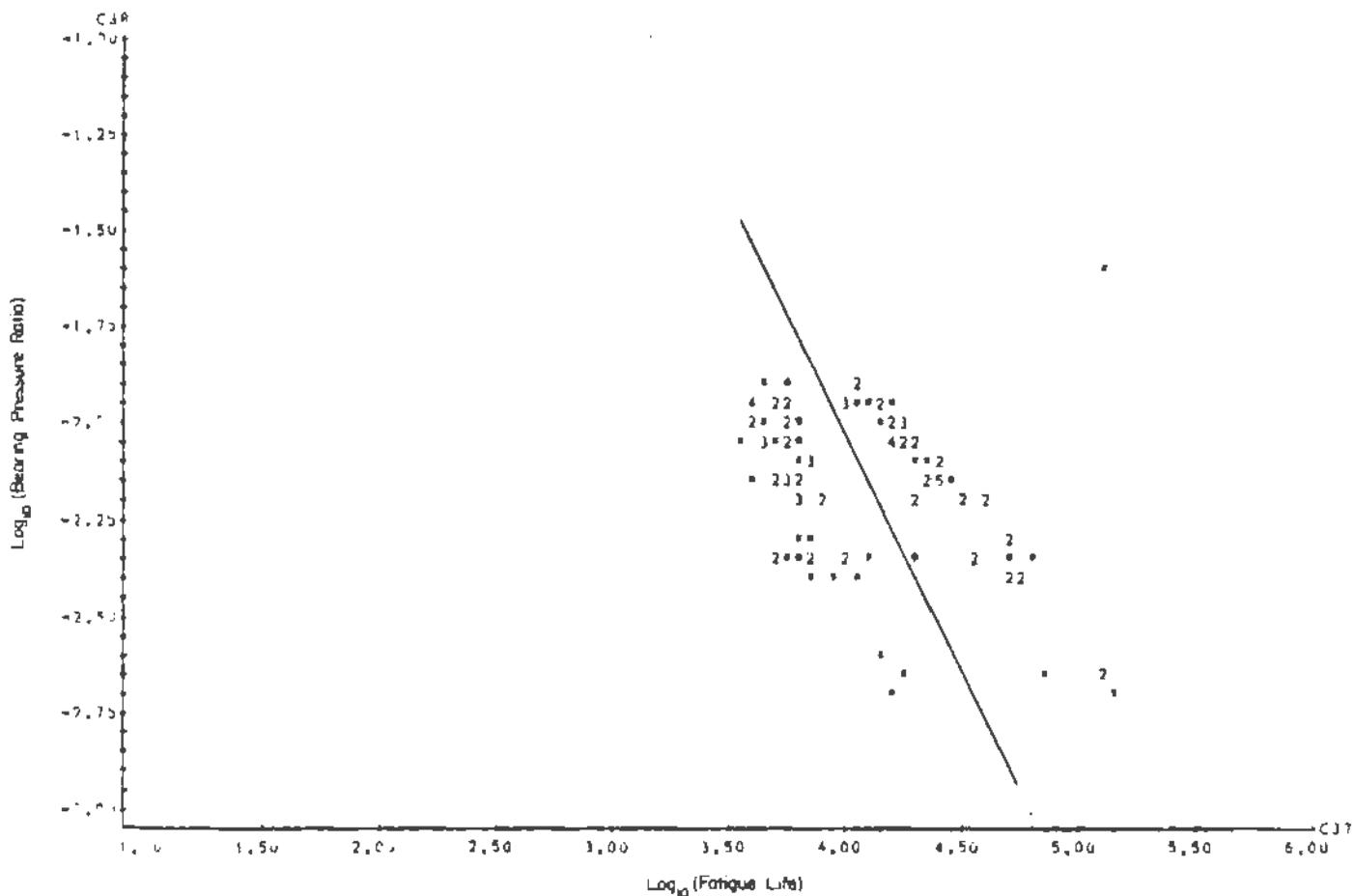
THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.3044$
 WITH (237 - 2) = 235 DEGREES OF FREEDOM

R-SQUARED = 79.7 PERCENT
 R-SQUARED = 74.4 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANTS

	D.F.	SS	MS
DUE TO REGRESSION	1	11.8061	11.8061
RESIDUAL	235	27.9455	0.1189
TOTAL	236	39.7516	

FIGURE 60. 6 x 36 WS, FC, RL, single bend, preformed.



-- REGR C37 3 C3A

THE REGRESSION EQUATION IS
 $Y = 2.33 + 0.820 X_1$

	COLUMN	COEFFICIENT	ST. DEV. OF COEF.	T-RATIO = COEF/ST. D.
--		2.3340	0.3597	6.49
X1	C3A	-0.8201	0.1665	-4.93

THE ST. DEV. OF Y ABOUT REGRESSION LINE IS
 $S = 0.3546$
 WITH (116 - 2) = 114 DEGREES OF FREEDOM

R-SQUARED = 17.6 PERCENT
 R-SQUARED = 18.6 PERCENT, ADJUSTED FOR D.F.

ANALYSIS OF VARIANCE

DUE TO	DF	SS	MS=SS/DF
REGRESSION	1	3.0554	3.0554
RESIDUAL	114	14.4517	0.1259
TOTAL	115	17.4073	

FIGURE 61. 6 x 36 WS, FC, RL, single bend, nonpreformed.

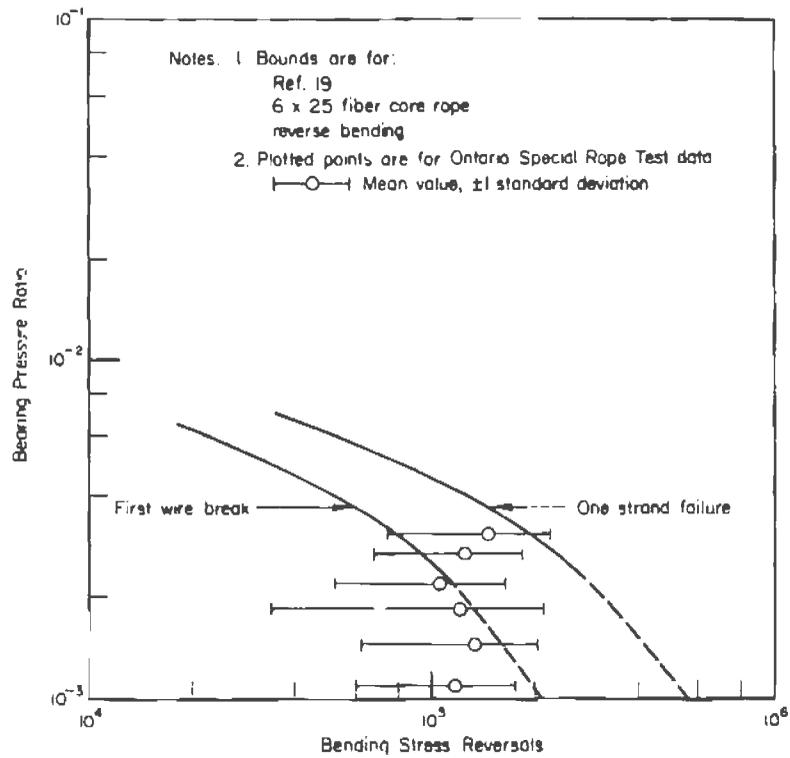


FIGURE 62. A comparison of laboratory and field bend-over-sheave fatigue behavior.

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APPENDIX A

ONTARIO SPECIAL ROPE TEST
DATA FORMAT INFORMATION

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TABLE A-1. SPECIAL ROPE TEST DATA-CARD NO. 1

Variable No.	Columns	Format	Description	Options/Comments
1	1-3	A3	Department of Mines Record No.	
	4	A1	Card No.	(1)
2	5-8	F4.3	Rope Diameter (in.)	
3	9-10	I2	Rope Construction (Code Number)	see Table A-5
4	11	I1	Type of Service (Code Number)	see Table A-6
5	12-15	I4	Length of Service (Days)	
6	16-20	F5.1	Tonnage Hoisted (1,000 Tons)	
7	21-23	F3.0	Live Load (1,000 lb)	
8	24-28	F5.0	Dead Load (lb)	
9	29-32	F4.0	Rope Speed (ft/min)	
10	33-35	I3	Rope Lubricant (Code Number)	see Table A-7
11	36-37	I2	Lubricant Application Method (Code Number)	see Table A-8
12	38-39	I2	Lubrication Interval (Days)	
13	40	I1	Continuous Lubrication	1 = yes; 2 = no
14	41-43	F3.0	Drum Diameter (in.)	
15	44-46	F3.0	Sheave Diameter (in.)	
16	47	I1	Number of Rope Layers on Drum	

TABLE A-1. Continued

Variable No.	Columns	Format	Description	Options/Comments
17	48-49	F2.0	Acceleration Time (sec)	
18	50-51	F2.0	Deceleration Time (sec)	
19	52	I1	Type of Chairs	1 = with; 0 = without
20	53	I1	Shaft Conditions	1 = vertical; 2 = slope
21	54	I1	Shaft Ventilation	1 = upcast; 2 = downcast
22	55	I1	Environment	1 = wet; 2 = dry; 3 = humid
23	56-58	F3.1	Mine Water (pH)	
24	59	I1	Loading Operation (Code Number)	see Table A-9
25	60	I1	Reason for Removal (Code Number)	see Table A-10
			Initial Test Results	
26	61-65	I5	Test Number	
27	66-71	F6.0	Breaking Strength (lb)	
28	72-73	F2.1	Extension (in.)	
			Torsional Strength (Turns)	
29	74-75	F2.0	I.W., Inner Wires	
30	76-77	F2.0	O.W., Outer Wires	
31	78-80	F3.1	Core Lubrication (%)	

TABLE A-2. SPECIAL ROPE TEST DATA-CARD NO. 2

Variable No.	Columns	Format	Description	Options/Comments
	1-3	A3	Department of Mines Record No.	
	4	A1	Card No.	(2)
32	5-6	F2.0	Length of <u>Initial</u> Test Piece (in.)	
33	7-12	F6.0	Minimum Breaking Load (lb)	
34	13-18	F6.0	Maximum Breaking Load (lb)	
35	19-21	F3.0	E.M. Prediction at Point of Minimum Strength (percent of maximum)	
36	22-24	F3.1	Extension at Minimum Point (in.)	
37	25-27	F3.1	Extension at Maximum Point (in.)	
			Diameter at "Total Static Load" (in.)	
38	28-31	F4.3	at Minimum Point	
39	32-35	F4.3	at Maximum Point	
40	36-37	F2.0	Length of Test Piece at Minimum (in.)	
41	38-39	F2.0	Length of Test Piece at Maximum (in.)	
			Appearance of Rope at Minimum Point	see Table A-11
42	40-41	I2	External (Code Numbers)	
43	42-43	I2	Internal (Code Numbers)	
	44-47	4X		

TABLE A-2. Continued

Variable No.	Columns	Format	Description	Options/Comments
			Lubrication Rating at Minimum Point	see Table A-12
44	48	I1	Exterior of Strand (Code)	
45	49	I1	Character (Code)	
46	50	I1	Interior of Strand (Code)	
47	51	I1	Character (Code)	
48	52	I1	Core (Code)	
49	53	I1	Character (Code)	
			Corrosion Rating at Minimum Point (Code No.)	see Table A-13
50	54	I1	Lock Wires	
51	55	I1	Outer Wires (Rail)	
52	56	I1	Inner Wires (Round, second layer)	
53	57	I1	Filler Wires (Round, third layer)	
			Torsion Tests at Minimum Point (Number of Turns)	
54	58-59	F2.0	Lock Wires	
55	60-61	F2.0	Outer Wires (Rail)	
56	62-63	F2.0	Inner Wires (Round, second layer)	
57	64-65	F2.0	Filler Wires (Round, third layer)	
			Lubricant in Core at Minimum Point	

TABLE A-2. Continued

Variable No.	Columns	Format	Description	Options/Comments
58	66-68	F3.1	(Percent by Weight)	
59	69-73	F5.3	Length of Lay at Minimum Point (in.)	
60	74-78	F5.3	At Maximum Point (in.)	

TABLE A-3. SPECIAL ROPE TEST DATA-CARD NO. 3

Variable No.	Columns	Format	Description	Options/Comments
	1-3	A3	Department of Mines Record No.	
	4	A1	Card No.	(3)
61	5-8	F4.0	Total Length of Rope in Service (ft)	
62-68	9-22	7A2	Remarks	see Table A-14
69	23	A1	Other Service	see Table A-15
70	24-27	F4.0	Length of Rope from Sprout to Point of Minimum Breaking Load, ft	Drum Hoist: from attachment on drum FH: from CWT Balance Rope: from CWT
71	28-29	I2	No. of broken wires at cause of Retirement Point	
72	30	I1	Galvanized Wire	1 = yes; 2 = no
73	31	I1	Classified Rope Construction	see Table A-16
74	32-33	I2	No. of Breaking Strength Tests Done	
75	34-35	I2	No. of Tests Encoded with B.S. \leq 95%	No. of 4 cards after this one
76	36-38	I3	Extra Idlers, pulleys, sheaves, diam. (in.)	
77	40	I1	No. of ropes for friction hoist	
78	42	I1	Rope wind	1 = over; 2 = under; 3 = both
79	69	I1	Lubricant Application Category	see Table A-17

TABLE A-3. Continued

Variable No.	Columns	Format	Description	Options/Comments
80	70	I1	Rope Usage (Service) Category	1 = Drum Hoist 2 = Friction Hoist 3 = Friction Tail 4 = Slope Hoist
81	71-74	14	Date of Test (mo/yr)	
82	75-80	16	Mine/rope Identification Code	see Table A-18

TABLE A-4. SPECIAL ROPE TEST DATA-CARD NO. 4

Variable No.	Columns	Format	Description	Options/Comments
	1-3	A3	Department of Mines Record No.	
	4	A1	Card No.	(4)
	5-10	F6.0	Breaking Load (16)	
35	11-13		E.M. Prediction	
36	14-16	F3.1	Extension (in.)	
38	17-20	F4.3	Diameter (in.)	
			Appearance (see Table B-5)	
42	21-22	I2	External	
43	23-24	I2	Internal	
			Lubrication Code	
44	25	I1	Exterior	
45	26	I1	Character	
			Corrosion Rating	
50	37	I1	Lock Wires	
51	32	I1	Outer Wires	
52	34	I1	Inner Wires	
53	34	I1	Filler Wires	
			Torsion Tests	
54	35-36	F2.0	Lock Wires	
55	37-38	F2.0	Outer Wires	
56	39-40	F2.0	Inner Wires	
57	41-42	F2.0	Filler Wires	

TABLE A-4. Continued

Variable No.	Columns	Format	Description	Options/Comments
58	43-45	F3.1	Lubricant in Core (Percent by weight)	
59	46-50	F5.3	Length of Lay	
71	51-52	I2	Broken Wires	
70	53-56	F4.0	Location	

TABLE A-5. ROPE CONSTRUCTION
Code Numbers

<u>Code</u>	<u>Description on Original Record</u>
1. 6 x 14/12/3/3	Left Lang Lay, Galv.
2. 6 x 12.6.6.1	Lang Lay
3. 6 x 12/12/3/3	Lang Lay
4. 6 x 12/6/6/1	
5. 6 x 12/12/3	Lang Lay
6. 6 x 14/12/3/3	Right Lang Lay - Galv.
7. 6 x 12/12/3	Galv. - Lang Lay
8. 6 x 12/6/6/1	12 Core, Galv., Armoured, Lang Lay
9. 6 x 9.12.3.3	Galv., Lang Lay
10. 1 x 45,40,28,24,16,16,8,8,1	Locked Coil
11. 6 x 12/12/3/3	
12. 6 x 12/12/3	
13. 1 x 32,24,16,16.8.8.1	Galv., Locked Coil
14. 6 x 12/12/3/3	Galv. Lang Lay
15. 1 x 39,32.22.17.12.6.6.1	Galv. Locked Coil
16. 1 x 44,36,26.21.16.16.8.8.1	Locked Coil
17. 1 x 33,28.17.12.6.6.1	Galv. Locked Coil
18. 1 x 33.24.16.16.8.8.1	Locked Coil
19. 1 x 40.38.27.22.17.12.6.6.1	Locked Coil
20. 12/6 x 7/4	Lang Lay
12/6 x 12/212	Lang Lay
21. 1 x 42.38.25.19.16.16.8.8.1	Locked Coil
22. 1 x 36.26.17.12.6.6.1	Galv. Locked Coil
23. 1 x 35.26.16.16.8.8.1	Locked Coil
24. 35.32.22.17.12.6.6.1	Locked Coil
25. 6 x 12.12. -6	Lang Lay
26. 6 x 9.9.1	Galv. Lang Lay
27. 6 x 12.12.3.3	Galv., Right Lang Lay
28. 1 x 40.40.27.22.17.12.6.6.1	Locked Coil
29. 12/6 x 12.2.2	Lang Lay
12/6 x 7.6.1	Lang Lay
30. 1 x 37.28.17.12.6.6.1	Galv. Locked Coil
31. 6 x 12.6.6.1	12/Core (Arm. Core)
32. 6 x 8.8.1	
33. 6 x 10.5.5.1	Lang Lay
34. 6 x 8.8.1	Lang Lay
35. 6 x 12/12/	
36. 6 x 13.12.3.3	
37. 6 x 12.6.6.1	Regular Lay
38. 1 x 31.26.22.12.12.5.1	Galv. Locked Coil
39. 1 x 37.30.28.17.12.6.6.1	Galv. Locked Coil
40. 34 x 6/1	Galv.
41. 1 x 31.26.22.14.14.7.1	Locked Coil
42. 6 x 12.12. -6	
43. 6 x 10/5/5/1	Armoured Core 12/Core

TABLE A-5. Continued

<u>Code</u>	<u>Description on Original Record</u>
44.	12 Strand, 6 x 12/2/2 6 x 7/
45.	6 x 6/1
46.	6 x 12/12/1
47.	18 x 6/1
48.	6 x 10/5/5/1
49.	1 x 31/26/22/14/14/7/1
50.	18 x 7
51.	6 x 9/6/1
52.	6 x 9/12/3/3
53.	6 x 9/12/
54.	6 x 13/12/
55.	6 x 10/5/5/1
56.	6 x 27 Type 403 (IHC)
57.	6 x 10/12/
58.	6 x 12/12/3
59.	6 x 19
60.	6 x 10/12/3/3
61.	6 x 12/12/3/3
62.	Lang Lay, High Tensile Locked Coil, Galvanized
63.	1 x 176 Locked Coil
64.	6 x 12/12/ 6/1 Galvanized
65.	6 x 12/12/3/3 Nylon Core
66.	1 x 31/24/16/16/8/8/1 Locked Coil, Galvanized
67.	17 x 6/1 34 11 x 6/1 6 x 6/1
68.	17 x 7 34 11 x 7 6 x 7
69.	17 x 6 34 11 x 6 6 x 6
70.	1 x 35/28/16/16/8/8/1 Locked Coil
71.	6/7

TABLE A-6. TYPE OF SERVICE
Code Numbers

<u>Code</u>	<u>Description</u>	<u>Classification</u>			
		<u>Light Duty</u>	<u>Heavy Duty</u>	<u>Tail and Counterweight</u>	<u>Sinking</u>
0.	Tail Rope			X	
1.	Skip		X		
2.	CWT (Counterweight)			X	
3.	Cage	X			
4.	C.B.			X	
5.	Car		X		
6.	Double Deck Cage	X			
7.	Bottom Dump		X		
8.	B.D. Skip		X		
9.	Skip Under Cage		X		

TABLE A-7. ROPE LUBRICANT CODE NUMBERS

Code	Lubricant
0	None
1	Keystone WRD 00 and 0
2	Grease-Keystone Medium
3	Float Coat
4	Elbac 0
5	Keystone Light
6	Crater A and 9 in equal parts
7	Elbac #2
8	Elbac 75
9	Elbac 75
10	Leadolene 55
11	Shell Ensis and Rustban
12	Crater X and Crater A
13	Elbac #3
14	Brooks 617
15	Keystone Semi-Solid
16	Keystone
17	BA 65-964
18	Shell
19	Borcote #900
20	Keystone "M"
21	Marathon
22	Whitmore #65
23	Shell Ensis 260
24	Prestige 740 AEP "Sun Oil"
25	Klingfast Brooks Oil
26	Rustban (to 1964), Bryto P-1 (after 1964)
27	QS-1268-F
28	Elbac 1
29	Prestige 740
30	BA 70 904
31	Klingfast
32	Shell Ensis
33	Fina Cable-Semi-Fluid
34	Keystone "M"
35	Klingfast 900
36	Keystone 400
37	Elbac 3F
38	Shell Cable Dressing
39	BA Duralube
40	Rustban
41	Shell Ensis 260 and Rustban 390 in equal parts

TABLE A-7. Continued

Code	Lubricant
43	Winter-Keystone; Summer-Elbac 3F
44	Elbac #2, "Pen-o-led"
45	Crater "A"
46	Keystone Heavy
47	BA 70 949
48	Float Coat (Jan '55-Nov. '59) #704 AEP "Sun Oil" (Nov. '59-Dec. '60)
49	Keystone Light and Heavy
50	BA 49 430
51	Duralube 5150
52	Keystone Heavy and Medium
53	Ba 5150
54	Elbac (First 6 months) Float Coat (Second 6 months)
55	Imperial Colbex 46
56	Donald WR Lube
57	Imperial #2 Elbac
58	Shur-stay L2
59	Duralube 5140
60	McColl Fron. Vesta, Hot
61	Imperial X39 46
62	Vesta
63	A & B Chapman
64	McColl Frontenac
65	Imperial Elbac 3F & 2
66	Keystone & Elbac #2
67	McColl Vesta
68	BA 5140 Duralube
69	Hodson 7 MEH
70	Elbac 3F & #0
71	E 415 Hodson "Donald"
72	Shur-stay & Keystone
73	Campbell's Black Diamond
74	Colban 70
75	Donald Rope Lube
76	Campbell & Cyl. Oil
77	MCFR Marathon
78	Imperial Tridox #0
79	Keystone "0"
80	Brooks 617
81	Shell Shur-stay
82	Bryto Light
83	Keystone K620C 410 Neet
84	Keystone WRD #0
85	Bryto P-1

TABLE A-7. Continued

Code	Lubricant
86	Keystone WRD #00
87	Keystone/Brooks 617
88	Imperial Elbac
89	Black Oil
90	Wyrex B
91	Imp. Tradox
92	Imp. Surett 1000
93	Metal Master (CL-3)
94	Petrolatum
95	"E" Standard
96	Sinclair #2
97	Sinclair L-811
98	Gulf No-Rust #2
99	Water Soluble Oil
100	Molube 118 (MoS ₂)
101	Citgo Premium WR Compound

TABLE A-8. LUBRICANT APPLICATION
Code Numbers

Code	Description in Original Records	Continuous Drip	Spray	Hand Brush	Box Gland
1	Grease box (lubricator box)				X
2	V box				X
3	Funnel and brush			X	
4	Spray		X		
5	By box				X
6	Norgren spray		X		
7	By hand heated			X	
8	Split box				X
9	By hand (manually)			X	
10	Gravity feed at sheave, brush on drum	X			
11	Split box and spray		X		
12	Pot and spray		X		
13	McLard force feed lubricator (continuous)	X			
14	Box funnel				X
15	Conical gland				X
16	Grease pot and brush			X	
17	Farval air spray		X		
18	Funnel, hot				X
19	Box and air blast		X		
20	Pressure spray		X		
21	Nozzle spray		X		
22	80-100 PS 1 air spray		X		
23	Drip, brush	X			
24	Hot spray		X		
25	Grease through-air cleaned				X
26	By drip	X			
27	Air gun		X		
28	Spray and hand		X		
29	Funnel				X
30	Continuous lubricator	X			
31	Concave box				X
32	Spray and split grease pot		X		
33	Spray and box		X		
34	Box and brush			X	
35	Hand and brush			X	
36	Trough and hand			X	
37	Spray and swab		X		
38	Split box and hand		X		
39	Pacini rope dresser	X			
40	Brush			X	

TABLE A-8. Continued
Code Numbers

Code	Description in Original Records	Continuous Drip	Spray	Hand Brush	Box Gland
41	Funnel and hand			X	
42	Drip and spray		X		
43	Block and gland				X
44	Cone box				X
45	Blocks				X
46	Cone lubricator				X
47	Through box				X
48	Trough				X
49	Piccini application	X			
50	Spray and grease box		X		
51	Hot, through funnel				X
52	Hot, by box and by hand			X	
53	Drip and hand	X			
54	Press, pump operated with sheave wheel shaft	X			
55	Hot, cone box				X
56	Split cone box				X
57	Bucket			X	
58	Pump	X			
59	Hot, through split box				X
60	Hot, by hand and cone-type box			X	
61	Hot, through conical box				X
62	Hot, through box				X
63	Hot, funnel with rubber bushings				X
64	Hand and box			X	
65	Grease block				X
66	Humphrey box				X
67	Run through lubricator				X
68	Pressure pump	X			
69	Through trough				X
70	Cone and bushes				X
71	Hot, box				X
72	Slip lubricator box				X

TABLE A-9. LOADING OPERATION CODE NUMBERS

Code	
1	One Loading Pocket
2	Three Loading Pockets
3	Two Loading Pockets
4	Loading Pockets at 1900 and 3000 feet
5	2 Loading Pockets Plus Car Loading on Lower Levels
6	20 Operating Levels

TABLE A-10. REASON FOR REMOVAL CODE NUMBERS

Code

- | | |
|----|---|
| 0. | Due to low torsions |
| 1. | Low EM Test results |
| 2. | EM Device results |
| 3. | Broken wires |
| 4. | Lengthy service |
| 5. | Discovery of bad section by 10 CPS EM Device |
| 6. | Shortness |
| 7. | The hoisting ropes developed a waviness or spiral appearance and had to be taken out of service |
| 8. | Opened at low point indicated by EM Device and removed from service |
| 9. | Accidentally damaged |
-

TABLE A-11. CLASSIFICATION OF ROPE CONDITION BASED ON RECORDED COMMENTS ABOUT APPEARANCE, REASON FOR REMOVAL, AND "REMARKS"

Code	External Appearance of a Rope at Weakest Point	Classification			
		Worn	Broken Wires	Damaged	Other
1.	Worn - numerous broken wires		X		
2.	Badly worn	X			
3.	Some wear	X			
4.	Worn - 7 broken wires		X		
5.	Good				X
6.	Worn	X			
7.	Worn on 1 side, at least 10 broken wires		X		
8.	Fair				X
9.	Worn, many split wires		X		
10.	Badly worn - 2 broken wires - several split wires	X			
11.	Worn - severe rough wear - one broken wire	X			
12.	Good - grooved streak on one side				X
13.	Good - vertical streaks of wear				X
14.	Some wear - 3 broken wires				X
15.	Worn - 4 broken wires - 2 split wires	X			
16.	Damaged Section - 3 broken wires			X	
17.	Good - except for wavy distortion				X
18.	Some wear on one side - 18 broken wires		X		
19.	Fair worn				X
20.	Worn - 1 broken wire	X			
21.	Badly worn - 6 split wires - one broken wire	X			
22.	Good - some wear				X
23.	Worn on one side				X
24.	Some wear; many broken wires		X		
25.	Damaged section; many broken wires			X	
26.	Bulge in test piece			X	
27.	Worn - 2 split wires - one broken wire	X			
28.	Fair - outer wires worn	X			
29.	Fair - 2 broken wires				X
30.	Worn - 20 broken wires		X		

TABLE A-11. Continued

Code	External Appearance of a Rope at Weakest Point	Classification			
		Worn	Broken Wires	Damaged	Other
31.	Some wear - 4 broken wires				X
32.	Numerous broken wires		X		
33.	Worn - 25 broken wires in damaged area			X	
34.	Fair - some wear				X
35.	Fair, worn, loose wires				X
36.	Poor, some wear, 9 broken wires		X		
37.	Good, some wear on one side				X
38.	Poor, worn on one side, 28 broken wires		X		
39.	Badly worn, 5 broken wires	X			
40.	Worn - 8 broken wires		X		
41.	Worn - 6 broken wires		X		
42.	Badly worn - slack strands	X			
43.	Poor				X
44.	Good - 1 clamp mark			X	
45.	Poor, some wear, 11 broken strands		X		
46.	Fair some wear, 9 split wires		X		
47.	Fair, worn, 4 split wires				X
48.	Some wear on one side - 13 broken wires		X		
49.	Worn on one side - 45 broken wires		X		
50.	Badly worn; strands and wires slack	X			
51.	Some wear; kink halfway between sockets			X	
52.	Worn, 4 broken wires	X			
53.	Some wear, slack wires, broken filler wires protruding		X		
54.	Worn on one side, 31 broken wires		X		
55.	Fair, some wear, clamp mark			X	
56.	Damaged section, severe kink distortion, worn			X	
57.	Some wear on one side, 29 broken wires		X		
58.	Worn, 21 broken wires		X		

TABLE A-11. Continued

Code	External Appearance of a Rope at Weakest Point	Classification			
		Worn	Broken Wires	Damaged	Other
59.	Badly worn, 5 split wires, 3 broken wires	X			
60.	Worn, kink 15 in. from socket			X	
61.	Worn on one side, 7 broken wires		X		
62.	Badly worn, 30 broken wires		X		
63.	Fair, worn on one side, 3 clamp marks			X	
64.	Poor, badly worn, 4 broken wires	X			
65.	Badly worn, outer wires slack	X			
66.	Worn, 7 split and 8 broken wires		X		
67.	Some wear on one side	X			
68.	Distortion in test piece			X	
69.	Worn, two split wires				X
70.	Some wear on one side - 11 broken wires		X		
71.	Some wear - one broken wire				X
72.	Worn - 2 broken wires		X		
73.	Worn on one side - clamp marks			X	
74.	Worn - one broken wire				X
75.	Good - some wear	X			
76.	Some wear on one side - 3 broken wires		X		
77.	Worn on one side, 5 broken, 2 split wires		X		
78.	Worn - 2 outer wires broken		X		
79.	Fair - 2 vertical grooved streaks on one side				X
80.	Distortion - wires unlocked			X	
81.	Damaged - several worn spots on one side of test piece			X	
82.	Good - one broken wire				X
83.	Good - several unlocked wires				X
84.	Fair, 4 broken wires		X		
85.	Some wear, 4 clamp marks			X	
86.	Three clamp marks			X	
87.	Kinked section			X	

TABLE A-12. LUBRICATION RATING CODE NUMBERS

1	Good	Viscous
2	Fair	Gummy
3	Poor	Caked
4	Dry	Dry

TABLE A-13. CORROSION RATING CODE NUMBERS

0	No corrosion
1	Very slight corrosion
2	Corrosion scale established
3	Wire completely scale covered
4	Surface completely corroded
5	Surface completely corroded with loss of cross-section
6	Very severe corrosion

TABLE A-14. REMARKS CODE NUMBERS

Slope	1)	22-degree incline	
	2)	47-degree 30-inch incline with 6-1/2-inch diameter rollers at 200-foot intervals	
	3)	5-3/4-inch diameter rollers every 50 feet	
Test	4)	Test piece appeared damaged	
	5)	Test piece broke at bulge	
	6)	Test piece broke at point of broken wires	
	7)	Numerous wires found broken	
	8)	Many inner wires found broken	
	9)	Broken wires found on opening ends for socketing	
	10)	Strands slack	
	11)	Rope broke at clamp mark	
	12)	Wires began breaking at 40,000 lbs	
	13)	At minimum point wires began breaking at 157,000 lbs.	
	14)	At point of minimum strength test piece broke at marker	
	Wear	15)	Flange crossover point (minimum)
		16)	Corrosion spotty in all test pieces
		17)	Internal wear
18)		Severe internal wear	
19)		Nicking between strands	
20)		Deep nicking between strands	
21)		High humidity	
22)		100% RH	
23)		Warm	
24)		Dusty	
Water		25)	Seepage
	26)	Seepage - surface to 280 feet	
	27)	Saturated from 52 levels	
	28)	Water sump	
Hoist	29)	Crossover not changed	
	30)	Poor alignment 10 to 20 levels	
	31)	Plastic treads	
	32)	Automatic hoisting	
	33)	Hoist is air operated	
	34)	Bicylindrical conical hoist	
35)	Hydraulic equalizer used at skip end		
Other	36)	Drum end cut to change crossover	
	37)	Rope changed to counterweight after sinking stopped	
	38)	Shaft out of line	
	39)	Nonspin rope	
	40)	Spin released once per month	

TABLE A-15. OTHER SERVICE CODE NUMBERS

Code	
1	Skip
2	Counterweight
3	Cage
4	Counterbalance
5	Car
6	Bottom-Dump Skip

TABLE A-16. ROPE CONSTRUCTION CODE NUMBER CLASSIFICATIONS

Code	Construction	Percent of Total Cases
1	6 x 30G	28
2	6 x 27H	10
3	6 x 25FW	36
4	6 x 21FW	1
5	6 x 19S	1
6	6 x 17S	4
7	6 x 7	1
8	Locked Coil	7
9	8-Strand nonspin	2
0	Balance rope constructions	<u>10</u> 100

TABLE A-17. LUBRICANT APPLICATION CODE NUMBERS

Code	
1	Continuous Drip
2	Spray
3	Hand Brush
4	Box Gland

TABLE A-18. ONTARIO SPECIAL ROPE TEST BREAKDOWN
BY COMPANY AND MINE

Company Number	Mine Number	Record Number(s)
1	1	91, 92, 121, 148, 163, 209
2	1	93, 94, 119, 120
3	1	95, 96, 112, 113
	2	176, 177, 326, 365
4	1	97, 98
5	1	99, 128, 150, 167, 195, 196, 229, 258, 309, 341
	2	155, 156, 194, 391
	3	
	4	169
6	1	100, 137, 151, 182, 186, 193, 220, 244, 269, 273, 284, 285, 297, 302, 325, 327, 328, 338, 385, 397, 398, 416, 422, 424, 471
	2	104, 105, 154, 206, 251, 299, 300, 344, 363, 428

TABLE A-18. Continued

Company Number	Mine Number	Record Number(s)
	3	126, 127, 132, 149, 153, 172, 173, 174, 187, 199, 213, 298, 318, 340, 360, 364, 380, 388, 421, 433
	4	
	5	
	6	160, 212, 281, 342, 343, 375, 384
	7	247, 311, 312, 358
	8	440
	9	458
7	1	101, 159, 185, 201, 219
8	1	102, 103
	2	115, 116
9	1	106
10	1	107, 125
	2	164
11	1	108, 122, 142
12	1	109, 117, 191, 192, 337

TABLE A-18. Continued

Company Number	Mine Number	Record Number(s)
13	1	110
14	1	111, 188, 210, 211, 221, 222, 346, 414, 417
15	1	114
	2	162, 190, 227, 263, 361, 371, 377, 425
	3	291, 314, 351, 352
	4	431
	5	
16	1	144
17	1	123, 124, 165, 166, 272, 282, 367, 382
18	1	129, 135, 158, 250, 255, 294, 295, 359, 395, 404, 407
	2	178, 205
	3	237, 259, 260, 372, 373
	4	253, 347, 348, 349, 410, 426, 430, 432
	5	333

TABLE A-18. Continued

Company Number	Mine Number	Record Number(s)
	6	381
	7	399, 400
	8	401, 409
	9	413, 423, 427, 456
19	1	130, 131, 203, 204, 238, 274
20	1	133, 134, 170, 171
21	1	136, 141, 183, 189, 207, 208, 261
22	1	138, 139, 319
23	1	140
24	1	143, 233, 239, 240, 304
25	1	145, 146
26	1	147
27	1	152, 157, 214, 215, 216, 217, 254, 277, 308, 315, 394
28	1	161, 168, 202, 276, 383
29	1	175, 181, 232, 279, 287, 296, 317, 330, 331

TABLE A-18. Continued

Company Number	Mine Number	Record Number(s)
	2	439
30	1	179, 180, 228, 230, 322
31	1	184, 241, 307, 332, 334, 335
32	1	197, 198, 231, 234, 262, 275, 306, 329, 390
	2	472
	3	473
33	1	200
34	1	223, 226
35	1	224, 225, 270
36	1	235
37	1	236
38	1	242, 345
39	1	243, 264, 266, 286, 366, 368, 389, 435, 438
40	1	245
41	1	246
42	1	248, 256, 257, 288
	2	271

TABLE A-18. Continued

Company Number	Mine Number	Record Number(s)
	3	376
	4	378
43	1	249
44	1	252
45	1	265, 313, 418
46	1	267, 268, 280
47	1	278
48	1	289, 437
49	1	290, 374
50	1	292, 293
51	1	301, 323, 324, 362, 365, 370, 379, 393
52	1	303, 339, 408
53	1	305, 350
54	1	310, 336, 356, 357
55	1	316, 420
56	1	320, 321, 355, 396
57	1	353, 387, 403
58	1	354, 460
59	1	386, 419, 429

TABLE A-18. Continued

Company Number	Mine Number	Record Number(s)
60	1	402
61	1	405
	2	436
62	1	406
63	1	411, 412
64	1	415
65	1	434
66	1	441, 485
67	1	442

APPENDIX B

ROUTINE ROPE TEST DATA FORMAT INFORMATION
(ROPE CUTOFF DATA FROM ONTARIO, MANITOBA
AND NEWFOUNDLAND MINES)

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B-3. Routine Rope Test Data Card No. 3.	B-4

TABLE B-1. ROUTINE ROPE TEST DATA CARD NO. 1

Variable No.	Columns	Format	Description	Options/Comments
1	4	I1	Card No. (Survey No.)	(4)
2	5-20	A16	Company Name	
3	21-30	A10	Mine Name	
4	31-36	A6	Rope ID	
5	37-40	F4.3	Rope Diameter, in.	
6	41-42	I2	Rope Construction	see Table A-5
7	43-44	I2	Service	see Table A-6
8	45-49	F5.1	Initial Breaking Strength, kips	
9	50-55	I6	Installation Date (Mo., Day, Year)	March 12, 1969, e.g., 031269
10	56-61	I6	Removal Date (Mo., Day, Year)	
11	62-63	I2	Reason for Removal	see Table A-10
12	64-66	F3.1	Weight of Conveyance, kips	
13	67-70	F4.1	Total Load	
14	71-72	I2	No. of Tensile Tests	
15	73-74	I2	No. of NDI (Electro-Magnetic) Tests	
16	76-79	I4	Sequence No.	

TABLE B-2. ROUTINE ROPE TEST DATA CARD NO. 2

Variable No.	Columns	Format	Description	Options/Comments
	1	A1	Tensile Test Card ID	(T)
	2-3	I2	Sequence No.	
	4	I1	Card No.	(4)
	5-10	A6	Rope ID	
18	11-15	A5	Test No.	
19	16-21	I6	Test Date	
20	22-25	F4.1	Breaking Load, kips	
21	26-28	F3.1	Extension, in.	
22	29-31	F3.1	Length, in.	
23	32	A1	Lubrication Rating Character	
24	33-35	F3.2	Strand	
25	36-38	F3.2	Core	
26	39-41	F3.2	Corrosion Rating, Outer Wires	
27	42-43	I2	Torsions Outer Wires	
28	44-45	I2	Inner Wires	
29	46-49	F4.1	Remaining Strength, %	
30	50-53	F4.0	Length of Rope Installed	
31	54-57	F4.0	Maximum Length in Service Below	
32	58-59	A2	Core Type	FC (for Fiber Core) of IW (for IWRC)

TABLE B-2. Continued

Variable No.	Columns	Format	Description	Options/Comments
33	60-61	A2	Lay Type	RL (regular) or LL (Lang)
34	62-65	F4.1	Wire Breaking Stress (ksi)	
35	66-69	F4.2	Weight of Rope/ft (lbs)	

TABLE B-3. ROUTINE ROPE TEST DATA CARD NO. 3

Variable No.	Columns	Format	Description	Options/Comments
	1	A1	Electro-Magnetic Test Card ID	(E)
	2-3	I2	Sequence No.	
	4	I1	Card No.	(4)
	5-10	A6	Rope ID	
36	11-16	I6	Test Date	
37	17-19	F3.1	Indicated Strength Loss, %	
			Location of Strength Loss	
38	20	A1		Above (A), Below (B)
39	21	A1		or Skip Convey- ance (S), C.W. (C)
40	22-25	I4	Distance, ft	

APPENDIX C

LABORATORY ROPE TEST DATA FORMAT INFORMATION

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TABLE C-1. LABORATORY DATA CARD NO. 1

Variable No.	Columns	Format	Description	Comments
1	1-2	A2	Type of data	AX - Axial BS - Bend-over-sheave
	3	I1	Card number	"1"
	4	Blank		
2	5-8	F4.2	Diameter of rope, inches	Nominal rope diameter
	9-10	Blank		
3	11-20	A10	Rope construction	Examples 6x25 FW Where 6 = No. of Strands 25 = No. of Wires/Strand FW = Filler Wire Construction
	21-22	Blank		
4	23-24	A2	Lay type	RL - Right Lang Lay LL - Left Lang Lay RR - Right Regular Lay LR - Left Regular Lay
5	25-26	A2	Wire material code number	Table A-4
6	27-28	A2	Core type	IW - Independent Wire Rope Core (IWRC) FN - Fiber Core - Natural FS - Fiber Core - Synthetic IS - Independent Strand Core WS - Wire Spring PC - Plastic Core

TABLE C-1. Continued

Variable No.	Columns	Format	Description	Comments
7	29-30	A2	Lubricant code number	Table A-5
8	31-35	F5.2	Rated breaking load, kips	Catalog breaking load value
	36-37	Blank		
9	38-42	F5.2	Actual breaking load, kips	
	43-44	Blank		
10	45-49	F5.2	Actual average exterior wire strength, ksi	
	50-51	Blank		
11	52-53	I2	Number of exterior wire per strand	8,10,12,14 or 16
	54-55	Blank		
12	56-65	A10	Manufacturer of rope	
	66-75	Blank		
13	76-77	I2	Data source number	Table A-6
	78-80	I3	Coding sheet number	

TABLE C-2. LABORATORY DATA CARD NO. 2

Variable No.	Columns	Format	Description	Comments
14	1-5	F5.2	Sheave groove radius, inches	
	6	I1	Card number	"2"
	7	Blank		
15	8-12	F5.2	Sheave throat angle, degrees	The angle included between the sheave flanges
	13-14	Blank		
16	15-19	F5.2	Fleet angle, degrees	
	20-24	Blank		
17	25-26	A2	Sheave groove hardness (Rockwell C)	1 $R_C \geq 50$ 2 $25 < R_C < 50$ 3 $R_C \leq 25$
	27-28	Blank		
18	29-33	F5.2	Cycling speed (feet/ minute)	
19	34-35	A2	Wrap angle	1 - 180° 2 - 173° 3 - 165° upper & lower sheaves, 150° center 4 - 90° 2 sheaves
20	36	I1	Type of bend	1 = 1/2 single bend 2 = single bend 3 = reverse bend 4 = 2 sheave single bend 5 = 3 sheave single bend 6 = 3 sheave reverse bend 7 = 5 sheave - 8 stress reversals

TABLE C-2. Continued

Variable No.	Columns	Format	Description	Comments
				8 = 5 sheave - 10 stress reversals 9 = 2 sheave - 8 stress reversals
	37-38	Blank		
21	39-42	A4	Environment	LA = laboratory air HA = humid air WB = water bath SW = sea water, no prior exposure SW2 = sea water, 2 week prior exposure SW12 = sea water, 12 week prior exposure
	43-45	Blank		
22	46-47	A2	Termination type	ZA = zinc socket CL = clips SW = swaged socket ES = epoxy socket CA = cappel's TS = thimble splices TP = torpedo sleeve AL = aluminum com- pression sleeve CT = tuck splice

TABLE C-3. LABORATORY DATA CARD NO. 3

Variable No.	Columns	Format	Description	Comments
23	1-6	A6	Test number or identification	Special designation to trace particular result to specific test conditions
	7	I1	Card number	"3"
	8	Blank		
24	9-14	F6.2	Design factor (max. load)	Ratio of rated breaking strength to operating load
25	15-20	F6.2	Design factor (min. load)	
26	21-26	F6.2	D/d	Ratio of sheave pitch diameter to rope diameter
27	27-30	F4.2	Direct tensile load, kips	
28	31-37	F7.3	Stroke length, inches	
29	38-41	F4.0	Rope surface temperature, degree C	
30	42-48	F7.3	Cycling frequency, bending, or axial, cycles/minute	
	49	Blank		
31	50	A1	Swivels Used?	S-swivel
	51-52	Blank		
32	53-60	F8.0	Fatigue life, cycles	Sheave No. 1
	61-64	Blank		
33	65-72	F8.0	Fatigue life, cycles	Sheave No. 2

TABLE C-3. Continued

Variable No.	Columns	Format	Description	Comments
34	73	I1	Failure criteria	1 - One strand failure 2 - 6 wires/lay or 2 wires/strand/ lay 3 - Rope failure 4 - One wire
35	74-80	F7.3	Breaking strength at failure criterion, kips	

TABLE C-4. WIRE MATERIALS

- (1) Extra-Improved Plow Steel
- (2) Improved Plow Steel (IPS)
- (3) Plow Steel
- (4) Mild Plow Steel
- (5) Traction Steel
- (6) Iron Grade
- (7) Hot-Dipped Galvanized IPS
- (8) Al Coated IPS
- (9) 304 L Stainless Steel
- (10) CuNi Clad Stainless Steel
- (11) CuNi Clad Tenelon
- (12) High Grade Plow Steel
- (13) Bethanized IPS
- (14) Drawn Galvanized IPS
- (15) Buton Plastic-Coated IPS
- (16) Electroplated Zn Coated IPS
- (17) Hot-Dipped Zn Coated IPS
- (18) Phoscoat IPS
- (19) Borax Coated IPS

TABLE C-5. CODES FOR LUBRICANT TYPES

Code	Lubricant Type
0	None
93	Metal Master (CL-3)
94	Petrolatum
95	"E" Standard
96	Sinclair #2
97	Sinclair L-811
98	Gulf No-Rust #2
99	Water Soluble Oil
100	Molube 118
101	Citgo Premium WR Compound

TABLE C-6. LITERATURE SOURCES FOR LABORATORY DATA

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APPENDIX D

Examples of AID Inputs and
Outputs for Rope Strength-Loss Analysis

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D-1. AID Variables Input.	D-1
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TABLE D-1 AID VARIABLES INPUT

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE
1 DIAMPTONC	30	EXCLUDE	LT. CR. EQ. TO	-1
		1	0 TO	0
		2	1 TO	400
		3	201 TO	410
		4	411 TO	420
		5	421 TO	430
		6	431 TO	440
		7	441 TO	450
		8	451 TO	460
		9	461 TO	470
		10	471 TO	480
		11	481 TO	490
		12	491 TO	1000
		13	1001 TO	1010
		14	1011 TO	1020
		15	1021 TO	1030
		16	1031 TO	1040
		17	1041 TO	1050
		18	1051 TO	1060
	EXCLUDE	1061 OR OVER		
2 LONGSERV	2	EXCLUDE	LESS THAN	-1
		0	0 TO	198
		1	199 TO	398
		2	399 TO	598
		3	599 TO	798
		4	799 TO	998
		5	999 TO	1198
		6	1199 TO	1398
		7	1399 TO	1598
		8	1599 TO	1798
		9	1799 TO	1998
		10	1999 TO	2198
		11	2199 TO	2398
		12	2399 TO	2598
		13	2599 TO	2798
		14	2799 TO	2998
		15	2999 TO	3198
		16	3199 TO	3398
		17	3399 TO	3598
		18	3599 TO	3798
		19	3799 TO	3998
		20	3999 TO	4198
		21	4199 TO	4398
22	4399 TO	4598		
	EXCLUDE	4599 OR OVER		

TABLE D-1. (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE	
3 LUBRICANT	3	EXCLUDE	LT. OR EQ. TO	7	FREE-FLOATING
		1	1 TO	1	
		2	2 TO	2	
		3	3 TO	3	
		4	4 TO	4	
		5	5 TO	5	
		6	6 TO	6	
		7	7 TO	7	
		8	8 TO	8	
		9	9 TO	9	
		10	10 TO	10	
		11	11 TO	11	
	EXCLUDE	12 OR OVER			
4 LUBAPPLIC	15	EXCLUDE	LT. OR EQ. TO	0	FREE-FLOATING
		1	1 TO	1	
		2	2 TO	2	
		3	3 TO	3	
		4	4 TO	4	
		5	5 TO	5	
	EXCLUDE	5 OR OVER			
5 LUBINTERVL	4	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	4	
		5	5 TO	7	
		6	4 TO	10	
		7	11 TO	14	
		8	15 TO	21	
		9	22 TO	29	
		10	23 TO	35	
		11	34 TO	55	
		12	55 TO	99	
	EXCLUDE	100 OR OVER			
6 O/D	15	EXCLUDE	LESS THAN	40	NONSTOKIC
		0	40 TO	44	
		1	45 TO	49	
		2	50 TO	54	
		3	55 TO	59	
		4	60 TO	64	
		5	65 TO	69	
		6	70 TO	74	
		7	75 TO	79	
8	80 TO	84			
9	85 TO	89			

TABLE D-1. (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE	
		10	90 TO	96	
		11	95 TO	99	
		12	100 TO	106	
		13	105 TO	109	
		14	110 TO	114	
		15	115 TO	119	
		16	120 TO	126	
		17	125 TO	129	
		18	130 TO	136	
		19	135 TO	139	
		EXCLUDE	140 OR OVER		
7 PIPELAYS	5	EXCLUDE	LT. OR EQ. TO	-1	MONITONIC
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	3	
		5	4 TO	4	
		6	5 TO	5	
		7	6 TO	6	
		8	7 TO	7	
		9	8 TO	8	
		10	9 TO	9	
		EXCLUDE	10 OR OVER		
9 CHAIRS	5	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		EXCLUDE	2 OR OVER		
4 SHETCNO	7	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		EXCLUDE	2 OR OVER		
10 SHAFTVNT	8	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		EXCLUDE	3 OR OVER		
11 ENVIRON	4	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	3	
		EXCLUDE	4 OR OVER		

TABLE D-1. (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE	
12 WATEPRH	10	EXCLUDE	LESS THAN	-1	FREE-FLUJATING
		0	0 TO	9	
		1	1 TO	19	
		2	20 TO	29	
		3	30 TO	39	
		4	40 TO	49	
		5	50 TO	59	
		6	60 TO	69	
		7	70 TO	79	
		8	80 TO	89	
		9	90 OR OVER		
13 INITOVRTORS	13	EXCLUDE	LT. OR EQ. TO	-1	MONOTONIC
		1	0 TO	0	
		2	1 TO	2	
		3	3 TO	4	
		4	5 TO	6	
		5	7 TO	8	
		6	9 TO	10	
		7	11 TO	15	
		8	15 TO	20	
		9	21 TO	25	
		10	26 TO	30	
		11	31 TO	40	
		12	41 TO	50	
		13	51 TO	59	
		14	61 TO	70	
		15	71 TO	80	
		16	81 TO	100	
		17	101 OR OVER		
14 INITOVRLOS	14	EXCLUDE	LESS THAN	0	MONOTONIC
		0	0 TO	19	
		1	20 TO	39	
		2	40 TO	59	
		3	60 TO	79	
		4	80 TO	99	
		5	100 TO	119	
		6	120 TO	139	
		7	140 TO	159	
		8	160 TO	179	
		9	180 TO	199	
		10	200 TO	219	
11	220 TO	239			

TABLE D-1. (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE	
		12	240 TO 259		
		13	260 TO 279		
		14	280 TO 299		
		EXCLUDE	300 OR OVER		
15	MAXCAGEACC	35	EXCLUDE	LT. OR EQ. TO	-1
		1	0 TO	0	
		2	1 TO	10	
		3	11 TO	20	
		4	21 TO	30	
		5	31 TO	40	
		6	41 TO	50	
		7	51 TO	60	
		8	61 TO	70	
		9	71 TO	80	
		10	81 TO	90	
		11	91 TO	100	
		12	101 TO	110	
		EXCLUDE	111 OR OVER		
				FREE-FLOATING	
16	WIRESTRENG	36	EXCLUDE	LESS THAN 100000	MONOTONIC
		0	100000 TO	149999	
		1	150000 TO	199999	
		2	200000 TO	249999	
		3	250000 TO	299999	
		4	300000 TO	349999	
		5	350000 TO	399999	
		EXCLUDE	400000 OR OVER		
				MONOTONIC	
17	BEARINGPRS	37	EXCLUDE	LT. OR EQ. TO	-1
		1	0 TO	3	
		2	4 TO	6	
		3	7 TO	9	
		4	10 TO	12	
		5	13 TO	16	
		6	17 TO	20	
		7	21 TO	24	
		8	25 TO	29	
		9	30 TO	32	
		10	33 TO	35	
		EXCLUDE	36 OR OVER		
				MONOTONIC	
18	HACHCYLLES	38	EXCLUDE	LESS THAN	-1
		0	0 TO	1999	
		1	2000 TO	3999	
		2	4000 TO	5999	
		3	6000 TO	7999	

TABLE D-1. (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE
		4	7999 TD 9998	
		5	9999 TD 11998	
		6	11999 TD 13998	
		7	13999 TD 15998	
		8	15999 TD 17998	
		9	17999 TD 19998	
		10	19999 TD 21998	
		11	21999 TD 23998	
		12	23999 TD 25998	
		13	25999 TD 27998	
		14	27999 TD 29998	
		15	29999 TD 31998	
		16	31999 TD 33998	
		17	33999 TD 35998	
		18	35999 TD 37998	
		19	37999 TD 39998	
		20	39999 TD 41998	
		21	41999 TD 43998	
		22	43999 TD 45998	
		23	45999 TD 47998	
		24	47999 TD 49998	
		25	49999 TD 51998	
		26	51999 TD 53998	
		27	53999 TD 55998	
		28	55999 TD 57998	
		29	57999 TD 59998	
		30	59999 TD 61998	
		31	61999 TD 63998	
		32	63999 TD 65998	
		33	65999 TD 67998	
		34	67999 TD 69998	
		35	69999 TD 71998	
		EXCLUDE	70000 OR OVER	
				MONOTONIC
19	09EDSTRLOSS	20	EXCLUDE LT. OR EQ. TO	-1
			1 0 TO	0
			2 1 TO	2
			3 3 TO	5
			4 5 TO	10
			5 11 TO	15
			6 13 TO	20
			7 21 TO	25
			8 25 TO	30
			9 31 TO	40
			10 41 TO	50
			11 51 TO	60
			12 61 TO	70
			EXCLUDE 71 OR OVER	
				MONOTONIC
20	ELONGATION	39	EXCLUDE LESS THAN	0
			0 0 TO	9
			1 10 TO	19
			2 20 TO	29
			3 30 TO	39
			4 40 TO	49
			5 50 TO	59
			6 60 TO	69
			7 70 TO	79
			8 80 TO	89
			9 90 TO	99
			EXCLUDE 100 OR OVER	

TABLE D-1. (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE	
21 LUBINCORE	29	EXCLUDE	LESS THAN	0	FREE-FLOATING
		0	0 TO	19	
		1	20 TO	39	
		2	40 TO	59	
		3	60 TO	79	
		4	80 TO	99	
		5	100 TO	119	
		6	120 TO	139	
		7	140 TO	159	
		8	160 TO	179	
		9	180 TO	199	
		10	200 TO	219	
		11	220 TO	239	
		12	240 TO	259	
		13	260 TO	279	
14	280 TO	299			
	EXCLUDE	300 OR OVER			
22 INCRLAYLENRAT	40	EXCLUDE	LT. OR EQ. TO	-20	FREE-FLOATING
		1	-19 TO	-15	
		2	-14 TO	-10	
		3	-9 TO	-5	
		4	-4 TO	-1	
		5	0 TO	0	
		6	1 TO	5	
		7	5 TO	10	
		8	11 TO	15	
		9	16 TO	20	
	EXCLUDE	21 OR OVER			
23 ROPEAPPAN	11	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	3	
	EXCLUDE	4 OR OVER			
24 LUBRATFXT	22	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	3	
		5	4 TO	4	
		6	5 TO	5	
		7	6 TO	6	
		8	7 TO	7	
	EXCLUDE	8 OR OVER			
25 LUBCHREXT	23	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	3	
		5	4 TO	4	
		6	5 TO	5	
		7	6 TO	6	
		8	7 TO	7	
	EXCLUDE	8 OR OVER			

TABLE D-1. (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE	
25 LUBRATOR	24	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	3	
		5	4 TO	4	
		6	5 TO	5	
		7	6 TO	6	
		8	7 TO	7	
		EXCLUDE	9 OR OVER		
27 LURCHRCR	25	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	3	
		5	4 TO	4	
		6	5 TO	5	
		7	6 TO	6	
		8	7 TO	7	
		EXCLUDE	9 OR OVER		
23 CORROSION	26	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	1	
		3	2 TO	2	
		4	3 TO	3	
		5	4 TO	4	
		6	5 TO	5	
		7	6 TO	6	
		8	7 TO	7	
		EXCLUDE	8 OR OVER		
29 THROUGHPUTS	27	EXCLUDE	LT. OR EQ. TO	-1	FREE-FLOATING
		1	0 TO	0	
		2	1 TO	2	
		3	3 TO	4	
		4	5 TO	6	
		5	7 TO	8	
		6	9 TO	10	
		7	11 TO	15	
		8	16 TO	20	
		9	21 TO	25	
		10	26 TO	30	
		11	31 TO	40	
		12	41 TO	50	
		13	51 TO	60	
		14	61 TO	70	
		15	71 TO	80	
		16	81 TO	90	
		17	91 TO	100	
EXCLUDE	101 OR OVER				

TABLE D-1. (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE
30 LENFRQMDRUM	41	EXCLUDE	LT. OR EQ. TO -2	FREE-FLOATING
			1 -1 TO -1	
			2 0 TO 0	
			3 1 TO 10	
			4 11 TO 20	
			5 21 TO 30	
			6 31 TO 40	
			7 41 TO 50	
			8 51 TO 60	
			9 61 TO 70	
			10 71 TO 80	
			11 81 TO 90	
			12 91 TO 100	
	EXCLUDE	101 OR OVER		
31 BRONWIRE	39	EXCLUDE	LT. OR EQ. TO -1	FREE-FLOATING
			1 0 TO 0	
			2 1 TO 5	
			3 5 TO 10	
			4 11 TO 15	
			5 16 TO 20	
			6 21 TO 30	
			7 31 TO 49	
	EXCLUDE	50 OR OVER		
32 GALVWIRE	15	EXCLUDE	LT. OR EQ. TO -1	FREE-FLOATING
			1 0 TO 0	
			2 1 TO 1	
			3 2 TO 2	
	EXCLUDE	3 OR OVER		
33 CMINEIO	19	EXCLUDE	LT. OR EQ. TO -1	FREE-FLOATING
			1 0 TO 0	
			2 1 TO 1	
			3 2 TO 2	
			4 3 TO 3	
			5 4 TO 4	
			6 5 TO 5	
			7 6 TO 6	
			8 7 TO 7	
			9 8 TO 8	
			10 9 TO 9	
			11 10 TO 10	
12 11 TO 11				
	EXCLUDE	12 OR OVER		
34 DATE	19	EXCLUDE	LESS THAN 47	MONOTONIC
			0 47 TO 43	
			1 49 TO 50	
			2 51 TO 52	
			3 53 TO 54	
			4 55 TO 56	
			5 57 TO 58	
			6 59 TO 60	
			7 61 TO 62	
			8 63 TO 64	
9 65 TO 66				

TABLE D-1 (Continued)

VARIABLE	FIELD NO.	RECODE	CORRESPONDS TO	TYPE	
		10	57 TO	56	
		11	69 TO	70	
		12	71 TO	72	
		13	73 TO	74	
		14	75 TO	75	
		15	77 TO	78	
		16	79 TO	80	
		17	81 TO	82	
		EXCLUDE	83 OR OVER		
				FREE-FLOATING	
35	RDPEUSAGE	17	EXCLUDE	LESS THAN	1
			0	1 TO	1
			1	2 TO	2
			2	3 TO	3
			EXCLUDE	4 OR OVER	
				FREE-FLOATING	
36	RDPEYTYPE	31	EXCLUDE	LESS THAN	1
			0	1 TO	1
			1	2 TO	2
			2	3 TO	3
			3	4 TO	4
			4	5 TO	5
			EXCLUDE	6 OR OVER	
				MONOTONIC	
37	MINIDYNDES	33	EXCLUDE	LESS THAN	0
			0	0 TO	9
			1	10 TO	19
			2	20 TO	29
			3	30 TO	39
			4	40 TO	49
			5	50 TO	59
			6	60 TO	69
			7	70 TO	79
			8	80 TO	89
			9	90 TO	99
			10	100 TO	109
			11	110 TO	119
			12	120 TO	129
			13	130 TO	139
			14	140 TO	149
			15	150 TO	159
			16	160 TO	169
			EXCLUDE	170 OR OVER	

DEPENDENT VARIABLE-Y IN FIELD NO. 33 IS STRENGTHLOSS

YMAX. IS 100...YMIN. IS 1...EXCLUDE 200 200. WEIGHT IN FIELD NO. 30

TABLE D-2. VARIABLE BY VARIABLE SPLITTING ON STRENGTH LOSS

STEP NO.	PARENT GROUP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	100	3012.0000	67334.000	16.021277	10.073652	1353.6292	124021.57												
2	7	224.0000	7552.0000	32.000000	7.4065008	2145.2225	123229.22												
3	6	255.0000	14044.000	44.000000	20.116328	3279.0845	121795.32												
4	14	145.0000	12781.000	27.357143	12.826352	5231.6472	120083.53												
5	36	35.0000	14522.000	17.388889	9.9673851	6131.8341	114243.47												
6	105	1596.0000	35623.000	19.200000	10.522263	6667.2452	118307.95												
7	118	118.0000	38434.000	13.898305	11.512992	5370.2986	119404.00												
8	145	145.0000	33250.000	12.993103	7.775065	4970.6259	120404.58												
9	126	126.0000	35602.000	12.968254	10.694856	4586.1775	120789.02												
10	114	114.0000	21902.000	11.526316	7.6984967	3327.0303	122043.17												
11	128	128.0000	24306.000	11.453125	7.6626727	2219.3996	123155.80												
12	141	141.0000	21210.000	10.255319	6.7271064	403.53782	124965.64												
13	22	22.0000	1537.0000	7.772723	3.0738164	72.165467	125333.04												
14	50	50.0000	12092.000	12.100000	9.7718985	7718.7007	125374.43												
15	18	18.0000	6693.0000	13.025556	14.141047	3001.7871	125374.70												
16	16	16.0000	4417.0000	13.562300	3.5977734	14283532	125373.77												
17	4	4.0000	1802.0000	20.000000	7.1063352	171.40177	125233.80												
18	3	3.0000	110.0000	6.000000	6.61643658														

STEP NO.	PARENT GROUP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19	855	5407.2452	355733.0000	13.000000	8.8981361	10.557083	125364.04												
20	34	34.0000	8438.0000	13.000000	3.2624209	18.363459	125355.84												
21	291	291.0000	52321.000	13.344259	9.7212659	3.8619671	125371.34												
22	293	293.0000	72911.000	13.316996	9.7212659	155.19224	125254.01												
23	337	337.0000	6312.000	12.813056	9.1422542	1712.7813	123635.42												
24	128	128.0000	20450.000	13.406255	7.1745488	757.33291	124617.87												
25	120	120.0000	47137.000	15.925000	11.798420	62.923117	125312.30												
26	74	74.0000	3378.000	16.835443	11.922893														

TABLE D-2. (Continued)

TRY ON PREDICTOR 5	LUBM14VL	SUM OF Y	SUM Y-SQUARE	MEAN	STO. DEV.	d S S	M S S
CODE	TOTAL WEIGHT						
4	1.000000	4.000000	16.000000	4.000000	0.	91.267579	122603.93
5	16.000000	143.000000	1475.000000	8.937500	3.5083605	414.25106	124362.94
6	6.000000	64.000000	692.000000	10.666667	1.2472191	448.67952	124726.52
7	210.000000	2594.000000	44017.000000	12.376190	7.5123013	635.40159	124738.80
8	153.000000	1457.000000	52157.000000	12.725490	10.658229	841.73884	124933.60
9	327.000000	5732.000000	50934.000000	13.224902	7.9452197	1121.7372	124253.47
10	159.000000	2170.000000	41610.000000	13.647799	8.6853729	1285.0492	124090.15
11	10.000000	145.000000	2825.000000	14.500000	8.6625631	1270.3036	124104.90
12	197.000000	2929.000000	73618.000000	14.862944	12.360757	740.04697	124635.16
13	113.000000	1745.000000	53573.000000	15.442478	12.129783	355.53682	125014.67
14	19.000000	334.000000	7245.000000	17.842105	5.0997931		

MAX. ASS. 1255.0492 155755 - .01025 BETWEEN CODES 4 9 12 5 8 10 7
AND CODES 3 1 11 6

TRY ON PREDICTOR 6	270	SUM OF Y	SUM Y-SQUARE	MEAN	STO. DEV.	B-S-S	M-S-S
CODE	TOTAL WEIGHT						
1	1.000000	36.000000	1296.000000	36.000000	0.	504.42887	124370.77
2	69.000000	1207.000000	28735.000000	17.492754	10.509655	1313.3453	124061.86
3	58.000000	819.000000	19091.000000	17.052500	10.324740	2008.8970	123366.31
4	78.000000	1063.000000	22367.000000	13.628205	10.051299	1334.3698	124040.83
5	29.000000	343.000000	6939.000000	11.827586	9.9691558	954.65899	124420.54
6	133.000000	2116.000000	59580.000000	15.909774	13.958832	2110.7775	123264.42
7	81.000000	723.000000	10055.000000	8.925259	6.6881068	453.63185	124921.57
8	248.000000	3553.000000	75767.000000	13.923387	10.556522	654.55847	124710.64
9	270.000000	3272.000000	56670.000000	12.118519	7.9351686	17.335629	125355.87
10	60.000000	859.000000	1782.000000	14.316667	9.5629346	67.241377	125307.96
11	185.000000	2459.000000	46889.000000	13.291692	5.7624006	106.51953	127268.68
12	15.000000	200.000000	3796.000000	13.333333	8.6759170	153.92511	125221.28
13	7.000000	59.000000	853.000000	9.251429	4.9979288	70.340328	125304.85
14	15.000000	162.000000	2230.000000	10.800000	6.0711922	418.55790	124956.64
15	1.000000	34.000000	1156.000000	34.000000	0.		

MAX. ASS. 2110.7775 455755 - .01684 BETWEEN CODES 1 2 3 4 5 6 7 8 9 10 11 12 15 17 18
AND CODES

TABLE D-2. (Continued)

TRY ON PREDICTOR 7	CHAIRS	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	M S S
CODE M	TOTAL WEIGHT						
1	131.00000	1429.0000	30318.000	11.740994	10.231762	15.312201	125358.34
2	130.00000	1674.0000	33586.000	12.908824	9.767874	37.114822	125248.03
3	407.00000	5146.0000	23742.000	12.638521	8.4014064	806.69354	124566.52
4	507.00000	7101.0000	154221.000	14.005917	13.393157	863.91607	124311.29
5	56.00000	977.0000	2653.000	15.265675	14.490563	997.52303	124385.62
6	6.00000	104.0000	4315.000	27.000000	18.708287	507.30642	124565.93
7	2.00000	403.0000	467.000	19.151812	7.5675615		
MAX. BSS =	484.55303	BSS/TSS = .00789	BETWEEN CODES	1 2 3 4 5			
			AMD CODES	6 7			
TRY ON PREDICTOR 8	CHAIRS	SUM OF Y <td>SUM Y-SQUARE <td>MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td></td></td>	SUM Y-SQUARE <td>MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td></td>	MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td>	STD. DEV. <td>B S S <td>M S S</td> </td>	B S S <td>M S S</td>	M S S
CODE M	TOTAL WEIGHT						
2	370.00000	4746.0000	92610.000	12.827027	9.2609219	275.21168	125079.97
1	671.00000	12059.000	260601.000	13.856487	10.353214		
MAX. BSS =	275.11168	BSS/TSS = .03220	BETWEEN CODES	1 2			
			AMD CODES	3 4 5			
TRY ON PREDICTOR 9	CHAIRS	SUM OF Y <td>SUM Y-SQUARE <td>MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td></td></td>	SUM Y-SQUARE <td>MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td></td>	MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td>	STD. DEV. <td>B S S <td>M S S</td> </td>	B S S <td>M S S</td>	M S S
CODE M	TOTAL WEIGHT						
2	1008.00000	10215.000	336519.000	13.423013	9.9195740	727.52293	124657.25
1	33.00000	601.0000	16692.000	13.181818	13.237812		
MAX. BSS =	727.52293	BSS/TSS = .00580	BETWEEN CODES	2			
			AMD CODES	1			
TRY ON PREDICTOR 10	SHAFTVENT	SUM OF Y <td>SUM Y-SQUARE <td>MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td></td></td>	SUM Y-SQUARE <td>MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td></td>	MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td>	STD. DEV. <td>B S S <td>M S S</td> </td>	B S S <td>M S S</td>	M S S
CODE M	TOTAL WEIGHT						
3	81.00000	422.0000	1396.000	13.148148	8.3134743	1002.5740	124372.03
2	860.00000	11692.000	246216.000	13.595349	10.072942	245.11739	125130.08
1	300.00000	4301.0000	92055.000	14.336667	10.229532		
MAX. BSS =	1022.5740	BSS/TSS = .00800	BETWEEN CODES	3			
			AMD CODES	2 1			
TRY ON PREDICTOR 11	ENVIRON	SUM OF Y <td>SUM Y-SQUARE <td>MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td></td></td>	SUM Y-SQUARE <td>MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td></td>	MEAN <td>STD. DEV. <td>B S S <td>M S S</td> </td></td>	STD. DEV. <td>B S S <td>M S S</td> </td>	B S S <td>M S S</td>	M S S
CODE M	TOTAL WEIGHT						
3	346.00000	4482.0000	91742.000	12.953757	9.8666338	170.30415	125204.90
2	607.00000	7954.0000	163156.000	13.120264	9.8310456	989.94830	124340.25
4	158.00000	2422.0000	49684.000	16.416667	9.3116777	950.40884	124424.29
1	120.00000	1947.0000	46824.000	16.225000	11.985729		
MAX. BSS =	984.44830	BSS/TSS = .03786	BETWEEN CODES	3 2			
			AMD CODES	4 1			

TABLE D-2. (Continued)

TRY ON PREDICTOR 12	4ATRP4	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	W S S
3	21.00000	217.00000	2831.00000	10.23000	3.4753975	234.4514	25140.26
5	13.00000	153.00000	2001.00000	11.769231	8.7719277	259.77889	125115.62
6	30.00000	372.00000	5914.00000	12.400000	6.5850434	255.43781	125108.76
7	105.00000	14541.00000	309383.00000	13.604303	10.213604	47.793868	125327.41
8	65.00000	925.00000	18200.00000	14.156250	9.1639174	20.952007	125354.25
9	45.00000	618.00000	14102.00000	14.227273	10.855679		
MAX. BSS =	255.43781	ISS/TSS =	.00213	BETWEEN CODES	3 4 5 6		
			ANO CODES	7 8 9			
TRY ON PREDICTOR 13	INITIATORS	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	W S S
1	357.00000	4447.00000	99107.00000	13.779444	4.2831677	25.811147	125344.34
4	1.00000	4.00000	16.00000	4.000000	0.	21.342932	125354.26
5	32.00000	32.00000	545.00000	15.200000	10.000000	24.377700	125350.82
7	32.00000	313.00000	11491.00000	16.031250	10.104097	93.392408	125281.81
8	54.00000	593.00000	6835.00000	10.240741	4.6584658	11.4255606	125373.78
9	123.00000	1391.00000	23827.00000	11.308943	8.0123178	283.82341	125091.38
10	158.00000	1939.00000	34743.00000	12.272152	8.3238629	623.34531	124551.86
11	255.00000	3213.00000	54185.00000	12.124528	4.7370153	3872.2383	121902.96
12	132.00000	2125.00000	52737.00000	15.340409	12.813245	3910.8097	121464.39
13	71.00000	1346.00000	37352.00000	18.973239	13.034007	1502.8950	123772.31
14	20.00000	567.00000	18933.00000	23.450000	19.918272	157.62406	125207.58
15	9.00000	154.00000	3188.00000	17.111111	7.8378632	63.836351	125311.37
16	9.00000	90.00000	1100.00000	11.250000	3.3071891	347.10666	125028.10
17	7.00000	144.00000	5352.00000	20.571429	14.090089		
MAX. BSS =	3910.8097	ISS/TSS =	.03119	BETWEEN CODES	1 4 6 7 8 9 10 11 12		
			AND CODES	13 14 15 16 17			
TRY ON PREDICTOR 14	INITIATORS	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	W S S
5	2.00000	35.00000	977.00000	17.500000	13.500000	31.262385	125343.94
6	36.00000	593.00000	12461.00000	13.694444	12.593692	4.6706904	125370.53
7	41.00000	696.00000	8758.00000	12.097561	9.2011447	29.124270	125346.08

TABLE D-2. (Continued)

CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	W S S
MAX. BSS = .05451 BETWEEN CODES 5 6 7 8 AND CODES 9 10 11 12								
TRY IN PREDICTOR 15 TAXCAGE4EC								
0	42	42.000000	367.00000	3913.0000	8.7380952	4.1002876	555.68861	12809.73
1	33	33.000000	561.00000	11741.000	17.181818	11.261236	280.83348	125094.37
2	10	10.000000	1453.000	305237.00	14.755198	1.9648230	19.575900	123356.83
3	17	17.000000	276.00000	9252.0000	16.235294	16.752527	325.93103	124979.27
4	12	12.000000	34.000000	922.00000	7.6333333	2.6718099		
MAX. BSS = .03799 BETWEEN CODES 12 4 5 3 1 5								
TRY IN PREDICTOR 16 WIRESTREN5								
0	2	2.000000	21.00000	261.00000	10.500000	4.5000000	18.624917	125356.97
1	2	85.000000	1201.0000	23887.000	14.129412	8.6831254	23.056008	125352.15
2	81	81.000000	11707.000	263593.00	14.417488	10.803460	2259.0278	123117.17
3	317	317.000000	3831.0000	65271.000	11.367953	8.0282095	32.632677	125342.57
4	5	5.000000	55.000000	659.00000	11.000000	4.3358967		
MAX. BSS = .01901 BETWEEN CODES 0 2 3 4 5								
TRY IN PREDICTOR 17 BEARINGRS								
0	4	48.000000	1738.0000	59634.000	17.775510	14.745827	4124.6245	121250.78
1	43	43.000000	475.00000	7985.0000	11.046512	7.9794897	2020.4760	123354.73
2	7	7.000000	195.00000	1763.0000	15.000000	5.1823878	2015.3174	123356.87
3	145	145.000000	2206.0000	47260.000	15.213793	9.7196468	2537.8923	122835.31
4	30	30.000000	374.00000	6490.0000	11.150824	8.1445441	11.174925	123366.03

TABLE D-2. (Continued)

CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B \$ S	# \$ S	
6	412	412.00000	5710.0000	120304.00	13.854223	9.9900957	28.607436	125246.59	
7	145	145.00000	1922.0000	39102.000	13.255172	9.6937800	13.852116	125361.35	
8	26	26.00000	223.0000	2483.0000	8.5769231	5.0836301	435.28282	124339.92	
9	22	22.00000	377.0000	8221.0000	17.136364	8.9457733	198.14141	125177.06	
10	3	3.00000	55.00000	1569.0000	21.666667	7.3181661			
MAX. BSS= 4124.4245 4557155 = .03290 BETWEEN CODES 1 2 3 4 5 6 7 8 9 10									
TRY ON PREDICTOR 18 MACHCYCLES									
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B \$ S	# \$ S	
0	251	151.00000	2273.0000	48413.000	15.052980	9.6955810	399.58390	124986.02	
1	117	117.00000	1413.0000	26881.000	12.076923	9.1596979	14.249410	125360.95	
2	495	495.00000	7034.0000	164566.00	14.606186	11.594149	1036.4369	124288.77	
3	191	191.00000	2447.0000	45491.000	12.811518	8.6045205	804.09557	124571.11	
4	97	97.00000	1155.0000	19777.000	11.907215	7.8806594	424.64418	124950.50	
5	74	74.00000	970.0000	7085.0000	9.0540541	3.7158908	33.193392	125337.01	
6	18	35.00000	415.0000	5721.0000	10.921053	7.5896025	335.57145	125339.63	
7	23	53.00000	932.0000	17172.000	15.698113	3.0073402	74.763896	125276.42	
8	14	19.00000	351.0000	9711.0000	18.673684	13.031817	110.29124	125264.61	
9	3	3.00000	28.00000	286.00000	9.3333333	2.9674418	55.024117	125304.17	
10	2	2.00000	9.00000	65.00000	4.5000000	3.5000000	11.149618	124354.01	
11	1	1.00000	4.00000	16.00000	4.0000000	0.	160.31496	125234.88	
12	7	7.00000	71.00000	825.00000	10.142857	3.8703678	81.700057	125233.50	
MAX. BSS= 1095.4367 1557155 = .00367 BETWEEN CODES 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20									
TRY ON PREDICTOR 19 PREDSTRLOSS									
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B \$ S	# \$ S	
1	734	733.00000	939.0000	18550.00	12.740791	9.5252079	1171.2708	124203.93	
2	50	20.00000	615.0000	10665.000	12.300000	7.8746428	1436.3343	123889.17	
3	104	109.00000	1059.0000	15517.000	9.8073394	6.7951371	4506.2497	120868.95	
4	185	185.00000	2330.0000	41998.000	12.594595	8.2699700	10301.061	114574.14	
5	106	106.00000	1945.0000	50329.000	18.349057	11.752192	9668.1449	115707.06	

TABLE D-2. (continued)

MAX. BSS	10901.061	35571.5	.08615	BETWEEN CODES AND CODES	1	2	3	4	5	6	7	8	9	10	12	STD. DEV.	0 5 5	W 5 5
TRY ON PREDICTOR 20	ELONGATION	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.													
CODE N	TOTAL HEIGHT																	
6	36.00000	813.00000	22215.000	22.583333	10.347772												7624.3770	117750.83
7	11.00000	351.00000	14331.000	32.918182	15.026148												3450.4472	121924.76
8	4.00000	89.00000	2282.000	22.000000	9.3005376												3694.9304	121690.27
9	5.00000	149.00000	4719.000	29.800000	7.4672619												3117.6994	122257.50
10	1.00000	49.00000	2401.000	49.000000	0.												1889.4635	123685.74
12	1.00000	57.00000	3249.000	57.000000	0.													
MAX. BSS	10901.061	35571.5	.08615	BETWEEN CODES AND CODES	1	2	3	4	5	6	7	8	9	10	12			
TRY ON PREDICTOR 21	LUBRICOME	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.													
CODE N	TOTAL HEIGHT																	
12	1.00000	1.00000	1.000000	1.000000	0.													
11	4.00000	44.00000	1216.000	4.333333	5.9282032												157.61639	125217.58
3	21.00000	177.00000	2237.000	4.3809524	4.3035661												257.05157	125118.15
4	45.00000	435.00000	5826.000	4.6666667	5.3659114												633.39258	124744.81
16	14.00000	274.00000	5852.000	12.000000	12.508795												1362.3551	124012.80
4	40.00000	440.00000	4699.000	42.120000	8.3943693												1324.7651	124050.42
6	68.00000	476.00000	19102.000	12.911765	10.686351												1324.6894	124000.33
4	65.00000	954.00000	15592.000	13.138462	8.2010824												1162.4335	124212.77
5	87.00000	1144.00000	23852.000	13.169425	10.062462												1050.2197	124315.18
7	54.00000	721.00000	17851.000	13.351822	12.348575												1016.5777	124353.62
4	32.00000	1173.00000	252973.000	14.177536	10.223523												981.16691	124344.64
MAX. BSS	1302.3561	35571.5	.01067	BETWEEN CODES AND CODES	12	11	3	9	10	8	6	4	5	7	0			

TABLE D-2. (Continued)

TRY ON PREDICTOR 22 INCRLAYLENXAI									
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	W S S	
5	1083	1083.0000	14324.000	241226.00	13.226223	9.7082832			
6	143	143.00000	2235.0000	52487.000	15.619580	11.370070	889.29156	124495.91	
7	15	15.000000	236.00000	9198.0000	19.066667	15.800703	462.16370	124713.64	

MAX. BSS = 889.29156 BSS/TSS = .00709 BETWEEN CODES 5
AND CODES 6, 7.

TRY ON PREDICTOR 23 ROPEAPPEAR									
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	W S S	
2	769	769.00000	9833.0000	186621.00	12.786736	8.8482856			
1	422	422.00000	5737.0000	120545.00	13.594787	10.041585	1176.5250	124198.68	
4	14	14.000000	248.00000	10134.000	21.285714	16.455258	6712.0574	118663.14	
3	36	36.000000	967.00000	35911.000	26.305556	17.479861	6032.7617	119342.44	

MAX. BSS = 6712.0574 BSS/TSS = .05354 BETWEEN CODES 2, 1
AND CODES 4, 3.

TRY ON PREDICTOR 24 LUBRATERT									
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	W S S	
3	171	171.00000	1867.0000	34407.000	10.918129	9.0556608			
2	107	107.00000	1431.0000	32331.000	13.373832	11.104031	1373.3055	124001.90	
4	546	546.00000	7376.0000	152292.00	13.509158	9.8196609	1018.5686	124336.33	
1	274	274.00000	3873.0000	78979.000	14.135036	9.4049345	870.12015	124505.38	
5	143	143.00000	2263.0000	55202.000	15.860140	11.596721	952.87651	124512.33	

MAX. BSS = 1373.3055 BSS/TSS = .01095 BETWEEN CODES 3
AND CODES 2, 4, 1, 5.

TRY ON PREDICTOR 25 LUBCHREXT									
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	W S S	
5	12	12.000000	139.00000	2672.0000	11.500000	9.5067677			
3	157	157.00000	1893.0000	40403.000	12.057325	10.730777	50.900385	125326.30	
2	367	367.00000	4833.0000	90133.000	12.488372	9.7716901	459.06148	124916.14	
4	254	254.00000	3532.0000	76620.000	13.905512	10.406262	1450.7540	123914.45	
1	410	410.00000	5921.0000	128561.00	14.597605	10.037896	1192.2747	124182.42	
5	3	3.0000000	44.000000	740.00000	14.666667	5.4442222	1140.7202	124234.49	
7	15	10.000000	344.00000	13532.000	21.000000	15.012248	1270.2242	124104.40	

TABLE D-2. (Continued)

MAX. BSS = 1450.7540 ASS/TSS = .01165 BETWEEN CODES 6 3 2
 AND CODES 4 1 5 7

TRY ON PREDICTOR 26	LUBRATOR								
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B	S	W
2	473	473.00000	12218.000	217044.00	12.557040	8.0862567			
3	74	74.00000	1191.000	32085.000	13.810127	14.677181	4438.3904		120736.81
1	54	54.00000	1419.000	30585.000	17.271186	14.842665	5575.4611		114744.74
4	109	109.00000	1940.000	53526.000	17.748165	13.236577	4523.3290		120351.87
5	21	21.00000	547.0000	19771.000	25.547519	15.217205	3336.6958		122038.51

MAX. BSS = 5575.4611 ASS/TSS = .04447 BETWEEN CODES 2 3
 AND CODES 1 4 5

TRY ON PREDICTOR 27	LUBRICATOR								
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B	S	W
6	11	11.00000	106.0000	1648.0000	7.6363636	7.5470973			
3	490	490.00000	12554.000	229402.00	12.600808	3.4211415	169.95030		125205.25
4	57	57.00000	884.0000	27034.000	13.509772	15.289169	4213.1243		121162.08
2	81	81.00000	1336.0000	34504.000	16.493827	12.406812	4014.7754		121360.43
7	23	23.00000	428.0000	13648.000	18.608696	13.719661	3255.9692		122109.23
1	79	79.00000	1507.000	46975.000	17.075949	15.189747	2576.7733		122798.43

MAX. BSS = 4213.1243 ASS/TSS = .03360 BETWEEN CODES 6 3
 AND CODES 4 2 7 1

TRY ON PREDICTOR 28	CORROSION								
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B	S	W
3	181	181.0000	1455.000	19573.000	8.0939227	6.5284002			
4	373	373.0000	3997.000	61741.000	10.715818	7.1201629	6307.1763		119068.03
1	55	55.00000	625.0000	14894.000	11.016182	12.222916	13628.880		111746.32
2	47	47.00000	531.0000	9939.000	11.247872	9.1556630	15375.011		110550.19
5	422	422.0000	6155.000	117595.00	14.585308	8.1197245	15751.061		108424.14
6	116	116.0000	2435.000	68753.000	21.422414	11.566284	24235.132		101140.07
7	47	47.00000	1575.000	60716.000	33.531915	12.939879	19505.576		105859.63

MAX. BSS = 24235.132 ASS/TSS = .19330 BETWEEN CODES 3 4 1 2 5
 AND CODES 5 7

TRY ON PREDICTOR 29	MINORITERS								
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B	S	W
1	1	1.00000	6.000000	36.000000	6.000000	0.			
5	74	74.00000	574.0000	7744.0000	6.584211	4.4268495	57.641772		125318.16
							1927.6660		123547.54

TABLE D-2. (Continued)

IC	25	25.00000	224.00000	3466.0000	6.960000	7.532670	2441.1943	122934.00
9	37	37.00000	332.00000	5195.0000	7.0540541	7.572746	3356.1148	122011.04
11	41	41.00000	727.00000	13185.0000	9.7437407	8.4516459	5010.7267	120325.63
11	19	19.00000	191.00000	2645.0000	10.052632	8.1769835	3384.5296	119940.67
5	134	134.00000	1366.0000	17116.0000	10.194030	6.8798667	8271.3760	117103.83
7	120	120.00000	1245.0000	20367.0000	10.375000	9.1905052	11516.873	113858.33
4	197	187.00000	2033.0000	3185.0000	11.192513	6.568022	17070.094	106305.11
1	138	38.00000	493.00000	8839.0000	12.973664	8.0966648	17574.203	107701.00
3	270	270.00000	3837.0000	73391.0000	14.100000	8.5877389	23248.433	102126.77
12	14	14.00000	264.00000	5278.0000	14.571429	12.832516	23346.611	101428.54
14	2	2.00000	33.00000	684.0000	16.500000	8.5000000	23968.455	101406.75
2	236	236.00000	5319.0000	161365.0000	22.538136	13.258297	536.42887	124870.77
13	1	1.00000	36.00000	1296.0000	36.000000	0.		

MAX. BSS	23069.455	355/TSS	-19117	BETWEEN CODES	15	6	10	9	8	11	5	7	4	1	3	12	14
TRY ON PREDICTOR 30	LENFROMDRUM	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.												
9	140	140.00000	1694.0000	31338.0000	12.100000	8.8803957	331.57592	125063.63									
7	95	95.00000	1179.0000	22235.0000	12.410526	8.9460309	508.19919	124867.00									
9	159	159.00000	2001.0000	36317.0000	12.584306	8.3683305	802.43719	124572.77									
12	219	218.00000	2833.0000	55555.0000	12.995413	9.2713912	1104.5095	124270.69									
10	175	175.00000	2303.0000	44445.0000	13.160000	8.9880937	1483.3170	123891.89									
5	66	66.00000	898.00000	20242.0000	13.606061	11.025973	1583.1168	123792.09									
6	62	62.00000	954.00000	20264.0000	13.774144	11.709411	1692.0345	123593.17									
4	28	28.00000	414.00000	9667.0000	14.607143	11.483962	1623.0117	123752.19									
11	201	201.00000	3015.0000	68779.0000	15.000000	10.825160	1107.5113	124267.64									
2	51	51.00000	331.00000	22645.0000	15.244118	13.213621	689.18086	124696.02									
3	46	46.00000	798.00000	21724.0000	17.347826	13.088640											

MAX. BSS	1062.0345	953/TSS	-01342	BETWEEN CODES	8	7	9	12	10	5	6
TRY ON PREDICTOR 31	BRKENTURES	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.						
1	1116	1116.0000	14582.0000	297064.0000	13.152524	7.6442646	1176.8433	123658.35			

TABLE B-2. (continued)

CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	M S S
2	14	14.00000	14.00000	14.00000	1.00000	0.00000	3664.0000	121711.16
3	14	14.00000	14.00000	14.00000	1.00000	0.00000	2016.8889	122858.11
4	7	7.00000	7.00000	7.00000	1.00000	0.00000	1921.5309	123453.67
6	10	10.00000	10.00000	10.00000	1.00000	0.00000	1053.6860	124311.31
5	4	4.00000	4.00000	4.00000	1.00000	0.00000	645.47707	124729.73
7	2	2.00000	2.00000	2.00000	1.00000	0.00000		
MAX. BSS = 3664.0231 BSS/TSS = .02922 BETWEEN CODES 1 2 3 4 5 7								
TRY ON PREDICTOR 32 GALV#IRE								
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	M S S
1	1146	1146.0000	13375.000	318127.00	13.416230	9.8793975	256.11256	125109.09
2	75	75.00000	1460.0064	35084.000	15.157895	11.812853		
MAX. BSS = 266.1125 BSS/TSS = .00212 BETWEEN CODES 1 2								
TRY ON PREDICTOR 33 C3MINEID								
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	M S S
3	53	53.00000	401.00000	5263.0000	8.6981132	5.4134177	1303.0863	124072.12
4	36	36.00000	331.00000	4135.0000	9.1944444	5.2065598	2073.6827	123301.52
12	26	26.00000	262.00000	2756.0000	9.3571429	3.2973307	2553.7669	122711.64
2	67	67.00000	683.00000	9483.0000	10.194030	6.1334386	3548.0321	121727.17
4	52	52.00000	650.00000	10462.000	12.500000	7.2549718	3438.8176	121936.38
5	96	96.00000	1127.0000	14477.000	12.522222	7.7204314	3193.5806	121981.62
1	705	704.00000	9540.0000	201048.00	13.551136	10.096844	6546.2982	120728.90
11	69	59.00000	1128.0000	2584.000	15.347826	10.245998	3996.9876	121378.21
10	36	30.00000	494.00000	14326.000	16.666667	14.366009	3730.2835	121564.92
7	24	29.00000	494.00000	10934.000	17.034483	9.2199184	3496.5331	121878.67
9	70	70.00000	1330.0000	37012.000	19.000000	12.951558	1438.8490	123076.35
6	13	11.00000	315.0000	11931.000	24.230769	16.183483		
MAX. BSS = 5646.2982 BSS/TSS = .03706 BETWEEN CODES 3 4 12 2 4 5 1								
TRY ON PREDICTOR 34 IAIT								
CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.	B S S	M S S
2	154	154.00000	2367.0000	56527.000	15.370130	9.6179967	582.74584	124722.60
1	192	182.00000	2327.0000	56253.000	11.686813	9.1972130	14.038497	123361.16
2	144	144.00000	1876.0000	51256.000	13.027778	10.480103	60.610064	125114.39

TABLE U-2. (Continued)

CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.
1	105	105.00000	1261.0000	22423.000	12.009524	3.1260865
4	77	77.00000	1182.0000	25326.000	15.331129	19.437647
5	53	53.00000	572.00000	11406.000	12.579145	7.9923869
7	181	181.00000	2332.0000	45190.000	12.718232	9.3763043
8	140	140.00000	2172.0000	55333.000	15.514286	12.422034
9	81	81.00000	1049.0000	20357.000	12.950617	9.1036712
9	33	33.00000	393.00000	5697.0000	11.90991	5.5500082
10	19	19.00000	165.00000	10160.000	19.315799	14.116257
11	14	14.00000	125.00000	1410.0000	9.0000000	4.4400772
12	4	4.0000000	65.00000	1491.0000	16.250000	10.425330
13	36	36.00000	557.00000	11647.000	15.472222	9.1726832
14	4	4.0000000	40.00000	534.00000	10.000000	5.7879105
16	5	5.0000000	95.00000	3211.0000	19.000000	10.759019
17	9	9.0000000	223.00000	7393.0000	24.777778	14.4050175
MAX. BSS=	1189.3084		.00949	BETWEEN CODES AND CODES	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14	

CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.
1	53	53.00000	620.00000	10576.000	11.698113	7.9112047
0	1156	1156.0000	15369.000	312319.000	13.294983	9.5651736
2	32	32.00000	326.00000	30322.000	25.812500	16.771325
MAX. BSS=	4939.5216		.03940	BETWEEN CODES AND CODES	1 0	

CODE	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	MEAN	STD. DEV.
3	66	66.00000	826.00000	13906.000	12.515152	7.3530913
1	560	560.00000	7111.0000	137089.000	12.698214	9.1409595
0	555	555.00000	7586.0000	161326.000	13.668468	10.190174
4	56	56.00000	1193.0000	36259.000	21.303571	15.144447
2	4	4.0000000	99.00000	2637.0000	24.750000	5.8328252
MAX. BSS=	4018.7397		.03205	BETWEEN CODES AND CODES	3 1 0	

TABLE D-3. STATISTICS FOR FIRST MAJOR SPLIT

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SPLIT GROUP 1 ON PREDICTOR 20 ELONGATION INTO GROUP 2 WITH CODES 0 1
AND GROUP 3 WITH CODES 2 3 4 5
BSS = 48998.249 BSS/TSS = .39061 T-VALUE 28.19
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CURRENT SUMMARY

NCF	TOTAL TSS	TOTAL BSS	TOTAL MSS	R-SQUARED	R	F-RSQ	DF1	DF2	F-ANOVA	DF1	DF2
2	125375.20	48998.249	76376.953	.39061292	.62515	794.8580	1	1239	794.8580	1	1239

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CANDIDATE GROUPS ARE AS FOLLOWS.

GROUP	N	TOTAL WEIGHT	SUM OF Y	SUM Y-SQUARE	T S S	MEAN	STD. DEV.
3	1173	1173.0000	14119.000	236873.00	66927.424	12.036658	7.5535837
2	68	68.000000	2696.0000	116338.00	9449.5294	39.647059	11.788285