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*Wire Rope Battelle*

# RESEARCH REPORT

WIRE ROPE APPLICATIONS AND PRACTICES  
ASSOCIATED WITH UNDERGROUND COAL  
MINING IN THE UNITED STATES

to

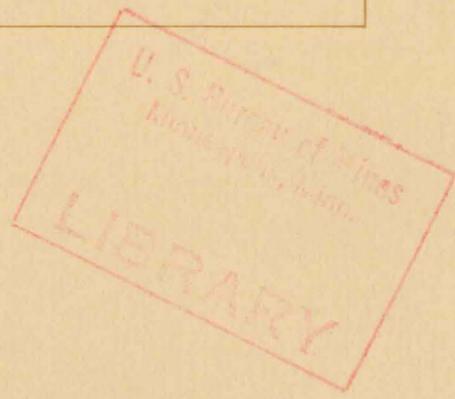
PITTSBURGH MINING AND  
SAFETY RESEARCH CENTER  
U. S. BUREAU OF MINES  
DEPARTMENT OF THE INTERIOR

June 22, 1971



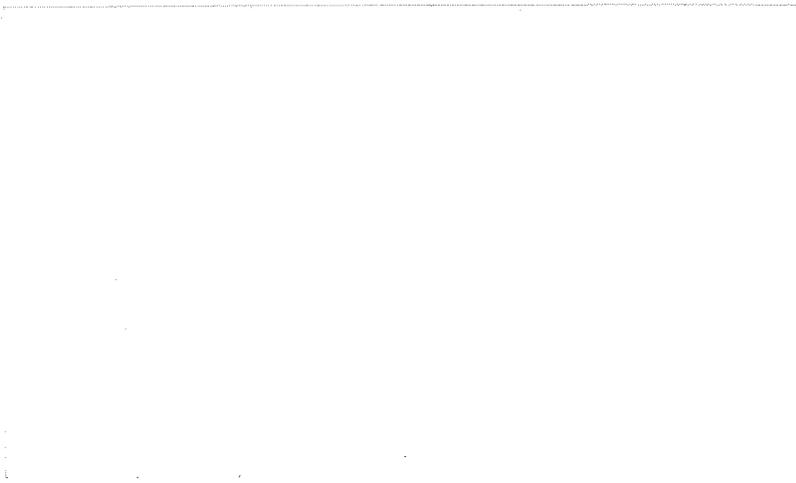
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FINAL REPORT

on

WIRE ROPE APPLICATIONS AND PRACTICES  
ASSOCIATED WITH UNDERGROUND COAL  
MINING IN THE UNITED STATES

to

PITTSBURGH MINING AND  
SAFETY RESEARCH CENTER  
U. S. BUREAU OF MINES  
DEPARTMENT OF THE INTERIOR

June 22, 1971

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## FOREWORD

The subject of wire rope in underground coal mines has been investigated in great detail during the program herein discussed. To describe the procedures and present the results this report is organized into seven major sections with very little common material. As a result, no major section alone is fully representative of the program effort. The seven sections, identifiable by colored indexing sheets, are titled

SUMMARY  
CONCLUSIONS  
RECOMMENDATIONS  
DETAILED DISCUSSION OF RESULTS - HOISTING  
APPLICATIONS OF WIRE ROPE  
DETAILED DISCUSSION OF RESULTS - NONHOISTING  
APPLICATIONS OF WIRE ROPE  
EVALUATION OF RESEARCH PROCEDURES  
APPENDICES

Preceding these sections are the Abstract and Introduction.

The Summary section provides a statement of the program objectives, a brief discussion of the procedures followed, and a still briefer discussion of the kinds of information obtained.

The Conclusions section presents the conclusions resulting from the work without supporting arguments.

The Recommendations section lists the recommendations, also without supporting arguments.

These first three sections together cover all aspects of the program and can, to some extent, stand alone.

The Detailed Discussion of Results presents and discusses in great detail the information obtained and the evaluation thereof. It is divided into two subsections entitled "Hoisting Applications of Wire Rope", and "Nonhoisting Applications of Wire Rope". These sections present the arguments in support of the Conclusions and Recommendations.

The Research Procedures section details how the program was conducted and provides an evaluation of the approach used.

The Appendices contain much detail related to both the information obtained and the research procedures. They are related to the main body by references in the Detailed Discussion of Results and Research Procedures sections.

Appendix A is a bibliography of all publications obtained during the program as well as those which were initially on file that were related to the program. Though all items were studied, not all are specifically referenced in the text. To avoid the partial duplication which would occur if a separate reference list were appended, the bibliography item number is used in the text where specific publications are referenced. Thus, text reference numbers do not appear in the usual chronological order.

The final appendix, Appendix O, presents illustrative cross sections of wire rope constructions and some basic wire rope terminology. These rope constructions and terms are used frequently in this report, so, to obviate redefinition, Appendix O is prepared in foldout format to easily permit continual reference.

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# WIRE ROPE APPLICATIONS AND PRACTICES ASSOCIATED WITH UNDERGROUND COAL MINING IN THE UNITED STATES

## ABSTRACT

A 9-month study of the uses of wire rope associated with U. S. underground coal mining is reported.

Rope applications are broken down into hoisting and nonhoisting applications where "hoisting" refers to transport in vertical and inclined shafts. The former receives the greatest emphasis since it represents the most critical rope application from the standpoint of production and safety.

The discussion of hoisting practice includes aspects related to the mine operators as well as those related to the equipment builders and wire rope manufacturers. U. S. state and Federal laws regulating hoisting and wire rope use are also presented and discussed. Canadian and other foreign hoisting practice and laws are included.

The state of the art in electromagnetic nondestructive inspection of hoist ropes is presented. Capabilities and use of one Canadian electromagnetic device are discussed in great detail.

Conclusions are drawn regarding the present state of wire rope and hoisting technology in U. S. coal mines.

Recommendations are made for improving rope practice, in general, and hoisting, in particular, consistent with greater safety.

## INTRODUCTION

This is the final report of a 9-month study of wire rope applications and practices associated with underground coal mining in the United States.

Wire rope as a machine and structural component has been in use for about a century. During most of this period the problems that it presented to users were solved in many instances by making it larger or stronger or by empirically determining a constructional configuration which "worked better". Isolated instances of failure prompted people to wonder about the detailed mechanical workings of the wire and strands of wires making up a rope, but the geometrical complexities and localized internal self-loading effects defied description in a meaningful manner. In the late 1920's theories relating to very localized loading and stress situations began to take shape and laid the groundwork for detailed investigations into the behavior of wire rope. The term "contact stresses" is often applied to these very localized stresses, which are characterized by high loads over small areas and which are typically very high. However, to this day there is still no adequate analytical description of the behavior of wire rope; it is an extremely complicated mechanical component. Thus far, the most rewarding approach

has been to analyze experimental and field data, mostly of the failure type, to determine a rational approach to designing with wire rope.

Implicit in any desire to be able to design systems with and for wire rope (or any component) is the desire to use a minimum amount of material as long as possible short of disabling partial failure and, definitely, short of total failure. Beyond just knowing in an academic sense, the impetus behind much of the desire to design with rope stems from the fairly recent use of wire rope in mechanical systems which demand reliability of operation under high loads, where excess material is very undesirable, and where a failure can be catastrophic. A prime example is the use of wire rope in aircraft carrier arresting-gear systems for aircraft.

Though use of wire rope in coal mining was not expected to rank with aircraft arresting-gear rope in terms of performance requirements, the idea of using it as long as possible is the same as knowing when to stop using it. The user of wire rope in mine hoists has historically been faced with the question of when to replace the rope. In many mining countries efforts to understand the behavior of wire rope and to learn how to design for it have been initiated principally as a result of deaths or gross destruction following hoist-rope failures.

The program reported here was conceived several years ago in discussions between Battelle and Bureau of Mines personnel. The thought was to study the use of wire rope in U. S. coal mines - man-hauling ropes in particular - to determine the service conditions and usage practices with the aim of improving rope practices and so to avoid tragic accidents. The passage of the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173), which provided funds for research, made the program possible.

• SUMMARY

## SUMMARY

PROGRAM OBJECTIVES

The overall objective of this program was to determine current usage and service conditions for wire ropes in U. S. coal mines. To meet this general objective, the following specific goals were set:

- (1) To determine, in detail, the service conditions, the problems, and the practices related to the use of wire rope in U. S. coal mines including
  - (a) The inspection activities of the state agencies
  - (b) The design practices of wire rope manufacturers and their suggestions and opinions regarding inspection and replacement criteria.
- (2) To determine details of foreign experience with wire rope in mining operations.
- (3) To perform physical tests and examinations of specimens of wire ropes from mines and to make a preliminary evaluation of the performance of the Canadian McPhar nondestructive inspection machine.
- (4) To develop, through the analysis of these data, a firm technological base for formulating wire rope safety standards and practical methods for enforcing their use in U. S. coal mines.

RESEARCH PROCEDURESGuiding Principles

The program objectives relate to all applications of wire rope in underground coal mines. Since the impetus for this program derives from the Federal Coal Mine Health and Safety Act of 1969 (162) it is clear that the general intent is to consider these wire ropes as potential health and safety hazards and to approach the evaluation of their applications and associated practices from the viewpoint of reducing these hazards where possible and practical. Implicit in this intent and approach is the need to make a judgment regarding "safety". The assumption by which safety or its reciprocal - hazard - has been judged is that any rope that breaks under load may be a safety hazard. Even if it is not carrying men, someone may be close enough to be struck by the flailing rope or the released load or by flying pieces of whatever the released load may damage.

Another principle which has guided the evaluation of practices, the drawing of conclusions, and the formulation of recommendations follows from regarding the rope as a machine component which is as essential to the performance of function as any other major machine component. Thus, it follows that a rope should be cared for in the same way that one cares for the other major components if one is to get the most service for his investment.

A program of this nature is of little value without specific examples of practices and the opinions of those industry people involved. To obtain these as well as general information, all requests for information indicated that the responses would be treated as "business sensitive" and that no sources would be specifically identified in reporting results.

### Data Gathering

Battelle's wire rope experience includes much experimental and theoretical study of modes of failure of wire ropes and the contributing service conditions. To relate this experience to underground coal mine applications of wire rope and to pursue the program objectives, data were needed regarding engineering details, maintenance, inspection, and replacement procedures for wire ropes and the associated machinery. These data were chiefly obtained from a series of questionnaires, telephone conversations, letters of inquiry, and visits to companies and individuals in the following groups:

- (1) U. S. and foreign coal mine operators
- (2) U. S. and foreign metal and nonmetal mine operators
- (3) U. S. and foreign governmental mining regulatory and research agencies
- (4) U. S. wire rope manufacturers
- (5) U. S. builders of mining equipment including elevator manufacturers.

An additional source of information was Battelle's file of wire rope and rope-applications technical papers and the many papers related to mining and wire rope which were obtained during this program.

### Shifts in Program Directions

The program objectives as stated relate to all applications of wire rope in U. S. coal mining, including surface (strip) and underground coal mining. Prior experience suggested, and early program efforts supported, the conviction that strip mining rope applications are, for the most part, related to excavators (drag lines, shovels) whose rope problems form a subject unto itself. After discussing this with the Bureau's Project Officer, it was concluded that the Bureau's goals would be better served by restricting the efforts of this program to applications of wire rope associated with underground coal mining operations.

Still later, as a result of program work, it became obvious that hoist ropes, above all others, have been and still are of major concern to mine operators and regulatory agencies. Safety catches notwithstanding, a broken hoist rope poses a greater potential for death, destruction, and loss of production than any other rope in underground coal mining use. Conversely, a gain in hoist-rope lifetime would be a direct benefit to the industry. Thus, hoisting became the rope application receiving the greatest attention for the remainder of the program.

RESULTS

In brief, the efforts of this program have determined the following:

- (1) Design, installation, maintenance, inspection, and repair practices associated with hoisting applications for rope.
- (2) The major uses of wire rope in nonhoisting applications associated with underground coal mining; engineering details of these applications and rope maintenance, inspection, and replacement practices.
- (3) U. S. state and Federal regulations for ropes hoisting in coal mines and, to a lesser extent, in noncoal mines.
- (4) Canadian and other foreign regulatory practices for ropes and hoisting in underground coal and noncoal mines.
- (5) General current capabilities and limitations of electromagnetic rope-inspection devices; specific capabilities and limitations for one in particular.
- (6) The practices and attitudes of domestic manufacturers of mining equipment using or associated with rope in coal mines.
- (7) The practice and attitude of domestic and some foreign manufacturers of wire rope used in underground coal mines.
- (8) Some attitudes of state regulatory officials, cognizant industry people, and faculty members of schools of mines about wire rope and hoisting in coal mining.

- CONCLUSIONS

## CONCLUSIONS

HOISTING APPLICATIONS OF WIRE ROPE

The design and use of mine hoist systems present enough specialized considerations and problems to allow hoisting to be regarded as a distinct engineering technology. Furthermore, hoisting as a technology has generally stagnated in the U. S. coal mining industry relative to foreign efforts. There are, of course, coal-mine hoisting installations which, in all aspects, represent the latest and the best that the technology offers, but these are the exception rather than the rule.

Hoisting technology in the U. S. coal industry appears to have stagnated for at least two major reasons:

- (1) No individuals, groups, or associations appear to be sufficiently interested in hoisting to have kept abreast of developments (mostly foreign) and to have accumulated and prepared such information in a form that directs attention to the benefits to be gained from the advances that occur.
- (2) Mine personnel responsible for maintaining hoist installations in running order generally have so many other areas of responsibility that they have little time to think about eliminating their hoisting problems. Furthermore, were the time available it appears in many cases that the approach that would be taken would be strictly empirical rather than experimental and deductive.

Though no one is following technology development with the aim of disseminating this information industry-wide, much of what has developed and is in use elsewhere in the mining world is known by some individuals and groups supplying components, including wire rope. For reasons best known to themselves, but not entirely unobvious from without, this knowledge is imparted, if at all, only to their customers. However, many customers - the mine operators - indicate they don't often get the information they would like to have. There is no reason to suspect that this situation will change in the foreseeable future.

In general, it is concluded that if improvements in existing coal-mine hoisting technology are to be achieved, accompanied by proper recognition and elimination of safety hazards, the initiative will have to come from outside the mining industry and its related, supplier industries.

During the course of this program many contacts have indicated that since hoisting is such a small part of mine's total operations it gets little emphasis in the area of design, installation, maintenance, and inspection. The hazards of underground operations are pointed to as more worthy of improvement. This viewpoint of the relative importance of hoisting is contrary to some very basic facts.

While hoisting systems may represent a small part of a mine's total investment and operating expenses, without them all production would stop. Even in operations where the product is conveyed to the surface, supplies must be renewed daily. At mines where coal is hoisted, the capacity of the hoist represents a production limit for the mine; to increase production would require an additional shaft or increased hoist and skip capacity. Although underground production may be readily increased, once a hoist system is installed, increasing the capacity is difficult and expensive.

Therefore, it is apparent that hoisting does play an extremely important role in a mine's operation and that proper hoist system selection and maintenance is important. It is also apparent that improvements in wire rope use in a coal-mine hoisting system would benefit operations and increase safety.

There have also been contacts with individuals who feel hoisting practices currently used in the coal mining industry are as safe as necessary and that hoisting safety is not a problem. They point to the statistics on mine injuries and fatalities and emphasize the lack of wire rope associated accidents. The safety record for hoisting in U. S. coal mines appears to be relatively good. However, it is also clear from observations made during this study that hoisting practices exist today that are unsafe and that considerable misunderstanding exists with respect to wire rope use and the associated safety problems. The improvements in hoisting practice which foreign countries have made have usually been the result of a mine hoisting disaster. It would be regrettable if increased attention to hoisting problems in the U. S. also came about only as a result of such a disaster.

Thus, with respect to hoist rope practice, the following conclusions have been drawn:

(1) Machinery Design and Selection, and Rope Selection:

- (a) There is a desirable trend toward the use of larger diameter sheave and drums for new equipment. However, old equipment with smaller diameters in many cases will present hoist-rope problems for years to come.
- (b) There appears to be a desirable trend toward single-layer rope winding on the drum and toward the use of improved drum-grooving geometries which mitigate rope spooling problems. Retrofit of old winch-drums with sleeves using improved grooving geometries occurs, but more of this would be beneficial. This applies strictly to cylindrical drums, which, incidentally, are the only kind currently being manufactured.
- (c) There is a divergence of opinion on the effect of sheave-groove hardness on rope life and no consistent definitive data with respect to this is known to exist.

- (d) There is considerable difference of opinion on the reliability and effectiveness of the various types of conveyance-rope terminations available and in use, on the effects of these terminations on rope strength degradation, and on when to reterminate.
  - (e) Many mine operators do not know what rope to use, or why they use what they do. Some don't even know exactly what kind of rope they are using! Most rely heavily on the recommendations of the rope supplier and in some instances it can be questioned whose interests are served.
  - (f) Most rope records kept by hoist operators are of the check ("✓") type and are of little use in selecting a "better" rope or in solving problems.
  - (g) The commonly suggested safety factors for rope-selection computations are 56 years old. They were initially recommended along with maximum hoist speeds and accelerations, presenting a consistent body of data which implicitly included consideration of dynamic rope loads, but explicitly eliminated the need for users to make the computations. With time and reprinting, the speed and acceleration data disappeared and only the safety factor data are typically presented in current publications. The lack of speed and acceleration data present problems to mine operators who want to increase production through increasing hoisting speeds. The 56 intervening years have brought technological changes, and the need for a rationalization of safety factors, maximum speeds, and acceleration limit regulations are clear.
  - (h) Certain safety devices in hoist control systems, such as overwind- and overspeed-prevention controls, are not necessarily installed in a manner which assures that they will function as intended. Furthermore, reliability considerations suggest the need for redundancy of some safety control devices the proper functioning of which is absolutely vital. A number of "safety feature" failures have been noted.
- (2) Maintenance:
- (a) Many rope inspection and maintenance programs and procedures are of a casual nature and little useful data are gathered and recorded for improving rope life.
  - (b) Much good, descriptive maintenance-procedures information is available but obviously is not used in many cases.

- (c) Service or materiel slope-hoist ropes tend to be severely abused and further degraded through lack of sensible maintenance of sheaves, support-rollers, and winding equipment.
- (d) Rope-lubrication practices vary widely; there is much difference of opinion of what type of lubricant to use, and often there is simply just insufficient lubrication of any type. The best-appearing shaft-hoist ropes were oiled and there is literature which indicates oil or a light lubricant is better than heavier, thicker lubricants.

(3) Inspection and Replacement:

- (a) Visual inspection for rope-strength degradation is the predominant practice and can result in serious defects being inadequately judged or entirely missed. There are no quantitative criteria for relating what is seen during visual inspection to the actual strength condition of the rope.
- (b) To be most effective, visual inspection must be done in detail over the entire length of the rope. This is a time-consuming process and there is a tendency not to do it often enough or in enough detail.
- (c) Electromagnetic, nondestructive inspection devices used in conjunction with visual inspection can provide much more knowledge of the condition of a rope than visual inspection alone. There is much confusion over their value, principally because of a lack of knowledge about them. They are in limited use in U. S. coal mines but in some instances they are not well understood nor is their value fully appreciated.
- (d) No quantitative criteria for rope strength are available for use in determining when to replace a rope. In general, short of strand breaks or other gross damage, when to replace a rope is one of the greatest problems hoist users face.
- (e) Because of this lack of quantitative replacement criteria it appears that the majority of shaft ropes are replaced too soon. That is, they could be safely used longer though the users generally don't know how to judge this and, justifiably, don't take chances.
- (f) Slope ropes generally tend to be used too long and many that have been seen are considered to be distinct safety hazards.
- (g) Practically no inspection and testing of discarded hoist ropes, destructive or otherwise, is made to determine the cause of damage, how to avoid it in the future, and how strong the rope was at discard.

- (h) Rope records provide few data for use in improving inspection and replacement practice.
  - (i) Attention to rope inspection and replacement practices and rope degradation histories associated with elevators used in coal mine applications would be beneficial. These installations are essentially the same as Koepe-type friction hoists. There is uniformity of design, maintenance, and inspection because strict and detailed elevator codes are being applied. Furthermore, as mine elevator installations are maintained by elevator manufacturers under contract, the personnel involved do nothing else and would be a valuable source of information on rope behavior and degradation.
- (4) Laws and Regulations:
- (a) The majority of U. S. federal and state laws related to hoisting and hoist ropes appear directly related to a study, similar to the one herein reported, completed in 1915.<sup>(38)</sup> Many good suggestions of that study were never implemented or incorporated into law. A majority of those that were incorporated are still in effect, basically unchanged.
  - (b) Those laws and regulations requiring safety devices appear to be enforced in accord with the letter of the law rather than the intent.
  - (c) Rope-replacement criteria given in terms of minimum safety factors are useless since there is practically no domestic practice which can relate inspection results to rope strength conditions.
  - (d) Some foreign laws and practices, Ontario's in particular, are often more comprehensive and reflect a great deal of continuing study of the the engineering problems.
  - (e) Most state inspection agencies do not appear to be actively involved in hoist-rope inspection in coal mines. State law places this responsibility on the operator.
  - (f) Most state inspection agencies show little knowledge of the origin of their hoisting laws pertaining to coal mines or of the technical aspects of hoisting and hoist rope. Consequently, little guidance in improving practices appears to come from the state level.
  - (g) Hoisting regulations pertaining to noncoal mines are generally more comprehensive and sometimes more quantitative than those for coal mines.

The final objective of this program was to develop a technological base for formulating wire rope safety standards and practical methods for enforcing their use in U. S. coal mines.

Safety standards appear to be most appropriate to the removal of hoist ropes from service.

The rope usage practices, summarized in the previous conclusions, indicate that the long-standing problem of hoist rope replacement still exists because there is insufficient technical data domestically available to relate wire-rope strength to the kinds of data obtained from the visual inspection practices in use.

There is a body of technical data available nearby in Ontario. However, hoisting practice there is sufficiently different to require experimental study to determine the extent to which it would be applicable to U. S. coal mine hoisting practice.

Thus, available data do not allow establishing a technological base for formulating hoist rope safety standards that would represent an improvement over any of those which currently exist.

#### NONHOISTING APPLICATIONS OF WIRE ROPE

Wire ropes in non-shaft-hoisting applications generally are neglected and misused even where service conditions are not severe. The ropes are bent around sheaves and drums that are too small even where space limitations do not prevent the use of larger diameters. The ropes are often not lubricated properly.

Better care in use and lubrication, and larger sheaves and drums, can produce greater rope life. What cost trade-offs exist are unknown, but machine downtime and labor costs must be included when figuring costs, not just rope and initial machinery costs. Any degree of cost consciousness or concern for machinery utilization would appear to call for more care and maintenance than is evident in most mines.

Broken ropes can lead to extensive machinery damage and could easily cause injury and death. No general conclusion can be drawn about the degree of hazard of nonhoisting applications of wire rope. Each case must be judged individually.

● RECOMMENDATIONS

## RECOMMENDATIONS

To promote the advancement of hoisting technology in the U. S. underground coal mining industry, to assist mine operators in obtaining the maximum utilization of their hoists and other equipment using wire rope, and to promote a greater awareness of safety and a reduction of hazards, it is recommended that

- (1) Research and development efforts be initiated for the purpose of rationalizing the many aspects of hoisting technology, recommended codes and specifications, and laws and for generating specific, quantitative information to the limit of present and developing technology. The results of such efforts would be useful and beneficial to mine hoist operators in selecting, operating, and maintaining hoist equipment and in selecting, maintaining, inspecting, and replacing hoist ropes and thus would promote mine safety. Specifically,
  - (a) A detailed study of hoist-rope degradation in service should be made coupled with a detailed study of rope characteristics and remaining strength after replacement, using destructive techniques and devices and nondestructive electromagnetic techniques and devices. This effort should be directed toward establishing specific, quantitative criteria for hoist-rope replacement. Such a study would also demonstrate to potential users the value of electromagnetic inspection devices and techniques.
  - (b) A study of all typical hoist installation and maintenance costs is recommended. This study should cover the mining effort in general to provide operators with information needed for evaluating present practices versus potential benefits occurring from increased maintenance of hoist rope and machinery and from modifications of practices and equipment which could extend rope life.
  - (c) An analytical and experimental study of the dynamic behavior of hoist ropes and attached conveyances directed toward establishing rational hoist-rope safety factors is needed. Some of the information for such a study already exists.
  - (d) A research and development program directed toward increasing present-day capabilities of electromagnetic wire rope inspection devices is recommended. It should cover application of techniques both in use and under development in the general field of eddy-current non-destructive inspection - techniques suggested but not as yet applied to wire rope inspection.
  - (e) A study of the relative merits of available hoist-rope termination techniques and devices, directed toward

establishing and confirming the rope-degradation effects of each, and the relative strengths of each with respect to the breaking strength of rope should be made. Such information is necessary for overall safety considerations and for the design and selection of machinery and rope with rational safety factors.

- (f) A detailed study of the apparent patterns occurring in hoist-rope degradation is recommended, directed toward establishing the causes and subsequently mitigating or eliminating them.
- (g) A study should be made of hoist-control techniques and devices used with such safety features as overwind- and overspeed-prevention controls to determine the extent of their actual effectiveness and to establish techniques and devices for improving and/or assuring their effectiveness.

Either for assisting these efforts or as a result of them, it is further recommended

- (2) That mine operators be required to report the occurrence of all hoisting incidents and accidents which involve safety devices or hoist-control-system safety features which are supposed to prevent such incidents and, in addition, that they be required to indicate the suspected causes of the incidents. Such information would aid the rationalization of requirements for safety devices and control-system safety features.
- (3) That the Bureau of Mines call for a revision of the presently recommended specification for the use of wire rope in mine hoisting - ANSI M11.1-1960 - and that the section dealing with rope replacement be patterned somewhat after the related sections in the standard elevator codes - ANSI A17.1 and A17.2 - which give specific quantitative procedures and criteria for rope replacement. Sufficient information exists to make a good beginning in this direction.
- (4) The Bureau of Mines establish an information data center for collecting and distributing information generated from studies as suggested above as well as from any such efforts anywhere in the world. The information deposited would be useful in the suggested educational efforts directed to the U. S. coal mining industry. With proper staffing, it could also serve the U. S. mining industry as a center for solving specific hoisting problems as they arise.

As stated, there is a need for quantitative criteria for both inspection and replacement of hoist rope. It would be easy enough to recommend the immediate use of those criteria in use in Ontario, for example, because of the soundness of the developmental efforts behind them and their value in use. Prudence dictates against, this, however.

From the beginning, the Ontario effort involved mine operators, rope manufacturers, and regulatory agency personnel. The course of time brought to all a recognition and understanding of the problems and the needs for studying them to achieve solutions. There is no indication that anyone in Ontario unduly chafes under the regulations which subsequently evolved. This might occur, however, were these regulations or similar ones brought into effect in this country without prior education and demonstration of their value. Furthermore, work continues in Ontario in an ongoing effort to improve hoisting technology and hoisting-safety law. Such an approach would be beneficial in shaping and supporting attitudes in this country as well.

Hoisting and hoist-rope problems definitely appear to be essentially the same whether coal or some other product is involved. It would appear desirable in the long run to rationalize hoisting practice and law for all U. S. operations - coal as well as noncoal mining operations.

The above actions will benefit both hoisting and nonhoisting applications of wire rope. To obtain maximum advantage of these advances, it is further recommended that

- (5) Through the use of circulars or otherwise, updated as technological advances permit, the coal mining community be made aware of
  - (a) The machinery utilization and safety benefits that can accrue through good rope- and machinery-maintenance procedures
  - (b) Changes in machinery and/or rope types that would promote longer rope life
  - (c) Practices which are detrimental to rope life regardless of the specific application.

Examples of good maintenance practice should be included in such publications with the specific procedures for specific applications as necessary.

DETAILED DISCUSSION OF RESULTS -  
HOISTING APPLICATIONS OF WIRE ROPE

DETAILED DISCUSSION OF RESULTS -  
HOISTING APPLICATIONS OF WIRE ROPE

INTRODUCTION

The term "hoist" is applied to many devices used to lift loads. In this section the terms "hoist" and "hoisting" apply to systems used to transport men, materiel and product (coal) between the surface and the underground working level(s) either through vertical or inclined shafts. Vertical shafts are commonly enough called "shafts" and inclined shafts "slopes" so that these terms are used throughout this report.

Shaft slope hoists usually differ in the number of ropes involved. Most slope hoists use one hoist rope while vertical shaft hoists use at least two. Two ropes (at least) on shaft hoists stem from the use of the principle of counterbalancing - that is, for an ascending load there is some assisting, descending load - to minimize the input power requirements. All shaft hoists apparently use the counterbalancing principle. Some slope hoists used for hauling coal are reported to use the counterbalancing principle.

Shaft hoists are divided into two basic types differing in how the hoisting force is transmitted to the rope. In one the rope is directly fastened to a revolving drum, these systems generally being known as "drum hoists" or "drum winders". In the other system the rope passes over a driving wheel, and the friction between the rope and the wheel surfaces is used to transmit force. These systems are called "friction hoists" or "traction drives" (elevator terminology). The friction hoist most commonly in use finds the rope passed about 180 degrees or more around the drive wheel with several parallel ropes being used. In mining applications this type of friction hoist is generally called a Koepe hoist after the originator; the most common, nonmining application of this type of friction hoist is the elevator. Beyond the number of ropes involved, drum and friction hoists differ in other significant ways.

The majority of recent innovations and developments in hoisting technology appear to have been made in foreign countries. This is partly because mining was a well-established industry before the U. S. was settled. (A wood-cut in Sebastian Münsters "Cosmographiae Universalis", published in Basle, Switzerland in 1550, shows an early, balanced-skip shaft hoist. The skips are baskets, the rope is undoubtedly fiber rope, and the drum is hand operated.) The more developed mining operations can usually be expected to encounter new problems first. Furthermore, the need to go deeper has generally first occurred in foreign operations.

The need to go deeper appears to have been the single, greatest challenge to innovation in hoisting and hoist-rope technology. It must be understood that the "load" being hoisted is not just that of the conveyance and its cargo but also that of the rope; that is, part of the rope's load is its own weight. Thus, as shafts go deeper the rope weight becomes a significant portion of the maximum load on the rope. There is therefore a depth limit beyond which a single-rope hoist cannot be applied because of the lack of an available rope of sufficient strength to carry its own weight in addition to the conveyance and cargo weight. To overcome this problem multiple-rope systems were developed. These systems can be used at greater depths because the ropes share the conveyance and cargo weight. The Koepe friction hoists are one such development. Multirope drum hoists have also been developed, the most notable being the "Blair" system (after its

innovator) in use in South Africa. In addition to the number of ropes involved there have been a variety of other innovations related to rope problems. However, none of these innovations appears to be used (or needed) in U. S. coal mines, and thus they are discussed no further. (Reference 10 in the bibliography, Appendix A, discusses some of these innovations.)

Though this program is directed to wire ropes associated with underground coal mining in the United States it is necessary to point out that hoisting, as a transportation method, is in general use throughout the mining world. If the product mined has any effect on hoisting it is usually a result of the mine depth or the corrosive conditions involved. Thus, though this discussion of hoisting derives from the study of coal mines in particular, most of the problems and practices appear to generally apply to all mining applications of hoisting. Where comments apply strictly to coal mining, the distinction is made.

For safety considerations, various types of hoists were studied during this program because, sooner or later and for valid reasons (e. g. shaft inspection, maintenance), men can be expected to ride hoists not normally used for the purpose.

DESCRIPTIONS OF HOISTING  
INSTALLATIONS IN U.S. COAL MINES

Requirements for Hoisting

Mining requires getting men and machinery in and out, supplies in and product out. How this is done today in underground coal mining depends upon the depth of the seam.

Drift mines were not studied specifically in this program since they generally don't use hoist installations and the wire ropes in use are essentially covered in the section on nonhoisting applications.

Shallow coal mines – operations up to about 400 feet below ground – no longer require hoisting in the historic sense for removal of coal. It is common in shallow mines today to use continuous conveyors installed in slopes for removal of coal.

Typically, however, these mines will use slope hoists for transporting equipment and supplies, and elevators for hoisting men. These elevators are almost always built, installed, and maintained by elevator manufacturers, and mine operators know little about them. Consequently elevators in coal mines were studied to some extent and are discussed separately later. A few shallow mines still use slope and shaft hoists for all transport but such practice in shallow mines is expected to diminish. In new shallow mines it is common to find a service hoist (equipment and supplies) installation below a conveyor in the same inclined shaft.

Deep coal mines – operations, say, below 400 feet – usually require some application of vertical shaft hoisting. The cost trade-offs between sinking vertical and inclined shafts and the initial costs and upkeep of hoists versus conveyors were not determined, such information being beyond the scope of this study.

Typical Installations

During this program 35 shaft hoists (elevators excluded) and 28 slope hoists were inspected during visits to 41 coal mines. Questionnaires supplied information on an additional 16 installations. The uses for the hoists inspected are listed in Table 1.

The use for a particular hoist determines the type of conveyance attached. Those shaft hoists used for coal alone used skips. The skips seen were predominantly of the bottom-dump variety which, while dumping, appear to induce less rope vibration than the tip-dump type. (The effects of vibration on rope degradation are discussed later.)

The shaft hoists used for men alone or for men and materiel use cage conveyances which differ widely in configuration. All appear to affect the rope similarly in that they are generally required to carry a safety bridle which attaches to the rope and can be a source of rope problems.

TABLE 1. USES OF COAL-MINE HOIST INSTALLATIONS THAT WERE INSPECTED

Use	Number Inspected
Shaft-Hoist	
Coal	17
Men	6
Men, materiel	10
Men, materiel, coal	2
Total	35
Slope-Hoist	
Coal	1
Materiel	20
Men, materiel	5
Men, materiel, coal	2
Total	28

Shaft hoists used for men, materiel, and coal commonly use a skip/cage combination which, in the skip mode, carries a mine car. The whole arrangement tips at the unloading level. Skip/cage combinations were seen using two such conveyances in balance where only one of the conveyances was normally used for men, and thus only one safety bridle was attached.

Slope-hoist conveyances are track-guided vehicles which commonly are specially built for the purpose of hauling coal, or men, or supplies. One or more cars per "trip" is common as is a weighted "dummy" or "Barney car", semipermanently attached to the rope, which provides a constant, minimum load on the rope at all times. The term "service slope hoist", in this report, is applied strictly to materiel-hauling hoists; these installations commonly don't have the semipermanently attached dummy car. Where this is the case the rope is often hauled up without any load on it, a situation which leads to slack-rope conditions and accompanying problems.

### Shaft Hoists

Drum Type. A typical configuration for a drum shaft-hoist is shown in Figure 1. The drum is driven by an ac or dc motor, either directly or through reduction gears. It is doubtful that there are any steam- or air-driven shaft hoists in use in coal mines. Many ex-steam drum hoists, now electrically driven, are still in use however, some still fitted with practically all the steam-engine components. Figure 1 shows two conveyances but it is fairly common to find one conveyance and one simple counterweight on man and materiel hoists. Figure 1 shows one configuration for head-sheaves; the other common arrangement is to have the two sheaves side-by-side on the same axle centerline.

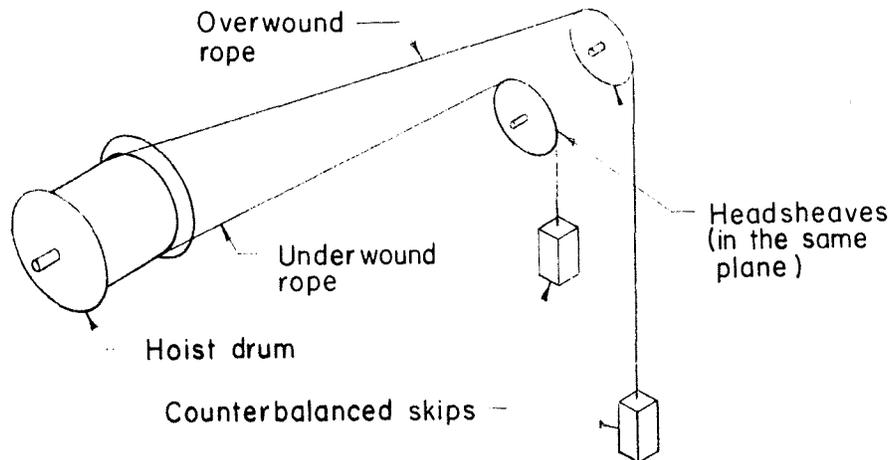


FIGURE 1. TYPICAL DRUM-SHAFT-HOIST CONFIGURATION

Figure 1 also shows the simplest drum configuration for counterbalanced hoisting—a simple cylinder with one rope wrapped onto the drum from the top (overwound) and one wrapped on to the drum from below (underwound). The terms "overwound" and "underwound" should not be confused with the terms "overwind" and "underwind" which refer to winding a conveyance too far up and too far down.

In addition to a simple cylinder a hoist drum may be conical, or some combination of a cylinder and a cone. A very common combination is a conical section between cylindrical sections, the so-called bicylindro-conical form. The configurations using the cone are reportedly no longer made. In use, a loaded conveyance is started up from the bottom with its rope on the small diameter. As the conveyance rises so does the rope on the cone. At the same time the empty conveyance starts down with its rope on a large diameter and as it lowers so does the effective drum diameter associated with its rope. This changes the moment arm from the drum centerline to the rope to reduce the starting torque requirements on the drive motor or engine. In steam and early electric drives these conical shapes had a value which has been negated by improved electrical technology and supply capacity. Although they have other desirable features, fabrication costs for such a complex shape has eliminated them from use in new systems.

No matter what their shape, drums are used either singly or in pairs. Paired drums are either series-mounted, two drums on one shaft, or parallel-mounted, one drum on each of two parallel shafts. In the coal mines visited the most common arrangements are a single drum or a series-mounted pair. Finally, it is common to find a single drum which is, in essence, two conical or bicylindro-conical shapes joined together, a configuration herein called a double drum. Some typical drum configurations seen in coal mine hoists are shown in Figure 2. Note that one rope is always overwound and the other underwound. This is basic to the counterbalanced hoisting principle.

The use of two drums, series- or parallel-mounted, is required when balanced hoisting with two conveyances is desired and the mine configuration requires hoisting between more than two levels. In this case one or both drums are free-turning on their respective shafts, but coupled to their shafts with some clutch mechanism. The clutch allows changing the relative position of the conveyances with respect to one another along the rope path when hoisting between two other levels is desired. The free-spinning

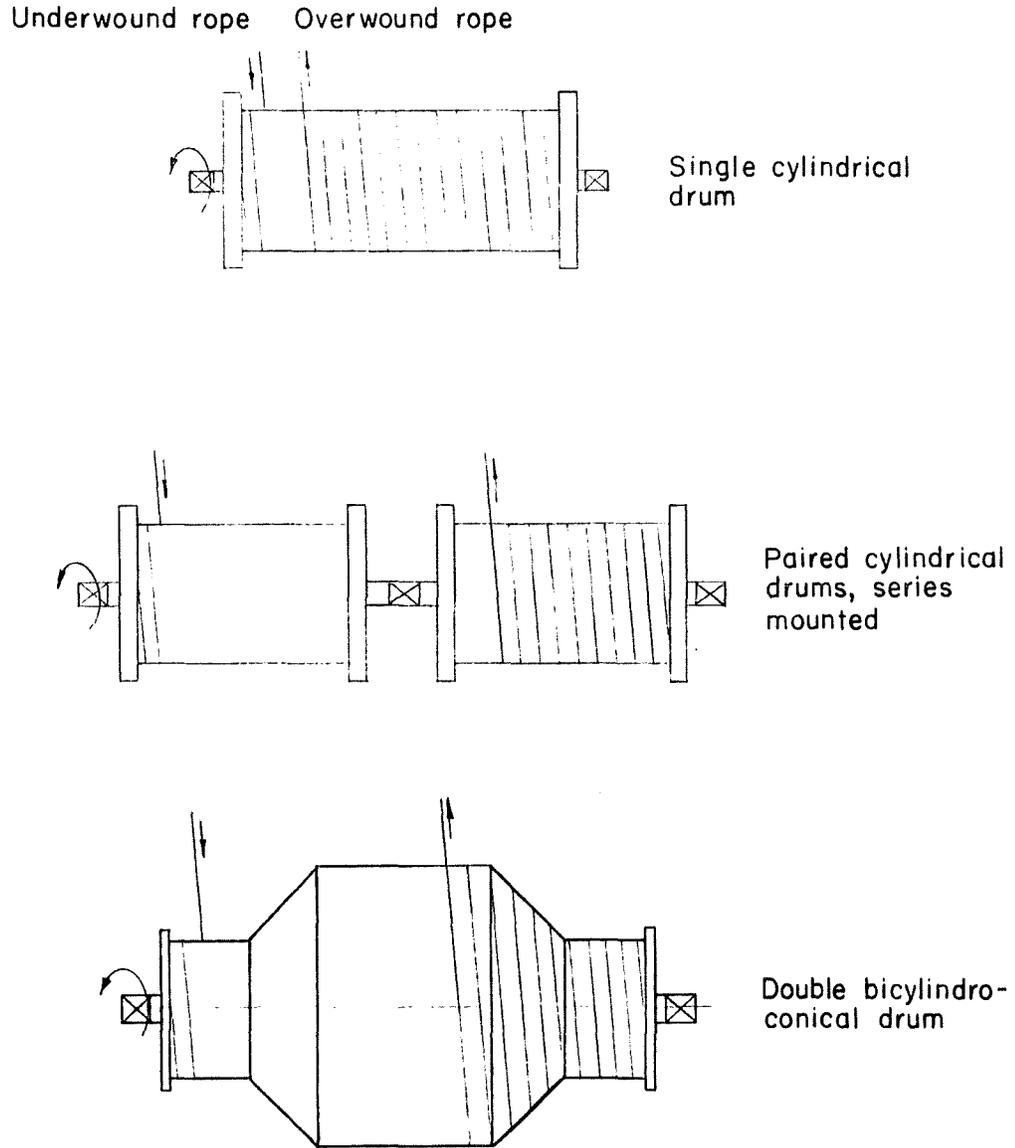


FIGURE 2. TYPICAL COAL-MINE-HOIST DRUM CONFIGURATIONS

potential of a clutched drum has profound ramifications for safety and will be discussed later.

In all the coal mines visited shaft hoisting between one underground working level and the surface was the rule and is reportedly typical of U. S. coal mines. Nonetheless several clutched-drum hoists were seen though the clutches are reportedly not used.

While many manually-operated drum-type shaft hoists are still in use the trend today is toward automatic control with manual-backup capabilities. This is generally true of new systems and is commonly applied to hoists relocated for use at new mines or shafts. Automatic man and materiel hoists are push-button operated at the shaft much like modern elevators. Automatic product hoists are generally controlled by the flow of the product at the loading station below ground.

Friction (Koepe) Type. Two configurations for Koepe hoists are shown in Figure 3.

The application of Koepe hoists to coal mining in the U. S. is fairly recent, as is the general use of these systems in North America. The drive or Koepe wheel is typically driven by a dc motor and the whole system automatically controlled, having a backup manual-operation mode of control. Figure 3 shows two conveyances but one conveyance and one counterweight is more common on man and materiel hoists.

Since the driving force arises from the friction between the rope(s) and the wheel surface it is important that the tension in the hoist rope be controlled on both sides of the wheel. Since these systems were primarily developed for deep mines, wherein the load of the ropes themselves can be significant, the use of tail ropes, whose weight per foot closely approximates that of the hoist ropes, achieves a constant rope load due to the weight of the ropes themselves. Thus, with empty conveyances, the rope loads or tensions are effectively constant no matter where the conveyances are in the shaft and, except for torque-induced tension changes across the wheel, only the product weight unbalances the system. Tail ropes usually hang free although devices are sometimes installed at the bottom of the loop to prevent fouling.

This type of hoist can only be used between two levels as there is no practical method allowing a change in the relative positions of the conveyances with respect to one another along the path of the rope.

A cross section of the rim of a typical Koepe wheel is shown in Figure 4. Koepe-wheel systems have at least two ropes and as many as six have been seen. Normally an even number of ropes is used. Special composite materials, often like hard rubber, are used to support the rope and to provide a higher coefficient of friction than is possible with steel-on-steel.

### Slope Hoists

All slope hoists inspected and all known of are drum hoists, a typical installation being shown in Figure 5. Furthermore all slope hoists inspected in coal mines were single-rope systems using cylindrical drums. The majority seen have one drum permanently attached to the main drive shaft. Hoist machinery is often used in more than

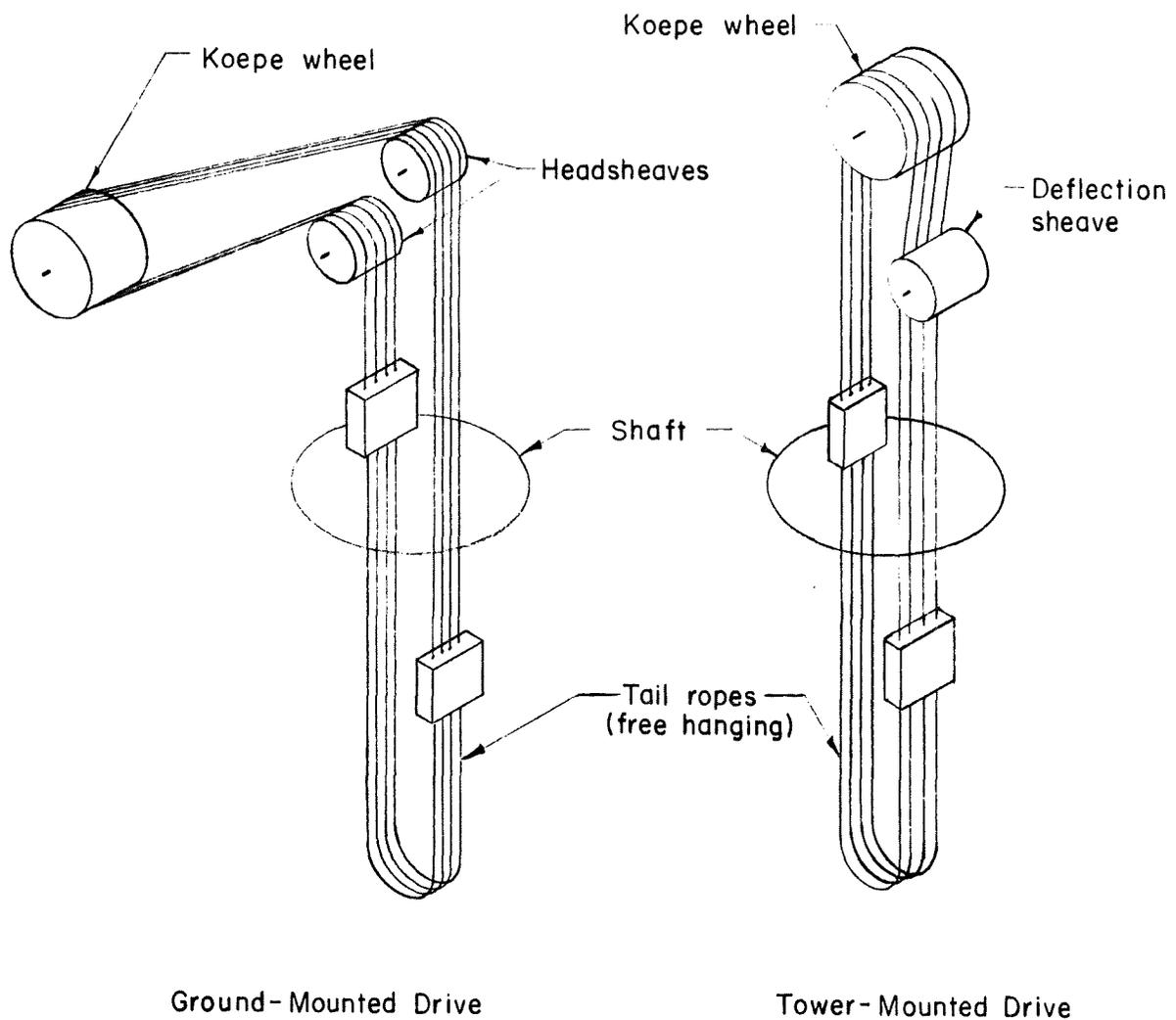


FIGURE 3. KOEPE HOIST CONFIGURATIONS

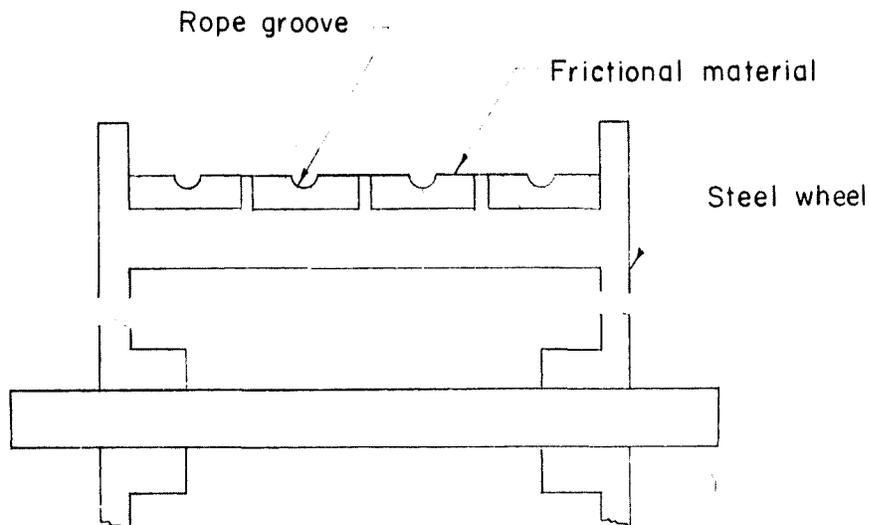


FIGURE 4. CROSS SECTION OF A KOEPE WHEEL

one place in the course of its life. This accounts, in part, for the use of double-drum slope hoist systems wherein only one drum is in use although the other is still being driven. Two single-drum hoists with clutched drums were also seen in coal mine service. In at least one case the hoist was original equipment, being used as delivered. In both cases the clutches were of the Lane friction-band type (see Chapter 12, page 16, Peele's Handbook)<sup>(109)</sup> and were reportedly locked in the engaged position and never used. No practical reason for using a clutched, single-drum, single-rope hoist in this service has been determined. The point is made for safety considerations to be discussed later. The drums are ac or dc motor-driven and no automatically controlled installations were seen though some are reported to be in coal-mine use.

The use of at least some rope-support rollers is a characteristic of slope-hoist installations. Typically, they are located at the crown of the slope as shown in Figure 5. The better-maintained systems will have support rollers well distributed along the rope path. Furthermore, rollers can be found on the roof where, because of slope changes, the rope might otherwise drag the roof.

Common also to slope-hoist installations is a track turnout (switch) above ground as illustrated in the plan view in Figure 5. Typically, vertical rollers are found at or near these turnouts along the inside of the curve. These rollers are meant to direct the rope around the curve rather than allow it to tend to assume a straight line and drag on anything in its path.

Though Figure 5 is typical in that a more or less straight rope path exists, it is not rare to find a slope hoist installation which utilizes a number of turning sheaves (not to be confused with vertical track rollers) to lead the rope to the hoist drum. In addition there are slope hoists serving two levels or reaching the working level through a curved or 180-degree bend shaft. Examples of these installations are shown in Figure 6. These kinds of arrangements are less desirable from the standpoint of rope use as the additional turning sheaves and turning rollers in the shafts (if installed) provide additional rope-bending. In general rope-bending should be kept to an absolute minimum.

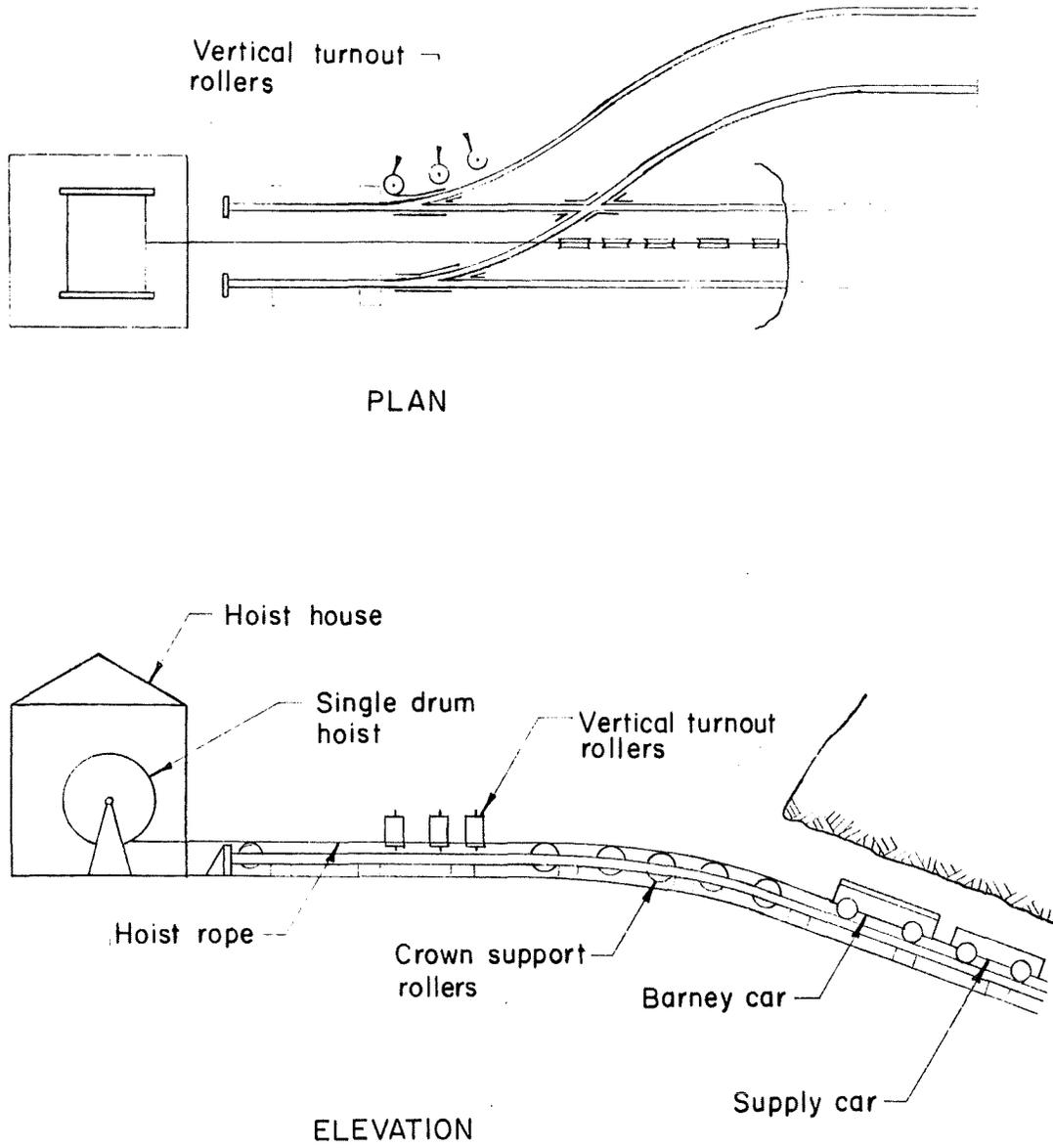


FIGURE 5. TYPICAL SLOPE-HOIST CONFIGURATION

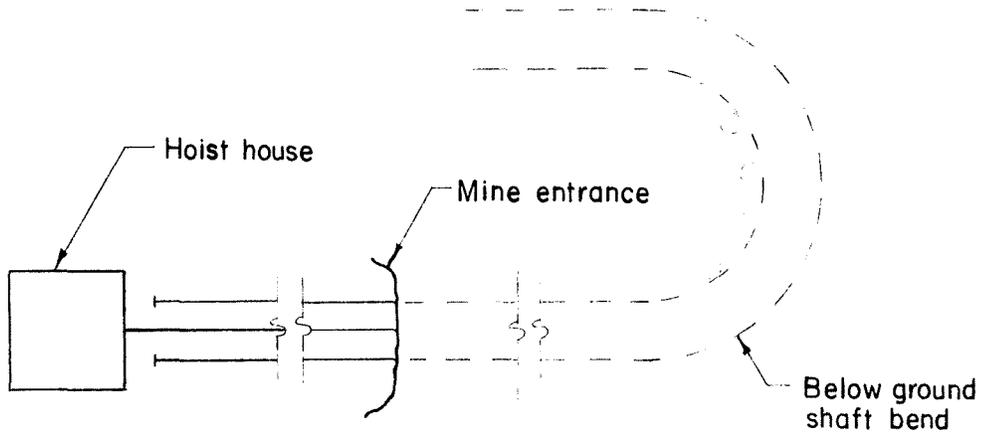
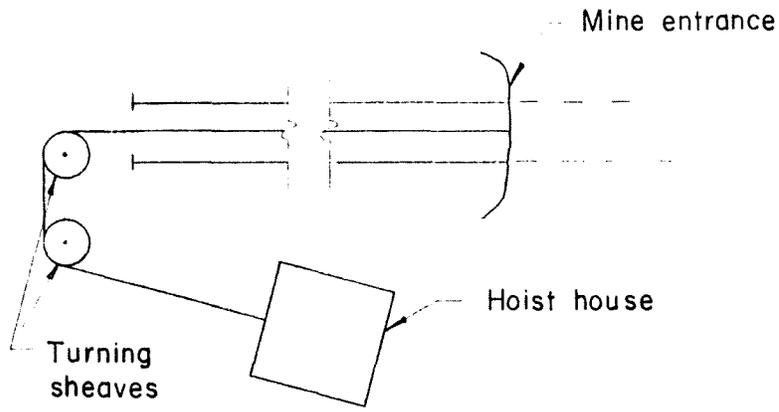


FIGURE 6. LESS DESIRABLE SLOPE-HOIST CONFIGURATIONS

Where men normally ride a slope the rolling stock may be provided with some type of safety device which actuates if the rope breaks. Those seen are controlled by over-speed or travel-direction sensing mechanisms.

### Typical Duty Cycles

The duty cycles of a hoisting system vary considerably. Product hoists operate at an essentially continuous pace during production hours. Men and materiel shaft hoists are used heavily at shift changes and less frequently during shifts; but the total number of trips per day is much less than for a product hoist. Generally in coal mines, the least-cycled hoisting systems are those used on slopes. As illustrated in Table 1 coal-mine slope hoists are predominately used for materiel haulage. These hoists may operate a maximum of ten or fifteen trips per shift. Duty cycles have a direct and obvious influence on rope life.

### Hoisting Environment

The environment in which hoist ropes operate can strongly affect their service life. Environmental factors such as upcast or downcast ventilation, shaft dampness, water pH (acidic or basic condition of water) and weather conditions play important roles.

Shafts and slopes that have upcast ventilation often surround the hoist rope with extremely moist, warm air providing a good atmosphere for corrosion. Shaft water with high pH readings, indicating an acidic condition, provides increased possibilities for corrosion. Upcast shafts and slopes with acidic conditions are quite common in United States coal mines. Downcast shafts and slopes generally provide a cooler, dryer environment for the hoist rope. However, during winter months ice buildup on the rope can occur since virtually all shafts and slopes are open to the weather.

An additional environmental factor prominent in slope-hoist systems is dirt. Dirt and small pebbles can be picked up by the rope lubricant and pressed into the strands as the rope is wrapped onto the drum. Light lubricants such as oil tend to minimize this. Such particles cause very high local stresses which can lead to wire breaks. Furthermore, ropes dragged through dirt are abraded by it.

### Applications for Rope

Wire rope is commonly used in the following applications in mine hoisting systems:

<u>Drum Hoisting Systems</u>	<u>Koepe Friction Hoisting Systems</u>
(1) Hoist rope	(1) Hoist rope
(2) Balance rope (vertical shaft systems only).	(2) Tail rope
	(3) Guide rope
	(4) Rubbing rope.

The ropes commonly used are illustrated in Figure 7.

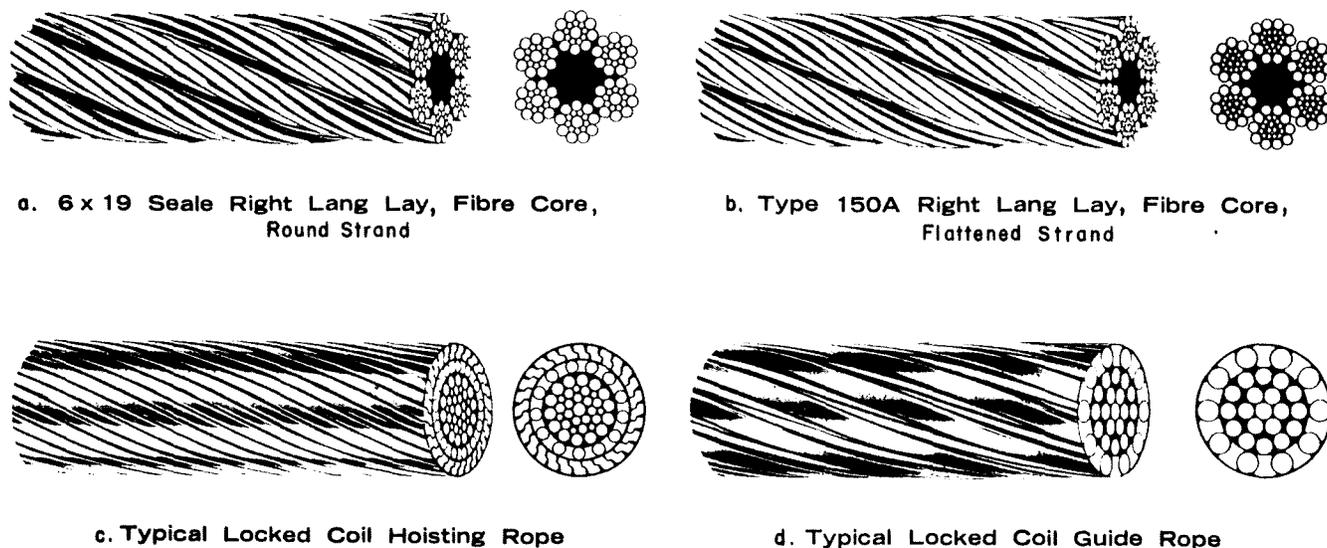


FIGURE 7. ROPES COMMONLY USED IN HOIST SYSTEMS

### Hoist Ropes

Hoisting is the most critical application of wire ropes from a safety standpoint. These ropes are also the most heavily-loaded and are put to the most operationally-demanding use. The type of rope most commonly used is a 6 x 19 classification as shown in Figure 7a. (Again consult Appendix O for rope terminology and construction examples.) This classification includes several different constructions with the number of wires in each strand varying from 9 to 26. Round strand construction is the most widely used in the United States with flattened strand, Figure 7b, the most popular in Canada. Locked coil rope, Figure 7c, is commonly used for Koepe installations in Canada but sees limited use in the United States.

### Balance Ropes

The term balance rope applies to that rope associated with a simple counterbalance in balanced systems using only one conveyance. Balance ropes are generally of the same construction as the hoist rope.

### Tail Ropes

Tail ropes are used in Koepe installations to achieve a constant weight of hanging rope regardless of conveyance position as discussed earlier. (The exact relationship between the hoist rope and tail rope weights can be varied slightly to improve system acceleration.) Tail ropes are unguided and free hanging. The free hanging aspect of the tail ropes requires considerable flexibility and nonrotational properties are desirable.

### Guide Ropes

Guide ropes can be used in place of fixed wooden or steel shaft guides to reduce system vibrations and minimize obstructions in the vertical shaft. They require less

overall maintenance than fixed guides and permit the use of heavier skips. The cleaner, less obstructed shaft improves air flow for ventilation purposes. The recommended guide rope is shown in Figure 7d and has a half-locked outer-layer configuration. This rope provides a smooth bearing area for side load support and some relief for lubricant retention.

### Rubbing Ropes

Rubbing ropes are used in situations where the two conveyances traveling in the same shaft need more positive separation to assure they will not strike each other. The rubbing rope is suspended between the conveyances and acts as a deflector. Half-locked ropes are recommended for this purpose.

Due to the predominance and importance of hoist rope within the hoisting system, the following sections of this report will be oriented in that direction. Where the discussion applies to other applications as well (i.e., tail ropes, balance ropes...) it will be so noted.

## MACHINERY DESIGN CONSIDERATIONS

Each hoisting system is composed of several components which have some effect on the service life of the hoist rope. Typically these are the hoist machinery, rope attachments, and the conveyance guide system. Their design and use can do much to influence rope life and the assurance of a safe hoisting system.

As previously mentioned there are essentially two types of hoists used currently in the coal mine industry - drum hoist and friction hoists. Many design considerations with respect to rope life are valid for both types, however, there are important differences.

### Drum-Hoist Systems

Important considerations in drum-hoist system design which affect the hoist rope's service life are:

- (1) Drum and sheave diameter
- (2) Type of drum grooving
- (3) Layers of rope on the drum
- (4) Flange margin
- (5) Riser blocks
- (6) Rope attachments
- (7) Conveyance guidance.

### Drum and Sheave Diameter

For a given rope diameter,  $d$ , the diameter of the drum and sheaves,  $D$ , around and over which the rope is wrapped has a very strong effect on the rope life. For a given rope load this diameter,  $D$ , establishes the magnitude of (1) the contact stresses between the individual wires in the ropes, and between the outer wires and the drum- and sheave-groove surfaces and (2) the bending stresses in the wires. Generally, for a given rope diameter,  $d$ , the larger the  $D$  the longer the rope life, providing, of course, that wear and corrosion are not the prime sources of rope strength degradation. Thus, the ratio of drum or sheave diameter to rope diameter,  $D/d$  is constantly encountered in discussions of rope life. Consideration of the effects of flexibility differences in ropes of the same diameter but different constructions had lead to use of the ratio  $D/d'$ , where  $d'$  is the diameter of the outer wires. Again, generally, the larger the  $D/d'$  ratio, the longer the rope life.

In the United Kingdom  $D/d \geq 100$  appears to be common. In Ontario a  $D/d \geq 80$  is specified by law. In the United States a hoist manufacturers' catalogue recommends  $D/d \geq 60$ <sup>(134)</sup> although he currently builds predominately with  $D/d \geq 80$ . Rope manufacturers suggest  $D/d' \geq 1000$ .

Hoist drum and head sheave data obtained during this program are presented in Appendix B in Tables B-1 and B-2, for shaft- and slope-hoist installation, respectively. Appendix B in general contains the details of hoist installation which were collected during this program. The drum  $D/d$  are in the range of from 27 to 110, with majority grouped around  $D/d = 64$ . Though not indicated in Tables B-1 and B-2, the majority of these installations reflect  $D/d'$  ( $d'$  = wire diameter) ratios grouped around 800. For head sheaves (where applicable) the  $D/d$  range from 48 to 105 with the majority grouped around  $D/d = 70$ . The newer installations tend to have a  $D/d$  of at least 80.

The best time to consider  $D/d$  is during the design stages. However, where wire fatigue failures due to cyclic bending over existing smaller diameters is a primary cause for rope replacement there are still possibilities for improving the situation. Little significant improvement in drum  $D/d$  can be realistically effected short of a new drum. However, when a head sheave is due for replacement, a larger one, say with  $D/d \geq 80$ , could be installed, space permitting. Of all the cyclic bending events induced in the rope by the drum and head sheave in the course of one complete hoisting cycle, the head sheave is responsible for 2/3 of them. Thus, a larger head sheave alone could significantly add to rope life in many systems with currently low  $D/d$  values.

### Drum Groove Types

Three types of drum grooving are in use - parallel, helical, and LeBus\*.

Parallel grooving is made up of relatively shallow, circular grooves evenly spaced across the drum face. This grooving configuration induces wear and localized high contact stresses in the rope where the rope crosses from one circular groove to the next. The wear comes from the scrubbing action which occurs when the previous wrap pushes the rope into the next groove. The localized high contact stresses are induced by the ridge between grooves. This type of grooving is only found on cylindrical drums and was once recommended for multilayer winding; but, though the grooves are easy to machine, because of the rope problems it induces it is not used on new hoist equipment.

Helical grooving, as the name implies, is a continuous spiral across the drum face. On cylindrical drums it eliminates the rope problems inherent in parallel grooving but does induce rope whip or vibration at the cross over points in successive layers where multilayer winding is used. Drums with conical shapes must use helical grooving and are limited to single layer winding.

The relatively recent LeBus grooving is a combination of parallel and helical types. This groove travels circularly for one-half the drum circumference and then moves across the drum face a distance equal to one-half of the groove width. It continues parallel for the other half of the circumference and then moves over the remaining

\*Configuration patented by LeBus International Engineers, Inc.

half of the groove width. This type of grooving is particularly desirable for high speed, multilayer winding, since it reduces rope whip at the crossover point on successive layers. The groove is relatively deep and gives good rope support.

Ungrooved or plain faced drums have been seen in use, predominantly in older slope-hoist installations. They are undesirable for many reasons and hopefully no longer made by anyone. If rope is correctly installed on these drums, spooling will be as even as with helical grooving, but, since the rope is always guided by the previous wrap, scrubbing-induced wear occurs all along the rope.

If the wraps are not tight, however, even if the spooling is even, the rope of successive layers will work between the rope of the layer below causing pinching and additional scrubbing. It is not uncommon on ungrooved-drum slope hoists to find the rope coming onto the drum and then disappearing between and under the wraps. Adding a grooved drum-liner would be advantageous in these situations.

Groove shape also affects rope life. Many references are available which recommend groove configuration. (130, 110). Grooves that are too small have a pinching effect on the rope, increasing the contact stresses in the wires and creating unnecessary abrasion between the rope and groove. Grooves that are too large do not properly support the rope, permitting it to become elliptical and damaging the core.

Groove surface hardness has an effect on rope and is discussed later under rope selection considerations.

#### Layers of Rope on Drum

When more than one layer of rope is applied to a hoist drum, crossover points arise where the rope crosses over a lower-layer crest to lay in the next valley. The crests crossed over induce nonuniform, localized, contact stresses in the ropes wires and have a mashing effect on the rope strands. As additional layers of rope are applied these contact stresses and mashing effects increase in the lower layers. Therefore, to obtain maximum hoist-rope life, sufficient drum capacity should be used to minimize the number of layers required or to eliminate additional layers entirely.

Ontario's mining law states that "The drums shall have sufficient rope-carrying capacity to permit hoisting from the lowest regular hoisting point to the highest point of travel in the shaft without necessity of winding more than three layers of rope on the drum". (217) The basis for a three-layer limit is not clear. Permission to exceed three layers can be obtained for drums with LeBus grooving. Hoist drums in United States coal-mine service are commonly of multilayer design, with few examples exceeding three layers on the drum.

#### Flange Margin

The purpose of the drum flange is to prevent the rope from slipping off the ends of the drum. A hoist rope loaded only by an empty conveyance can jump around on the drum because of poor spooling, or poor ramping from one layer to the next. Thus, it is reasonable to expect the flange to extend above the last rope layer to some extent. In some installations, however, the margin appears to be much more than enough, and

some states require an extension of 4 or more inches, an amount which can be equivalent to three to four additional rope layers. The reason for apparently excessive flange margins is not known but it is suspected that it may be to provide protection in slack-rope situations. This is justifiable. However, since all slack rope situations should be avoided, it would appear judicious to include a slack-rope detector which would shut the system down, rather than to rely solely on a large flange margin.

### Riser Blocks

Where multilayer winding is required it is important to provide a means for the rope to rise evenly from one level to the next. Riser blocks, properly fitted, can provide the ramp effect necessary to minimize rope whip and jump, and strand mashing at the level-change point between the first and second layers of wrap. This practice is commonly found on coal mine hoists.

### Rope Attachments

There are numerous techniques for terminating wire rope at the drum and conveyance. Most states require that a minimum number of wraps exist on the drum with the conveyance at the bottom of the shaft. These wraps, through friction, reduce the load carried by the drum termination. At the conveyance end there is no similar aid.

Drum Termination. One method of drum termination commonly used is shown in Figure 8. The rope is generally directed through the drum spout and around the drum shaft before being clamped with rope clips or with flange-mounted clamping plates. Any rope motion coupled with the high contact stresses from the mashing effects of the clamping pressure can produce fatigue failures. Where excess rope is stored coiled inside the drum it is common to secure the rope only with the flange-mounted clamping plates.

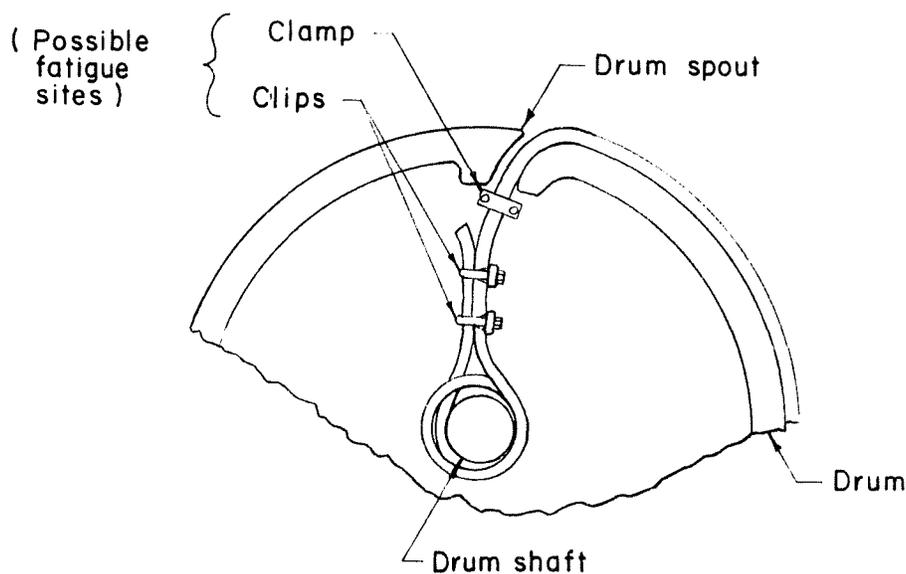


FIGURE 8. TYPICAL HOIST-ROPE DRUM TERMINATION  
BATTELLE - COLUMBUS

Conveyance Termination. There are three commonly used techniques for attaching hoist ropes to conveyances:

- (1) Thimbles and clips (or clamps)
- (2) Spelter (zinc) sockets
- (3) Wedge-type terminations.

Techniques for proper installation of these fittings are discussed in many references. (106, 124, 126, 133, 156) Thimble and clip (or clamp) terminations appear to be the most common. Recommendations for the number of clips to use, clip spacing, and length of rope to turn back can be found in ANSI M11.1-1960, page 25. (156) This type of fitting, properly installed, is generally considered to be 80 percent efficient; that is, it develops 80 percent of the breaking strength of the new rope. However, this efficiency results from the clamping pressure of the clips which is a function of the tightness of the clip nuts. Many mine operators have indicated a need for recommended values for clip-nut tightness, expressed as a torque value (e. g. , in. -lb) for installing clips as well as checking them later. It has been learned that this is being studied by the Bureau of Mines experimental laboratory in Denver. Publication 681, issued by the Wire Rope Industries of Canada, Ltd. , contains this information. (133) Thimble and clip terminations are the most commonly used in coal-mine hoisting due to the ease in field application. When used, it is important to include their termination-efficiency factor in the calculation of operating safety factors.

Spelter (zinc) sockets are the second most commonly-found conveyance termination. They are considered to be 100 percent efficient. In many cases the rope is supplied to mines with the socket attached. This eliminates the need for the mine to develop a zinc-socket-pouring capability. However, the rope is then often discarded solely because of weakness developing at the termination. A few operators indicated they had had difficulty with poured sockets and had reverted to use of the less-efficient thimble-and-clip arrangement.

Tapered-wedge terminations are commonly used in British and Canadian mines; few are being used in U. S. coal mines. Efficiency figures range from 80 to 90 percent. In one type, shown in Figure 9, the rope is held by the clamping action of the wedges moving within the tapered body. The wedges are interlocked to prevent independent movement. The configuration provides protection for incidents of shock loading. The safety block fitted to the rope end assists the wedge action if the wedges should loosen for any reason. This block is a poured attachment and uses white metal, a lead alloy similar to babbitt. There are, however, other configurations using the wedging principle, many of which have been seen in use.

Swaged end fittings, which are generally considered to be 100 percent efficient, do not appear to be supplied for hoist rope use. They are more difficult to attach than zinc sockets since large presses are required.

The efficiency figures quoted result from tensile tests. All of these terminations result in fatigue damage to the rope, but no relative rating with respect to this type damage is known. The fatigue damage occurs mainly at or near the entrance to sockets

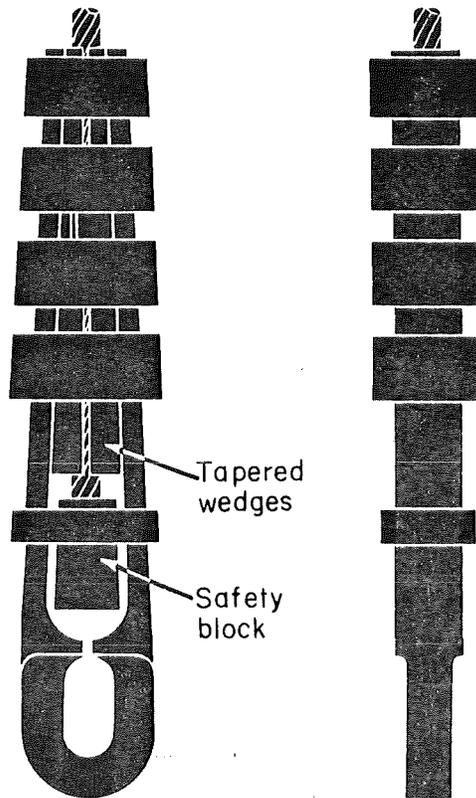


FIGURE 9. RELIANCE\* HOIST ROPE TERMINATION

\* U. S. Distributor: Lakeshore, Inc., Iron Mountain, Michigan.

and at or near the first point of attachment of clips or wedges in the other devices. This damage appears to result from these points acting as nodes when the rope vibrates. Thus, local cyclic bending occurs. Furthermore, the fatigue damage can easily be accelerated by corrosion which can readily develop at these points because water is easily trapped by the apparatus. These types of fittings find wide use and, in the case of sockets, bell-shaped entrances have been developed to mitigate fatigue damage. No such devices were seen in coal mine use, however.

Conveyance termination of hoist ropes is a subject that should be investigated with the aim of evaluating its relative reliability and damage-inducing characteristics. Some operators show much concern for rope damage at this location, but others appear insufficiently informed of the potential for trouble at this location. There is much literature directed in a qualitative manner to this subject but its general use seems low.

At this point it is sufficient to say that regardless of which attachment technique is used, proper installation is a necessity.

#### Relative Position of Head Sheaves and Drum

The relative positions of the head frames and the hoist drum establish the fleet angle; that is,  $1/2$  the total angle formed by the motion of the hoist rope as it passes across the drum face. A complete analysis of this problem is presented in the Roebbling Wire Rope Handbook<sup>(124)</sup>. Improper selection of fleet angle can cause excessive rope scrubbing on adjacent wraps or drum flanges and mispooling. Several examples of mispooled slope hoists have been observed due to excessive fleet angles and the extensive rope distortion due to the mispooling was very evident.

#### Conveyance Guidance

Vertical Shaft Guides. Wooden guides are the prevalent type of guidance used in the coal mines visited. The conveyances are equipped with steel guide shoes or rubber-tired wheels for tracking the guides. The wooden guides are also often used for a clamping surface where required for safety devices. This type of guide system must be continually maintained to minimize conveyance drag and vibrational loading of the hoist rope which will result from misalignment, looseness, and wear.

Slopes. In addition to the above considerations, rope-support rollers, guide rollers, and knuckle sheaves in slope-hoist installations are very important.

Popular support roller and sheave designs are shown in Figure 10. The roller of Figure 10 is the most commonly used but provides no centering mechanism and the rope can and does slide off the roller if it is not properly aligned. The sheave-like wheel of Figure 10 provides a little better rope support and guidance, however, the tread diameter is commonly smaller than the roller. The tread diameters of these devices are consistent with recommended  $D/d$ 's.

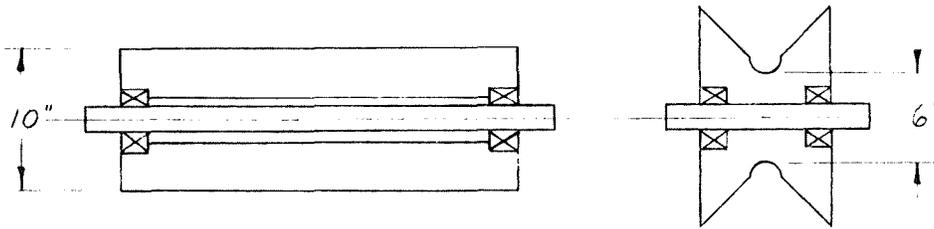


FIGURE 10. TYPICAL SUPPORT ROLLER AND SHEAVE DESIGNS

Slope support and guide roller or sheaves are, of course, meant to reduce the abrasive effects which occur if the rope simply drags across everything in its path. But the number, diameter, and placement of these support and guide devices directly affect rope life insofar as they affect cyclic bending, contact stresses, and the propensity to vibrate and impact against or jump off the rollers.

A good treatment of this subject is given in the Roebing Wire Rope Handbook(124), the material including much detail for selecting support rollers and deflection sheaves. The subject is also discussed in a paper(35) which makes use of some data generated by W. A. Scoble and presented in 1930.(70) Study of this work raises doubts about the general applicability of the data because of coarseness of the rope (6 x 7 construction) and a number of factors related to the experimental procedures and conditions.

One of the greatest problems observed in slope-hoist systems is the wear of support rollers and the resulting rope degradation. The Roebing Handbook points out that rubber-surfaced rollers have much to offer in this regard. None have been seen in use, however.

Vibration-induced problems can be mitigated by irregular spacing of support rollers which can reduce or prevent rope vibration.

The need to prevent dragging of slope-hoist ropes does not apply just to the shaft region or that adjacent to the opening. It applies everywhere, particularly on the ledge over which the rope passes going into the hoist house.

In addition to wear, abrasion can induce the local formation of untempered martensite on the surface of the rope wires, a very brittle form of steel, which provides enhanced opportunities for the initiation of fatigue cracks.

A few slope installations use sheaves to achieve above-ground directional changes as previously shown in Figure 5. In one system, two 30-inch sheaves guided a 1-1/8-inch wire rope onto a 72-inch hoist drum. Using the techniques developed by Drucker and Tachau(19) for predicting fatigue life, it appears that the addition of the two 30-inch sheaves to the slope system can greatly reduce the fatigue life of the slope rope. In designing slope installations bends around sheaves, rollers, etc., should be avoided as much as possible.

In retrospect the slope-hoist installations seen more often than not appear to disregard much of the design and installation data readily available. The contrasts between good and bad systems are so great that a good system is easy to spot and not quickly forgotten. The newer slope-hoist installations are generally well done. The older ones were well done in many cases but have been let go through the years. Age is not the contributing factor because one older slope system ranks with and, in some respects, exceeds new systems insofar as design and upkeep are concerned. In general, however, the older slope systems weren't well designed even though an adjacent coal shaft hoist was.

### Friction Hoist Systems

Many design considerations for drum hoisting are also valid for friction hoist systems. However, there are basic differences in the hoist itself which affect the design of the total system. Some of these have been previously discussed. Two other important differences are the type of shaft guidance used and the inherent design inability to permit end-fitting retermination.

#### Rope Attachments

Conveyance terminations in friction hoist systems can be very similar to those used in drum hoist systems. The differences relate not so much to the rope end as to the conveyance end since some method for permitting rope-tension adjustment is often provided in these terminations.

As far as the rope is concerned, however, it is important to use fittings which induce a minimum of rope degradation because retermination is generally impossible. The ropes used in the friction system are continuous elements, going from one conveyance over the friction wheel to the other conveyance or counterweight, and no excess exists in the system.

If a retermination is required because of rope problems at the terminations the lack of stored rope on balanced-conveyance systems usually means the entire rope must be replaced. Since one new rope used with the other old ropes can lead to other problems it is sometimes necessary to replace all ropes. In a conveyance-counterweight system, retermination of one rope would probably require retermination of all ropes which, however, could be done since the relative location of the counterweight along the rope path is not critical. However, it should be noted that since these systems invariably have tail ropes, some readjustment of these might be necessary in any of the above operations.

It is theoretically possible to provide movable idler sheaves which could be used to store extra rope in the system for use in retermination. This appears to be an undesirable solution since it would induce additional rope bending, increasing wire rope fatigue problems.

For the above reasons the end fitting to be used on friction hoists should be carefully selected for corrosion and fatigue resistance. Proper installation and maintenance are essential.

## Conveyance Guidance

Rope guides, used widely in other countries for many years, are beginning to be used in the United States on Koepe friction hoist systems. They offer many advantages over fixed guides such as the following:

- (1) They are easier to install
- (2) They don't use as much material
- (3) There are no alignment problems which, in fixed-guide systems, limit conveyance speed and payload weight and induce hoist rope vibration
- (4) They require relatively little maintenance
- (5) They present a shaft clear of obstructions.

In guide-rope systems, the ropes are usually half-locked coil ropes passing through lubricated bronze bushing affixed to the conveyance. Properly installed, tensioned, and lubricated, they will last many years and generally do not appear to be a source of trouble. The guide-rope configuration seen in use with a Koepe coal hoist is shown in Figure 11.

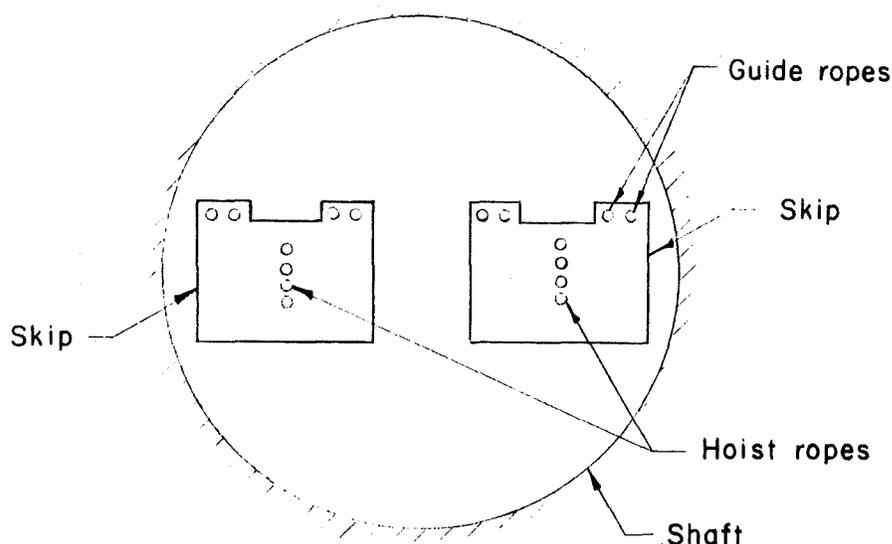


FIGURE 11. GUIDE-ROPE CONFIGURATION - SKIPS IN BALANCE

Rope guides in drum-hoist installations can present problems and none have been seen. Hoist ropes tend to unlay or twist under load. This would cause the conveyance to twist in a drum-hoist system using one rope per conveyance, the apparent universal approach in U. S. coal mines. Rope guides would not resist this twist as well as fixed guides. The problem is eliminated in multirope systems, such as Koepe hoists, because more or less nonrotational locked coil rope is used or because conventional multistrand ropes with alternate lay directions are used in every other rope.

ROPE SELECTION CONSIDERATIONSGeneral

Wire rope plays so many important roles in many industries around the world that specific needs have led to the development and production of many different combinations of wire arrangements and cores. To achieve optimum results from wire rope in hoisting systems it is necessary to select from this large number of candidates the role having the desired special capabilities.

The American National Standards Institute's "Specifications for Use of Wire Ropes for Mines", ANSI M11.1-1960, has been designated by the U. S. Government as a guide in the use, selection, installation, and maintenance of wire ropes used for hoisting.<sup>(163)</sup> This specification provides a good summary of general wire rope information with some advice pertinent to wire rope selection, but is of limited value as a source of quantitative data.

The selection of a wire rope to satisfy the needs of a particular system requires consideration of many factors which influence rope performance. In this section the major factors are discussed. The considerations generally apply to systems being designed as well as to presently installed systems. In the latter case, however, there is some loss of decision flexibility since the sheave diameter and groove size fairly well fix the rope diameter. In actual practice a system may have conflicting requirements which cannot be met by a particular wire rope construction and therefore compromises must be made. It is quite common for the wire rope supplier to make replacement recommendations based on the life histories of ropes previously used.

For a given application, the major factors to be considered in rope selection are:

- (1) Tensile loading
- (2) Groove bearing pressure
- (3) Resistance to crushing
- (4) Flexibility
- (5) Environment (abrasive, corrosive, etc.)
- (6) Nonrotational requirements.

Before discussing these factors a few comments on tensile loading are in order. The direct tensile load on a hoist rope is only one contributor to the stress pattern in a wire rope. Groove bearing pressures and crushing loads also contribute. In addition to the stresses due to sources of direct loading, additional wire stresses are induced when the rope passes over a sheave or onto a drum. It is common to call these "bending stresses" but they are not the same as bending or flexural stresses in simple shapes as computed by simple beam theory. These additional bending-induced stresses do include a contribution from simple bending of the wire, but there is an additional wire stress due to the general elongation of each wire whether it is on the outside of or inside of the bend of the rope. As mentioned earlier there is yet no adequate analytical method for treating the general stress distribution within a rope resulting from all direct loading sources plus the bending contribution. For this reason the above-listed factors must be still treated semiquantitatively as discussed below.

## Tensile Loading

### Load Computation

The total tensile load in a hoist rope just below the head sheave is a summation of the following components:

- (1) Conveyance weight
- (2) Payload weight
- (3) Weight of rope below the point of interest
- (4) Acceleration-induced forces
- (5) Guide-system drag forces.

Typically the tensile load is multiplied by a safety factor to yield the minimum rope-breaking strength to be used in selecting a rope. This approach requires repeating the calculation a number of times because, presumably, the weight of the unselected ropes is unknown, or at best estimated.

In practice, however, recommendations for use in this country often exclude the acceleration-induced forces. Acceleration-induced forces can be due to a number of things: forces due to accelerating and decelerating the conveyances, forces due to impacts on the rope because of sudden removal of slack, impacts on the rope due to misaligned guides jolting the conveyance, and forces resulting from the rope acting as a spring. All these forces are more properly called dynamic forces.

Dynamic forces may not be easy to compute but they are relatively easy to measure. Such measurements are now being made in Ontario to establish allowable maximum dynamic loads in emergency stop situations.

It is, nevertheless, easy to include the tensile load contribution from accelerating the conveyance to speed. Most laws do not limit acceleration rates. One limit commonly applied, however, is 6 feet/second<sup>2</sup> or about 0.2 g (g = gravitational acceleration). If, for example, a hoist can accelerate at 0.2 g, then the acceleration load adds 20 percent to the readily calculatable static tensile load in the rope.

The hoist rope acts like a spring, being more easily extended and compressed as the rope gets longer. For shallow depths, there is little springiness. For deep shafts the springiness can be significant. In any case springiness is beneficial as it reduces rope tension. There is no reason why the spring factor could not be included in computations of rope tensile loads. It is not a particularly easy computation, but on the other hand, it could be reduced to charts and graphs making its use relatively easy.

### Safety Factors

Table 2 shows the currently recommended safety factors for use in hoisting in United States coal mines. In contrast, Figure 12 presents some international safety factors.<sup>(134)</sup> The data of Table 2 are not reproduced from the many available sources for it, such as ANSI M11.1-1960, but from Bulletin 75, Rules and Regulations for Metal Mines, Department of the Interior, Bureau of Mines, 1915. This publication appears to

TABLE 2. HOISTING-ROPE SAFETY FACTORS FOR  
VARIOUS DEPTH OF SHAFTS

Length of Rope, feet	Maximum Safety Factor of New Rope	Minimum Safety Factor When Rope Must be Discarded	Percentage Reduction
500 or less	8	6.4	20
500 - 1000	7	5.8	17
1000 - 2000	6	5.0	16-1/2
2000 - 3000	5	4.3	14
3000 and over	4	3.6	10

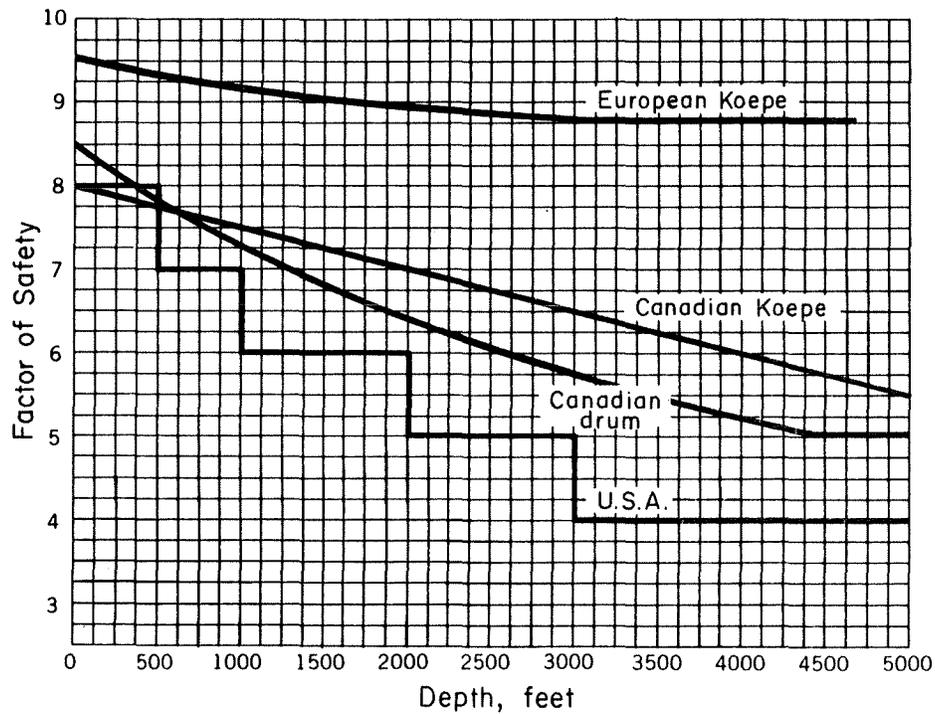


FIGURE 12. FACTORS OF SAFETY - U. S. A., CANADA, EUROPE

be the origin of today's safety factor standards. It contains a clear discussion of the dynamic factors previously mentioned and indicates that for ease of use and enforcement these factors were eliminated in favor of making the safety-factor values proportionately greater to effectively include them. The safety factors of Table 2 are based on an actual factor of 4. Moreover this Bulletin gives permissible maximum hoisting speeds versus rope length, and maximum accelerations versus maximum speed, all consistent with the safety factors presented in Table 2. While one-half of the maximum speed data are presented in ANSI M11.1-1060, none of the acceleration data appear. It is interesting to note, and will be shown later, that state laws limiting hoist speed do not appear cognizant of these data, speed limit being generally much lower. For example, the maximum speed associated with the 500-foot-or-less rope length and the safety factor of 8 in Table 2 is 1200 feet/minute and the maximum speeds go up with increased rope length. The maximum speed allowed by any of the major coal mining states is 1000 feet/minute with the others ranging between 600 and 900 feet/minute (West Virginia indicates no legal limit).

The safety factor, maximum speeds, and maximum acceleration as presented in Bulletin 75 make sense and form a useable package for all. These data are reproduced in Appendix C. Regretably, with time and repetitious use, only the safety factor data are commonly presented, although, as stated, ANSI M11.1-1960 does present some maximum speed data. The problems this situation presents to operators is summed up in one example. In discussing the laws of one state with a state official, he indicated that a proposed change in maximum speed from 600 to 1000 feet/second was under consideration as a result of operators desiring to hoist faster from lower depths to increase productivity. The individual further indicated he was not comfortable with this idea because he didn't know what effect it would have on the rope in relation to safety-factor requirements. It was pointed out that acceleration loads were of more importance than speed assuming good machinery and guide alignment and he indicated he had never looked at it that way. Of course, as pointed out in Bulletin 75, "...high-speed hoisting is harder on a rope than low speed... a consideration of importance in determining safety factors".

Table 2 also presents the minimum safety factors where rope must be discarded. This particular presentation also includes the percentage reductions which these safety factors represent with respect to the safety factors for new ropes - percentage factors rarely included in current presentations of safety-factor data. Realistically, operators generally cannot relate inspection data to safety factors since they can't generally relate inspection data to rope strength. In this regard required, minimum-safety-factor data are useless. As will be discussed later, there are techniques in current use in foreign countries and to a very limited extent here which allow a nondestructive measure of rope-strength degradation.

The stepped nature of U. S. safety factors (Figure 12) might be better smoothed out with an averaging curve. In addition, rope constructions and materials as well as the design of hoist machinery have changed in 56 years.

Clearly, it is time to reevaluate the entire area regarding safety factors, maximum speeds, and accelerations, at least with respect to recent hoist installations and definitely with respect to those yet to be built.

Groove-Bearing Pressure

Groove-bearing pressure, the radial pressure exerted by the rope on the sheave or drum groove, may be expressed as

$$P = \frac{L}{RD}$$

where

P = radial pressure, psi

L = total rope load, lb

R = tread radius, in.

D = rope diameter, in.

The total rope load, L, should include acceleration and drag forces, not just static loads.

As indicated in Table 3, the maximum recommended bearing pressure is a function of both sheave material and rope construction. For example, flattened-strand rope places more material in contact with the groove than round-strand, regular-lay, reducing the contact stresses in the wires for a given load.

TABLE 3. MAXIMUM RADIAL GROOVE-BEARING PRESSURE

Rope Construction	Cast Iron, psi	Cast Steel, psi
6 x 19 regular lay	500	900
6 x 19 Lang lay	575	1025
8 x 19 regular lay	600	1075
6 x 37 regular lay	600	1075
6 x 37 Lang lay	700	1225
Flattened strand	800	1450

If the recommended radial pressures are exceeded, the groove surface will become permanently deformed. This deformation will abrade new ropes since even ropes of the same construction will have a different lay length when new. Several examples of deformed or fluted grooves have been observed at coal mines. One example was a cylindro-conical drum hoist used to hoist coal. In the worst static condition the radial pressure on the smallest drum diameter was about 493 psi. Conveyance drag and acceleration forces increase this number considerably. The drum material was not determined.

Where bearing pressures are high and cannot be lowered, ropes providing maximized contact area with the sheave or drum groove, such as flattened strand, should be considered. Permanent deformation, caused by exceeding the yield strength of the

groove material, can be avoided also by reducing the rope load or by increasing the yield strength of the drum surface. However, once deformation of the groove surface occurs, correction is a difficult task.

### Resistance to Crushing

The outer layers of rope on a multilayer drum have a detrimental crushing effect on the lower layers. The problem is further aggravated with smaller diameters. These crushing forces tend to distort the rope shape and can even destroy the core resulting in load imbalances among the strands, reducing rope life. Although the problem cannot be eliminated by selecting the proper rope, the damage being done can be minimized by selecting a rope whose properties provide maximum support. Such a rope is one having a wire rope core rather than fiber.

Independent Wire-Rope Core (IWRC) is commonly used for multilayer winding where crushing of fiber core ropes would be a problem. In extreme crushing conditions the outer wire size can be increased. Both of these changes reduce rope flexibility, however. Therefore, before deciding on the construction, the crushing conditions should be carefully weighed to determine whether the crushing problems or the problems arising from loss of flexibility would be greater. One wire rope manufacturer also indicated that IWRC is not recommended for general use in hoisting ropes because it has a poorer fatigue life. Again, these problems could be mitigated or eliminated by drum modifications.

### Nonrotational Requirements

Characteristic of standard wire-rope constructions under repeated loadings is the tendency to elongate through straightening of the helical strands, i. e., to unlay. In drum-hoist systems this normally causes no severe problems but can cause the conveyance to wear the guides unless the torque buildup is relieved somewhat, a procedure known as spin releasing. It can be overdone to the detriment of the rope. In some instances nonrotational characteristics are extremely desirable. During shaft sinking there are usually no guides available for the conveyance and nonrotational wire rope helps control the problem of conveyance spin.

Tail ropes for Koepe installations normally must run in close proximity to other tail ropes. Ropes with a nonrotating design will run at high speed in close parallel arrangement without entangling. They will also eliminate the possibility of knot formation such as is shown in Figure 13<sup>(85)</sup>. This tail-rope knot developed due to a torque imbalance in the rope caused by unlaying of the strands. Eventually the loop caught on a shaft obstruction and was pulled into a tight knot by the ascending cage.

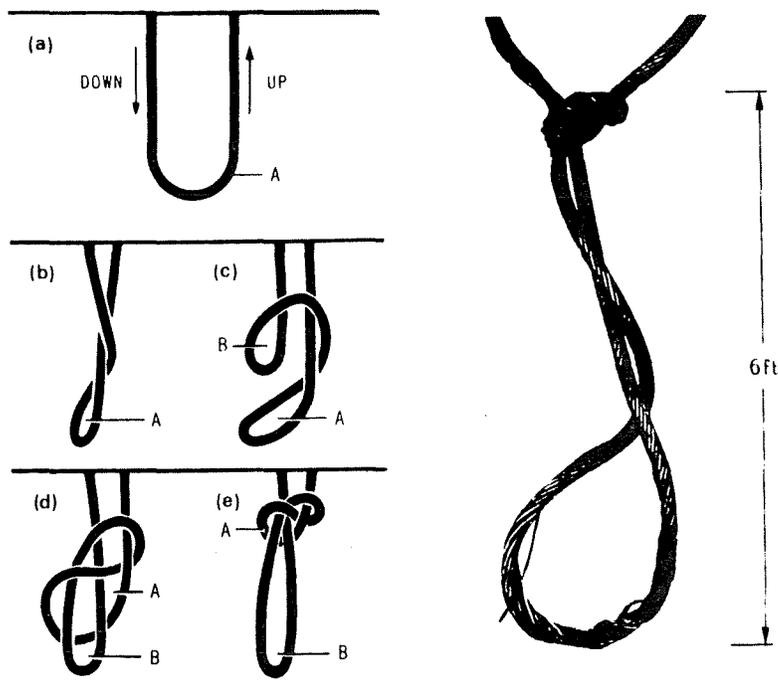


FIGURE 13. STAGES IN THE FORMATION OF A KNOT FOUND IN A TAIL ROPE DURING SERVICE (85)

#### Flexibility Requirements

Where flexibility is a major requirement, such as when small sheaves or drums are present, when many bends are made, or when free hanging ropes are being flexed, ropes with a greater number of wires and/or strands are recommended. Wire diameters must decrease if the number of wires or strands is increased, creating a rope more susceptible to corrosion and abrasion. As a result very few hoisting installations in the United States use rope constructions finer than 6 x 27. As previously discussed from a bending fatigue standpoint, it is desirable to select a rope construction that will provide a  $D/d^*$  ratio of at least 1000. However, many mine hoists have such small drum diameters that to obtain this ratio would require using extremely fine outer-wire sizes.

#### Rope Environment

The environmental factors of dampness, water, acidity, or basicity, and dirt in slope hoists and their effects on rope have been mentioned. Where these sources of rope strength degradation cannot be controlled, selecting the proper rope can help to some degree. For shaft hoists, many operators feel that their rope lubrication practices control corrosion problems. Whether or not this is generally true has not been

\* $D/d^*$  - drum diameter divided by outer-wire diameter.

established, but little evidence of shaft-hoist-rope corrosion was seen where the likely trouble spots could be inspected. Slope-hoist maintenance is generally neglected and evidences of corrosion are not uncommon.

Many manufacturers produce galvanized ropes for corrosive conditions. None have been observed in hoisting use, however. It appears that galvanized ropes are not trusted, are generally not known, or are not recommended for hoisting applications. Galvanized hoist-system ropes appear to be commonly used to advantage in Great Britain in corrosive environments.<sup>(56)</sup> However, most U. S. manufacturers hedge somewhat in discussing their value although some manufacturers note in their catalogs that galvanized rope has about 10 percent less strength than a bright (uncoated) rope of the same grade and construction. Also, galvanized ropes can experience fatigue problems, although their nature and severity are not known.

Where abrasion cannot be eliminated, regardless of the source, the usual approach (and only one known) is to use a rope construction with as large an outer wire diameter as is possible while maintaining the necessary flexibility. In the majority of hoist systems inspected, the major sources of rope abrasion could be eliminated by better maintenance, minor modifications in the components, or adding support rollers in the case of slope hoists. It would appear that eliminating or skirting the sources of abrasion would be better than trying to select a rope which is least affected by them.

ROPES RECOMMENDED FOR AND OBSERVED IN MINE HOISTING

Recommended Constructions

Table 4 lists constructions and diameters of wire rope recommended by rope manufacturers for mine hoisting service. (Refer to Appendix O for rope nomenclature). This listing is not all inclusive but contains the majority of those constructions commonly recommended by manufacturers. This Table indicates that manufacturers favor Lang-lay, fiber-core ropes for both vertical shafts and slopes. Lang-lay rope is said to provide greater resistance to wear, greater flexibility, and produce lower bearing pressures than regular-lay rope of the same groove size. Fiber-core ropes are more flexible than IWRC ropes and the core can store a good supply of lubricant.

TABLE 4. WIRE-ROPE MANUFACTURERS ROPE RECOMMENDATIONS -  
MINE HOISTING APPLICATION

Application	Construction	Lay <sup>(a)</sup>	Core	Diameter Range
Shaft hoist ropes	6 x 19 Seale <sup>(b)</sup>	Lang	Fiber	3/4" - 2-1/4"
	6 x 21 F.W.	Lang	Fiber	3/4" - 2-1/4"
	6 x 25 F.W.	Lang	Fiber	3/4" - 2-1/4"
	6 x 27 F.S.	Lang	Fiber	7/8" - 2-1/4"
	6 x 30 F.S.	Lang	Fiber	7/8" - 2-1/4"
	Locked-coil	NA <sup>(c)</sup>	NA	3/4" - 2-1/4"
Slope hoist ropes	6 x 7	Lang	Fiber	1/2" - 1-1/2"
	6 x 19 Seale	Lang	Fiber	3/4" - 2-1/4"
	6 x 21 F.W.	Lang	Fiber	3/4" - 2-1/4"
	6 x 25 F.W.	Lang	Fiber	3/4" - 2-1/4"
	6 x 27 F.S.	Lang	Fiber	7/8" - 2-1/4"
	6 x 30 F.S.	Lang	Fiber	1/2" - 1-3/4"
Shaft sinking ropes	18 x 7 nonrotating	Reg.	Fiber	1" - 1-3/4"
	19 x 7 nonrotating	Reg.	Fiber	1" - 1-3/4"
	Locked coil	NA	NA	3/4" - 2-1/4"
Guide ropes	6 x 25 F.W.	Reg.	IWRC	1/2" - 3/4"
	Half-lock guide rope	NA	NA	Unknown <sup>(d)</sup>
Friction hoist ropes	6 x 27 F.S.	Lang	Fiber	1" - 2"
	Locked coil	NA	NA	3/4" - 2-1/4"
Tail ropes	18 x 7 nonrotating	Reg.	Fiber	1/2" - 1-3/4"
	34 x 7 nonrotating	Reg.	Fiber	Unknown <sup>(e)</sup>
	34 x 17 nonrotating	Reg.	Fiber	Unknown <sup>(e)</sup>

(a) Right lay is normally provided but left lay is available upon request.

(b) Regular lay recommended for limited use only.

(c) NA - not applicable.

(d) Very few manufacturers supply these ropes and only one or two sizes are available.

(e) Manufacturers don't quote sizes available.

Note: The wire material commonly suggested and used is improved plow steel (IPS). Most manufacturers will supply XIPS (extraimproved plow steel) if desired.

Ropes In Use

Details of the hoist ropes in common use in coal mines are included in Tables B-3 and B-4 of Appendix B. Construction details for these ropes are summarized in Table 5.

TABLE 5. SUMMARY OF ROPE CONSTRUCTIONS USED  
IN COAL-MINE SHAFT- AND SLOPE-HOIST  
INSTALLATIONS

		Shafts, percent	Slopes, percent
Core	- IWRC	11	13
	- Fiber	89	87
Lay	- Lang	46	34
	- Regular	54	66
Construction	- 6 x 7	--	6
	- 6 x 19	54	58
	- 6 x 21	5	27
	- 6 x 25	27	--
	- 6 x 26	3	--
	- 6 x 27	5	3
	- 6 x 30	3	--
- 6 x 37	3	6	

The predominant use of fiber core compares well with the manufacturers recommendations. On the other hand, regular-lay ropes are more used than the recommended Lang-lay ropes for reasons unknown. The most widely used construction is 6 x 19. This is available in Warrington and Seale configurations but as far as could be determined the Seale configuration predominates.

The use of 6 x 19 rope on slopes appears predicated mainly on its resistance to wear as a result of its fairly large wire sizes. Its extensive use on shaft hoists is questioned, however. Spot checks of several cases shows that the D/d' ratios are generally below the recommended minimum of 1000. It appears that rope life in some shaft installations could be improved by using a finer construction, such as 6 x 25. This 6 x 25 construction represents about an 18 percent increase in the D/d' also.

Attempts were made to evaluate the performance of the various constructions in use. This requires being able to get data related to the total number of cycles. This is fairly well established by the tonnage hoisted if the load capacity of the skip is known, for example. Otherwise, knowledge of the total number of trips is necessary. Total tonnage hoisted, or years or months of rope life, are available but not correlatable without other data, often unobtainable. In addition, the drum conditions, end-fitting conditions, D/d's, and maintenance practices vary so much from installation to installation that a meaningful comparison of performance versus rope constructions could not be made.

## OPERATIONAL CONSIDERATIONS

In addition to hoist-machinery components that directly affect the hoist rope there are several features of hoist control systems that can indirectly affect rope life. Furthermore, and again indirectly, the existence of safety catches on man-hoist equipment can have a detrimental side effect on rope life. Apart from rope considerations, other aspects of control system components were noted to strongly affect hoisting safety and, hence are worth discussing.

### Control System Features

Overspeed and overwind preventers are commonly a part of coal-mine hoist-control systems, and failures are common. Several overwinds have occurred in the last year or so, and one rope failure and one severely strained rope have been discovered during this study. In two instances of overwind, limit-switch failures are said to have been the cause. Another recent overwind in a noncoal mine broke the hoist rope and was said to have been partially caused by a faulty solenoid-operated valve in the brake system. Valve-operating solenoids and limit switches are prone to malfunctioning. Thus, great care must be taken when either of these devices is used to control a vital function. In such instances, the use of two such devices, in parallel or series as the circuit demands, will greatly improve the probability that the vital function will be performed. While such redundancy is common in other industries, it has yet to be seen in a coal-mine application.

Slack-rope detectors were seen in some U. S. coal-hoist systems. These devices shut down the hoist or prevent its operation when there is a slack rope condition. They tend to eliminate snap loading of the hoist rope by directing the hoistman's attention to an abnormal or undesirable situation. Wider use of such devices would be desirable.

Discussions with a hoist manufacturer and various mine personnel have indicated that some hoist-drive systems can develop sufficient torque to break a weakened rope or pull apart a less-than-100-percent efficient termination if the conveyance jammed before reaching full speed. (At speed, drum inertia alone could part a rope if the conveyance jammed.) Many operators do not know what load is actually placed on the hoist rope in many situations. Most mines rely on the hoistman's sensitivity and awareness of the response of the hoist to indicate whether lifting should continue. One hoistman admitted that the hoist was "pulling pretty hard" immediately prior to a rope failure. It seems rather useless to establish operational factors of safety for hoist ropes if excessive rope-loading conditions can occur.

An automatic overload protection system has been developed by engineers of the National Coal Board.<sup>(104)</sup> The system detects conditions of rope overload, rope slip, hoist overspeed, or broken strands and shuts down the hoist. Such a device would have been of use on an automated Koepe hoist (not in a coal mine) which was reported to have started to hoist although the lower skip had jammed at the loading pocket. The ropes started wearing into the composite material on the wheel, damaging the ropes, before the situation was observed and the hoist shut down. It is not known how close to failure the ropes were but it is known that all the hoist ropes had to be replaced.

It is common to find overspeed and overwind controllers being driven by the hoist-drum shaft. As mentioned earlier, it is also common to find shaft hoists with clutched drums. Although only a few of these have been seen in coal mine installations, one Lane-type friction-band clutch inspected on a slope hoist was reported to slip occasionally if the load was too heavy. Overspeed and overwind safety devices driven by drum shafts in systems with clutched drums are potentially useless in the event of a clutch failure. During clutch-failure the drum can free-wheel, but if this loss of load doesn't result in a sufficient increase in the shaft speed, the overspeed device will not shut the system down nor apply the brakes. The use or development of safety devices which would be driven by or sense the motion of the drum(s) in such cases is worth serious consideration.

### Safety Catches

United States Federal regulations require that "cages or platforms, or other devices which are used to transport persons in shafts and slopes, shall be equipped with safety catches or other no less effective devices approved by the Secretary that act quickly and effectively in an emergency, and that such catches be tested at least once every two months". (162)

Whatever safety-catch-test technique is used should not induce abnormally high or low rope loads. Safety-catch testing procedures vary from mine to mine. At one mine the following procedure is used every 60 days:

"The cage is brought to ground level. Four beams are placed across the shaft collar through the cage between the floor and the bonnet. With the cage resting on the beams, the socket clevis pin is removed and a special trip hook is connected to the rope socket and the cage. The cage is then raised two feet off the beams and the special hook is tripped allowing the cage to drop free. A measurement is taken of the distance the cage drops before the safety dogs stop it."

This test procedure, while meeting the need for safety-catch inspection and testing, has a bad side effect. When the conveyance is released by the special trip hook, the hoist rope recoils unrestrained into a no-load condition. This unloading shock could cause wire bends at the end fitting, and kinking or unlaying of the rope.

At another mine the safety devices are tested statically. The hoist rope is slacked and the safety catches energized. The catches have never been tested on a falling conveyance. Again, the slack in the rope could lead to unlaying of strands or wire if not controlled.

## MAINTENANCE CONSIDERATIONS

### Introduction

Assuming that the correct rope construction is selected, the causes of subsequent poor and unreliable rope performance on hoists can generally be broken into five categories:

- (1) Rope damage following incorrect rope cutting and installation procedures
- (2) Rope damage due to conditions at the drum
- (3) Rope damage due to conditions at the sheaves, Koepe drive wheel, and support rollers
- (4) Rope damage due to conditions at the conveyance termination
- (5) Rope damage following as a result of inadequate lubrication in service.

Rope longevity and safety require attention to each of these five categories. Unfortunately, the importance of each category is not always understood and, consequently, some operators are replacing ropes because of accelerated wire fatigue, wear, and other malfunctions which could have been readily avoided.

"Hoisting equipment, including automatic elevators, that is used to transport persons shall be examined daily".<sup>(162)</sup> The frequency and thoroughness of inspection and maintenance, however, varies from mine to mine and the practices in a given mine are commonly the same whether the hoists carry men, materiel, or coal. Few records are kept which include observations which could later be beneficial for improving practice. Records that are kept are usually of a check-list type which include little quantitative or qualitative information.

As far as the rope is concerned, slope hoists generally require more attention than vertical shaft hoists but in many cases are the least maintained.

Included in Appendix D is a listing of inspection items for shaft hoists and service slope hoists received from a Pennsylvania mine. It is probably the most comprehensive program presently pursued by a U. S. coal mine. However, it is also the mine, previously mentioned, that permits the shock unloading of the hoist rope during tests of safety catches.

The following discussion relates to the five major sources of rope degradation and generally applies to all types of hoist systems. Special considerations for slope and Koepe shaft hoists are noted.

## Rope Cutting and Installation

Installation of new rope is an important operation. Wire-rope handbooks can be consulted for the correct procedures for transferring ropes from a storage reel to the hoist drum, applying seizings prior to cutting and installation of end fittings. Emphasis should be placed on proper seizing of nonrotating rope of either full-locked-coil or stranded construction. These ropes are balanced by design to provide nonrotational properties under tension. If rope components are permitted to slide away from their designated position, the rope characteristics can be impaired.

In an earlier discussion of drum grooving patterns, it was mentioned that ungrooved or plain faced drums can evenly wrap the first layer of rope if the rope is properly installed on the drum. When being wrapped on a plain drum the rope tends to move transverse to its long axis in a direction which depends upon whether the rope has a right or left strand helix - its lay direction. Taking advantage of this characteristic will provide a closely wrapped bottom layer; neglecting it can lead to an unevenly wrapped bottom layer. Where multilayer spooling is used the evenness of the bottom layer obviously affects the evenness of subsequent layers which, in turn, all affect rope wear. Most rope handbooks describe how to take advantage of this transverse-travel tendency; it is a simple task. The procedures also apply to grooved, cylindrical drums. They apply also to grooved cylinder-conical drums but in reverse, the drum shape dictates which rope lay to select. In grooved drums, though spooling is predominately controlled by the grooves, paying attention to rope lay direction will reduce the wear by lessening the tendency of the rope to work against the grooves.

Neglect of the tendency for transverse motion due to rope lay with subsequent poor spooling has been observed in several instances of multilayer winding. On one fairly large service slope hoist, the bottom rope layer spooled badly because of drum surface wear and neglect of the lay-direction influence. It appears as if it is common practice to use a track-aligning bar to beat the rope wraps closer together on the bottom layer before returning a trip to the surface (the rope is overwound on to the drum). After having observed this operation twice, it was discussed with the personnel involved, pointing out the obvious rope damage inflicted by the bar and suggesting that, next time, the rope be terminated at and wound from the other flange. Incidentally, the drum and drum-support apparatus were in such disrepair that a major breakdown of the winding apparatus should surprise no one. There was no indication that the operation is being "phased out" either.

## Drums

Minimization of rope damage at the drum through design of groove shape and geometry and drum conditions near the spout were discussed previously. Rope damage can occur where these desirable conditions do not exist in old equipment. In situations where excess rope is stored inside the drum, unreeling some of it onto the drum will reduce the possibility of fatigue failure at the termination and spout and will also change the crossover points. As unreeling extra rope means excess rope at the conveyance end, this requires retermination there. More often than not, rope-maintenance aspects related to the drum follow conveyance-end retermination automatically. However, in the case of bad drum conditions, which have been observed, periodically shifting

all rope on the drum would be of value in itself, regardless of the fact the conveyance end may have to be reterminated.

Needed renewing of drum grooves is neglected or overlooked in many cases. In a properly designed system where rope bearing pressures are suitable for the hoist-drum material in use, extremely long groove life can be anticipated. Corrective action on worn or rope-fluted drum grooves is more difficult. Hoists drums of the cylindro-conical type are very difficult to remachine. One mine has a cylindro-conical drum with badly fluted grooves but continues to use it as is. Cylindrical drums can be remachined but the downtime required usually dictates that they be replaced when badly worn. Most mines cannot tolerate downtime with their hoisting equipment and their maintenance practices appear to interfere with production as little as possible.

### Sheaves

Head-sheave grooves see more duty than drum grooves and usually require resurfacing more frequently. Corrective action is often delayed, many mines choosing to install a new sheave instead of remachining the old. Sheaves are available with removable tread inserts which can be readily replaced, reducing the overall time and cost for groove repair. They have been seen in use. Sheaves can also be remachined "in situ" with head-frame-mounted tooling.

It is also important that the alignment of all sheaves be periodically checked and realigned when there are indications that the rope is rubbing the flanges. Rope surface wear is not the only consideration. The rubbing may also induce formation of martensite on the wires which as stated earlier can lead to rapid fatigue failure of the wires. Sheave alignment cannot be overstressed. Several slope service hoists were seen where the misalignment of bull wheels and the deflection and turning sheaves was very bad and obviously the greatest single source of hoist-rope degradation.

### Slope Rollers

The value and use of vertical and horizontal slope rollers have been discussed. Slope rollers are however very susceptible to locking up if not properly maintained. Far more locked rollers with flat spots and grooves were seen than rollers in good shape and freely turning. These flat spots and grooves are made by the rope which obviously wears also. Slope rollers have been seen worn completely in half by the rope. Badly grooved rollers are worse in most cases than no rollers at all.

Once a roller freezes up it does no good to free it if it has been grooved or flattened. At one mine a support roller with a 1/2-inch flat had been freed and retained in service. The hammering effect of the flat spot creates considerable rope vibration, hastening fatigue and producing very localized wire damage. A frozen roller should be resurfaced or replaced before reuse.

Except for slope hoists used to transport men, a large majority of slope hoists inspected lacked good guide and support roller maintenance. Bad roller maintenance and bad drum-spooling conditions are typical and are the reasons so many slope-hoist ropes are short-lived.

## Koepe Wheels

It is essential that the ropes on multiple-rope hoists share the load equally. Where ropes have different tensions the most heavily loaded may deteriorate first. However, the ropes under lighter load may also have accelerated wear due to the rope slippage that results.

On Koepe hoists, if the tread diameters of each rope groove are not equal, rope tensions won't be equal. It is extremely important that the grooves be checked periodically and remachined as necessary to minimize rope imbalance and slip. Most Koepe friction hoists use a urethane-type tread material which is readily machined by hoist-mounted tooling. A useful technique for establishing the machining requirements is discussed in Reference 16 of the Bibliography, Appendix A.

## Terminations

### Drum and Conveyances

In normal rope service where a rope is properly lubricated there is considerable relative strand and wire motion as the rope readjusts itself for a particular loading configuration. At rope terminations, both at the drum and the conveyance, the capability for relative motion is eliminated and, as a result, flexing of the rope results in considerably higher stress levels there than seen further along the rope. In terminations using wire-rope clips the rope is distorted under clamping pressure and high contact stresses are developed. Crevice corrosion under clips, at socket spouts, and at drum-contact surfaces can rapidly reduce the wire metallic area, increasing the stress level in the remaining area. These high stress levels combined with cyclic loading due to conveyance vibration, rope vibration, and changes in conveyance load, cause the end fittings to be sites of accelerated bending fatigue.

Difficulty in visual examination adds to the uncertainty of the situation. At one mine visited, an upcast, man and materiel shaft was so wet that it rained continuously at the opening. The conveyance top, safety-catch apparatus, rope termination, and several feet of hoist rope were well covered with moss.

It is very common to see broken wires, kinking, and unlaying of the rope at slope-hoist conveyance terminations. Rope deterioration at conveyance terminations presents definite safety hazards.

Many mines have learned the desirability of periodically (about every 6 months) remaking the conveyance termination by clipping off a short segment near the conveyance and then reattaching the hoist rope. This is done to assure that the fitting efficiency is being maintained. This practice is required by the States of California, Colorado, Illinois, Oregon, and in most Canadian provinces. As mentioned, retermination at the conveyance usually changes the rope position on the drum, an automatic benefit in almost every case. Inspection and maintenance of drum and conveyance terminations also cannot be overstressed. Rope deterioration at these points is common and a definite safety hazard.

### Safety Bridles

Where safety bridles are attached to the rope, broken wires can occur for much the same reasons as they occur at the conveyance-end terminations. Thus these locations must be carefully inspected also. Where retermination is made because of problems developing at the termination, care must be taken to assure that that portion of the rope where the bridle attaches is also removed at the slightest indication of rope damage. Since fatigue damage is often not obvious short of broken wires, the best practice would be to always cut off above the bridle clamp when reterminating at the conveyance. The extent to which this is practiced in coal mines is unknown.

The design of Koepe installations is such that periodic trimming at the rope ends is not always possible. Therefore, it is extremely important that the terminations be well made, carefully inspected for degradation, and maintained as well as possible.

### Rope Lubrication

Each wire in any rope construction must remain as free as possible from any of its neighbors in order to move as required to accommodate its share of varying rope tension. This is even more important as rope speed and contact pressure increase.

Many hoist ropes are also subjected to corrosive environments. Though galvanized hoist ropes are used extensively in England to combat corrosion, none are known to be in use in coal mines in the States.

It is desirable, then, to provide lubrication that will aid the individual wire motion while slowing corrosive degradation. Desirable qualities of a lubricant used as a rope dressing are:

- (1) Maximum penetration
- (2) Ability to displace moisture
- (3) Resistant to emulsification
- (4) Good adhesion properties
- (5) Compatibility with lubricant applied during manufacture
- (6) High-pressure resistance properties.

Wire rope comes from the manufacturer properly lubricated. This lubrication requires augmentation, however, during the operating life. Unfortunately, much of the lubrication practice in coal mines is like oiling the outside of a watch case to maintain the mechanism inside. It is quite common to see six-stranded rope that has the appearance of a bar with the valleys of the rope heavily coated with a lubricant and grime composite. There are very few mines that do any cleaning of the wire rope prior to relubrication and therefore the fresh lubricant lays on the dirt-and-oil clogged exterior as a shield against future lubrication efforts instead of penetrating to the inner wires. Internal rope corrosion and wear proceed as usual.

In coal mines, hoist-rope lubricant is commonly applied by hand brush or a lubrication box as the rope passes by. In many cases it is applied at the head sheave where the strands are most open to lubrication penetration. In other mines it is poured directly from the container onto the rope.

A few mines visited used no rope lubricant at all. Some slope operators feel that the lubricant becomes a magnet for dirt and dust particles and is therefore undesirable. Koepe hoist installations have a special problem in that they rely on friction to develop the propelling force. Lubricants applied to the rope surface or exuding from the rope core can be detrimental to the operation by causing premature rope slip. In some cases Koepe ropes are dressed with a fine powder to counteract the presence of surface lubricant.

There are many approaches to lubricating wire rope and opinions on proper procedure are diverse. Possible lubrication problems and solutions have been printed in several technical papers. (39, 72, 86) Additional information is available in most wire-rope handbooks provided by wire-rope manufacturers. Although it is difficult to put quantitative values on lubricating procedures it is very clear that lubrication can promote life. In general, the use of a light, oil-like lubricant appears to be most favored. Of those systems inspected, those using light lubricants had generally cleaner ropes which also appeared to be in the best condition.

### Rope Reversal

It is fairly common practice in slope operations to reverse a rope at the midpoint of its expected life. That is, the rope is removed from the drum, turned end-for-end, and then reinstalled. This practice makes it extremely difficult to predict consistently the types of rope degradation to be expected towards the end of life because of the way in which the rope may be reinstalled and possible damage at reinstallation. Isolated instances of such practice on shaft hoists have been found.

It is assumed that those operators who do reverse the rope get extended use from the practice. As stated, however, unless the strength of the rope is conservatively judged the practice is potentially dangerous. If slope-hoist equipment were better maintained, extended rope usage might occur without the need of turning the rope end-for-end.

### Splicing

Splicing of a hoist rope is outlawed in some states but it appears to be used quite effectively on at least two fairly long slopes. In one, the hoist rope consists of approximately four segments of rope spliced together. When the segment nearest the conveyance has been trimmed as much as possible through retermination, the hoist rope is removed from the drum. A new segment is terminated at the drum and spliced to the old hoist rope. As time passes each segment then propagates from the drum to the conveyance and is eventually replaced. This technique minimizes material costs, drum cross-over point problems, and periodically provides for retermination at both ends of the hoist rope. Mine personnel have been trained to make these splices and reterminations in a matter of hours, resulting in little downtime.

At the other slope, the rope is spliced wherever and whenever it is judged to be necessary. Incidentally, this slope-hoist system is about 40 years old and was one of the most well designed and beautifully maintained systems seen. This may explain their success with splicing.

Splicing of rope requires considerable skill and is barely visible to the eye when in service. When properly done it appears to result in successful operation. Splices of a six-stranded fiber-core rope can be, at best, about 83 percent efficient. If this efficiency is considered in selecting the rope in accord with safety factors the practice would appear to be adequately safe.

### Rope Reuse

On one man-carrying shaft hoist it has been common practice to reuse a worn hoist rope as a counterbalance rope. The hoist uses a counterbalanced cage and operates six or seven times a day. The counterbalance rope (former hoist rope) now begins a new life. The onset of fatigue failure of individual wires is accelerated because of the new loading pattern. The counterbalance rope soon has many new wire breaks. Should the counterbalance rope fail the hoist would lose its counterbalancing load, increasing the braking requirements dramatically. The available brake capacity may not be sufficient to cause timely deceleration of the cage immediately after rope failure. The drag effect on the hoist rope, however, would probably prevent the safety catches from actuating. The obvious dangers of the situation were pointed out to mine personnel and they appeared quite concerned.

### General Comments

The maintenance practice examples in the previous sections more often than not illustrate poor practice rather than typical practice, except where slope hoists are concerned. It is difficult to describe typical maintenance practice with respect to coal mine hoists because practices vary so much from one mine to another.

Much maintenance-practice detail was obtained during this program but it defies any tabular presentation that would do more than illustrate the great variety involved.

When discussing any of the previously mentioned specific areas needing maintenance attention, the most prevalent reply was, "We do it when necessary". Obviously, what is necessary to one operator is not the same for the next.

On shaft hoists, rope lubrication is practiced more commonly than on other hoists. The "schedules" range from "daily or as needed" to "monthly or when necessary" with "daily" and "weekly" predominating. Even within one operation there may be a difference. For example, a balanced skip hoist is lubricated nightly; the accompanying man/materiel hoist is continuously drip-lubricated; another nearby man/materiel hoist is lubricated weekly. These two cage hoists appear to be used with about the same frequency. The continuously lubricated rope looked best.

At another mine, production-hoist ropes are cleaned and lubricated with oil each month, with a more-or-less home-made device using compressed air to clean and apply

the oil. The ropes were beautiful, better than the above rope which was continuously lubricated, but never cleaned. Thus, schedules can be meaningless - the details are important.

Lubrication schedules for slope-hoist ropes range from "daily as needed" through "monthly when necessary" to "very little" and "never". "Daily" to "weekly" predominate in words but inspection would indicate that "very little" is about average.

In all the mines visited, resocketing is not a common practice, but reattaching thimbles and clips or wedge-type end fittings is somewhat more common. Typically, this will be done at the midpoint of the rope's expected life. Oddly enough there is little range in the "schedules" quoted. It is either the life midpoint or never, with a very rare "as necessary". Instances were found where the "as necessary" was when a strand broke. Few operators specifically state they change the cross-over points on drums. Of course, those who reterminate achieve this automatically.

The problem with maintenance "as necessary" is that too often things are not recognized as potential problem sources or as potential sources for an accident. This report is full of instances where "as necessary" practices would seem to have to result in broken hoist ropes sooner or later. Of course, some do break and the lack of injuries appears simply providential. The bad or poor-practice examples are given in most cases because one hoisting accident accompanied by death and injury is one too many, unless the contributing circumstances are truly one-in-a-million.

## REPLACEMENT CONSIDERATIONS

### Symptoms of Rope-Strength Degradation

Much here will appear familiar by virtue of earlier discussion regarding machine design factors, rope selection, and maintenance practice for long rope life. In this section, however, the problem of knowing when to remove the rope is addressed and, because of its importance, some repetition is necessary.

Wire rope used in hoisting begins to deteriorate from the day it is placed in service (or before if not properly protected in storage). It is, therefore, critical that the rope be inspected frequently and that some quantitative data be available to indicate the strength condition of the rope and need for replacement.

The common symptoms of strength degradation in hoist ropes are:

- (1) Broken wires:
  - (a) At rope terminations
  - (b) At the crown of the rope
  - (c) Where strands contact
- (2) Reduction in rope diameter:
  - (a) From general wear of exterior wires (worn wires should not be confused with planished wires which are those which have been more or less flattened on one side from contact pressures at drums and sheaves, but which retain the original amount of material)
  - (b) From core failure
- (3) Corrosion:
  - (a) In the crevices at terminations and drum contact
  - (b) In the crevices inside the rope structure (although this is difficult and sometimes impossible to detect)
  - (c) External
- (4) Unlaying or other gross distortion of the rope.

Most of these items directly contribute to a reduction in the effective metallic area supporting the load. While the conditions are not necessarily additive, proper rope inspection must include an investigation of each to determine the worst point of strength degradation.

## Inspection Practice

### Visual Inspection

Most mine operators inspect their hoist ropes daily prior to each shift. The conveyance is operated through one complete cycle and the hoist man observes the rope going off and onto the drum. This examination is considered to be very superficial, often being accomplished somewhat distant from the moving rope. Occasionally a closer examination is made by surrounding the rope with a hand-held cloth. As the rope passes by, broken wires become entrapped in the material and their position noted. (Some inspectors substitute the cloth with their bare hands.) This technique for finding broken wires is questionable since, for preformed wire, it is possible to have broken wire which maintains a relatively normal position and cannot be snagged in the cloth. One hoistman indicated that he could hear each wire break even though the break occurred somewhere down the shaft.

Rope wear, whether uniform or localized, is also mainly checked visually. Occasionally, the rope diameter is measured and compared with the original size. Sometimes an operator will keep a record of lay-length changes as an indication of rope resiliency. As the lay-length increases the rope becomes less capable of withstanding shock loadings.

Conditions of internal rope corrosion are generally observed only as they become apparent through such symptoms as general diameter reduction or wire breaks. However, it is usually true that a rope showing such corrosion symptoms has well exceeded its safe life. In most cases corrosion symptoms either do not appear or go unnoticed and the extent of the existing corrosion is never known. However, very few operators have any rope inspection technique which can indicate and evaluate the presence of internal corrosion.

In many mines the requirements for achieving good visual inspection are not met. For this reason much of the inspection process becomes ritualistic and is of little value. The wire rope becomes so coated with lubricant, grime, rust, and water that little of the rope is truly visible. As indicated earlier, one man/material hoist was covered with moss at the conveyance.

### Destructive Inspection

While many external defects could be detected visually, internal defects cannot normally be detected. It is common practice elsewhere in the world to destructively test a piece of rope from the conveyance end as a general indicator of the rope strength. This end is often a point of serious strength degradation but there are many instances where it is not. Nonetheless it represents the only piece of rope easily obtained for testing, and direct knowledge of its strength is better than no knowledge at all. As indicated earlier such a practice has the added benefit of mitigating strength degradation at several critical points by shifting the relative position of the entire rope.

Such practice in coal mines appears to have been more common in the past than it is now. Several operators reported having done this regularly at one time, having stopped not out of lack of benefit but apparently because "the company" wanted to reduce

costs. No regular use of this practice has been observed in coal mines in the United States. However, it is a requirement of virtually all Canadian provinces. In Ontario it is required at least once every 6 months. The rope cut must be not less than eight feet long and must be cut above any clips or attachments. With the ends properly seized this segment is sent to the Government testing laboratory for examination and tensile testing. The results of this inspection are recorded on the form shown in Figure 14. As stated the results of this test are not construed to be valid for the entire rope but are used as an indicator of rope strength.

### Nondestructive Inspection

Difficulty in visual examination and the restrictiveness of destructive inspection has brought about the development of nondestructive inspection techniques and devices used to evaluate the condition of the entire hoist rope in situ. Two types of machines are available for use by U. S. coal mines but the most commonly applied is the electro-magnetic device manufactured by Rotesco Ltd. This machine has been demonstrated at a number of U. S. coal mines; however, regular use of this or other such devices are rather limited. The capabilities of this and other devices in general are separately discussed later.

### Lack of Quantitative Replacement Criteria

The most common response to the question "How often do you inspect the rope?" is "Daily", and to "What do you look for?" is "Broken wires, wear, and corrosion". The next question is "How many broken wires and how much wear will you accept?" The answer is rarely meaningful to anyone but the person making the statement.

Federal law<sup>(162)</sup> and most state laws require a daily inspection of hoisting systems. ANSI M11.1<sup>(156)</sup> is recommended as a guide for selection, installation, and maintenance procedures but contains little information of value to one charged with the responsibility of rope inspection and replacement. It offers little qualitative and no quantitative data relative to the determination of a rope's remaining strength such as:

- (1) Effect of broken wires and appropriate limitations
- (2) Allowable limits for corrosion
- (3) Effect of wear-induced rope-diameter reductions
- (4) Effect of abrasion-formed martensite.

In contrast, the elevator industry has found it possible to provide quantitative replacement criteria, as the discussion in the section of elevators will indicate.

The lack of quantitative replacement criteria which reflect rope strength presents the greatest problem to hoist operators. The study has indicated, furthermore, that no quantitative replacement criteria appear likely to be available in the near future unless some organization, such as the Bureau of Mines, initiates an effort to do so.

TEST NUMBER ..... DATE .....

TEST FOR ..... MINE .....

ROPE No. .... REEL No. .... SHAFT No. .... COMPT. No. ....

WT. CONVEYANCE LBS TOTAL LOAD LBS. ORIG. STRENGTH..... LBS.

NOMINAL DIAMETER No. STRANDS ..... No. WIRES PER STRAND .....

CONSTRUCTION OF STRAND .....

DIAMETER OF WIRES .....

**EXTERNAL APPEARANCE OF ROPE** .....

**INTERNAL APPEARANCE**

LUBRICATION—Exterior of strands, Visual Rating ..... Character .....

Interior of strands, Visual Rating ..... Character .....

Rope Core, Visual Rating ..... Character .....

CORROSION AND EROSION—Outer wires, Visual Rating .....

Inner wires, Visual Rating .....

Filler wires, Visual Rating .....

DIAMETER OF ROPE AT 0# ..... Wt. Convey ..... Total Load ..... } Orig. Str. ....

LENGTH OF TEST PIECE ..... BREAKING LOAD ..... LBS. EXTENSION .....

STRANDS BROKEN ..... LOCATION OF BREAK .....

**TORSION TESTS**

**ORIGINAL TORSION TESTS**

Average number of } Outer wires .....  
twists in 8" lengths } Inner wires .....

REMAINING STRENGTH ..... % ORIGINAL STRENGTH..... LBS. = 100%

PRESENT EXTENSION ..... " ON....." ORIGINAL EXTENSION..... " ON....."

NOTE: ORIGINAL DATA BASED ON TEST No. .... DATE .....

**VISUAL RATING:**

LUBRICATION—CHECK CONDITION OF YOUR ROPE WITH RATINGS GIVEN IN TEST REPORT

CHARACTER—Viscous (normal); gummy; caked

**STRANDS**

**ROPE CORE**

- |  |  |
|--|--|
| 1. Good Normal amount as in new rope.              | A. Good Greasy and flexible. Well lubricated.    |
| 2. Fair Lubricant somewhat depleted.               | B. Fair Lubrication fair. Core not deteriorated. |
| 3. Poor Very little lubricant present.             | C. Poor Little lubrication. Core hard.           |
| 4. Dry No lubricant left or completely decomposed. | D. Dry No lubrication. Core hard and dry.        |

**CORROSION**

- o. No Corrosion.
- i. Very slight corrosion. Merely a reddish brown film on the wire.
- ii. Corrosion scale well established. Some pitting of surface.
- iii. Surface of wire completely scale covered. Some well established pitting.
- iv. Surface completely corroded. Numerous deep pits.
- v. Surface completely corroded. Considerable loss of section. Only narrow ridge between pits.
- vi. Very severe corrosion. Loss of section up to 1/3 metal. Pits joined forming grooves.

REMARKS.....

SGD.....

CABLE TESTING LABORATORY, EAST BLOCK, PARLIAMENT BLDGS., TORONTO 2

FIGURE 14. SIX-MONTH TEST DATA SHEET - ONTARIO DEPARTMENT OF MINES

There seems to be no valid reason for this. Table 5 indicates that 81 percent of the hoist ropes in use in the coal mines visited are either 6 x 19, 6 x 21, or 6 x 25. Furthermore, as stated elsewhere in this report, 6 x 19 construction predominated in the metal mining industry over 50 years ago. It would be a surprise if 6 x 19, 6 x 21, and 6 x 25 do not dominate all hoisting in the United States today. Despite the range of diameters involved both in rope and drum and sheave sizes, enough experience has been obtained in the last half century with 6 x 19 rope to have established whether or not retirement criteria for this rope, as suggested 56 years ago in Bulletin 75, are valid. The criteria given then are six broken wires per lay length, 65 percent original crown wire diameter, or three broken wires per lay with 30 percent crown wire wear. It is recognized that there are additional considerations to be made but even these few criteria are rarely recommended in handbooks. Some state laws, however, require them.

The situation is too often excused with comments respecting the complexities of the problem with little or no discussion of the "complexities" involved and just how complex they are. The development of replacement criteria should be pursued in the United States as it has been throughout the world.

#### Replacement Criteria Used

As stated, the availability of useful quantitative and qualitative data which can aid the mine operator in decisions of rope replacement is extremely limited. As a result, much shaft-hoist rope is discarded with remaining useful life and some slope-hoist rope is maintained in service long after it should be replaced. Battelle has had many reports where ropes have failed (though, fortunately, no injuries occurred). Failure of hoist ropes can be of catastrophic proportions as was the 1945 Paymaster Mine Hoisting Accident in Ontario. (101)

Hoist rope replacement at U. S. coal mines is commonly based on consideration of the following factors:

- (1) Rope age
- (2) Tons hoisted
- (3) Number and location of broken wires
- (4) Condition of rope terminations
- (5) Reduction in rope diameter
- (6) Changes in lay length or rope stretch characteristics
- (7) Obvious gross damage
- (8) Corrosion
- (9) Supplier recommendations.

Rope history data is commonly accepted as a guide to replacement. Although this may be beneficial to the older mines, new mines or new hoist installations do not have this backlog of operational experience.

### Rope Age

A few operators have indicated that rope replacement at their mines is strictly a function of time. Experience has shown them that replacing the hoist rope once each year, regardless of condition, eliminates unscheduled downtime which can interfere with production. It is interesting to note that at one mine, although the skip-hoist ropes were replaced every year, the man-hoist counterbalance rope had not been replaced for 7 years. Another operator indicated an 18-month limit but then stated that he usually had to replace earlier because of wire or strand breaks.

### Tons Hoisted

Some mines use their hoist ropes until a pre-established number of tons or trips have been lifted. This practice is based on past performance and does not take into consideration changes which can occur in a system, such as groove wear, guide drag, and conveyance vibration. Conditions of corrosion can also change from time to time, greatly affecting the rope strength.

### Number and Location of Broken Wires

Ten coal-producing states require that the number of broken wires per lay be considered. Most of these require removal of a rope from service if the number of wire breaks exceed six per lay-length. This is a somewhat arbitrary criterion since the effect of a broken wire on a rope's remaining strength may vary with construction. However, this criterion appears to have been initially relative only to 6 x 19 constructions. (38) Generally, if all the outer wires were broken the "reserve strength"\* is still a function of construction. It is generally known, that construction should be considered in any replacement criteria which includes wire-break counts but such data have yet to be supplied. For example, the reserve strength of a 6 x 25 filler-wire rope construction is approximately 43.2 percent where the reserve strength of a 6 x 7 rope is about 16 percent.

Other states require that, when the crown wires are worn to less than 70 percent of their original diameter, the number of wire breaks per lay length shall not exceed three. This again appears to have been originally relative to 6 x 19 constructions. (38) How the crown wire wear is measured, except on cut off portions, has not been determined. Though many operators state they retire on the basis of number and location of broken wires, there is no uniformity in the criteria used.

### Condition of Rope Terminations

Some hoist applications require a fixed length of rope which does not allow retermination if problems develop at the end terminations. Koepe hoist ropes are of this type since there is no place in the system to store extra rope. Rope stretch is accounted

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\*Percent of total original strength inherent in inner wires, all outer wires excluded.

for with link and pin adjusters. Koepe-hoist rope terminations must therefore be well made and properly maintained to prevent end-fitting degradation requiring removal of the entire rope.

Some drum hoists have been seen where very little excess rope is stored on or within the drum. Thus, when retermination is necessary the entire rope must be replaced.

### Reduction in Rope Diameter

Anything that results in a reduction of the effective metallic area of a rope will reduce the ultimate strength of the rope. Again, however, there is no generally-available published data which permits the mine personnel to relate reduction in diameter to reduction in strength. Whether the wear is uniform around the circumference of the rope or is concentrated on one side is important, since concentrated wear could create a greater fatiguing condition on the worn wires and also represents a greater overall reduction in rope tensile strength. Some mines do measure reduction in diameter but how they use this information is not clear.

### Changes in Lay Length and Rope Stretch

When a hoist rope is first placed in service it goes through a period of "constructional stretch" during which the rope makes internal adjustments for its new loading configuration. During this period the rope stretches at a more rapid than normal rate. After this original period, rope stretch is fairly linear with time. The hoist operator could record the stretch versus time and watch for unexpected changes in the normal stretch rate. Reduction or acceleration in the rate of stretch are indications that the rope is undergoing physical change and rope replacement may be required. A few operators indicated that they used this approach.

### Obvious Gross Damage

Localized damage (e. g., kinking, mashed wires, unlaying) gross rope distortion, broken strands, and collapsing of the rope geometry due to core failure are conditions which clearly require rope replacement. Most operators will replace a shaft-hoist rope showing such signs. However, several have indicated that they usually do not replace their slope-hoist ropes until a strand fails. One said he replaces his slope rope when the old one breaks!

### Corrosion

Very few mines indicated corrosion as a primary cause for rope replacement. Most operators tend to feel that their lubrication practice controls the corrosion problem. Several did have concern over corrosion at the end fittings and indicated a need for a greater understanding of end-fitting degradation and failure modes.

## Supplier Recommendations

Wire rope engineers who understand the ways in which wire rope degrades can be of great help in establishing retirement criteria for a particular mine. If they are familiar with the hoisting system and its environment they can establish a replacement program which the operator could follow. However, it is still essential that the mine operator have some understanding of rope problems and be able to make an independent judgement as to when to replace a hoist rope. Instances have been noted where the rope supplier has made an extremely poor rope selection for a given application. The mine operator should understand what his rope needs are and be extremely cautious or inquisitive of substitutions. When a rope is installed with a construction different from that previously used cognizant personnel should be notified that the service life may be different and that they should be alert to possibly different indications of degradation.

### Some Patterns and Causes in Hoist-Rope Degradation

Some mine operators have observed that their greatest degradation appears at or near distinct locations on the ropes. This pattern of rope degradation was also observed in records of rope strength studied in Canada in conjunction with discussions of nondestructive testing devices. Koepe systems possess their own characteristic degradation patterns distinct from those of drum hoist.

On drum shaft hoists the rope-degradation locations most frequently mentioned by coal mine operators were:

- (1) At or near the conveyance termination
- (2) The positions at or near the head sheaves when loading and unloading
- (3) The portion that winds onto the drum at hoisting start-up with a loaded conveyance, particularly skips.

The conveyance and head sheave are both vibration nodal points for the vertical portion of the rope. The vibration which occurs results in localized bending at these nodes and leads to fatigue damage, particularly at the conveyance. Similarly, the rope portion from the drum to the head sheave vibrates. This coupled with an impact-like load application at start-up is thought to be the cause for fatigue damage in that portion of the rope which first contacts the drum.

Under varying loads, a hoist rope will also develop a lay-length gradient. This gradient, illustrated in Figure 15, increases with continued use. The decrease in lay length toward the conveyance is accompanied by an increase in rope diameter. It has been suggested<sup>(72)</sup> that when this portion of the rope reaches the head sheave there is ample opportunity for it to be pinched or squeezed in grooves normally sized for the nominal rope diameter accompanying a normal lay length. Furthermore, most grooves wear at the bottom. This wear usually results in less clearance between the rope and the groove sides, further aggravating pinching of the rope.

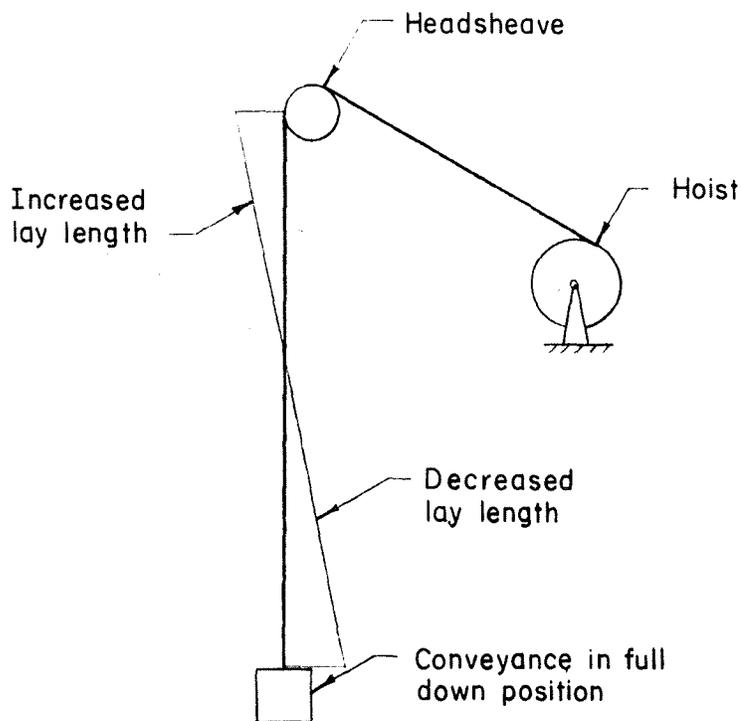


FIGURE 15. EFFECT OF VARYING LOADS ON LAY LENGTH IN A HOISTING ROPE

Battelle has discussed these apparent degradation patterns with a number of people, the Ontario mining officials in particular. There seems to be a general agreement that a careful study of the development of these apparent patterns should be made in an attempt to determine the causes. If the causes can be determined it appears logical that corrective action could be taken to minimize or eliminate some problem sources and thus, overall extend rope service life.

ELEVATORSIntroduction

Many coal mines use elevators for hoisting men and light supplies. All elevators seen, and all built for mine use by at least one major manufacturer, are essentially tower-mounted, multirope, friction hoists of the Koepe type, using a cage/counterweight configuration.

Most mine operators prefer to contract for elevator maintenance and inspection to the builder or to an elevator-maintenance firm. Consequently elevator manufacturers were contacted for this part of the study.

Manufacturers reported that elevators furnished for mine use are substantially the same as those furnished for any modern office building except that the cars are much more substantial, moisture-proof electrical fixtures are used, and moisture-proof treatment is given to shaft components.

While typical elevator-service requirements are quite different from those for mine hoists, the hoist-rope problems are of the same kind though, perhaps, differing in degree. Thus, it is informative to discuss some aspects of these codes, as they present an interesting contrast with mine-hoisting practice.

Before doing so a few quotes are presented from part of an article submitted by one elevator manufacturer. The article is identified as being from "Elevators" by "Annett", pp 302-305. It appears to be at least 5 years old. It forms a kind of Rosetta Stone, bridging the gap between the very detailed and specific elevator codes and the majority of codes or practices recommended for mine-hoist ropes since it reads so much like the latter.

"Wire ropes wear out from two causes: (1) a reduction in area caused by wearing of the outside wires; and (2) breakage of wires. In elevator service the latter is the reason for condemning most elevator ropes. From this the conclusion might be drawn that there has been a tendency to use elevator ropes that are too stiff for the service. Now the trend is toward the more flexible 6 x 19 Seale and 8 x 19 instead of the regular 6 x 19 constructions almost exclusively used at one time. [ This last sentence is confusing; it is not known what regular 6 x 19 means as opposed to 6 x 19 Seale or 6 x 19 Warrington, these being all the 6 x 19 types. ]

"It is recommended that sheave or drum diameter be as large as possible, consistent with other conditions. It is preferred not to have traction sheaves less than about 40-rope diameters. Larger diameters than this are favorable to rope life.

"Conditions of the sheave grooves have a marked effect on hoisting-rope life. [ The article goes on to qualitatively show why and discusses sheave alignment problems, all of which has essentially been stated in the previous sections on hoisting. The article continues:] If more attention were given this feature [ sheave conditions ] of elevator operation, the life of hoisting ropes would be greatly increased in many cases.

"Another factor in rope life is the judgement of the man who condemns them. There is no method by which the condition of a set of ropes may be exactly appraised. A general rule was to condemn the ropes when six wires were broken in one lay of strand in the worst section of the rope."

The article goes on to discuss specific recommendations allowing a greater number of broken wires which appear to have been accepted and are discussed later on.

### Applicable Standards

It appears that all elevators are constructed in accord with American Standard Safety Code for Elevators, ANSI A17.1.<sup>(143)</sup> Furthermore it appears that general maintenance, inspection, and replacement of rope is in accord with this code and with the American Standard Practice for the Inspection of Elevators, Inspectors' Manual, ANSI A17.2. These and related codes, as amended through 1970, were obtained and studied. (143-148)

In general these codes are very comprehensive, covering design, maintenance, inspection, and operation in great detail. Though there are far more elevators than mine hoists it is regrettable that there seems to be no equivalent compilation covering mine hoists.

### Discussion of Elevator Codes

#### Design Features - Machinery

Though the previous quotes make much of sheave-groove wear the codes do not specify groove configurations or dimensions and tolerances. A minimum sheave-pitch diameter of 40 times the rope diameter is, however, specified along with exceptions that don't apply to this discussion (Rule 208.2)\*.

Factors of safety for design are given for driving machinery and sheaves, the minimum being 8 based on rated car load (Rule 208.3).

Friction gearing or a clutch mechanism in the drive train are not allowed (Rule 208.7).

Elevators with winding-drum machines must be equipped with a slack-rope device and switch (manual reset type) which will remove drive power and set the brakes if the rope becomes slack (Rule 210.2a). Such have been seen on some mine hoists.

Broken-rope switches for shutting off power if the rope should break are required (Rule 210.2f). This is an interesting idea the details of which are still being sought.

\* This and subsequently indicated rules all refer to ANSI A17.1 as amended in 1970.

Design and Installation Features - Wire Rope

Material.

"Only iron (low-carbon steel) or steel wire ropes, having the commercial classification "Elevator Wire Rope," or wire rope specifically constructed for elevator use shall be used for the suspension of elevator cars and for the suspension of counterweights. The wire material for ropes shall be manufactured by the open-hearth or electric furnace process or their equivalent." (Rule 212.1).

Such a material specification is interesting. It means the elevator ropes are more ductile than hoist ropes made of improved plow steel or stronger grades. High ductility means less fatigue problems, all else being equal. It also means, coupled with the high safety factors required (to be discussed), that, the deeper the shaft or the higher the rise, the greater the required number of ropes, raising the prospect of a practical limit to hoist depth or rise. One manufacturer reported he lost a mine-elevator bid because of shaft depth coupled with elevator safety factors and the elevator code requirements. This specification seems somewhat limiting in the long run.

Data.

"Rule 212.2 Wire Rope Data

"212.2a On Crosshead Data Plate

"The crosshead data plate required by Section 207, Rule 207.3, shall bear the following wire rope data:

- (1) The number of ropes.
- (2) The diameter in inches.
- (3) The manufacturer's rated breaking strength per rope in pounds.

"212.2b On Rope Data Tag

"A metal data tag shall be securely attached to one of the wire rope fastenings. This data tag shall bear the following wire rope data:

- (1) The diameter in inches.
- (2) The manufacturer's rated breaking strength.
- (3) The grade of material used.
- (4) The month and year the ropes were installed.
- (5) Whether nonpreformed or preformed.
- (6) Construction classification.
- (7) Name of the person or firm who installed ropes.
- (8) Name of the manufacturer of the rope.

A new tag shall be installed at each rope renewal.

"The material and marking of the rope data tag shall conform to the requirements of Section 207, Rule 207.3, except that the height of the letters and figures shall be not less than one-sixteenth (1/16) inch."

The idea of this rule carried over to mine-hoist practice is worth considering. Rarely in the course of the present study could such information be found from one source, if it could all be found at all. Interestingly enough, Bureau of Mines Bulletin 75, 1915, strongly recommends that all these data be recorded and readily available.

Safety Factors. Rule 212.3 "... The factor of safety shall be based on the actual rope speed corresponding to the rated speed of the car." These values are shown in Figure 16 (reproduced from ANSI A17.1). Which data are applied to mine-elevator applications is not known but both give higher safety factors than are recommended (in the U.S.) for mine hoists when typical mine-hoist speeds are considered.

This rule also states:

"The factor of safety shall be calculated by the following formula:

$$f = \frac{S \times N}{W}$$

where: S = Manufacturer's rated breaking strength of one rope.

N = Number of ropes under load.

W = Maximum static load imposed on all car ropes with the car and its rated load at any position in the hoistway."

This use of maximum static load is similar to the approach used in many recommended mine-hoist safety-factor computations.

An important aspect of elevator safety factors is that they are based upon rope speed, while those for mine hoists are based upon hoist depth only. The subject of mine-hoist safety factors was discussed earlier. It was pointed out that it is more logical to use the maximum dynamic load on a rope in conjunction with safety factors when determining rope strength for rope selection. Though unconfirmed at this writing, the increase in elevator safety factor with operating speed may imply a concern for maximum dynamic load, as did the original mine-hoist safety factors.

Number of Ropes. For traction elevators, a minimum of 3 ropes is specified, whereas for drum-types, a minimum of 2 ropes is required (Rule 212.4).

Attachment and Socketing. Where winding drums are used, rope attachment specifications at the drum end are similar to mine practice - clamps or sockets on the inside of the drum (Rule 212.6).

With the conveyance all the way down, at least one turn of rope on the drum is specified (Rule 212.7) where in mines 3 turns is more common. This is consistent with the more lightly loaded ropes in elevator service.

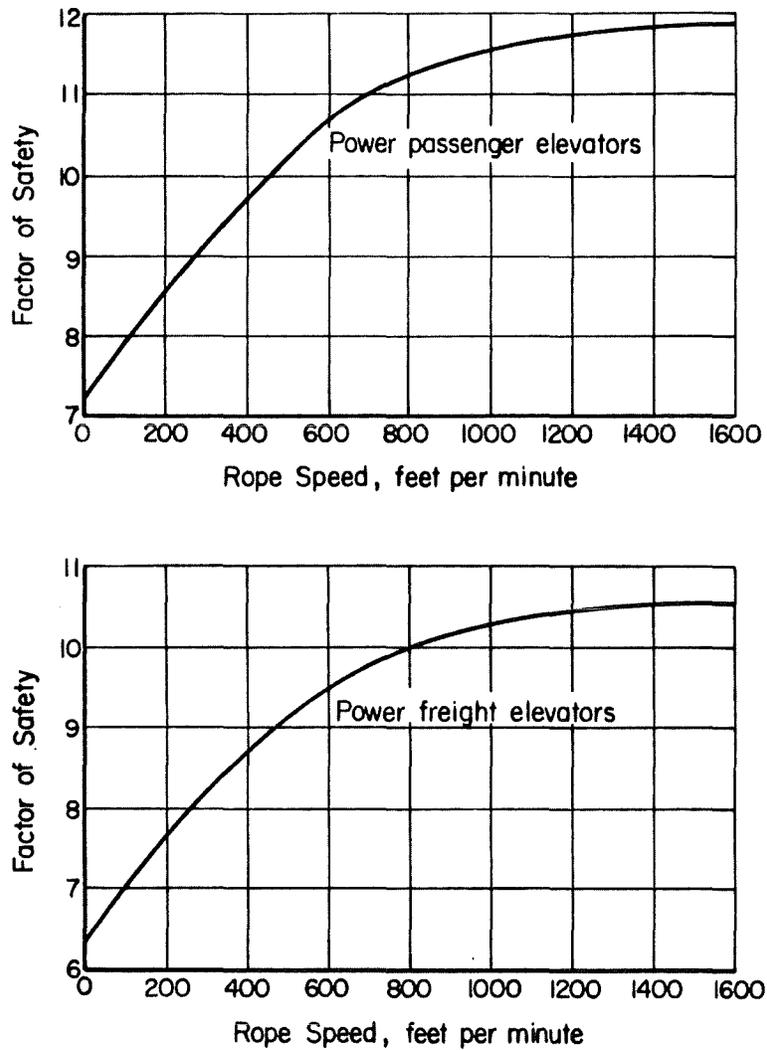


FIGURE 16. ELEVATOR ROPE SAFETY FACTORS AS PRESENTED IN ANSI A17.1

No splicing is permitted on elevator ropes (Rule 212.8).

At the car and counterweight ends of ropes, babbitted sockets are required (Rule 212.9a). Furthermore "The rope socketing shall be such as to develop at least eighty (80) percent of the ultimate breaking strength of the strongest rope to be used in such fastenings, and U-bolt type rope clips shall not be used for such fastenings".

One of the most interesting aspects of the code section on rope attachments is that describing how to make a babbitted socket. This section is included in its entirety as Appendix E of this report. The principle difference beyond requiring babbitt instead of zinc is the requirement that "...the exposed strands shall then be bent, turned in, and bunched closely together, each strand being turned back the same distance". This is illustrated in Figure 17 reproduced from the Inspector's Manual (ANSI A17.2).

The following is directly quoted from the Inspector's Manual, Appendix 4, p 135:

#### "Babbitted Sockets

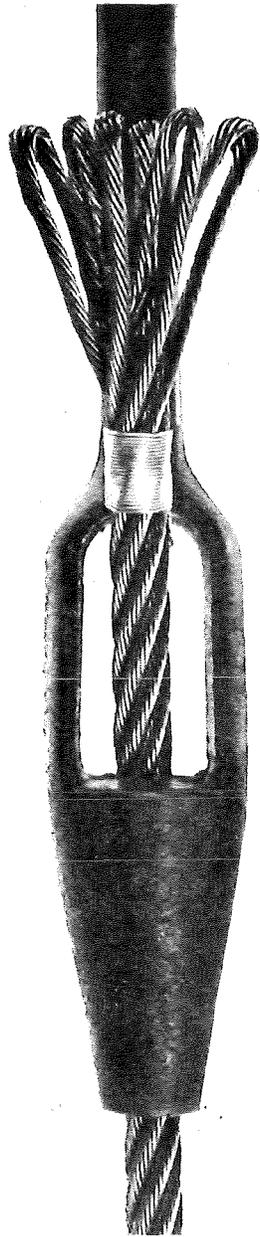
"While wire rope manufacturers universally advocate the use of zinc (spelter) for socketing wire rope and have developed a method of separating, straightening, and cleaning the individual wire, the difficulties of making a secure fastening in the field are so great that, without exception, elevator construction companies have used the turned-in-strand, babbitt-poured socket, even though this may give a finished socket which may develop a slightly lower percentage of the strength of the rope than will the "brushed-out" spelter method. With the turned-in strand, even a poorly made socket will develop a considerable portion of the rope strength, whereas, with individual wires separated and straightened (brushed out), if the bond between the metal and the wire is not good there is little or no holding power. Further, the melting point of zinc is considerably higher than that of babbitt and the danger of overheating and damaging the wire is greater.

#### "Removal of Grease or Oil

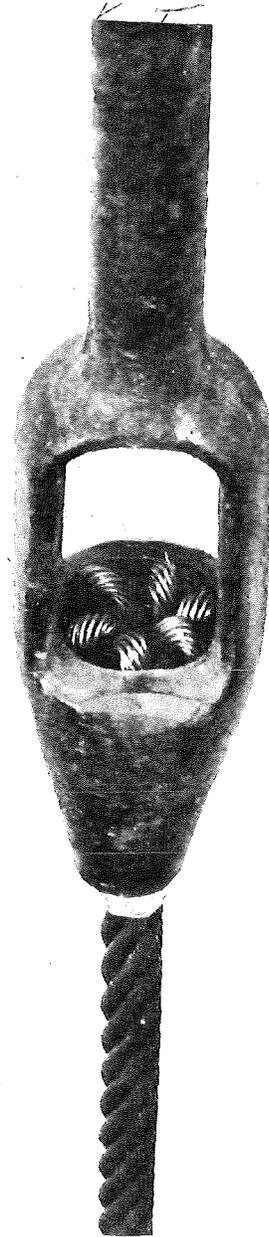
"Grease and oil should be removed by cleaning the outer surface of the exposed rope strands with a nonflammable low-toxic solvent.

"NOTE: Certain elevator companies now omit this washing with solvent, depending on the hot babbitt to burn off the lubricant. Tests of two sockets, one with the rope carefully cleaned, the other with the rope uncleaned, were made and both sockets gave more than the required 80 percent of the strength of the rope. They were both poured at the same time from a pot of metal, the temperature of which was determined by the pine splinter test. The difference in strength was 1-1/2 percent, the cleaned strands giving the slightly higher value."

It should be noted that the American National Standards Committee, A17, on a Safety Code for Elevators, which is responsible for the preparation of these codes (ANSI A17.1 and A17.2), includes representatives from wire rope manufacturers as well as the Wire Rope Technical Board, the latter being responsible largely for ANSI M11.1-1960,<sup>(156)</sup> the recommended code covering mine hoist ropes.



Strand ends turned in



Turned ends pulled into basket ready for pouring

FIGURE 17. STRAND CONFIGURATION IN ELEVATOR SOCKETS  
(FROM ANSI A17.2)

It appears that the above arguments in behalf of elevator socketing methods as opposed to typical mine speltering methods have value worthy of consideration in the mining industry. As mentioned, the entire area of hoist-rope terminations is worthy of reevaluation and study.

Reattachment. Periodic reattachment of the hoist ropes at the car ends is required for drum-type machines (Rule 1000.3), although there appear to be no specific similar requirements for the traction type. In the mine hoist equivalents of traction elevators (the friction or Koepe hoists), reattachment can be done to some extent on conveyance/counterweight systems. Since this is the configuration of elevators the apparent lack of a reattachment specification is puzzling. Whether or not reattachment is practiced on mine elevators has not been well established.

### Maintenance, Inspection, and Replacement Features

Machinery. The Inspector's Manual (ANSI A17.2) stresses the need for maintaining good sheave groove configurations as well as sheave alignment and structural integrity (Sections 26, 45, and 50, ANSI A17.2).

Rope. The need for continuing proper lubrication is stressed. The specification describes the proper procedure (Section 29, ANSI A17.2).

A most important feature of these elevator codes is the section dealing with rope inspection and replacement. It is presented below in its entirety from the Inspector's Manual, ANSI A17.2-1960 as amended through 1970. Though long, it is presented here rather than as an appendix because no such presentation for mine hoist ropes has ever been seen and it is of the sort that most mine operators would apparently welcome.

#### "Wire Rope Inspection

"Examine car hoisting and counterweight wire ropes and note whether they conform with the code requirements. Most codes require the wire rope data to be shown on the car crosshead data plate. For new elevators the wire rope requirements are specified in Section 212 of the Code.

"If ropes are dirty or overlubricated, a proper inspection may not be possible unless the dirt or excess lubricant is removed. (See Section 29 for proper lubrication.)

"For traction machines and for counterweight ropes of drum machines, examination of the ropes should preferably start with car located at the top of the hoistway and should be made from the top of the car, examining the ropes on the counterweight side.

"For overhead drum machines with 1-to-1 roping, the hoist ropes must be examined from the overhead machinery space.

"Where the driving machine is located below, the portions of the ropes leading from the driving machine drum or sheave and from the counter-weight to the overhead sheaves can be examined from the car top as the car descends except for a small portion which must be examined from the pit.

"On all elevators mark the ropes with chalk to indicate the location of the unexamined section of ropes and examine them later from the machine room or overhead machinery space, or from the pit.

"The following method based on field experience is recommended as a guide for the inspection and condemnation of wire ropes:

"Move the car downward two or three feet at a time and examine each rope at each of these spots.

"Note when broken wires begin to appear. Thereafter check at frequent time intervals to determine the rate of increase in the number of broken wires. Any rapid increase in the number of broken wires is significant, but frequently after a rapid increase, the number of broken wires will remain relatively constant for a considerable period of time.

"Count the number of broken crown wires in a rope lay measured along the length of a rope within which the spiral strands complete one turn about the axis. A lay may be considered as a section of rope approximately six and one-half times the diameter of the rope, that is, 3-1/4 inch for 1/2 inch rope and 4-1/16 inch for 4/8 inch rope.

"A. For Single- or Double-Wrapped Traction Machines have hoisting or compensating ropes removed under any one of the following conditions:

- "1. If the broken wires are equally distributed among the strands, when the number of broken wires per rope lay in the worst section of rope exceeds the values shown in Column A in Table No. 1.
- "2. If the distribution of broken wires is unequal and broken wires predominate in one or two strands, when the number of broken wires per rope lay in the worst section of the rope exceeds the values shown in Column B of the Table No. 1.
- "3. If four or five wires, side by side, are broken across the crown of any strand, when the number of broken wires per rope lay in the worst section of rope exceeds values shown in Column C of Table No. 1.
- "4. If any unfavorable factors, such as corrosion (red rust or rouge), excessive wear of individual wires in the strands,

unequal tension, poor sheave grooves, etc., exist, when the number of broken wires exceeds fifty percent of the values indicated in Table No. 1 for Conditions 1, 2, and 3, described above.

Table No. 1

Types of Wire Rope	A	B	C
6 x 19	24-30*	8-12*	12-20*
8 x 19	32-40*	10-16*	16-24*

"B. For Drum Machines have the ropes removed under either of the following conditions:

"1. If the broken wires are substantially equally distributed among the strands, when the number of broken wires per rope lay in the worst section of rope exceeds 12-18\*.

"2. If the wire breaks predominate in one or two strands, when the number of broken wires per rope lay in the worst section of rope exceeds 6-12.\*

"C. For All Types of Machines have the ropes removed whenever their actual diameter drops below the value shown in the following table:

Table No. 2

Nominal Diameter in inches	1/2	9/16	5/8	11/16	3/4	1
Actual Recorded Diameter in inches	15/32	17/32	37/64	41/64	45/64	15/16

"Caution:

"Breaks in the valleys of the ropes, while infrequent, may be an indication of internal breaks. Have the ropes removed when the total number of broken wires in the valleys of a rope lay exceeds one.

"A valley break is one in which the outside wire of a strand breaks in the immediate vicinity of the point where it contacts a wire or wires of an adjacent strand, generally at a point not visible when the wire rope is examined externally. In other words, one broken end of the wire is long enough to reach from one valley to the next one and the other end of the break generally cannot be seen. This is not to be confused with a broken outside wire when the original break occurred at a worn crown and a secondary fracture has occurred near the point where two adjacent strands make contact. In this

\* The upper limits may be used when inspections are made at least monthly by a competent person.

case, a piece of wire has broken out and is missing, and generally both ends of the broken wire remaining are visible.

"Note that where preformed rope is used, greater care is required on inspection in order to detect broken wires which do not protrude from the surface of the rope."

The differences between mine elevators and mine hoists notwithstanding, were the rope replacement section in ANSI M11.1 to be reformulated along these lines, even in a preliminary fashion, it would be a major step forward for the mining and wire rope industry.

### Elevators in Mines - Questionnaire Responses

In response to questionnaires, the three elevator manufacturers contacted indicated that the standards just discussed apply regardless of where elevators are installed.

Condensation and humidity appear to present greater problems in mine installations than in the majority of other cases. One manufacturer indicated he used galvanized wire in such instances. As stated earlier, the use of galvanized wire in coal-mine hoist applications has seen limited use in this country.

The responses indicate that elevator ropes have been replaced because of broken wires, wear, and corrosion. In response to a direct question as to the suspected probable causes of broken wires or broken strands, the answers included abrasives, slippage on traction wheel, normal wear, and too-sharp wheel radii. These answers are little different in essence from answers to similar questions about hoist ropes. They are all encompassing but rarely quantitative, indicating that little attention is paid to worn-out ropes in an attempt to get at the causes. One response did indicate however, that the company maintains records of the service histories of their elevator ropes.

Rope life on mine elevators is reported to vary considerably, though being usually 4 years or more.

### Value of Studying Elevator Ropes

A study of mine-elevator hoist-rope degradation would be of general value to hoisting technology. There is clearly more uniformity in machinery design and it is expected that those who inspect and maintain mine elevators might be particularly good sources of information. Furthermore, since these installations are so similar to Koepe friction hoists, it would seem that some insight and knowledge of the rope problems peculiar to Koepe hoists could be obtained.

## HOISTING LAWS AND REGULATIONS

### Introduction

During this program a large number of mining laws were obtained and studied to determine to what extent they contribute to wire rope practices in coal mines. In the United States, at least, only hoist ropes appear to be regulated. The study of these laws and regulations thus became a study of hoisting laws and regulations.

The titles of the laws and regulations collected are listed in Appendix A. Hoisting machinery and rope regulations are summarized in Table 6 as they exist under United States Federal Law, United States State Law, Canadian Provincial Law, and Laws of the United Kingdom. Table 6 includes only those regulations applying directly to the hoist ropes and those regulations applying to the hoist machinery where they affect the rope. The table was formulated around existing hoisting regulations of the type mentioned. Thus the states excluded do not have regulations of interest although their laws and regulations may treat such aspects of hoisting as engineer qualifications, signals, conveyance construction, etc.

Before discussing some details of these regulations a few general comments are in order. Preparation of Table 6 commenced as soon as the requested laws began to be received. It was noted early that distinctions were made between hoisting in coal mines and in noncoal mines. This was puzzling since there does not appear to be any technical or operational difference of any significant magnitude between hoisting in coal or noncoal-mine applications. The depths of noncoal mines may be generally greater which, in turn, causes some rope problems not common to shallow mines, but the problems are one of greater magnitude not of a different kind.

Thus, Table 6 presents hoisting regulations for both coal and noncoal mines to illustrate the situation. In general, the regulations in noncoal applications are of broader scope, including more items which, in a few instances, are more quantitative. In general, the entries in Table 6 are qualitative - as indicated by an "X" - meaning that the regulation simply stated that this or that item is required. Where quantitative data are presented in the laws and regulations they are numerically included in Table 6.

### Some History

The nonuniformity of hoisting regulations in the United States, apparent in Table 6, and the difference between coal and noncoal mining regulation would have remained a complete puzzle and accepted as an indication of regional differences in attitude except for the earlier mentioned Bureau of Mines, Bulletin 75, Rules and Regulations for Metal Mines, 1915. This bulletin reports a study which in many respects was similar in intent to this one. The scope was all encompassing, however, and the work was carried out over 9 years.

The committee making this report was initially appointed by the American Mining Congress in 1906 to draft a "modern" law governing quarrying and metal mining which would be recommended to the states for adoption in the hope of obtaining a uniform law

among the mining states. In the course of the study the committee was absorbed by the Bureau of Mines, and the final report published with the support and blessing of the Federal Government.

The committee's effort was largely the result of a general lack of uniform laws pertaining to noncoal mining. At the time the major coal mining states had laws applying to coal mining only. Unfortunately, these coal mine laws are not described in Bulletin 75, thereby making it impossible to determine the total extent to which the recommendations of Bulletin 75 influenced the coal mine hoist regulations of Table 6. Nonetheless, it is apparent that there was much influence, the safety-factor data presented (Table 6) and discussed earlier being exactly as presented in Bulletin 75.

The committee recognized the importance of hoisting regulations in the proposed law, yet their desire to achieve nation-wide acceptance of the law influenced many of their decisions. The committee members, through consultation with the wire rope industry, were cognizant of the problems of rope inspection, replacement criteria, and the many factors influencing the life of a hoist rope. Regulations were often simplified in lieu of a more complicated code which was feared would not be acceptable. The limitations of these regulations were understood by the proposing committee, and they hoped that future work in these areas would provide a better code. Regrettably, it seems that the suggested studies were never carried out.

A draft for a general law was also proposed in Bulletin 75. Synopses of two of the sections of this draft are quoted below and presented in their entirety in Appendix F.

#### "SECTION 31. HOISTING

"Maximum rates of speeds to be used in hoisting men shall be established and posted, proportional to the depth of the shaft. Maximum number of men to be allowed to ride on shaft conveyance shall be determined and posted. Appointee of superintendent shall see that this number is not exceeded in hoisting or lowering. If mine has more than one level and employs more than 99 men underground, shaft conveyance shall be in charge of conductor who shall give all signals. If more than 99 men are employed underground there must be an extra man on platform with hoisting engineer when handling men at change of shift. Buckets with men thereon shall not be hoisted at more than 200 feet per minute when bucket is within 100 feet of the shaft collar or at more than 500 feet per minute anywhere. "

#### "SECTION 34. HOISTING ROPES

"Metal-wire ropes required for hoisting other than by human or animal power. Safety factor of six required for new ropes, based on manufacturers' tables and maximum dead hoisting load. Safety factor must never fall below 4.5. Ropes of standard construction shall be

TABLE 6. SUMMARY OF HOISTING REGULATIONS

BATTELLE - COLUMBUS

Regulatory Agency	Coal mines in operation	Application of laws	Hoisting Machinery					Wire Rope																																	
			Controls			Hoist drum		Head and aux. sheaves	Selection and installation (new rope)			Maintenance and inspection			Replacement criteria																										
			Overwind	Underwind	Clutch-brake interlock Maximum acceleration & deceleration rates (fps)	Flange projection	Groove configuration	Minimum D/d	Minimum number rope wraps	Fleet angle	Minimum D/d	Groove configuration	Sheave-drum alignment	ANSI M11.1 rope stds. recommended	Rope manufacturer certificate	Safety factor	Use of spliced rope prohibited	Conveyance termination	Bridle chains	Drum termination	Periodic lubrication	Visual inspection	Record of inspection	Rope reversal recommended (vrs.)	Rope reversal prohibited	Periodic destructive test	Conveyance Retermination	Drum Retermination	Periodic nondestructive testing	Max. length of service (years)	Min. safety factor	Number wire breaks/lay length	Percent original diameter of crown wires	30 Percent wear and 3 breaks (crown wires)	Extensive corrosion	Loss of core lubricant	Rope stretch	Destructive test results	Nondestructive results		
United States (Federal)		X	X	X	X			3				X	X	X						D <sup>(1)</sup>	X																				
Alabama	X	X	X	X		900	2"	3				X	X <sup>(3)</sup>	X	X	X	X	X	X	D	X																				
Alaska		X	X	X		500	3d <sup>(4)</sup>	X <sup>(5)</sup> 3	X <sup>(6)</sup>	X <sup>(5)</sup>	X		X <sup>(7)</sup>	X	X	X	X	X	X	X	I		X	X																	
Arizona		X	X	X	X	1500	3d			2°			X <sup>(7)</sup>	X	X	X	X	X	X	D	X																				
Arkansas	X <sup>(6)</sup>	X	X			500																																			
California		X	X		X	X <sup>(9)</sup>		X	3	X <sup>(6)</sup>	X			X	X <sup>(10)</sup>	X	X	X	X	3M																					
Colorado	X	X	X <sup>(11)</sup>	X <sup>(11)</sup>		750	4"	3					X		X	X																									
Illinois	X	X				600	4"	3					X		X	X	X																								
Indiana	X	X	X <sup>(11)</sup>	X <sup>(11)</sup>		600		3						X		X	X	X		D	X																				
Iowa	X					400	4"	2 1/2																																	
Kentucky	X	X				600								X		X				D																					
Maryland	X	X	X <sup>(11)</sup>	X <sup>(11)</sup>		900							X																												
Michigan	X	X <sup>(12)</sup>	X <sup>(12)</sup>	X										X <sup>(7)</sup>	X												X <sup>(13)</sup>														
Missouri		X				500														2/W	X																				
Missouri		X	X	X		1500		3					X		X	X	X			D	X																				
Montana	X	X	X <sup>(11)</sup>	X <sup>(11)</sup>		600		3					X		X	X																									
Montana		X	X	X		800		3	X <sup>(6)</sup>						X	X	X	X	X	X																					
New Mexico	X	X	X	X		500		2																																	
Nevada		X	X	X	X	2500	4"	X	X	3	15 <sup>(6)</sup>	X	X	X	X <sup>(7)</sup>	X <sup>(14)</sup>	X	X	X						X	X	X <sup>(13)</sup>		X <sup>(7)</sup>												
North Dakota		X				600																																			
Oklahoma	X	X	X <sup>(11)</sup>	X <sup>(11)</sup>		600	4"	2 1/2					X <sup>(15)</sup>	X <sup>(15)</sup>	X					D	X																				
Oklahoma		X				500	4"	2 1/2																																	
Oregon		X	X	X		X <sup>(9)</sup>	2"	X	3		X			X <sup>(7)</sup>	X	X	X	X	X	X	I																				
Pennsylvania	X	X	X			900	4"							X		X	X			D	X																				
South Dakota		X	X											X <sup>(7)</sup>																											
Tennessee	X	X	X <sup>(11)</sup>	X <sup>(11)</sup>		500		3					X		X	X	X			D	X																				
Tennessee		X	X	X		1000		3					X		X	X																									
Utah	X	X	X	X		X <sup>(9)</sup>		X			X			X <sup>(7)</sup>	X					3M																					
Virginia	X	X	X <sup>(11)</sup>	X <sup>(11)</sup>		1000		3						X	X	X	X			D	X																				
Washington	X	X	X			600								X	X	X				D	X																				
Washington		X	X	X		X <sup>(6)</sup>	X	X	3		X			X <sup>(7)</sup>	X	X	X	X	X	D																					
West Virginia	X		X																																						
Wyoming		X				1200	5d	3	X				X		X					D	X																				
Alberta	X	X	X				4"	3							X	X																									
British Columbia	X	X	X	X	X		X	X	3		X	X	X	X	X					M	D	X						X <sup>(17)</sup>													
Manitoba	?	X	X	X	X		X	X						X	X	X				M	M	X																			
N. Brunswick	?	X	X					X	3		X	X		X	X	X	X	X																							
Newfoundland		X	X	X	X				3					X	X	X	X	X																							
Nova Scotia	X	X	X	X		1200	X	X	5		X	X		X	X	X <sup>(17)</sup>	X	X	D																						
Ontario		X	X	X	X	16		X	X	3		X	X	X	X <sup>(17)</sup>	X				M	D	X																			
Quebec			X	X					3					X						M	W	X																			
Great Britain	X	X	X				X							X	X	X				M																					

(1) D - Daily, W - Weekly, M - Monthly, 3M - 3 Months, etc.

(2) Shaft Depth      Max. Hoisting Speed (fpm)  
 0-500                      500  
 500-1000                  800  
 >1000                      1/2 regular hoisting speed

(3) Rope record book.

(4) d - rope diameter, 3d - three times rope diameter, etc.

(5) Tables of D/d given for various rope constructions and hoisting operations.

(6) Specified as minimum distance between drum and nearest sheave per foot of drum width.

(7) Require factors of safety presented in ANSI M11.1 -1960, Table 33.

(8) No shaft mines.

(9) To be determined by each mine operator.

(9) To be determined by each mine operator.

(10) Or some other similarly acting device.

(11) Not required if second engineer is on duty.

(12) Proposed only.

(13) Only can be used as a supplement to other tests.

(14) Recommended.

(15) Nonspin wire rope required with F.S. = 6.

(16) To be determined by the chief mine inspector for each mine.

(17) Unless approved by Chief Inspector.

(18) Less than 90 percent remaining strength of original breaking strength, or test piece extension less than 60 percent of original.

(19) Less than 85 percent remaining strength of original breaking strength, or test piece extension less than 60 percent of original.

discarded when there are six broken wires in one rope-lay, when wires on crown are worn to 65 percent of their original diameter, when there are more than three broken wires reduced by wear more than 30 percent in cross section, when marked corrosion appears. Record of every rope must be kept, showing kind of rope, how, when, and where used, etc. After three years in service, even if idle, rope may not be used unless tested for ultimate strength. New fastening of rope to shaft vehicle must be made at fixed intervals. New rope and new fastening must be tested by trips before used for men. Ropes must be superficially inspected every day and, whenever a new fastening is made, the piece cut off must be examined with care. Rope must be securely fastened to drum or reel with one lap always left thereon. Either socket or thimble required for fastening to shaft conveyance. Rope must be protected with dressing. Shafts over 3,000 feet deep and shafts in which no compartment is used for handling men exempt from all the requirements of this section. Depth of inclined shaft shall be its vertical component."

The safety factor and related speed and acceleration data discussed earlier and presented in Appendix C were recommended to the principal committee being a committee of wire rope manufacturers. The proposed law, just presented in synopsis form, represents the principal committee's final decisions. There are differences between the sets of recommendations of the two committees, notably in the area of safety factors and permissible speeds. The comparison of these recommendations and the state laws will show that some states apparently adopted one set (in whole or in part) while other states adopted the other set (also in whole or in part). Thus, some of the differences among the laws of the states are explained. Since these recommended laws were primarily directed to metal mining, it appears, in addition, that the recommendations were utilized in reformulating noncoal mining laws to a greater extent than coal-mining laws.

The hoisting and rope related discussions in Bulletin 75 show that, though many aspects of hoisting machinery and rope materials and constructions have changed and improved since 1915, the basic problems of rope-strength degradation and knowing when to replace a rope still exist. In this regard very little progress has been made in 56 years.

### United States Regulations

#### Federal

The United States Federal hoisting regulations presented in Table 6 have been gleaned from the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) and subsequent publication in the Federal Register.<sup>(163)</sup> These publications specify that ANSI M11.1-1960, "Specifications For and Use of Wire Ropes for Mines" is to be used as a guide in rope practice. Whether or not this conveys the status of law or a requirement to various aspects of M11.1-1960 cannot be judged. Therefore, the Federal regulations in Table 6 do not show the existence of speed limits, safety factors, etc., regulations, these being presented in M11.1-1960 but not specifically stated apart from this specification. The distinctive position of ANSI M11.1-1960 in the Federal regulations structure required some inquiry into the possibilities for reissue in an updated and more specific nature. The Wire Rope Technical Board reports it has begun the process of

revising M11.1; however, little progress has been made and no schedule has been set. The Board has indicated a reluctance on the part of the American Mining Congress to cosponsor a revision at this time. Information on the nature of the revisions could not be obtained.

The Federal Coal Mine Health and Safety Act also requires that hoisting equipment used to transport men must be examined daily. The details of the inspection have been specified in the Federal Register; visual examination of the hoisting rope for wear, broken wires, and corrosion, particularly at locations near the attachments, where the rope rests on the sheaves, and where the rope leaves the drum at both ends. This regulation clearly indicates the critical sections of a hoisting rope, but does not give explicit standards for evaluating the rope condition. Specific standards are a prerequisite for an inspection procedure, otherwise the examination is usually superficial.

The results of the inspections are also required to be recorded in an approved book, "Report of Daily Inspection of Hoisting Equipment", which is provided to mine operators by the Federal Government. Although this form, shown in Figure 18, is only a check list, it has value in that it is a standardized and uniform requirement of all coal mines in the country. The form does state that if the item is not in safe operating condition, the action taken is to be indicated. What is unsafe about the item(s) is not requested, however, and without such information no systematic improvements can be made. It is recognized, however, that such is not the specific intent.

### State

Many of the state agencies contacted indicated that their mining laws were currently in the process of being revised to conform to the Coal Mine Health and Safety Act of 1969. The State of Michigan is also in the process of formulating its laws on the state level, replacing the old system of individual county responsibility.

It is expected therefore that, where state laws are not compliant with the Federal law, time will achieve conformity. Table 6 illustrates the nonconformities.

Hoist drum and sheave D/d ratios are usually specified by reproducing all or part of Table 36, "Tread Diameters of Sheaves and Drums" from ANSI M11.1-1960. Interestingly, several states specify hoist-drum fleet angles in terms of a minimum distance from the hoist drum to the first sheave per foot of drum width. This is a very practical approach.

One-third of the states do not require overspeed and overwind controls if a second hoistman is on duty. This is a direct carry over from Bulletin 75 of 1915. This requirement is still sufficient except that no second hoistman was observed by the project staff.

The safety factors for a new hoisting rope, technically discussed earlier, are mentioned in almost all state laws, but a minority actually specify them. Several regulations contain data as it appears in ANSI M11.1-1960. A few other states specify a factor, usually 10 to 1 for hoisting men, and 5 to 1 for hoisting coal. The distinction between man and other hoisting does not seem justifiable because generally men will be hoisted sooner or later on systems not normally used for the purpose. It is interesting

INSPECTIONS OF HOISTING EQUIPMENT

Date \_\_\_\_\_ Time \_\_\_\_\_ Shift \_\_\_\_\_

NOTE: Use check (✓) mark after items listed if in safe operating condition, if not, state what action was taken.

Items 1 through 13 shall be entered daily.

- 1. Visual examination of hoist ropes. \_\_\_\_\_
- 2. Rope fastenings, alignment, and lubrication. \_\_\_\_\_
- 3. Safety catches. \_\_\_\_\_
- 4. Examination of cage, platform, elevators, etc. \_\_\_\_\_
- 5. Head sheaves, flanges, bearings, lubrication. \_\_\_\_\_
- 6. Ride top of cage or elevator to check guides buntons, power wires, etc. \_\_\_\_\_
- 7. Overwind, overspeed, and automatic stop controls. \_\_\_\_\_
- 8. Anchorage of hoist; check for loose bolts, etc. \_\_\_\_\_
- 9. Cage, platform, skip, bucket, or cars position indicator. \_\_\_\_\_
- 10. Signal systems. \_\_\_\_\_
- 11. 3 wraps of rope around drum; fastening to spoke, etc. \_\_\_\_\_
- 12. Cage operated one round trip before men transported. \_\_\_\_\_
- 13. Landing gates or doors. \_\_\_\_\_
- 14. Tests of safety catches. (every two months) \_\_\_\_\_

Previous test made \_\_\_\_\_

If unsafe conditions are noted, state action taken: \_\_\_\_\_

Examiner(s):

Countersigned:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

\_\_\_\_\_  
Mine Foreman—Mine Manager

\_\_\_\_\_  
Cert. No.

\_\_\_\_\_  
Superintendent or Assistant

GPO 890-9 22

FIGURE 18. REPORT OF DAILY INSPECTION OF HOISTING EQUIPMENT  
REQUIRED OF U. S. COAL MINES (FORM NO. 6-1494)

to note that no distinction was made in Bulletin 75 (1915) with respect to the use of the hoist rope, except for some cases where the system would not be used to hoist men under any circumstance. In these cases no restrictions were made.

Most states simply require the hoisting rope to be strong and have an adequate or proper factor of safety. Lack of specific requirements is considered to be undesirable because in such a case one can only hope that what is "adequate or proper" will be sought and provided. In most cases it will be. But where law is concerned and nothing specific is stated, enforcement can be problematic.

The state laws regarding hoist rope maintenance are minimal. Periodic retermination of the load end of the rope is considered good practice by wire rope manufacturers as is also cutting off the drum end of the rope to change the cross-over points. Only a few states require these practices of their mines. Very few even require periodic lubrication of the rope. Some states recommend ANSI M11.1 as a guide for rope maintenance. The proposals of Bulletin 75, which were quite specific and detailed in this matter of retermination, appear to have been ignored.

Most states require a daily visual inspection of the hoisting equipment including the hoist rope and attachments. Similarly, the state mine inspectors are required to examine the hoisting installation during their periodic inspections. Unfortunately, none of the state regulations clearly define the inspection items or present a criteria to be used in making judgments on the integrity of the mechanical equipment. Specific guidelines are necessary when an inspection procedure is used to maintain certain standards.

The majority of state regulations do present some criteria for judging when a hoisting rope must be replaced, calling for rope replacement when any one of the following occurs:

- (1) Six broken wires in one lay length
- (2) Crown wires worn to 65 percent of their original diameter
- (3) More than three broken wires and crown wires reduced by wear more than 30 percent in cross section
- (4) Marked corrosion.

These criteria are from Bulletin 75 with the regrettable omission of the fact that the first three apply strictly to 6 x 19 construction. Then as now, 6 x 19 construction is the most common for hoist rope, but not the only one. The criteria are difficult to apply except when an examination is made of a removed portion of the rope; only a few states require a periodic cut-off and examination.

In addition, many states have legislated the concept of minimum factor of safety as a criterion for rope replacement. This again is based on Bulletin 75. As the remaining strength in a wire rope is very difficult to determine, this requirement is worthless, as far as general practice is concerned.

Tensile testing of sections of a hoist rope is not required by any state, nor is any testing required of retired ropes. The only two states mentioning nondestructive testing by an electromagnetic device direct that such tests can only be used as supplements to visual inspection and, perhaps, rope diameter measurements.

Discussions with state officials and the response to questionnaires indicate little involvement in inspection of wire rope, the responsibility being legally that of the operator. States by and large do not appear to have the technical capability or interest to contribute to advancement in the area of hoisting and rope practice in coal mines.

### Canadian Regulations

#### Federal

Except for mining of uranium, the Canadian Federal Department of Mines exercises very little control and regulation of mining within the provinces. Practically all mining is controlled and regulated at the provincial level.

#### Province

The Canadian Provinces have been particularly conscious of hoisting safety, primarily as a result of the 1945 hoisting accident at the Paymaster Consolidated Mine in the Province of Ontario. This accident, in which 16 miners were killed, initiated an extensive investigation by a committee of the Ontario Department of Mines and the Ontario Mining Association to determine the causes of the failure and to relate that data to other hoisting ropes throughout the province. Consequently, the Province of Ontario has become a leader in hoisting safety research, and the other provinces have benefited from their work. The laws of several provinces reflect the results of these efforts. These laws dealing with hoist machinery and rope are summarized in Table 6.

Canadian laws use actual test results as the basis for making rope replacement decisions. This is supplemented by visual inspection criteria similar to that used in the United States. All provinces having shaft mines require that the section of the rope at the conveyance end be removed and tensile tested, usually at 6-month intervals. This applies strictly to drum hoists, the laws being worded to allow exceptions for those Koepe hoists for which rope cutoff is impossible.

The Ontario Department of Mines maintains a complete wire rope testing laboratory and many of the other provinces use this facility for the testing of ropes from their own mines. Others use an independent laboratory for their tests. In addition, a piece of every new hoisting rope is subjected to a breaking strength test before the rope can be installed. This information is used as a basis in making subsequent comparisons with the in-service tests. Typically, the following criteria are then used to indicate that a rope must be replaced:

- (1) Existing strength has decreased to less than 90 percent of the original strength of the rope
- (2) Rope test piece extension has decreased to less than 60 percent of its original extension when tested to destruction.

These test results along with the required visual examinations give mine operators better knowledge of when a rope should be removed.

Visual inspection of hoist ropes in the Canadian laws is usually divided into two levels of effort. A superficial examination of the rope and attachments is required daily. At least once each month a more detailed inspection of the rope is required, and both the portions of the rope to be examined and the conditions to be checked are clearly specified. The results of these examinations must be recorded.

Complete records of a hoisting rope are required to be maintained by each mine. Every new rope is required to have a manufacturer's certificate that completely describes the construction and strength of the rope. This data is recorded in a rope record book, required for each rope, which also contains all facts relating to the service history and performance of the rope. The record form used in the Province of Ontario is presented in Appendix G, and should be compared with the U. S. Federal hoist equipment record book shown in Figure 18. The back of the Ontario sheet contains the pertinent regulations extracted from the law, and instructions for preparing the test specimens for the laboratory.

Periodic lubrication of hoist ropes is required by all provinces. This requirement reflects the work of the Ontario Department of Mines which found that corrosion was the most common cause of rope degradation in Canadian mines.

The laws of several provinces are noteworthy in their safety factor requirement for new ropes. The law states that the minimum factor of safety of the rope at the headsheave must be 8.5 when the loaded conveyance is at the top of the shaft and be 5.0 when the conveyance is at the bottom. This requirement is independent of the depth of the shaft. Ontario and British Columbia also require safety factors for friction hoists as calculated by the formula  $S.F. = 9.5 - .00075L$  where L is the maximum length of rope suspended below the headsheave. This factor cannot be less than 5.5 for any depth of shaft. All of the safety factors are based on laboratory breaking-strength tests on the new rope.

The Canadian Provinces, then, appear keenly aware of hoisting safety, as reflected in their extensive hoisting regulations. The laws are also maintained consistent with current technology, and several of the provinces are active in research and development in mine-hoisting practice.

A few provinces permit the use of a nondestructive rope examination in lieu of the destructive test, but the periodic retermination and testing of the conveyance end is still required. The Province of British Columbia recognizes nondestructive test results as permissible data when considering if a hoist rope may be used longer than the statutory 2-year limit. Although other provinces do not mention nondestructive testing, many have indicated that they are considering revising their laws to require the test as a supplement to the other inspections. The Province of Ontario is currently in the process of revising their law to be consistent with the presently required use of electromagnetic nondestructive inspection devices. This revision will require inspection of tail and guide ropes as well as hoist ropes.

Ontario is also planning to require ultrasonic or other nondestructive testing of critical hoist machinery parts that are vital to safe operation. (218) These parts include sheave and drum shafting, brake control rods, conveyance termination, and safety device components. The inspection is to be required both before installation and periodically after.

Little has been said thus far about inspection of critical aspects of hoist machinery. Such inspection, if not explicitly stated, is intended by most states, and certain aspects of the United States Federal inspection requirement touch on this subject as indicated in Figure 18. During the course of this study a California limestone mine hoisting accident occurred that killed four miners. The report of this accident was obtained and studied.<sup>(102)</sup> It appears that a fatigue failure at a point of stress concentration in the anchoring portion of the band of a Lane friction-band clutch touched off the accident. These clutches apparently have not been made for about 40 years. There are indications that the hoist winding apparatus involved in this accident was built over 60 years ago. The general longevity of hoist machinery requires added concern for potential fatigue failures of components. Many coal mine hoists are so covered with dirt, dust, and grease that such components as brake-post anchors are almost impossible to inspect. The hoist may, indeed, run forever but components that are cyclically stressed-even at low stress levels - can fail in a fatigue mode. The older the equipment, the greater the possibility for such fatigue failures.

### British Regulations

The British law concerning hoisting is covered by "The Law Relating to Safety and Health", Vol. I, Mines of Coal, 1960, Shafts Outlets and Roads Regulations. There are also a number of British standards dealing with wire-rope design, wire ropes for different mine uses, wires, sockets, and other mining areas. The National Coal Board, which is an administrative agency of the government, produces supplemental information bulletins and other publications. The Safety in Mines Research Establishment (SMRE), a research agency with powers similar to the U. S. Bureau of Mines, also periodically publishes bulletins and reports.

The British law is rather limited in its extent. To the extent possible it is summarized in Table 11. The law does not mention any requirements concerning  $D/d$  ratios for drums and sheaves (although  $D/d \geq 100$  is common practice), but hoisting ropes are required to have a factor of safety of 6 when installed. A visual inspection at least once a month, and a retermination at the conveyance every 6 months are the only inservice practices required by the law. A maximum service life of 3-1/2 years for shaft-hoisting rope is the only replacement criteria given.

Where the laws are silent, mine operators have the aid of "The Ropeman's Handbook", published by the National Coal Board. The text was written for the most part by A. E. McClelland, of the SMRE, who is recognized as a leading authority on the use of wire rope in mines. The handbook is similar in intent to M11.1-1960, but is much more detailed. Discussions include rope maintenance, inspection and replacement.

The law is also silent on any form of testing of hoisting ropes. Correspondence to date has not indicated whether or not periodic destructive testing of ropes is being practiced by any mine operators. The SMRE has reported that they are studying the application of an electromagnetic nondestructive testing device to locked coil ropes but that no information has yet been published.

The British law makers apparently do not see the need for more complete hoisting regulations. The exact reasons for this can only be speculated because of the limited data received. Since the SMRE has been active in area of hoisting practice for many years, it is possible that the British coal mine industry is kept informed of safe hoisting practices and applies them without the need of governmental regulations. On the other hand, the generally nationalized character of the industry may result in little choice but to follow SMRE recommendations.

## NONDESTRUCTIVE INSPECTION OF WIRE ROPES BY ELECTROMAGNETIC METHODS

### Introduction

The historic approach to wire rope inspection is visual observation combined, perhaps, with measurement of the rope diameter. The approach is very time consuming if done in detail, and serious internal rope defects can be inadequately judged or missed entirely.

Almost 50 years ago work was in progress<sup>(37)</sup> on devices to provide a quantitative measurement of a rope's condition in a continuous manner over its full length using electromagnetic methods. The late 1940's saw another surge of interest which included investigation of X-ray and ultrasonic as well as electromagnetic techniques.<sup>(101)</sup> While the historic development of these devices may be of interest to some, their present-day status and future possibilities are more pertinent for this report. For those interested in developmental details, Items 4, 34, 37, 43, 44, 45, 54, 61, 67, 68, 75, 76, 77, 94, 97, 98, 101, 102, and 112 in the Bibliography, Appendix A, give fair coverage. Of all the techniques tried, those using electromagnetic principles have been most highly developed and still show the greatest potential.

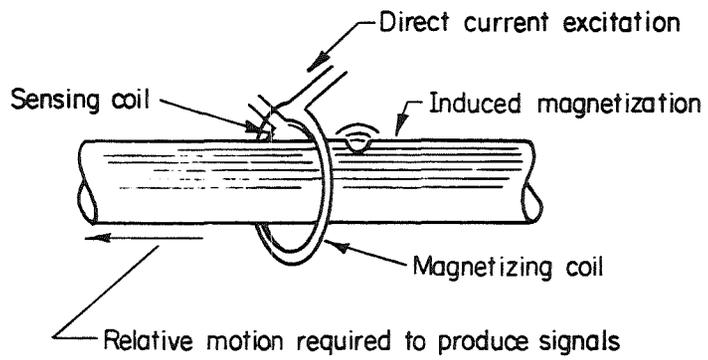
### Basic Principles

Two electromagnetic inspection methods are available for inspecting wire ropes made of electrically conducting ferromagnetic material. One is known as the ac (alternating current) method and the other as the dc (direct current) method. These names relate to the characteristics of the magnetizing field; the ac method uses an alternating field and the dc method a steady magnetic field.

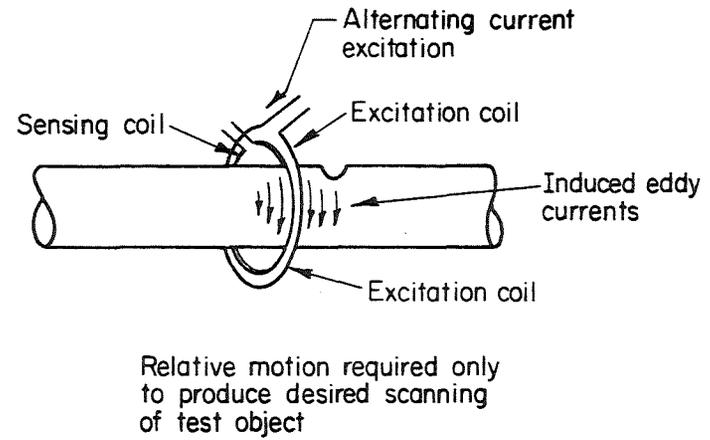
The concept of electromagnetic induction stated by Faraday's law is common to both methods. This law says that a voltage will be induced in a circuit (e. g. , a simple coil) which is exposed to a changing magnetic environment or "field".

### DC Method

The dc method is illustrated in Figure 19a. The test object (which must be magnetizable - e. g. , iron or most steels) is magnetized by the steady field produced by a steady dc current in the excitation coil. The excitation coil could be replaced by permanent magnets to produce the same results. If the test object has a uniform cross section and its magnetic characteristics are uniform, no change in the magnetic field occurs as this test object is moved through the coils. Thus, according to Faraday's law, no voltage is induced in the sensing coil. However, when an irregularity exists in the test object, such as the notch shown in Figure 19a, it changes the magnetic field as it approaches and passes through the coils. This change in the magnetic field induces a voltage in the sensing coil. The presence of the defect is indicated by the appearance of a voltage in the sensing coil. This induced voltage, according to Faraday's law, is proportional to the rate of change of magnetic field. Thus, the voltage induced in the



a. Direct Current



b. Alternating Current

FIGURE 19. TWO MAJOR ELECTROMAGNETIC TEST METHODS

sensing coil is higher as the test object is moved through the coils faster. The induced voltage also varies in a complex manner with the severity and geometry of the defect, the location of the defect within the test object, and the strength of the primary exciting field.

### AC Method

The ac method is illustrated in Figure 19b. The alternating current in the excitation coil creates an alternating magnetic field which, according to Faraday, induces voltages within the test object as well as in the nearby sensing coil. The induced alternating voltages in the test object create eddy currents in the test object which, in turn, produce a secondary alternating magnetic field. This secondary alternative field also induces voltages in the sensing coil. Thus, without moving the test object through the coils, a varying voltage exists in the sensing coil. If the test object is uniform in geometry and magnetic permeability (a measure of its magnetic characteristics) the induced changing voltage in the sensing coil has uniform characteristics when the object is moved through the coils. However, the eddy currents induced in the test object by the primary excitation field are a function of such test-object characteristics as electrical conductivity, magnetic permeability, and cross-section geometry. Thus, defects in the test object which change any or all of these characteristics would result in a change in eddy currents, which in turn changes the secondary (and to some extent, the primary) alternating field, which, in turn, changes the characteristics of the sensing-coil voltage as the defect passes near and through the coils. As long as the velocity of the test object through the coils is low with respect to the rate of change of the primary excitation field (the excitation frequency), the voltage in the sensing coil is independent of the velocity of the test object. The characteristics of the voltage induced in the sensing coil vary in a complex manner with the location of the defect within the test object and with the strength of the primary field and the excitation frequency.

In a simplified manner, the foregoing discussion of the ac method has related defects or variations in characteristics of the test object to the voltage induced in the sensing coil. Analytically, this can be viewed in a different but equivalent manner by saying that the output voltage (the voltage in the sensing coil) varies because the "impedance" of the coil system is changed by the variations of the test-object characteristics. Analytically, again, the circuit characteristic called impedance can be considered to have two components - a resistive component and a reactive component. Though somewhat oversimplified, it can be stated that changes in the electrical conductivity characteristics of a test object change the resistive component of the impedance; likewise, changes in the magnetic characteristics (the magnetic permeability) of the test object change the reactive component of the impedance. In applications, the instruments used to analyze the voltage of the sensing coil can be designed to discriminate between these two components. Thus, most ac-method devices are characterized by two output channels or strip charts, with one often called "X" for the reactive component and the other "R" for the resistive component.

Of primary interest here is a wire rope as the test object. Loss of metallic section through wear and corrosion would primarily change the reactive component. Inherent natural variations in the magnetic permeability of the material, variations in permeability due to imposed stresses, and the effects of the earth's magnetic field also primarily change the reactive component. Variations in the electrical contact between wires and strands in the rope primarily affect the resistive component.

Application of Principles - Equipment Characteristics

In application, both the dc and ac methods generally result in similar pieces of equipment and component groups. One group consists of the sensing and magnetizing elements. The other group consists of the signal-analyzing and presentation equipment and the power supplies.

Generally, the sensing/magnetizing unit is a coil or permanent magnet arrangement supported by a frame. This arrangement is constructed so that the frame can be opened, placed around wire rope, and then closed for use. The size of this unit varies, but it is generally 2 to 3 feet in length along the rope axis and about 1 to 2 feet in either direction transverse to the rope axis. Generally, one man can carry this piece of equipment.

Attached by electrical cables to the sensing/magnetizing unit is the analyzing/presentation/power-supply unit. The analyzing/presentation components are usually fitted into carrying cases about the size of a two-suitcase. Since portability is necessary, most systems use storage-battery power supplies, converting the dc voltage to ac voltage in accord with the electronic requirements of each system.

There are many variations from device to device, depending upon where and by whom it was developed. The most readily apparent variations are in the number, shape, and arrangement of sensing coils and, in some cases, the magnetizing coils. The reasons for these variations involve details of the physics of the problem and are beyond the scope of this discussion. All known devices use strip-chart recorders to present the data.

Correlating strip chart data with position on the rope requires synchronizing the chart and rope speeds. It is common to find attached to the sensing/magnetizing-unit frame a tachometer generator roller driven by the rope being inspected. The output of this generator controls the chart-drive motor. One dc machine is reported to use a time trace on the output chart. This and knowledge of the hoisting speed allow correlation of the chart record with position on the rope. The accuracy of this approach depends upon how constant the hoist speed can be maintained at the relatively low speeds needed for testing and how accurately the speed is known.

To make measurements with these systems is fairly simple. Typically, as has been observed, a conveyance is positioned just below the shaft collar. Planks or the equivalent are placed across the collar opening on either side of the hoist rope. The sensing/magnetizing unit is closed around the rope and left resting on the planks. The analyzing/presentation unit is placed nearby and the two units connected. After initial electronic adjustments have been completed, the hoistman lowers the conveyance at a speed appropriate to the electromagnetic device being used. Rope speeds in the range of 200 to 300 feet per minute have been observed.

Examples of electromagnetic devices using the dc method are the Bochum (Germany), the Tyer-Integra (Switzerland), the Magnetic Defectograph (United Kingdom, Poland, Canada in British Columbia), the A. C. M. I. based on the Berthold System (Belgium), and the Mitsui Miike (Japan). The Magnetic Defectograph uses permanent magnets for excitation. Known examples of electromagnetic devices using the ac method are the Plessey-Slack (South Africa) and the Rotesco instrument - formerly McPhar - (Ontario, Canada).

Symes<sup>(77)</sup> points out that the development of the dc method appears to have taken place only in continental Europe, where no interest in the ac method appears to exist. Conversely, he indicates that ac methods have been developed in South Africa and Canada to the virtual exclusion of dc methods. (The dc Magnetic Defectograph used in British Columbia was not developed there.)

Symes provides some useful insight into this development of the dc and ac systems. In Europe, friction hoists of the Koepe type predominate. The most common form of rope failure on these systems is from wires broken due to fatigue. As will be discussed later, the dc systems are superior for detecting broken wires. Until fairly recently (1966), Symes reports that, in Africa and Canada, plastic deformation (cold working, peening) and mechanical wear have been more serious than broken wires. These conditions are associated with drum hoists, which have widespread use in these countries. The ac systems are superior for detecting these latter rope-degrading mechanisms. Since the Symes investigation, Koepe hoists have been more widely applied in both Canada and Africa and, thus, a more favorable case for dc testing now exists.

### Interpretation of Electromagnetic Data

In discussing basic principles, it was mentioned that the output signals associated with both the dc and ac methods are affected by such things as the severity and geometry of the test object defect, its location within the object, and the strength of the primary exciting field. In addition, the ac-method output is complicated by test object characteristics which affect both output channel voltages in differing ways and are functions of the frequency of the alternating excitation current.

These complexities are compounded by wire rope as a test object because of its complex geometry and because the rope-degradation mechanisms of wear, corrosion, and broken wires (fatigue) can cause somewhat similar signals.

Thus, chart records are not easy to interpret. A fair amount of work has been done to provide graphs and example traces to assist in the interpretation of dc-device records. Little work of this nature appears to have been done for the ac devices. At this time, interpretation of electromagnetic-device chart records requires special skills which few people anywhere possess and which have been gained only through years of experience. This is partially the result of these techniques being relatively new and highly specialized. While interpretation of results requires skill, getting the results by using the devices is simple and requires only a modest amount of training of the operators.

### Capabilities and Limitations - Specific Electromagnetic Devices

Two Canadian-based electromagnetic devices were observed in use and studied through discussions and papers. They are the Magnetic Defectograph (a dc device) being used by the Wire Rope Industries of Canada, Ltd., Western Area, Vancouver, B. C., and an ac device currently being used and developed by Rotesco, Ltd., Don

Mills (Toronto), Ontario. This latter unit was commonly referred to at one time as the "McPhar device" of McPhar Geophysics, Ltd. (later McPhar Manufacturing, Ltd.). This device traces its lineage back to A. Semelink, who came from South Africa to Ontario in the 1950's and was heavily involved in early developmental efforts there. Rotesco was formed by people who were involved with this device at McPhar.

M. D.-6 Magnetic Defectograph  
(Vancouver, B. C.)

This dc device was discussed with and observed being used at Texada Mines, Ltd., B. C., by the manager and an operating technician of the Technical Services (division) Western Area, Wire Rope Industries of Canada. The device was manufactured in Poland. It is shown in Figure 20.

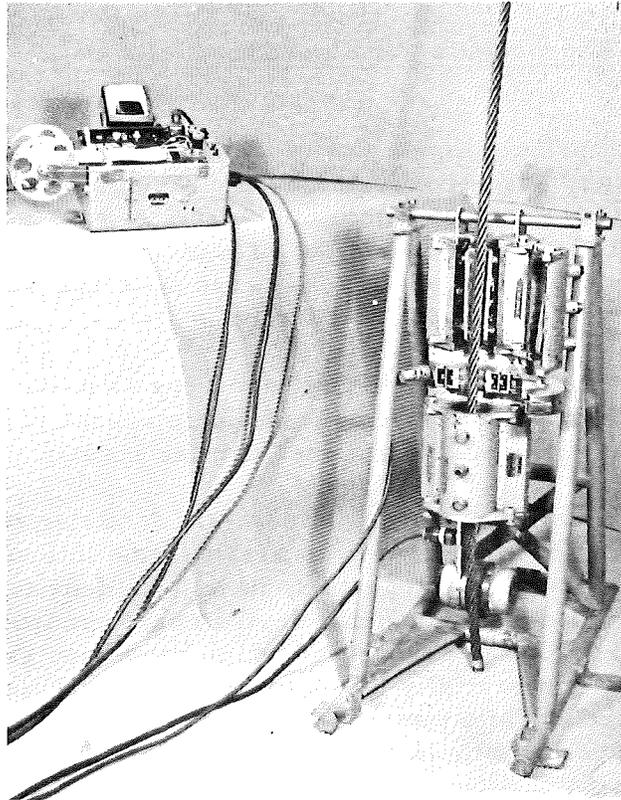


FIGURE 20. MAGNETIC DEFECTOGRAPH

The device is claimed to reliably "detect and assist in analyzing faults in a rope regardless of whether they exist internally or on the surface. These faults could take the form of broken wires, corrosion, heavy abrasion, or disfigurement of the wires. The instrument is sensitive to the extent that a detection will register as fine as 2/10 of 1 percent of the cross-sectional steel area, even if the fault is in the very center of a large-diameter rope".<sup>(65)</sup> The device is reported to have been thoroughly tested in 1962 in Italy, where it met the requirements of a "very strict code".

Calibration curves or, more realistically, chart-record interpretive aids were (and are) supplied by the manufacturer. They relate the instrument response to fault types, severity of fault types, and radial location of the fault. These interpretive aids appear to apply only to stranded rope.

The users report that very little destructive rope-test data are available for comparison with the data from the MD-6 device. They would like to obtain such data for correlation with MD-6 data but it appears that funding currently is lacking. The users also know of no current developmental effort with respect to the MD-6.

The results of some recent laboratory studies of dc devices, the MD-6 Magnetic Defectograph included, were uncovered during the program. As these results appear to be unpublished and, hence, "officially unsanctioned", no reference to them is given herein. With respect to the MD-6 device and other similar dc devices, some results are worth discussing, however. The work involved only laboratory work with ropes with artificial defects. Investigations showed that partial wire breaks and complete breaks with gap lengths less than 1 mm are undetectable. Single breaks in the outer three wire layers (rope construction unknown) were detected but, in lower layers, loss of sensitivity occurred because of the screening effects of the outer layers. What "loss of sensitivity" means with respect to wire-break detection is not clear.

Corrosion is characteristically indicated on chart records as general noise, a term descriptive of a general irregularity of the chart trace, forming a background or random pattern within or above which wire-break "blips" would appear. As corrosion increases this background noise also increases. The above mentioned laboratory studies showed that the background level may reach the same order of magnitude as the signal from a single wire break. Realistically, one or two wire breaks would be of little significance in a typical hoist rope with 100 or more wires. Furthermore, if the corrosion background noise is high, it may indicate that corrosion itself has seriously degraded the rope strength.

From the study of the MD-6, papers related to it and other dc devices make it clear that they are sensitive to wire breaks in the outer layers, less sensitive to wire breaks in the inner layers, sensitive to corrosion, and sensitive to some extent to wear and peening. No definitive study correlating device output with detailed study of actual ropes during and after service has been found.

Rotesco, Ltd., Alternating Current Device  
(Don Mills, Ontario)

This ac electromagnetic device was observed at Falconbridge Nickel Mines, Ltd., Sudbury, Ontario, while inspecting two 1-1/8" 6 x 27 flattened-strand, hoist ropes at the Fecunis Mine, Shaft No. 2. The device is shown in Figures 21 and 22. The instrument was discussed at length with the manager of Rotesco and chief personnel of the Inspection Branch, Ontario Department of Mines and Northern Affairs, Toronto, Canada.

The impetus for development of this device came from the 1945 Paymaster Mine hoisting accident (16 dead). This accident was caused by a broken rope resulting from severe internal rope corrosion not detectable visually. This accident also led to a profound continuing effort directed toward general hoisting inspection, maintenance, and safety-device improvement.



FIGURE 21. ROTESCO ELECTROMAGNETIC DEVICE

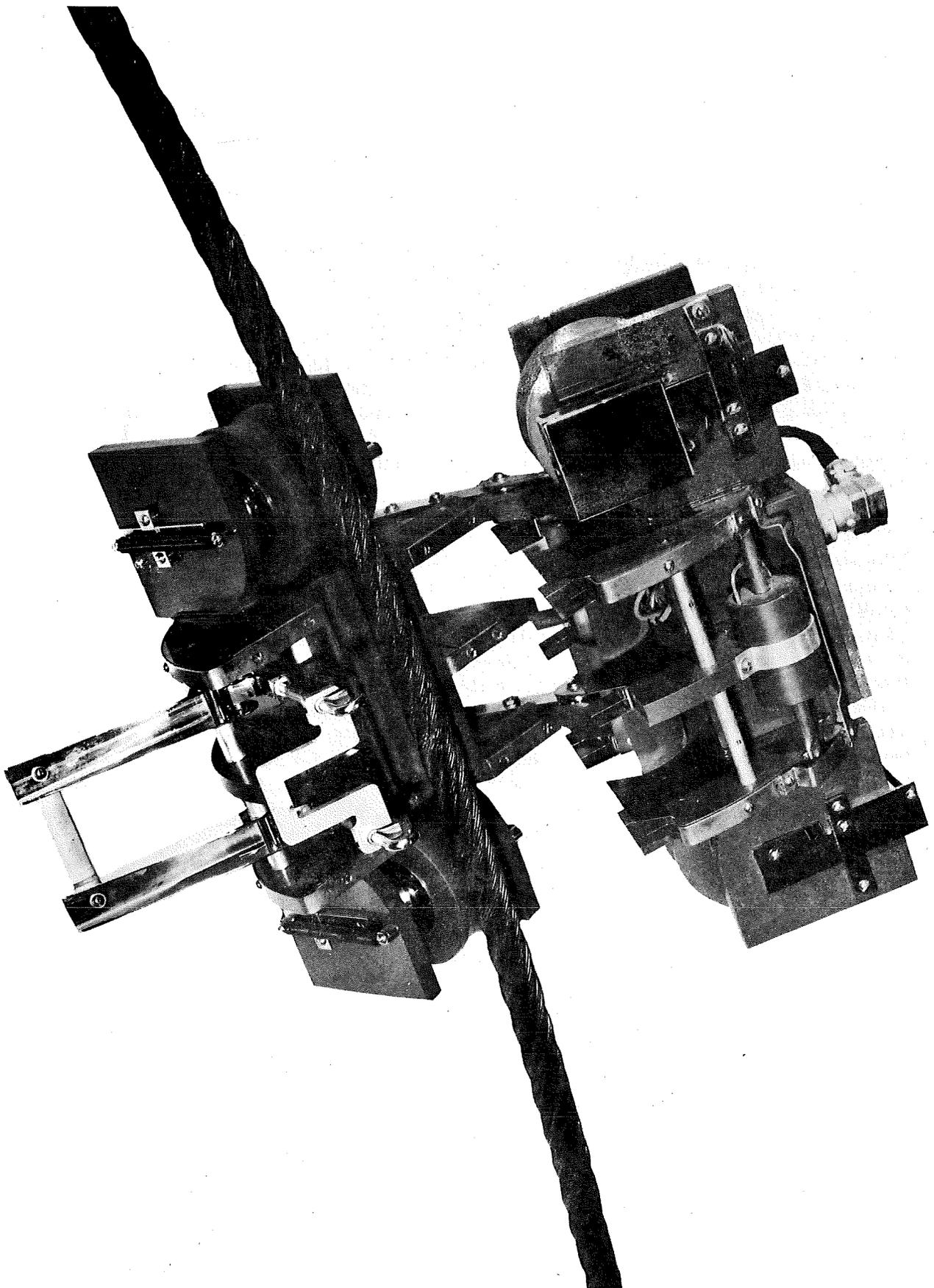


FIGURE 22. ROTESCO ELECTROMAGNETIC DEVICE DETECTING HEADS WITH ROPE IN PLACE

BATTELLE - COLUMBUS

The prototype of the current ac device, which uses either 30 or 80-cycle-per-second alternating current for primary excitation, was developed over a period of 10 to 12 years. The developmental effort involved comparing electromagnetic data with destructive laboratory tests of new and used rope. Diameter-reduction measurements were included.

In 1970, similar work began with locked-coil ropes using a 10-cycle-per-second excitation current in an effort to increase field penetration.

This developmental work is well documented. Hundreds of charts comparing the electromagnetic data with destructive tensile-test data, destructive torsional-wire-test data, rope diameter-reduction data, and rope-elongation data are available. Many of these charts were inspected by the Battelle program staff. All data determined from destructive tests on retired ropes are normalized to (divided by) like data obtained from samples of unused rope (a requirement of law in Ontario). All electromagnetic data from ropes in use up to retirement are normalized by like data obtained shortly after rope installation - that is, after the rope has had time to accommodate to use. Such normalized data can be directly read as a percent reduction in the rope tensile strength or cross-sectional area.

On the charts, the electromagnetic data are compared directly with destructive tensile-test data for the rope. Qualitatively, the correlation is very good. Tensile strength reductions of about 5 percent or greater are accompanied by reduction indications in the electromagnetic data. Such correlation is indicative of the primary sensitivity of ac devices to loss of metallic section. Quantitatively, the correlation is fair. An electromagnetic indication of 10 percent reduction in "strength" correlates anywhere from about 5 to 30 percent reduction in tensile strength measured destructively. Thus, if the electromagnetic device indicates a 10 percent reduction in strength, the chances are better than 50-50 (estimated from observations of charts) that the rope has lost at least 10 percent of its tensile strength and may have lost as much as 30 percent. Today, Ontario law requires rope replacement when a strength reduction of 10 percent is indicated by electromagnetic inspection. In Ontario, electromagnetic inspection is required every 4 months in addition to regular visual inspection. There are also replacement criteria other than that applicable to electromagnetic inspection (see section on Hoisting Laws and Regulations).

The Ontario Mines Inspection Branch personnel reported that, in 1958-1959, prior to requiring electromagnetic inspection, a hoist rope service life averaged about 15 months. In 1968-1969, 4 to 5 years after electromagnetic inspection was required, hoist rope service lives were averaging about 30 months. No direct rope failures are reported to have occurred since electromagnetic testing has been required. Ropes have been broken, however, as a result of hoist control-system failures. (Battelle project staff were 1 day late for one such accident - no injuries, minor equipment damage - apparently caused by a faulty valve-operating solenoid within the control system.)

No claim of sensitivity to wire breaks is made for the Rotesco ac device. As with other ac devices, however, experienced personnel have correctly identified surface wire breaks.

Originally, the Rotesco device was to have been purchased and evaluated as a part of this program. The above detailed discussion supports the conclusion that preliminary laboratory evaluation would not have produced anything new beyond that which is reported herein.

Capabilities and Limitations -  
General Comments

Instrumentation capabilities are commonly described in such terms as percent error, response time, parameter range, stability, and sensitivity. However, except for one characteristic of the MD-6 Magnetic Defectograph (0.2 percent sensitivity to rope cross-sectional area), no such data have been found in print for other dc or the ac devices available. If one were to form such information for the Rotesco ac device on the basis of its quantitative correlation with destructive tensile-test data, one would have to say that it has a full-scale error of 50 percent with a sensitivity on the order of 5 percent. This is poor accuracy from an instrumentation-accuracy standpoint, yet the earlier discussion of its correlation with test data leaves little doubt about its capability for indicating rope degradation.

Another difficulty in determining the capabilities and limitations of electromagnetic devices is that developmental efforts have been generally scattered, specific, and not well reported. In addition, several reports comparing existing devices do little but show the general lack of hard data on specific devices.

Capabilities and limitations cannot be determined in specific instances without the results of work of the kind carried out in Ontario. Relative capabilities and limitations of dc and ac devices cannot be realistically determined without similar efforts using destructive rope data common to all devices.

Generally, dc devices are most sensitive to outer-layer wire breaks and ac devices to cross-sectional losses. Devices using either method cannot "see" as far into the interior of the rope as desirable, particularly with locked-coil and IWRC constructions. There is some general disagreement about the effects of irregular rope magnetization due to the earth's magnetic field. Also, results are difficult to interpret.

The Rotesco ac device is backed up by destructive test data, but quantitatively accurate results cannot be obtained with the present machine. Furthermore, it should not be expected to detect broken wires; the extent to which this occurs is highly dependent upon operator skill and experience. Regrettably, even such meager definitive statements about other electromagnetic devices, including the MD-6 Magnetic Defectograph, cannot be made because no experimental data have been uncovered during this program to allow it.

Future Development of Electromagnetic Devices

Scattered through this discussion are indications of problems associated with electromagnetic devices. The biggest problems requiring development are (1) effecting field penetration to the center of the rope (if possible) and (2) sensing field changes due to rope defects in a manner allowing exact interpretation of the defects. Implicit in this statement is the possibility of using different techniques.

In Germany, considerable effort has gone into investigating excitation-and-sensing-coil configuration for dc devices, with some positive results. Rotesco is investigating lower ac excitation frequencies, with some indication of improved results with locked-coil ropes (increased field penetration). Other work with dc devices is directed toward

compiling data for specific known defects to aid interpretation of output charts. A few years ago, South African work included premagnetizing the rope before ac testing. Symes<sup>(77)</sup> mentions "new approaches", apparently yet untried, which might result in improved inspection techniques. What these efforts have achieved by now is unknown. Worldwide inquiries by Battelle have, as yet, produced nothing that was not known in early 1969, except in the case of the MD-6 and Rotesco devices.

Battelle is impressed with the field and laboratory developmental effort behind the current Rotesco ac device. Continuing developmental efforts with any dc or ac machine must sooner or later include such field-data and destructive-rope-data comparisons. This approach is necessary not only for confirming the capabilities of an electromagnetic device but also for illustrating its value and soundness to would-be users.

In general, ac methods or their equivalent, eddy current techniques, have been highly developed and successfully used in other industrial applications; considerable expertise exists in the United States. However, no U. S. rope work is known. Considerable basic expertise and experience with nondestructive inspection techniques also exists within Battelle although heretofore it has not dealt with electromagnetic inspection of wire ropes. As part of this program, a number of papers related to electromagnetic devices were given to these Battelle people for study and comment. The resulting report is included as Appendix H. The results of this brief interdisciplinary effort, though reflecting little wire rope experience, have value. The following is a direct quote from the Summary and Conclusions section of this report, edited where appropriate:

"Future development of these (ac and dc) techniques can proceed in several areas. Combining the magnetic-saturation technique (dc method) with the ac method should result in reduction of the ac method's sensitivity to variations in the magnetic characteristic of wire rope. This should reduce variations in (output) signals caused by magnetic permeability variations due to cyclic loading, (the) earth's magnetic field, and residual stresses. In addition, depth sensitivity would be increased, giving special advantages in the inspection of locked-coil ropes. In this technique, flaw conditions would be detected mostly by the eddy-current effect, (but) special problems may arise. For example, (it might be more difficult to detect differences) between cross-section loss and contact between wires (were magnetic saturation techniques used)."

"The use of multifrequency techniques, with or without the magnetic saturation technique, offers a means to increase the amount of information obtained from... electromagnetic inspection. More advanced development (of multifrequency techniques) could lead to the automatic interpretation of instrument output signals."

The multifrequency techniques relate to simultaneous excitation with more than one frequency. Presently, all known ac hoist-rope-inspection devices use a single frequency. Whereas a single frequency system can discriminate between two test variables, a two-frequency, multiparameter system can discriminate between four variables. The principles of this technique are described in a Battelle report.<sup>(48)</sup>

Combining dc and ac methods in a single device might combine the best of both. This appears to be behind the earlier mentioned South African work on premagnetization of the rope before ac testing. The multiparameter approach, however, appears unique.

The idea of automatic interpretation of output signals is of particular interest. The achievement of such capability is a necessary step toward acquiring instrumentation capable of indicating directly when to change a hoist rope - a worthy goal.

Symes reports that two approaches to use of computers in rope inspection were being explored in 1966. (Communication has produced no further information on this subject as yet.) One approach concerned the determination of optimum inspection procedures based upon rope construction, age, type of duty, location, and so forth. This could be an approach wherein all kinds of rope inspection data are computer analyzed to determine groups with common characteristics. This approach could require many inspection situations, each requiring specific inspection procedures. This is not particularly appealing but, nonetheless, it is a possible solution to current interpretation difficulties. The second approach that Symes mentions is "focusing attention on genuine anomalies on the (electromagnetic) record charts by comparing consecutive traces and eliminating unwanted noise". Although not clearly understood, this phrase suggests a number of possible techniques, e. g., discrimination between background and defect signals using Fourier-spectrum and Fourier-transform transient-analysis techniques. However, all descriptive discussions of these techniques are beyond the scope of this report.

#### Electromagnetic Inspection in the U. S. Coal Mining Industry

Several coal mines subscribe to the electromagnetic-inspection service offered by Rotesco, Ltd., Don Mills, Ontario, but it is evident from discussions that the idea is not highly regarded. This appears to result from a lack of knowledge of both the application of electromagnetic inspection and interpretation of the results. In one mine visited, inspection occurs at 6-month intervals. In this case, the hoist ropes are reported to last about a year. However, no electromagnetic inspection was made shortly after the rope was placed in service. Thus, the base against which rope deterioration is judged is lacking. The need for this base was either not mentioned initially or not fully understood. The electromagnetic inspection results submitted to this operator were studied. Although strip-chart copies were included there was no explanation of them. The accompanying letter did say that there were no problem areas in the rope.

It is very clear from this experience that electromagnetic inspection or, for that matter, any new inspection technique must be carefully presented and described until the idea is well understood. The users must become familiar with it and accustomed to its presence. Any lesser approach is likely to result in rejection.

A skip-hoist rope broke some 6 months prior to visiting another mine. It was reported that a month or so prior to the break the rope had been inspected with an electromagnetic device. Enough operational practice was seen to convince the project staff that there was an excellent chance that this rope parted because it was damaged, not because of excessive deterioration. On a subsequent visit to another mine in the area, the subject of electromagnetic inspection elicited critical statements about the aforementioned rope breaking shortly after electromagnetic inspection. After the individual was made aware of conditions at that mine, his criticism softened and the extent of his lack of knowledge of electromagnetic inspection became apparent. Many mine personnel visited had heard of electromagnetic inspection but could say little else. Many others visited had never heard of it at all.

The situation is little different with state inspection-agency officials. In the majority of cases, state personnel pay little attention to rope inspection and replacement activities because they are the mine operators' responsibility. One state official reported he knew of electromagnetic inspection being used at a salt mine in his state (also a coal-mining state) and that the records of these inspections were on file with his agency. Another state official reported he had heard about "the Canadian machine" but did not know if any companies (coal or otherwise) were using it in his state.

Faculty members from the schools of mines of several universities had little to offer on electromagnetic inspection beyond perhaps a knowledge of the existence of such devices and an indication that the idea was interesting.

Mention of electromagnetic rope inspection to wire rope manufacturers will evoke responses ranging from "no comment" through guarded acknowledgement of their existence and capabilities to outright rejection of the idea that any electromagnetic device has sufficient capabilities to be of value to the mining industry. One manufacturer reported that in-house studies showed that the Rotesco ac device gives results "quite compatible" with the results of destructive breaking-strength tests. This manufacturer also pointed out that the device is likely to show less loss of rope breaking strength than actual rope-strength tests, a point made earlier in the discussion of this device. This manufacturer summarized by indicating the device will not detect broken wires, particularly if the ends remain in their original position, but that it can detect loss of metallic area caused by wear and corrosion. He concluded with the hope that developmental work will continue in the direction of detecting loss of strength due to broken wires as well as wear and corrosion.

#### Potential Value of Electromagnetic Inspection for U. S. Coal Mining Industry

In Battelle's opinion, many mine ropes are discarded with no actual knowledge of their remaining strength and many appear to be capable of continued safe use. The use of present ac devices combined with actual strength tests of new and retired rope would allow a mine to build accurate case histories for its installations. This would provide a more accurate estimation of the strength remaining in its hoist ropes. Such knowledge would also provide a case for extending rope use where conditions permit, consistent with safety. Where conditions do not permit extended rope use, histories of strength degradation along the length of the rope could provide the knowledge necessary for mitigating or eliminating those conditions which degrade rope life.

If Ontario's experience is any indication, then, increased rope life consistent with greater safety through greater knowledge could be expected to follow the adoption of electromagnetic inspection in U. S. coal mines.

The economic benefits cannot be evaluated without knowledge of the relationship of rope costs to the total costs. There would seem to be an economic gain in retaining rope in service for as long as possible, providing that the means to do so costs no more than the potential savings.

Rope costs can be expected to gain in importance, because, as time goes on, hoisting depths in the coal industry are likely to increase. Also, the public concern with

the environmental problems created by strip mines may bring about more hoisting than is now the case.

It would be tragic if it were to require even one isolated hoist accident with 16 killed to awaken interest in improved wire rope practice in U. S. coal mines, as was the case in Ontario. Symes<sup>(77)</sup> reports that those countries in which electromagnetic inspection was generally accepted had had experience with accidents or near accidents due to rope failures. Unexpected hoist-rope failures have been learned of during this study. Several have occurred on skip/cage installations which, by chance only, were hoisting coal at the time.

MISCELLANEOUS CONSIDERATIONSSchools of Mines

Schools of mines of several universities were contacted during this program to determine if any wire rope research has been done and to determine what instruction is given the students on hoisting and hoist ropes. Discussions indicate that little or no research has been done. Students are instructed in hoisting matters with such references as Peele Handbook, manufacturers' catalogs, and Bureau of Mines circulars. Little or no treatment of hoisting and hoist-rope problems appears to be given beyond their mention.

Peele's Handbook

The present edition of the Mining Engineers' Handbook<sup>(109)</sup> – commonly referred to as Peele's Handbook – was published in 1941. A new edition of this handbook is currently being prepared.

The hoist manufacturer who is revising the material on hoisting and hoist ropes indicated that most of the rope data to be presented will be obtained from manufacturers' catalogs. It is possible, thus, that few new ideas on optimizing hoist-rope life will be presented. On the other hand, this manufacturer also indicated that he considered the Ontario Department of Mines his ultimate authority on hoisting and hoist-rope practice.

Sheave and Drum Groove Hardness Studies

There continues to be some disagreement over the matter of sheave-groove hardness effects on wire rope life. Most wire rope manufacturers' handbooks suggest maximum bearing pressures for sheave or drum grooves for a given material. These limits have been established to eliminate the occurrence of rope-fluted grooves which abrade the next rope installed. It could be concluded, then, that it is desirable to have the sheaves as hard as realistically possible to minimize abrasive wear as well. One study uncovered supports this general conclusion. <sup>(22)</sup>

There are, however, contradictory viewpoints. Drucker and Tachau<sup>(20)</sup>, reporting on previous works done by Martin Abraham<sup>(24)</sup> and W. A. Scoble<sup>(25)</sup>, indicate that several investigations have shown softer sheave grooves to provide longer life. The Acushnet Process Company of New Bedford, Massachusetts, has done some developmental work with elastomeric sheave liners and it reports them to significantly extend wire rope life. <sup>(27)</sup>

Further investigation and possibly an experimental program might shed some light on these conflicting positions. Developments toward the use of sheave and drum inserts to provide an easily renewable groove configuration are desirable, and further research into the effect of sheave hardness would be of value.

Hoist-Rope Failure Analysis

Examination of wire rope failures by experienced wire rope engineers will usually determine the exact cause of degradation. Many wire rope manufacturers can perform this function, although some mines visited have reported that they seldom hear the results of analyses made on submitted rope segments.

About 1 week prior to Battelle's visit to one mine, the operator replaced a skip/cage hoist rope because of a broken strand near the conveyance end. The rope had not yet been discarded and had been partially protected by the tippie from rain.

A 44-inch-long section, which included the broken strand, was brought back to Battelle for laboratory analysis of the break. (More samples would have been collected had other recently failed ropes been encountered. It is not practical to study broken ropes that have lain in a field for several weeks or months.)

The hoist rope had been attached to the skip/cage combination with a thimble and clips. Using the thimble-induced kink as a guide, the broken strand was judged to have been some 3 to 3-1/2 feet above the turned-back end of the rope, i. e., some 3-1/2 to 4 feet above the uppermost clip.

The rope construction is 1-1/2-inch-diameter, 6 x 25 filler wire, right-regular lay, Fiber Core. Other data are as follows:

Rope lay length	- 8 inches
Strand lay length	- 3.28 inches
Strand diameter	- 0.406 inch
Outer layer wire diameter	- 0.0802 inch
Inner layer wire diameter	- 0.0858 inch
Filler wire diameter	- 0.031 inch.

The rope specimen is shown (Figure 23) after brush cleaning of the surface in the laboratory. Figure 24 is a close-up of the break area. The strands were numbered sequentially around the rope so that the relative locations of the wires would still be known after rope disassembly. Figure 25 shows the disassembled rope in the break area, and Figures 26 through 30 show close-ups of those strands with broken wires in the area of the broken strand. One strand, called No. 4, is not shown since it had no broken wires in the strand-break area. Figures 31 and 32 show examples of interstrand wire notching at and away from the break area. This type of wire distortion is common in new and used rope and in this case there is no indication that this notching contributed to rope failure.

The general condition of the rope in the specimen was good. On the outer surface of the rope and in the area where the wire contacts the core there was minor corrosion. There were some traces of corrosion within the strands. Again, all this corrosion was very light. The core was in good condition throughout the sample except for some evidence of drying in the failure area.

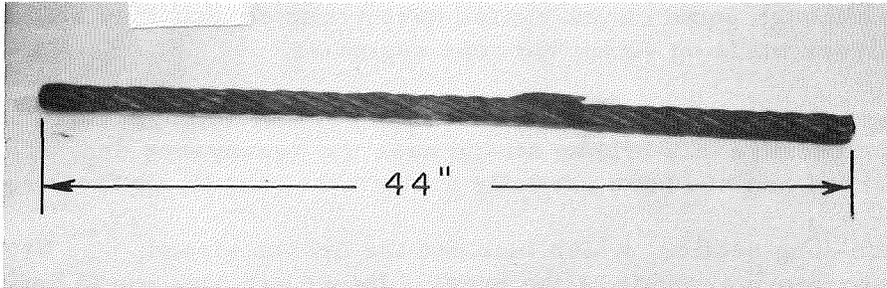


FIGURE 23. FAILED SKIP-HOIST ROPE SPECIMEN

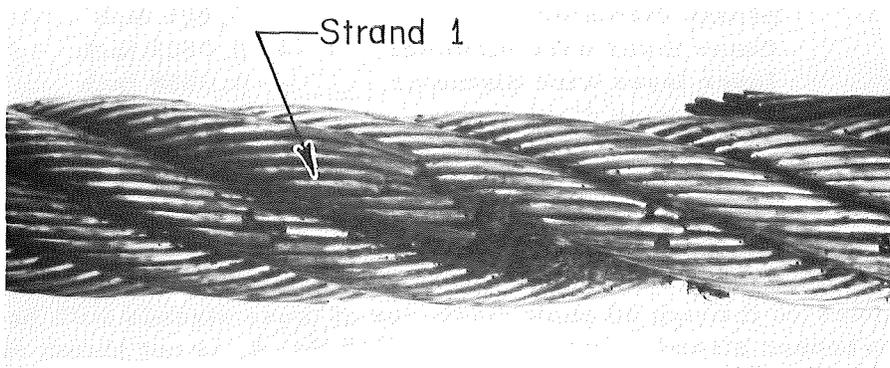


FIGURE 24. CLOSE-UP OF FAILURE AREA

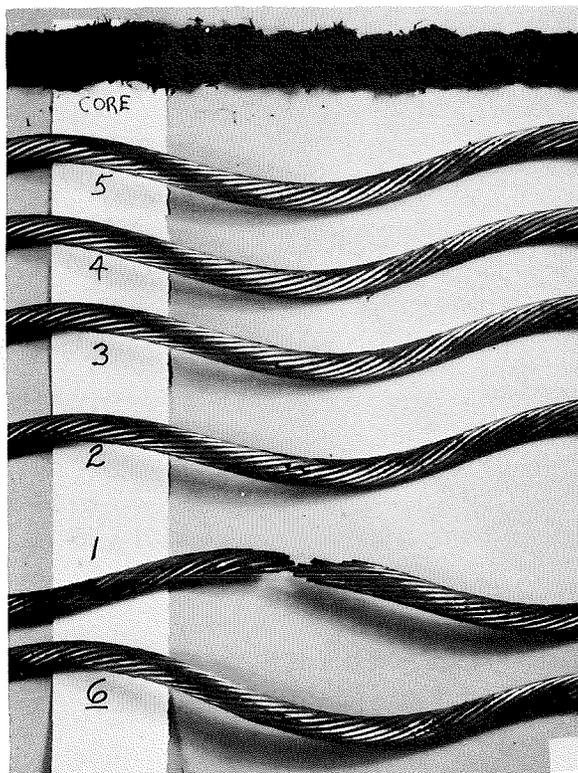


FIGURE 25. SKIP-HOIST ROPE INDIVIDUAL STRANDS AND CORE IN FAILURE AREA

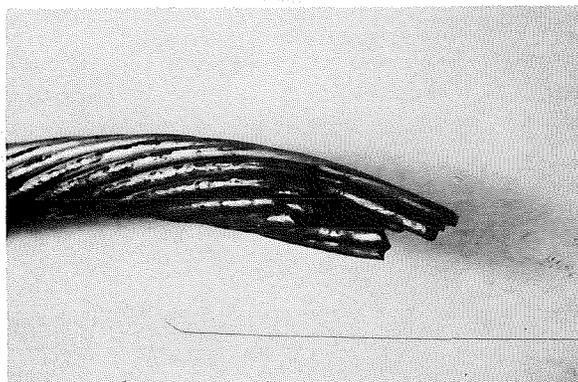


FIGURE 26. FAILED WIRES IN STRAND 1 (BROKEN STRAND)

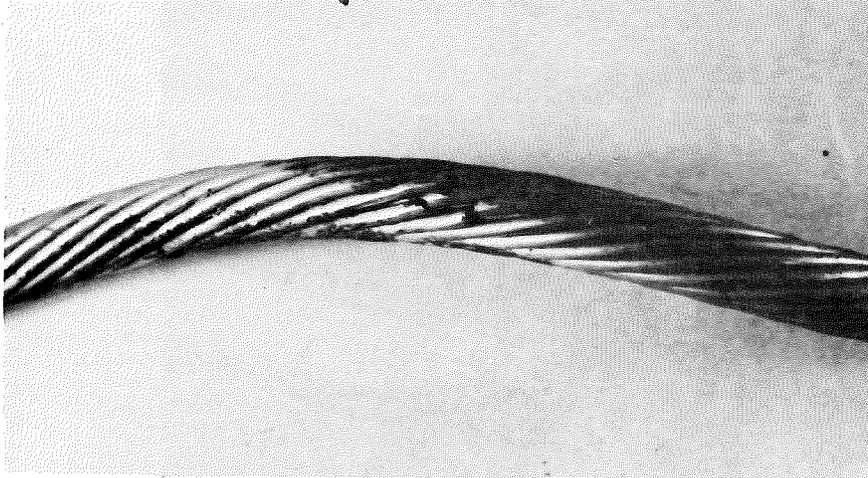


FIGURE 27. FAILED WIRES IN STRAND 2

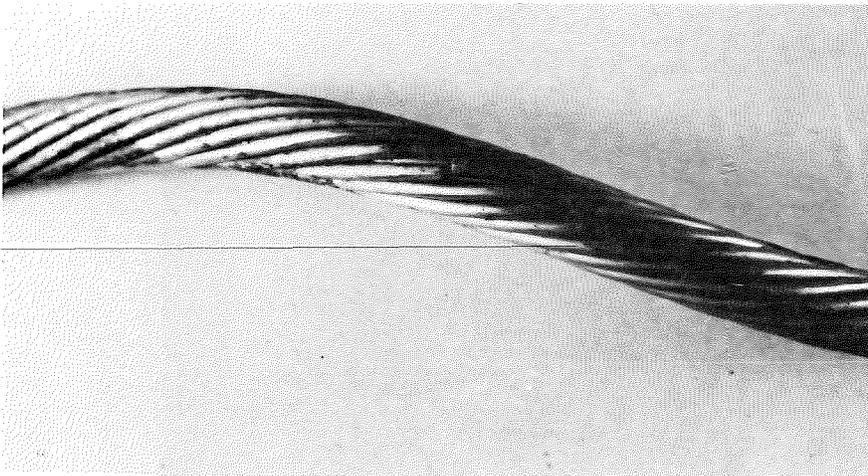


FIGURE 28. FAILED WIRE IN STRAND 3

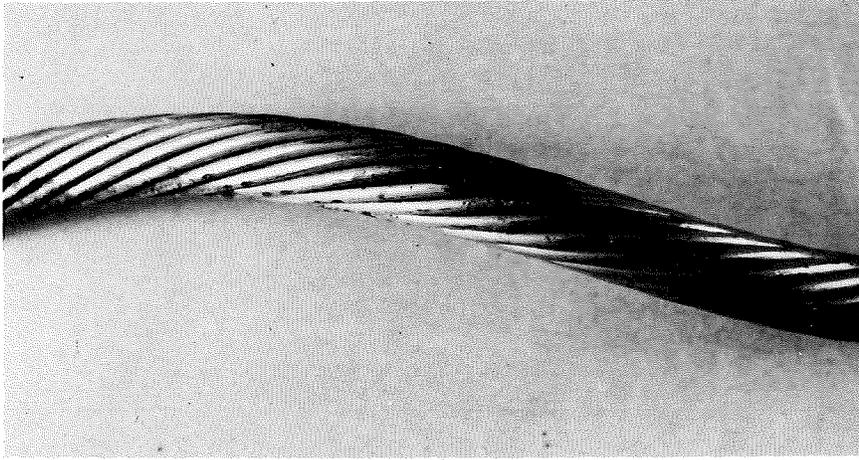


FIGURE 29. FAILED WIRE IN STRAND 5

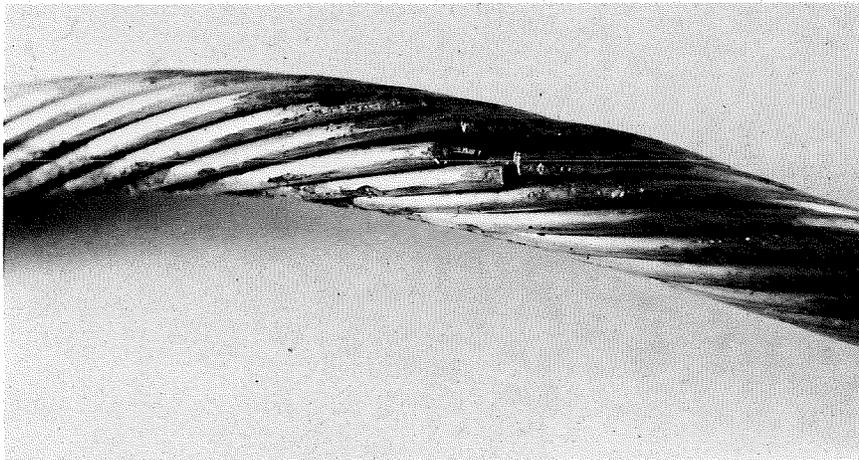


FIGURE 30. FAILED WIRES IN STRAND 6

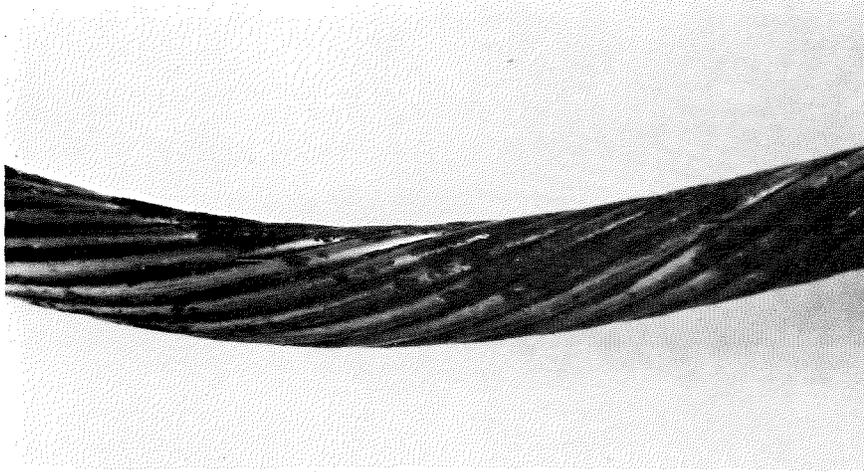


FIGURE 31. TYPICAL INTERSTRAND WIRE NOTCHES  
NEAR FAILURE AREA

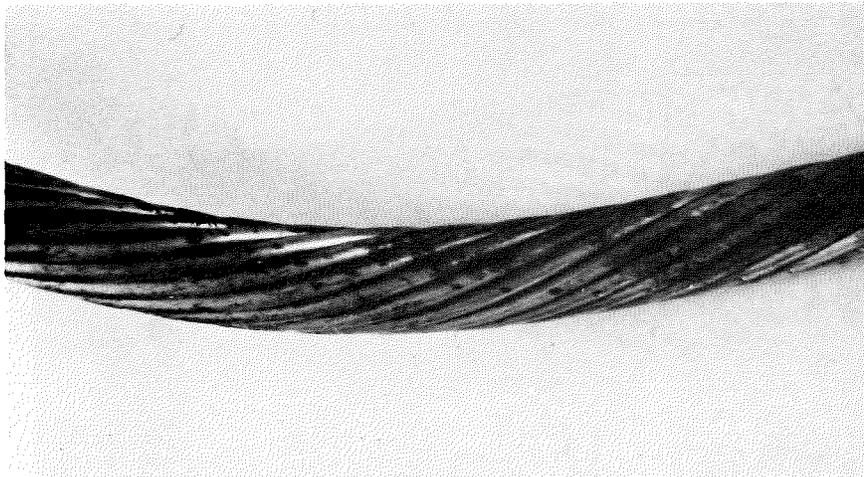


FIGURE 32. TYPICAL INTERSTRAND WIRE NOTCHES  
AWAY FROM FAILURE AREA

Crown wires in the area of the failed strand showed considerable abrasion, scoring, and gouging. (The crown of the rope is the outermost surface area at any point.)

Examination of the wires in the broken strand showed that almost all failed in fatigue. Two outside strand wires and a few filler wires show necking and cup-and-cone ends characteristic of tensile failure. Examination also shows that some of the fatigue cracks initiated at abrasion and gouge locations. Figure 33 shows a typical fatigue failure from crack-initiation occurring where the wire was abraded on the crown. Figure 34 shows a typical failure initiating where the wire was gouged at its crown. Figure 35 shows a partially failed wire and the propagation of the fatigue crack which initiated at a crown gouge.

The particular mode of fatigue failure exhibited by the sample is characteristic of wire rope subjected to low tensile loads and repeated bending or flexing.

Hoist-rope tensile loads are characteristically low with respect to the breaking strength. Furthermore, local rope bending is induced at the ends of any vibrating length of rope, with the conveyance end being the worst location since it is fixed. At the head-sheave end, the rope moves and the local bending occurs at different locations on the rope.

The circumstance of this particular failure (the gouges) would indicate that something had been attached to the rope at that point (3 to 3-1/2 feet above the last thimble clip) or that the rope had been otherwise mistreated somehow at that point. The operator was recontacted by phone to verify the bridle clamp location; it is reported to be clamped around both the "live" and "dead" portion of the rope, with three thimble clips above it and three thimble clips below it; nothing was attached to the rope above the last thimble clip.

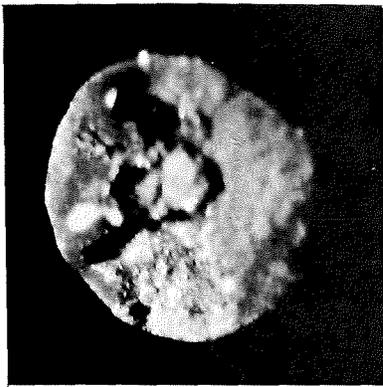
The number of failed wires, by strand and location within the strand, is given in Table 7.

TABLE 7. LOCATION OF WIRE BREAKS IN FAILED HOIST ROPE

Strand Number	Number of Failed Wires		
	Outer Layer	Inner Layer	Filler Wire
1	12	7	6
2	3	0	0
3	1	0	0
4	1(a)	0	0
5	1	0	0
6	2(b)	1	1
Total	20	8	7

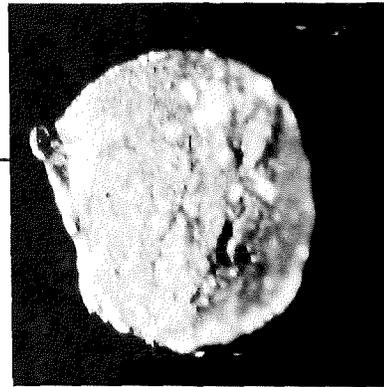
(a) Failed wire remote from main failure area.

(b) Also containing one outer wire with crack approximately 0.040-inch deep terminating in longitudinal crack.



20X

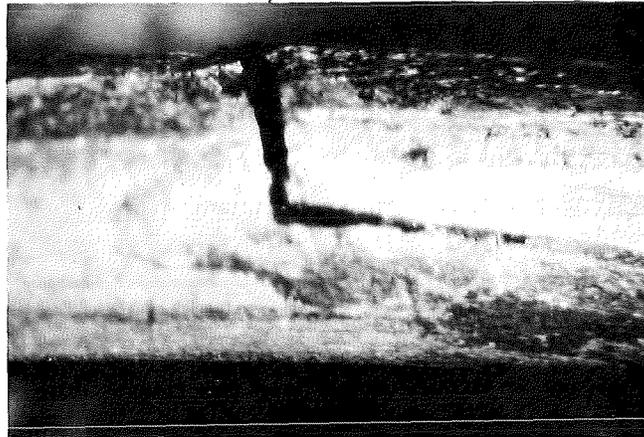
FIGURE 33. TYPICAL OUTER WIRE FATIGUE FAILURE WITH CRACK INITIATION AT ABRASION



20X

FIGURE 34. TYPICAL OUTER WIRE FATIGUE FAILURE WITH CRACK INITIATION AT GOUGE

Crack initiation site



20X

FIGURE 35. PARTIALLY FAILED OUTER WIRE WITH FATIGUE CRACK INITIATING AT CROWN AND DISPLAYING A LONGITUDINAL CRACK

The distribution of broken wires in all strands except the broken one (No. 1) and the generally good condition of the rope otherwise indicate that the rope failure was generally progressing from the outside toward the center. As such, a visual inspection should have detected trouble before complete strand failure.

Whatever circumstances caused the gouging and abrading of the rope above the last thimble clip, the broken strand at that location is evidence to support

- (1) The need for care of ropes
- (2) The need to carefully inspect rope near fixed ends
- (3) The value of periodic reattachment to the conveyance.

Periodic reattachment was not practiced at this particular mine prior to this strand break (there had been others earlier) and the value of this practice was stressed during the visit. During recontact with the operator to verify the bridle-clamp position, the results of the above mentioned investigation of the strand break were reported and discussed. It was also learned that the ropes on the hoist involved, which now are almost 6 months old, are shortly to be cut off and reattached at the conveyance end. At this installation, the hoist drums carry a single rope layer on helical grooving. Since conveyance-end cutoff will also result in rope redistribution on the drum, rope life should be improved at both ends.

#### Wire-Rope Testing Facilities

The utility of wire rope strength data obtained from destructive tensile tests has been discussed in terms of building rope-performance histories for use in selecting new rope and for use in determining quantitative retirement criteria. Such data are also needed if nondestructive electromagnetic inspection devices are to be further developed, since the destructive data form the base against which developmental electromagnetic results would be compared.

Going a step further, it appears that there is a lack of bend-over-sheave fatigue data for the range of rope and sheave diameters encountered in shaft and slope hoisting. Such data would significantly contribute to the goal of being able to relate the number of broken wires to remaining strength.

Similarly, rope-termination devices, which are currently rated in terms of their holding ability as a percentage of rope-breaking strength determined from tensile tests, are a point of fatigue damage in the rope. They can be evaluated by tensile-fatigue testing.

Since it may be desirable to carry out some of the studies suggested in this report, the following listings indicate the availability of the types of experimental equipment that would be needed. The types of testing possible include tensile, tensile-fatigue, vibration, bend-over-sheave, impact, and abrasion tests.

This list represents the facilities currently known to Battelle but does not include all of the companies that might have special-purpose rope-testing equipment.

Much of this information has been obtained through references included in various technical papers, company literature, and wire rope specifications. Unfortunately, in some cases the load capacity or physical size of the testing equipment is not known. Where possible, the details of the testing-machine capabilities are included.

### Tensile Testing Facilities

The following companies are capable of performing tensile tests on wire and wire rope. In addition to the wire rope manufacturers listed below, most of the other major manufacturers of wire rope are capable of performing tensile testing for the purpose of evaluating the breaking strength and elongation characteristics of their own products:

- (1) American Chain & Cable Co., Inc.,  
American Cable Division, Wilkes-Barre, Pennsylvania  
Hazard Wire Rope Division, Houston, Texas
- (2) Armour Institute of Technology, Chicago, Illinois
- (3) Bethlehem Steel Company, Williamsport, Division,  
Williamsport, Pennsylvania
- (4) Catholic University of America, Washington, D. C.
- (5) Haller Testing Laboratories, Inc., New York, New York
- (6) Hanks, Abbott A., Inc., San Francisco, California
- (7) Hunt Company, Robert W., Chicago, Illinois
- (8) Jones and Laughlin Steel Corp., Wire Rope Division,  
Muncy, Pennsylvania
- (9) Kansas City Testing Laboratory, Kansas City, Missouri
- (10) Los Angeles Testing Laboratory, Los Angeles, California
- (11) Macwhyte Company, Kenosha, Wisconsin
- (12) Patzig Testing Laboratories, Des Moines, Iowa
- (13) Pittsburgh Testing Laboratory, Pittsburgh, Pennsylvania,  
and San Francisco, California
- (14) Rice University, Houston, Texas
- (15) Rochester Ropes, Inc., Culpeper, Virginia
- (16) Sheffield Division, Armco Steel Corporation,  
Kansas City, Missouri
- (17) Shilstone Testing Laboratory, Houston, Texas

- (18) Smith-Emery Company, Los Angeles, California
- (19) Southwestern Laboratories, Houston, Texas
- (20) Steel Division, Armco Steel Corporation, Kansas City, Missouri
- (21) Tour & Company, Inc., Sam, New York, New York
- (22) Twining Laboratories, The, Fresno, California
- (23) Wire Rope Corporation of America, St. Joseph, Missouri.

### Tensile, Fatigue, and Other Testing Facilities

The organizations below have rope-testing capabilities in addition to or other than tensile testing:

- (1) Lehigh University, Fritz Engineering Laboratory  
Bethlehem, Pennsylvania

Tensile	5,000,000-pound capacity
Tensile fatigue	220,000-pound capacity 250 cycles per minute

- (2) Alcoa Electrical Conductor Laboratory  
Massena, New York

Vibration: Testing of overhead electrical conductors to evaluate fatigue performance at support hardware

20,000-pound capacity 120-foot specimen length	13 machines
20,000-pound capacity 50-foot specimen length	4 machines

- (3) Performed Line Products, Cleveland, Ohio

Tensile	600,000-pound capacity, 90-foot specimen length 50,000-pound capacity, 60-foot specimen length
Tensile fatigue	50,000-pound capacity, 60-foot specimen length 50,000-pound drop-weight impact-testing machine impact-fatigue machine
Vibration	Testing of overhead electrical conductors
Bend-over-sheave	50,000-pound capacity, 60-inch maximum sheave diameter, various rope wrap angles to 180 degrees
Creep testing	12,000-pound capacity, 11-foot specimen length

- (4) University of Alabama, Bureau of Engineering Research
- Bend-over-sheave 1/2-inch wire rope, 9-inch diameter sheaves,  
single-sheave bending, three-sheave reverse  
bending
- (5) Hackensack Cable Corporation, Hackensack, New Jersey
- Bend-over-sheave Aircraft control cable tests  
1/4-inch rope  
2-1/2-inch diameter sheaves
- (6) Anaconda Wire and Cable Company, Marion, Indiana
- Bend-over-sheave  
Abrasion tests on power cables  
for mine cars  
Tensile fatigue
- (7) Naval Research and Development Laboratory  
Annapolis, Maryland
- Bend-over-sheave 3/4-inch diameter rope  
15-inch diameter sheaves  
single-sheave bending  
three-sheave reverse bending
- (8) Naval Ship Research and Development Center  
Carderock, Maryland
- Tensile fatigue 35-foot specimen length
- (9) Naval Air Engineering Center  
Philadelphia, Pennsylvania
- Bend-over-sheaves 150,000-pound capacity  
33-inch diameter sheaves  
single-sheave bending  
three-sheave two-pane bending
- Tensile At least 250,000-pound capacity
- Terminal bending Evaluation of wire-rope fatigue at  
swaged terminals, 1-1/2-inch wire rope
- (10) United States Steel Corporation, Applied Research Laboratory  
Monroeville, Pennsylvania
- Tensile-fatigue About 1-1/2-inch wire rope
- Bend-over-sheaves About 3/4-inch wire rope  
About 12-inch sheaves

- (11) National Bureau of Standards, Gaithersburgh, Maryland  
Vibration tests of overhead power cables
- (12) Monsanto Research Corporation, Dayton, Ohio  
Tensile 30,000-pound capacity
- (13) Union Wire Rope, Sheffield Division, Armco Steel Corporation  
Impact fatigue Used for evaluating boom support ropes of earth moving equipment
- (14) Bethlehem Steel Corporation, Homer Research Laboratories  
Bethlehem, Pennsylvania  
Tensile-fatigue About 1/2-inch wire rope
- (15) Battelle Memorial Institute, Long Beach Ocean-Engineering Facility  
Long Beach, California

Two-Sheave Fatigue Machine (Figure 36)

Maximum rope tensile load	250,000 pounds
Maximum stroke during cycling	5-1/2 feet
Maximum stroking speed	50 feet/minute
Sheave size	24- to 40-inch diameter.

This machine was designed for and is owned by the Naval Air Engineering Center, Philadelphia, Pennsylvania.

Small Multipurpose Fatigue Machine (Figure 37)

Maximum rope tensile load	25,000 pounds
Maximum stroke during cycling	14 feet
Maximum stroking speed	150 feet/minute
Sheave size	4- to 28-inch diameter.

The modes of operation of this machine include simple two-sheave bending, six-sheave reverse bending, and miscellaneous bending configurations.

Large Multipurpose Fatigue Machine. The largest wire rope fatigue machine in the Long Beach Laboratory or in the United States is shown in Figure 38.

Maximum rope tensile load	70,000 pounds
Maximum stroke during cycling	15 feet
Maximum stroking speed	150 feet/minute
Sheave size	15- to 120-inch diameter.

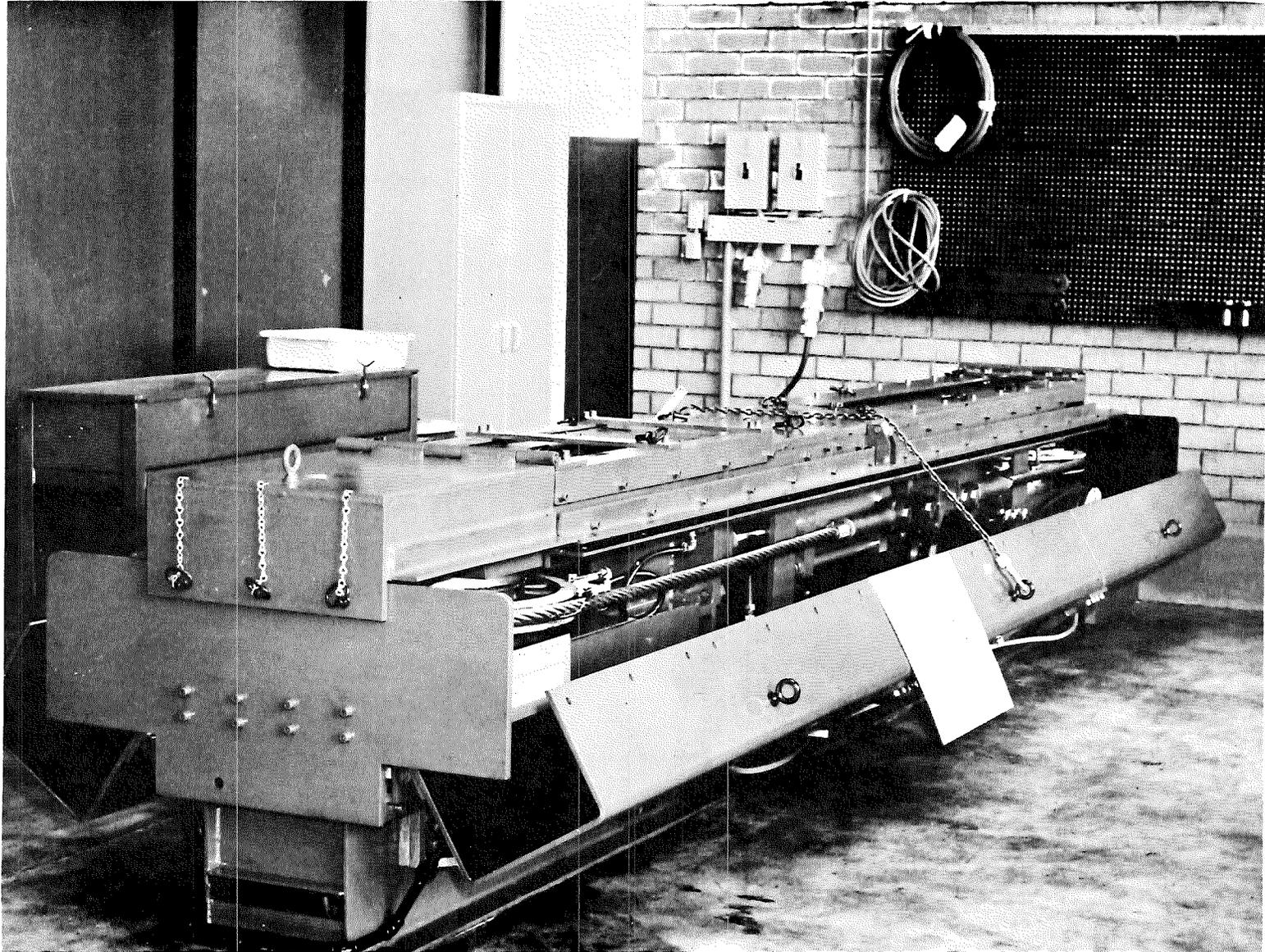


FIGURE 36. TWO-SHEAVE WIRE-ROPE FATIGUE-EVALUATION MACHINE

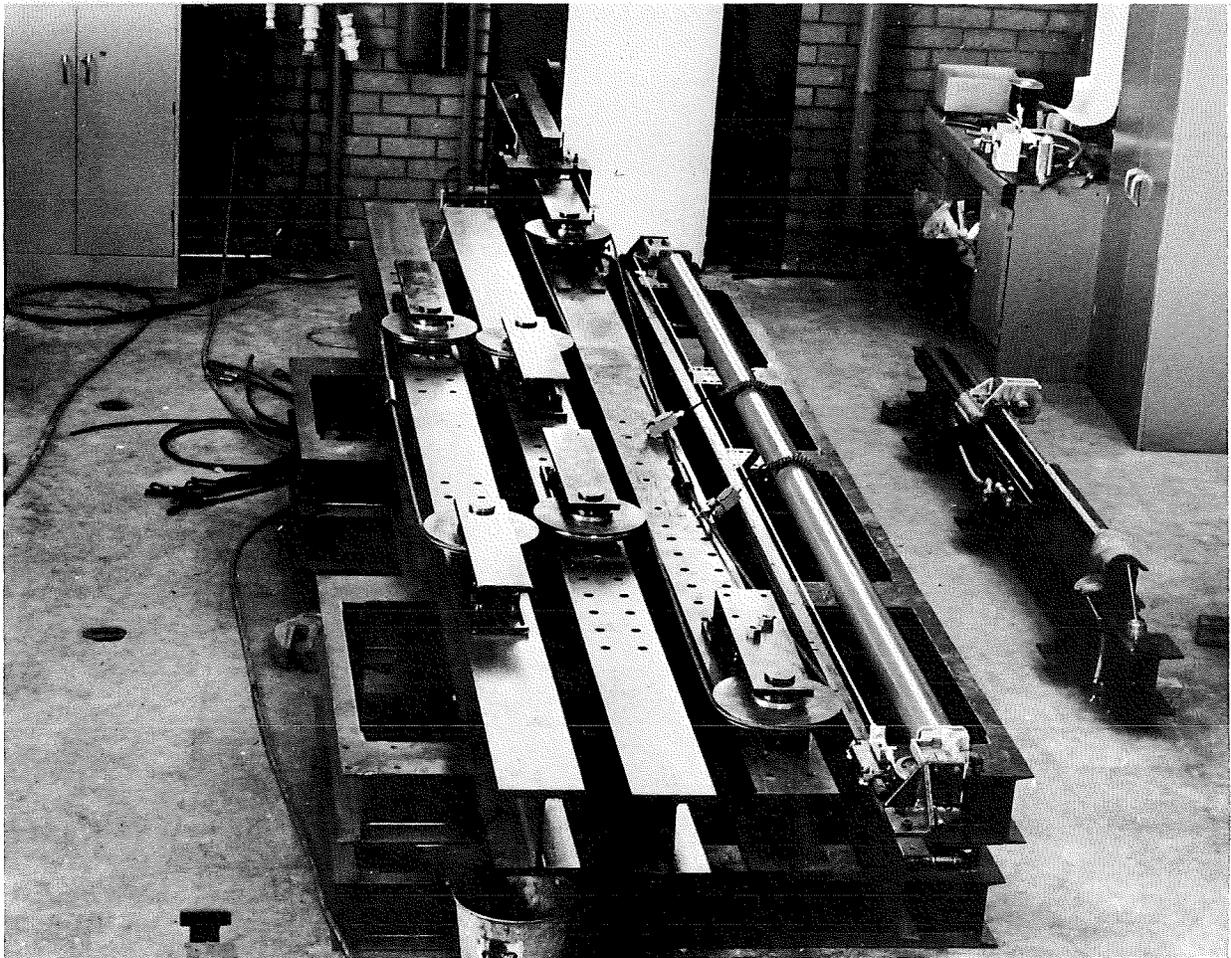


FIGURE 37. SMALL MULTIPURPOSE FATIGUE MACHINE

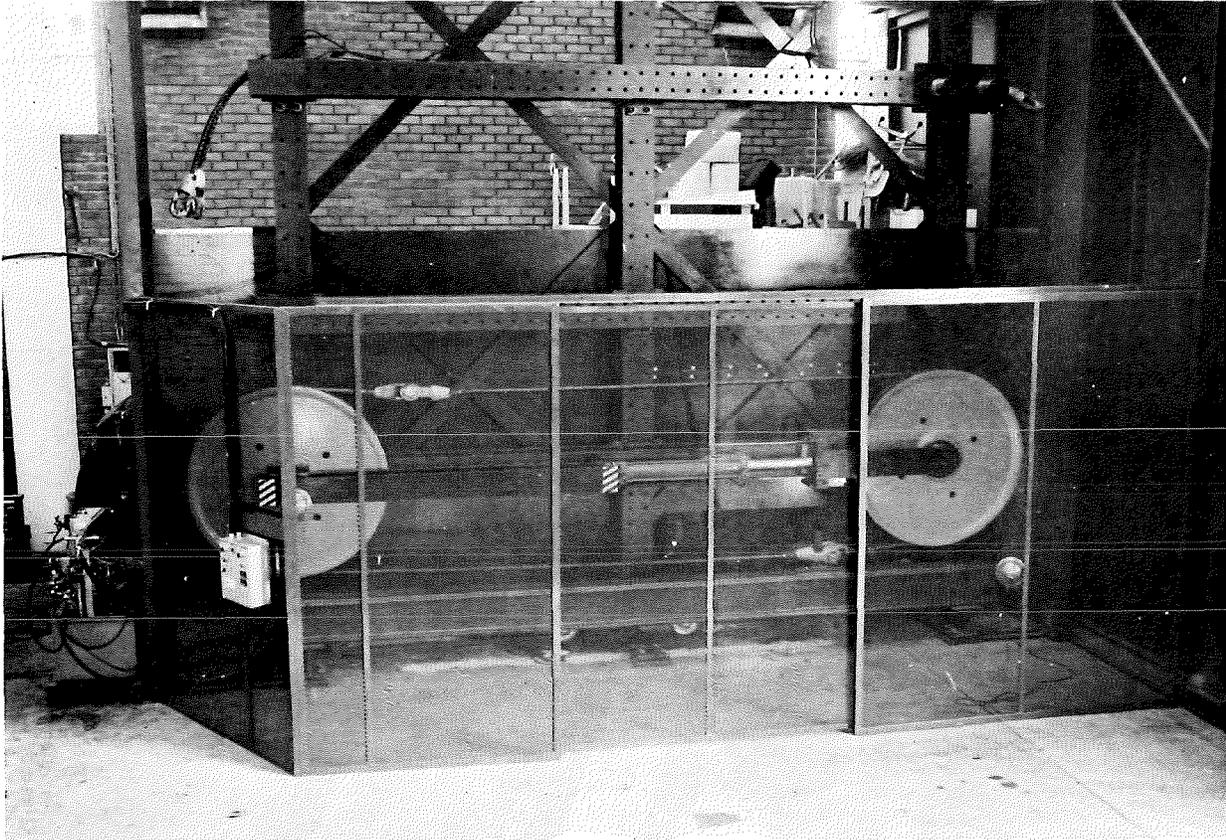


FIGURE 38. LARGE MULTIPURPOSE FATIGUE MACHINE

The modes of operation of this machine are similar to those of the smaller multipurpose fatigue machine.

This machine, constructed on a modular basis, can be relatively easily increased in size, thereby increasing stroke and sheave-size capacities.

#### Single-Wire Fatigue Machine (Figure 39)

Tensile load	3,000 pounds
Compressive load	3,500 pounds
Maximum flexural displacement	2-1/2 inches
Maximum flexural cycling	5 cycles/second.

This machine is designed to duplicate the tensile, flexural, and compressible loads experienced by a wire in a wire rope under load.

Wire Torsion Machine. This simple machine (Figure 40) is used to evaluate the ductility of wire material. Specimens are preloaded in tension and twisted to failure - the number of turns at failure providing an indication of material ductility.

Wire-Rope Impact Apparatus. This machine (Figure 41) is used to conduct transverse impact tests on rope specimens and has been used to simulate hook impact on aircraft arresting-gear cable. Specimens are placed across the bed and the shoe shot against it with the small attached cannon. Impact velocities of 150 knots have been achieved. The dynamics of the rope are observed with high-speed cameras.

Tensile and Tensile-Fatigue Machine. Soon to be fabricated is a high-capacity machine capable of conducting either tensile or tensile-fatigue experiments. As presently planned this machine will accommodate wire-rope specimens up to 60 feet in length and will permit testing with tensile loads up to 800,000 pounds. The machine will be constructed to allow testing either straight socketed ropes or ropes wrapped over sheaves.

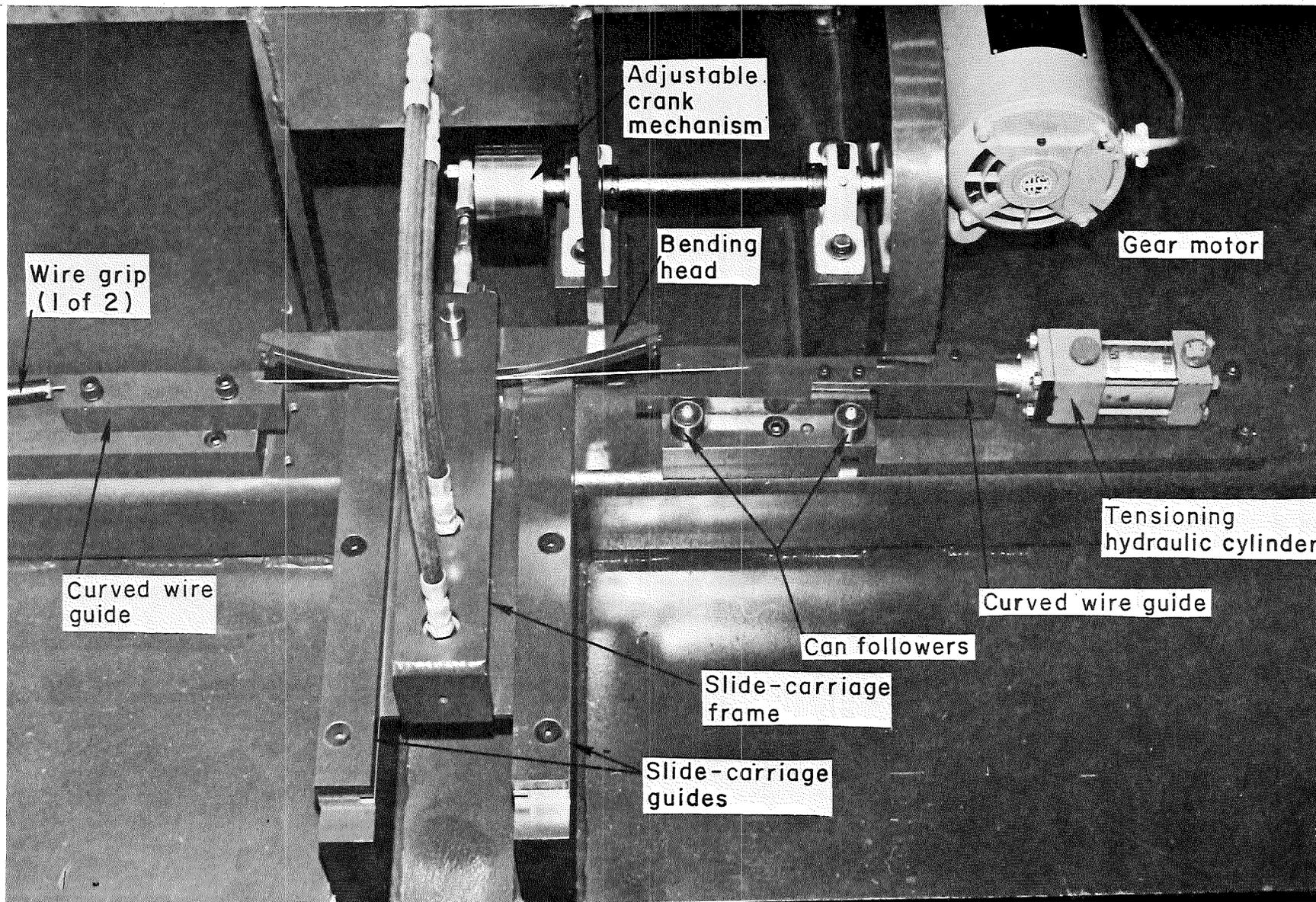


FIGURE 39. SINGLE-WIRE NOTCH-FATIGUE MACHINE DURING FABRICATION

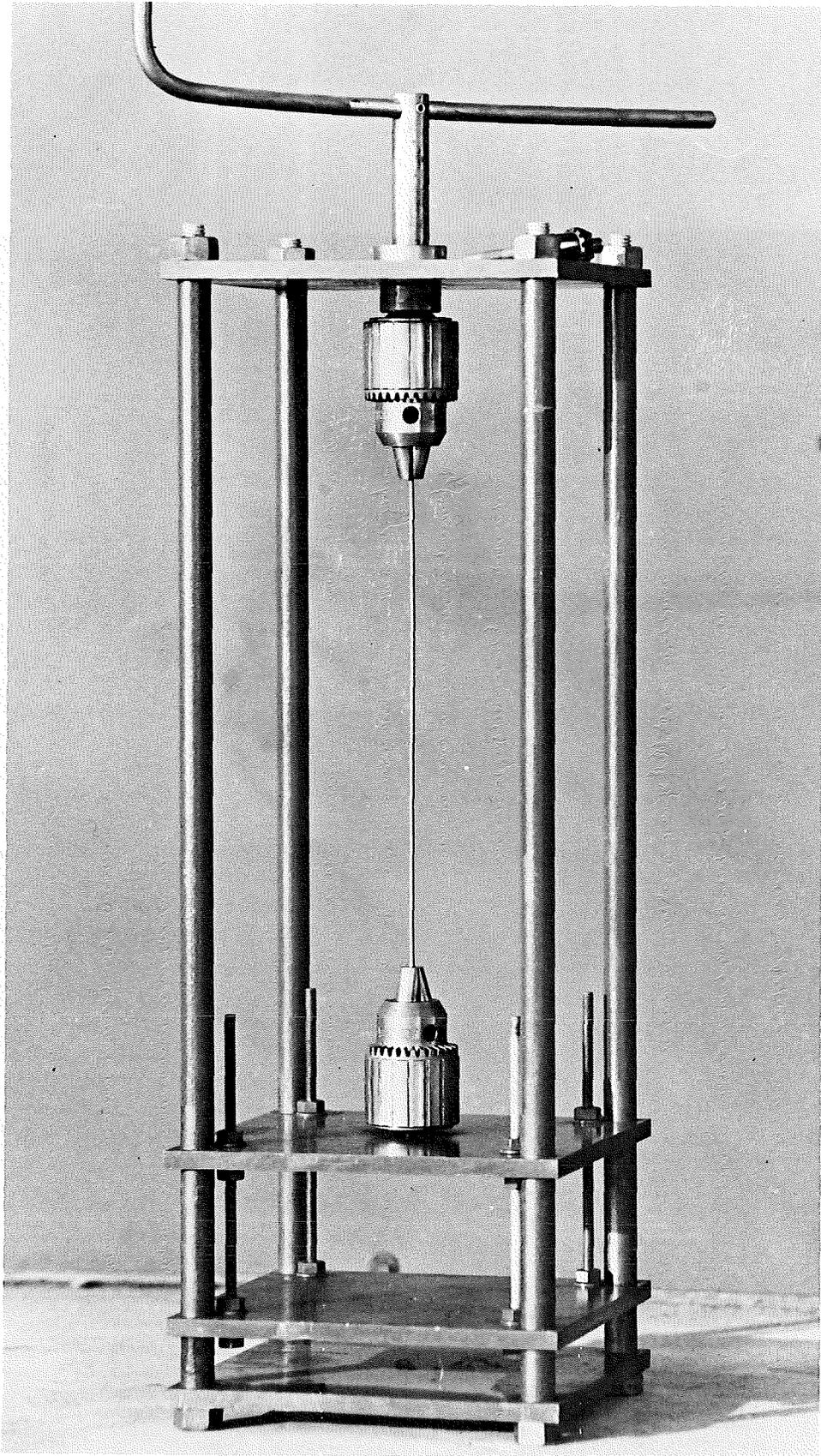


FIGURE 40. WIRE TORSION MACHINE  
BATTELLE - COLUMBUS



FIGURE 41. WIRE-ROPE TRANSVERSE-IMPACT APPARATUS

DETAILED DISCUSSION OF RESULTS -  
NONHOISTING APPLICATIONS OF WIRE ROPE

DETAILED DISCUSSION OF RESULTS -  
NONHOISTING APPLICATIONS OF WIRE ROPE

GENERAL USES, SERVICE CONDITIONS AND  
REQUIREMENTS, AND PRACTICES

Other than hoisting in vertical and inclined shafts, important uses for wire rope associated with underground coal mining which have been observed or identified in this program are described in Table 8.

Some of the surface equipment listed is found at tipples and preparation plants and applies to coal mining in general whether it be by deep, auger, or strip methods.

These rope applications fall into five general categories in accord with their function:

- (1) Winching: ropes wound on drums or capstans and reeved through one or more sheaves; generally long lengths and larger sizes; used to move loads.
- (2) Actuation: ropes fixed at both ends, reeved through one or more sheaves; generally short lengths and smaller sizes; commonly, the motion of a sheave causes motion of one end of rope, moving that to which the rope is attached.
- (3) Fixed Rigging: ropes fixed both ends, no sheaves, no general motion except for vibration; generally great lengths; used for supporting, staying, or suspending loads.
- (4) Slings: characterized best as being flexible load-carrying couplings which generally include very sharp bends; generally short lengths and smaller sizes.
- (5) Track ropes: generally fixed at both ends, usually no reeving through sheaves and no motion, except vibration; generally very long and of locked, or semilocked coil construction (smooth surfaces); function as tracks for wheeled loads.

The ropes in these applications will generally range in diameter from 1/2 inch to 1-1/2 inches; their constructions will include practically all available types. (Consult Appendix O for rope terminology and typical construction illustrations.) The service conditions vary widely but include conditions which are very severe and harmful to the rope. In these severe instances little can be done practically to improve conditions.

On these ropes there is little or no maintenance, little or no inspection, and it is not uncommon to find the ropes being replaced only after they break in two. This is indicative of the general attitudes of the users, which stems in part from the severe conditions. Furthermore, in some cases the ropes are considered to be entirely expendable and are treated accordingly. In some cases, however, these applications involve potential safety hazards.

TABLE 8. IMPORTANT NONHOISTING USES OF ROPE ASSOCIATED WITH UNDERGROUND COAL MINES

Equipment	Location <sup>(a)</sup>	Rope(s)	Function
Aerial Tramways	S	Track Haul and tail	Load support Load hauling
Barge Spotters	S	Haul and tail (Tag line)	Barge hauling (Connection between barge and haulage ropes)
Car Spotters or Pullers	S	Haul and tail	Move RR car on level or nearly level
Car Hoist Retarders	S	Haul	Move RR cars on grades
Car Hoist Retarders	UG	Haul	Move mine cars on grades
Conveyors, Belt	UG	Horizontal support stringers Belt tensioner	Carries components in roof attached systems Connects force supply to tension roller
Conveyors, Retarding	S	Retarding	Carries buttons or disks for controlling flow of coal from a higher to a lower level
Hand Ropes ("ski tows")	UG	Light haulage	Assist men walking slopes
Loading Booms	S	Actuator ropes	Connects boom and counterweight and allows positioning through a small winch or hoist
Loading Machines	UG	Boom swing	Boom positioning
Entry and Tunnel Driving Machines	UG	Various	Actuation
Mining Machines	UG	Pull and tail	Move miner across face
Rotary Pumps	S		Actuation
Scrappers/Slushers	UG	Haul and tail	Scoop actuation
Service Hoists/Cranes	S/UG	Haul Boom pendants	Load movement Boom support
Slings	S/UG	--	Weight support
Track Haulage	UG	Safety bridle or loop	Backup connection between cars
Tuggers/Room Hoists	S/UG	Hoist	Load movement
Various	S	Standing rigging	Support
Vibrating Screen	S	Suspension	Carry load

(a) UG - underground, S - surface. The distinction here is made to indicate where the application is generally found.

DISCUSSIONWinching Ropes: Barge and Car Pullers, Car Retarders

Generally, car pullers are designed to be used with slight grades and to allow bidirectional pulling. Car retarders are designed to work cars on grades, hauling cars upgrade and lowering them down. The pullers are either capstan- or drum-driven, but all the retarders seen were drum driven.

The ropes seen in use ranged from 3/4 inch to 1-3/4 inches in diameter, 6 x 19 through 6 x 41 construction, regular and Lang lay, and IWRC or FC centers. Typical life times ranges from 1 week to more than 1 year. The ratios of drum- or capstan-sheave diameters to rope diameters ranged from 16 to 47, while turning- or tensioning-sheave-to-rope-diameter ratios ranged from 16 to 24. Rope lengths ranged from several hundred to several thousand feet.

It is tempting to evaluate the wide range of rope constructions and sizes and the accompanying life in terms of the D/d's and loads. Beyond D/d comments this is useless in most cases as will be discussed.

Several manufacturers of this kind of equipment sent what appears to be design information, most of it fairly old. Some of this information discusses sheave/drum-to-rope-diameter ratios. It is not uncommon to find tables titled "average sheave and drum diameters", "minimum sheave and drum diameters" and, "critical diameters for sheaves and drums". Study of this literature reveals that such "average" data were averages for a variety of equipment in use, the "minimums" being those below which rope operation is said to be unsatisfactory, and the "critical" values those for which the rope is said to quickly go to pieces. (71) The critical values are about 3/4 of the "minimums" and about 1/3 to 1/2 of the "average" values. The D/d ratios observed and reportedly generally used by manufacturers of this equipment are in the range of the so-called "critical" D/d's. Space restriction can, of course, place upper limits on design D/d's. However, except for car-retarder ropes located on track centerlines, there appear to be no space restrictions on sheave and drum sizes for this kind of equipment.

Costs, of course, also become a consideration. However, it appears that use of "critical" D/d's or, at best, less than the "minimum" D/ds reduce only the initial costs of the installation. Larger sheaves and drums would undoubtedly promote longer life, but it is doubtful that anyone knows where the cost-of-machine versus cost-of-rope trade-off lies. It is also doubtful if anyone has seriously considered investigating such a trade-off.

One illustration here is sufficient. A barge puller was inspected and found to use a single-layer, spiral-grooved drum with D/d = 47. Accompanying this were two turning sheaves of D/d = 14. The rope showed many broken wires, particularly along that portion of the rope which passed only over the turning sheaves. There were significantly fewer broken wires over the length which was wrapped only on the drum. When inspected, the rope had been in service 8 months out of a typical 1-year service period. There was no space restriction against the use of larger turning sheaves. At each rope replacement these sheaves are reportedly disassembled and rebushed, but

not regrooved (and they needed it). There is no doubt that larger turning sheaves would increase the life of the rope. Larger sheaves could also have larger hub inside diameters and, hence, greater bearing areas, which in turn would probably eliminate the need to rebush at each rope change.

The consideration which makes general analysis beyond the D/d comments useless is the general way these devices are used. The ropes are commonly not lubricated and, generally, almost entirely exposed to the weather. Some systems have oilers available as optional equipment and their use has been seen, but they were the exception. The oft-repeated comment with respect to car pullers and retarders is that the ropes drag the ground and lubrication is useless. In most cases, this appears to be an excuse. There are systems with support rollers where part of the rope does not drag the ground. Except for those that are automatically oiled, no drum-driven system was inspected which would not benefit had the ropes been at least periodically soaked with oil. With capstan-driven systems it may not always be possible to lubricate without causing rope slippage on the capstan.

Though no galvanized ropes were seen on these devices it would appear that such ropes might be of particular advantage where lubrication is a "problem".

A number of car-retarder ropes inspected were badly kinked because the hook end was looped through the car structure and the hook hung back on the rope. In these cases, an intermediate sling or chain might increase the main rope life and save replacement time and effort. In several instances the first 30 feet of the rope were badly unravelled, and one had a strand missing for about 10 feet. How safe is such a rope? The manufacturer of the car retarder with the missing-strand rope designs with an initial safety factor of six, based on the ultimate rope strength when new. It is not possible to estimate the strength of a rope with a missing strand and several kinks, but obviously it is low. Many car retarders are remotely controlled and one can only wonder if a runaway car would be stopped without crashing into other cars or derailling. Car pullers, working with level or near level grades, don't present as obvious a potential hazard.

Often, the problem with rope on car retarders is further aggravated by impact loads. It is common practice to bring empty cars to the tibble by gravity with a man riding a car at the hand-brake station. If he judges properly he can make a coupling to the other cars on the hoist retarder with a reasonably low impact. On the other hand, if the impact is high, the rope can be parted. The 1-week rope-life mentioned earlier applies to a hoist retarder and is a direct result of high-impact coupling.

### Winching Ropes: Aerial Tramways

Aerial tramways have such extensive use throughout the world that they form an engineering subject unto themselves. A half dozen or so were seen during mine visits but no great attention was paid to them, as they were recognized as a subject for study in their own right. Nevertheless, some things were learned worth discussing.

There is little functional difference between the haul and tail rope setup in aerial tramways and that in car and barge pullers except that, in the case of tramways, the ropes do not drag the ground. These ropes are either drum or capstan driven. Although

there are stretches of the ropes which don't see the drum or capstan, those parts which do could be fairly easily lubricated manually or automatically.

One operator indicated he never lubricated these ropes. Another operator indicated his tram was no longer in use because of dumping restrictions but that, when it was, a haul or tail rope would break now and then. Another operator said he stopped using his tram after a haul rope broke and most of the moving parts disappeared over the hill.

Track ropes need lubrication, too. Obviously, they are not easy to lubricate, requiring special lubrication equipment or the sending of men up in a skip. One operator said he greased his track ropes as necessary (but never his haul ropes). Another, having to live with a dump fire, indicated he thought that greasing track ropes was somewhat futile in the fire area although the fire and heat caused track rope corrosion.

The lubrication of track and haulage ropes on aerial tramways leaves something to be desired. The hazard to life presented by these systems varies with each system. They are known to cross highways and the support towers are often rope guyed. Broken haulage ropes can certainly damage the system, and, depending upon the particular construction of the tram, a broken track rope could easily result in considerable equipment damage and possible injury if workers were in the area.

Not all trams have track ropes. Some are like ski lifts, using a pulley-supported haul rope with conveyances attached directly to it; the track and haul rope are combined. A broken rope in such systems could bring everything to the ground.

#### Winching Ropes: Scrappers, Slushers, Tuggers, Roomhoists

These hoist or winching systems, particularly scrappers and slushers, see the worst environmental conditions for rope longevity. It is doubtful that lubrication would materially increase rope life and it is doubtful that any general attempt will ever be made to find out. One manufacturer of a portable winch for in-mine use considers the rope to be completely expendable. None of these devices were seen in-mine. A tugger winch for in-mine use was inspected above ground, however. It uses about 1/2-inch rope which was poorly spooled in many layers on the drum. The rope was dry and generally abused.

Since space restrictions undoubtedly limit sheave and drum diameters in these applications and since the service conditions are often so bad, about all that can be said is that, whenever possible, larger D/d's should be used and ropes should be lubricated. Close inspection and sensible rope-replacement practice to minimize unexpected rope breaks is of great importance here.

#### Actuation Ropes: Belt Tensioners, Loader-Boom Swings, Etc.

These generally small and short ropes are applied with sheave-to-rope diameter ratios in the range 13 - 20 on the equipment observed. Again, these D/d ratios are in the "critical" range. Typically, they are unlubricated and exposed to dust, dirt,

water, and falling coal. A loader boom-swing rope is typically 1 foot long and conveyor belt tensioners are on the order of 6 feet long. One operator reports that a boom-swing rope will last about 6 weeks. Another operator with some 30 belt tensioners breaks "a lot" of these ropes in a year.

The boom-swing and belt-tensioning systems, again, suffer from small sheave-to-rope diameter ratios which are not obviously dictated by available space. The complete lack of lubrication is probably worse, particularly on the belt tensioners. Those systems seen have about 1 foot of rope travel and the rope doesn't cycle often. These ropes generally just rust to the breaking point. Dust, dirt, water, and falling coal notwithstanding, a good lubricant would certainly extend their lives and reduce machinery downtime. This, too, might be a good application for galvanized rope. In general, the hazards associated with broken swing and tensioning ropes and the like do not appear to be significant.

### Slings

Slings are abused, can wear out fast, and should be carefully inspected to prevent failure under load. Greasing does not appear practical since it would make handling difficult.

Slings or rope loops have been observed in use as backup or safety couplings between track-haulage cars used on service slope-hoist installations. Being looser than the prime coupler, they would be subjected to impact loads if the prime coupler parted. In addition, in the installations seen, if these slings came into use they would be bent around very short radii and probably be severely kinked. They are also subject to corrosion and no lubricated loops were observed. It is apparent that, if these loops or slings are to provide safety backup, they must be carefully inspected and discarded at the first sign of corrosion, kinks, broken wires, or unraveling. The extent to which this is practiced could not be meaningfully determined.

- EVALUATION OF RESEARCH PROCEDURES

## EVALUATION OF RESEARCH PROCEDURES

INFORMATION REQUIRED

At the start of the program, Battelle's wire rope experience included a large amount of experimental and theoretical study of modes of failure of wire ropes and the contributing service conditions. This background was derived in large measure from work with rope in high-performance applications. These applications generally highly stress the rope and require weight and space reductions wherever possible. Typically, a rope failure in such an application is likely to cause considerable damage or loss of equipment and lives. This and other experience pointed up the value of regard for the entire system using the rope, i. e., the associated machinery, the environment, and, to some extent, the people involved with operation and maintenance.

This experience accounts for the encompassing scope of the program objectives, reflecting a desire to learn as much as possible about "ropes in coal mines" from as many viewpoints as possible.

Thus, the kinds of information sought (and obtained) include

- (1) Uses of wire rope associated with underground coal mining in the United States
- (2) Typical sizes, lengths, and constructions of the ropes in these applications and the loads involved
- (3) Descriptions and operational characteristics of the machinery systems and components using or directly associated with these ropes
- (4) Various engineering details of this machinery
- (5) Information regarding the environment of the rope application
- (6) Maintenance and inspection practices applied to the rope and the immediate associated machinery components
- (7) Details of construction, development, operation, and capabilities of nondestructive electromagnetic wire-rope inspection devices
- (8) Experimental or theoretical efforts being made to extend wire rope technology with respect to coal mining applications
- (9) Federal and state laws and regulations governing the use of wire rope in coal mines
- (10) Recognized standard codes or specifications governing wire rope in coal mines
- (11) General personnel attitudes, opinions, and suggestions regarding wire rope uses in coal mines.

APPROACHGeneral Considerations

The kinds of information required suggested the following probable sources:

- (1) Coal mine operators
- (2) Mining equipment manufacturers
- (3) Wire rope manufacturers
- (4) Governmental regulatory agencies
- (5) Users or suppliers of electromagnetic, rope inspection equipment
- (6) Professional and industrial organizations
- (7) Research organizations or groups, universities
- (8) Technical papers.

Experience with research programs requiring much information showed that the following mechanisms would have to be used:

- (1) Questionnaires
- (2) Letters of inquiry
- (3) Phone calls
- (4) Visits
- (5) Literature search.

The effectiveness of each of these mechanisms generally depends upon many factors, and a few comments born out of experience are in order. However, it must be understood that these comments will relate to situations in which subject matters are basically technical, involve little proprietary information, and about which the requestor has basic knowledge.

Under these conditions, and if the subject matter is identified beforehand and a visit request is granted, visits can generally be expected to be 100 percent effective; that is, they will produce the desired results. If inspections or data are desired, they are usually had. If questions are not answered the first time, they usually are answered after rephrasing. If a question is not answered, an understanding for why not is usually obtained and this information is in itself valuable.

The general effectiveness of questionnaires and letters of inquiry depends heavily on what is requested. If requests are for printed material or technical data which are relatively easily collected, then these mechanisms typically are highly (if not 100 percent) effective. Requests for personal opinions or judgments may not bring an answer, but, depending upon how the question is phrased, a "no-answer", again, can be informative. Requests involving replies which could be interpreted against individual integrity or company image and policy will usually either not be answered or will be answered strictly in accord with stated policy.

Phone calls to strangers, while providing an opportunity for discourse, will be effective much like written requests.

Literature searches can be highly effective if the topics are well defined and if a body of literature of reasonable size exists.

In application, combinations of these mechanisms can often be more effective than one alone.

Another factor contributing to the effectiveness of these mechanisms is the attitude of the answerer not just to the mechanism employed, but to the subject matter involved. In addition, other demands on his time and whether or not he sees an advantage to him will affect his responsiveness.

The costs of application of these mechanisms is also an important consideration. Where wide coverage is desirable written requests and phone calls generally are much less expensive than visits. Library literature searches can be as inexpensive as written requests. If the above mentioned effectiveness considerations are not properly attended, however, resulting in low response to written request, then the costs per return could conceivably be much higher than costs per visit.

The final factor for consideration in using these mechanisms is the time between requests and responses. In general, the response time for written requests can range from a few weeks to several months, whereas for phone calls and visits the response time is essentially zero.

It is necessary to point out that all these mechanisms are generally subject to the "law" of diminishing returns. That is, at some point the responses essentially begin to give no new information. Furthermore, response to questionnaires and letters of inquiry will in general elicit about 25 percent response at best, and often less - sometimes 10 to 15 percent. While it would be ideal to combine these factors in judging how many written inquiries to initially send, it is generally impossible to do so unless the inquiry and the receivers have been used several times and a response pattern has been established.

#### Specific Approach

At the beginning of the program the project staff had little mining experience. However, they collectively had much experience with wire rope research, rope field problems, and the kinds of machinery involved. Furthermore they were well founded as mechanical engineers in the basic principles of mechanics and machine design and

had gained experience in the use of the previously mentioned information-gathering mechanisms in previous research programs.

The process by which the general considerations evolved into a specific approach is best described as an application of the scientific approach. Briefly, this involves proposing a specific approach, testing it, and, in accord with the results, either proceeding or reformulating the approach, retesting it, and, again, proceeding or reformulating.

Initial efforts involved collecting all wire rope technical papers related to mining from Battelle's extensive wire rope files. Typically, many papers had references pertinent to this program which were requested in turn. Concurrently, a brief search of technical abstracts back to 1960 was initiated at the Battelle-Columbus library.

Lack of direct mining experience dictated initial use of the mechanism promising the most immediate and complete response - namely, visits. Accordingly, visits were arranged with a hoist manufacturer, government regulatory officials, mine operators, and users and a supplier of electromagnetic wire rope inspection devices. Except for the equipment manufacturer, these people were contacted in a single 3-day visit to Ontario, where they interact closely and continuously. This trip also reflects the pattern for all visits made during the program, namely: schedule visits in groups of one or two a day in some logical, geographically tight sequence for a period of about a week. This approach is economically and humanistically efficient.

The early visit to Ontario appeared highly desirable since technical papers on hand indicated their eminence in addressing mine-hoisting and hoist-rope problems. The visit provided much insight into what could be expected from contacts with various groups in the United States as well.

Of the information source-groups listed earlier, the coal mine operators, wire rope manufacturers, and governmental regulatory agencies were expected to be the greatest sources of information. Since there had been much previous contact with wire rope manufacturers, machinery manufacturers, professional and industrial organizations, and research organizations and universities, it was decided early that written requests and phone calls could be expected to elicit the necessary response.

Questionnaires to mine operators and state regulatory agencies, who were less well known, were prepared and discussed on a subsequent visit which, though predominantly covering mines, included some state-agency contact. On the basis of the information obtained during this trip, questionnaires were finalized and mailed to the state agencies. These requests were sent not only to coal states but to the majority of states with mining industries. These questionnaires specifically included a request for a copy of state mining laws.

On the basis of another round of mine visits with a redrafted mines questionnaire, the questionnaire to the mine operators was finalized and mailed. This visit also provided the opportunity for addressing the Wire Rope Technical Board shortly after all members had received their questionnaires.

A final round of visits to coal mines also offered a few more opportunities to talk with state officials and equipment manufacturers. There were indications at this point that the law of diminishing returns was taking effect with respect to mine visits and, thus, no more were made.

Throughout, visits and written contacts produced papers which in turn indicated more papers. Visits and written requests also produced names of other potential sources, most of which were contacted in writing or by phone.

The questionnaires mailed were not all simple or easy to fill out in comparison with the typical questionnaire commonly found in the mail. The subject matter is, however, comprehensive and the trial runs appeared to indicate that the questionnaires would not generally be rejected because of the number of questions asked and the general requirement for a written answer.

Each questionnaire included a cover letter briefly outlining the program and indicating how the recipient's answers would be of use. All indicated that the answers would be treated as business confidential and that use of the information received would not identify the source. Several copies of the questionnaire were sent to each addressee, permitting him to scratch on one while having another for mailing and yet another to file if desired. Finally, all packages contained a return-addressed, stamped, envelope to facilitate mailing.

Letters of inquiry were sent where there were questions concerning the extent of involvement of the recipients or where the value of a questionnaire was not apparent.

Phone calls were generally used to follow up questionnaires and letters. In the case of university schools of mines, phone calls were used exclusively, with program efforts having indicated that they would be the most effective method in this case.

Table 9 summarizes the specific techniques which were used.

TABLE 9. SPECIFIC TECHNIQUES USED FOR INFORMATION GATHERING

Information Source Group	Inquiry Mechanism	Total Contacts	Appendix(a)
Coal mine operators	Questionnaires, visits	138	I
Metal mine operators	Visits	7	I
Equipment manufacturers	Letters of inquiry, some visits, and phone contact	40	J
Wire rope manufacturers	Questionnaires, some visits	18	K
U. S. state mining regulatory agencies	Questionnaires, some visits, and phone contact	45	L
Canadian provincial regulatory agencies	Letters of inquiry, some visits	8	M
Other foreign research groups	Letters of inquiry	15	N
Other sources	Letters of inquiry, some phone contact	10	N
U. S. universities	Phone contact	4	N

(a) Details in appendix indicated.

Complete lists of companies or groups contacted and examples of the questionnaires or letters of inquiry sent are included in Appendixes I through N, as indicated in Table 9.

The principle sources used to determine the individuals, companies, and groups to contact are

- (1) The "1970 Coal Mine Directory (United States and Canada)" published by Keystone Coal Industry Manual, McGraw-Hill, New York, New York
- (2) "Guides to Information Sources in Science and Technology; Volume 2, Mining, Minerals, and Geosciences", Interscience Publishers, John Wiley & Sons, New York, New York, 1965
- (3) Thomas Register of American Manufacturers, 58th Edition-1968, Thomas Publishing Company, New York, New York.

The bibliography of the papers, codes, specifications, etc., obtained during this program, as well as those initially on file but pertinent, is presented in Appendix A as stated earlier.

EVALUATION OF APPROACHGeneral Response

The response to questionnaires and letters of inquiry as of March 31, 1970, is shown in Table 10.

TABLE 10. QUESTIONNAIRES AND LETTERS OF RESPONSE TO INQUIRY

Information Source Group	Item Sent(a)	Number Mailed	Number Returned	Percent Returned
Coal mine operators(b)	Q	97(c)	13	13
Equipment manufacturers	L	37(d)	26	70
Elevator manufacturers	Q	3	3	100
Wire rope manufacturers	Q	17	9	53
U. S. state regulatory agencies	Q	45(e)	36	80
States involved		35	34	97
Canadian regulatory agencies	L	7	7	100
Other foreign research, industry, or government organizations	L	15	8	53
Miscellaneous U. S. sources	L	10	6	60

(a) Q - Questionnaire, L - Letter of inquiry.

(b) All coal mine operators contacted produced 150,000 tons or more annually.

(c) Does not include three visited.

(d) Does not include three coal mines visited.

(e) At this writing Michigan and Minnesota handle inspection on a county basis, although a change is forthcoming.

Excepting the response of the coal mine operators, the response is considered to be very good. The questionnaires returned filled out are almost completely answered, indicating that they were not too comprehensive or complicated for the recipients, with all things considered. The responses to questionnaires also include cases where letters were sent explaining why the questionnaires were not being filled out. In no case were these explanatory letters indicative of the questionnaire having been the wrong mechanism to use. The letters of inquiry are considered to have been 100 percent effective in practically every instance. In some cases the response included much more information than could have been anticipated. On the other hand, many returns indicated that the addressee was no longer involved with ropes or shaft hoisting in coal mines or mining in general; such information is considered to be well worth the effort of a letter. In several instances, questionnaire and letter response led to further correspondence and additional information received in return.

In retrospect, but again excepting the case of coal mine operators, it is concluded that the information-gathering mechanisms chosen for the various groups were the right ones to use for the study.

## Coal Mine Operator's Response

### Selection of Contacts

In the course of this program, 138 mine operator contacts were made. They were selected from the 1970 Keystone Register on the basis of their being "shaft" or "deep" mines producing 150,000 tons or more annually. Of this number, questionnaires were sent to 97 coal mine operators.

Visits were made to 41 coal mines operated by 21 different companies and operating divisions of large corporations and to seven metal mines operated by four different companies. The coal mines visited were also selected from the 138-member group. The biggest producers were contacted first, and the mines visited produced 500,000 tons or more annually. In addition, mines to visit were chosen from various geographical regions to cover possible regional variations in practice. Some mines visited were also recommended as being of particular interest.

Six of the seven metal mines visited were Canadian and were of interest because of the rope practices in use, including the use of electromagnetic wire rope inspection devices. One U. S. metal mine was visited while in the area for reasons unrelated to this program.

As the coal mines are the focal point of the entire program, a discussion of the response of the operators to both visits and questionnaires is in order.

### Response to Visits

Company or operating-division response to requests for visits was extremely gratifying - only one request for a visit being refused. In addition, all visits are considered to have been 100 percent effective in that in almost every instance, the rope installations of interest were inspected and all questions were adequately answered. Very often, equipment in addition to that specifically sought was shown. Furthermore, questions were often answered for which no answer was expected. Similarly, information was often given beyond that required by a question.

No requests for underground inspection were made. They were offered, however, and the first one was accepted. That instance supplied enough general and specific information to permit discussion of underground ropes to such an extent that further underground trips did not appear necessary.

All visits were prearranged by phone directly with mine operators. Using the Keystone Register as a guide, the procedure was to contact someone of authority, explain the purpose of the intended visit, and request permission for it. Generally, information on where to go and whom to contact upon arrival was proffered, as were offers to provide transportation or make motel/hotel reservations. Initial contact at the mine was usually with the superintendent and the reception was cordial if somewhat guarded. Discussion of interest in machinery and rope brought a more relaxed atmosphere and the assignment of a foreman, chief electrician, or electrical engineer as a guide. In due time, the "thaw" was complete and answers were given to practically any question except, perhaps those that involved engineering details. Usually, the hoistman

or ropeman was eventually contacted and, more often than not, proved to be one of the best sources of information. The value of talking with lower echelon mine personnel was recognized early and efforts to do so were made on all subsequent mine visits.

Engineering details important to analyzing rope requirements as well as details of the construction of the rope in use were often not available from any one person or place and often were somewhat difficult to obtain. After the initial coal-mine visits the project staff carried their own tape measures to ensure getting at least drum, sheave, roller, and rope diameters. In some instances the data were obtained only after mine personnel searched through files. It also became common practice to inspect the walls of the hoist rooms, as a few visits showed them to often have rope-life data chalked on them in the form of rope replacement dates. In contrast in the Canadian metal mines visited it was fairly common to have hoist-machinery data of all kinds hanging on hoist room walls, printed and framed.

One final point on visit conduct is pertinent and perhaps instructive. In an early program involving field inspection of machinery, the wearing of work shoes and clothes was adopted as a practical matter allowing much closer inspection. In subsequent similar programs, this one included, this simple expediency has been often found to have the added value of hastening acceptance and inducing talk. As far as coal mines are concerned, it may even be axiomatic that the dirtier you get the more you learn.

In addition to providing direct inspection of wire ropes and the associated machinery, the mine visits provided access to three general types of information usually not otherwise available:

- (1) An evaluation of what is said or written versus what is done as indicated by the conditions seen
- (2) Data and information about real problems which would probably not be related in writing
- (3) Attitudes of mine personnel.

#### Response to Questionnaires

The mine operators' questionnaire was the most comprehensive prepared, being formulated in two parts: Part I, General Information and Procedures, and Part II, Engineering Data. (The entire questionnaire is included in Appendix I.) Part I required written response to questions which in part asked for opinions and judgments and it treated all rope applications. Part II required checking the applicable items and filling blanks with numbers or one or two words in accord with a contrived, though realistic, example. It applied to hoist installations in vertical or inclined shafts. The questionnaire was separated into these two parts and several copies were sent to facilitate response, recognizing that the data portion might require circulation.

The questionnaire and cover letter were accompanied by a small form and an accompanying return-addressed, stamped envelope which was not included with the questionnaires to other groups. The form was, in effect, a rapidly executable, intent-to-reply indicator. It was included experimentally to determine the value of such a device and to what use it would be put.

The mine operator's response to questionnaires, shown in Table 10, is relatively poor. A breakdown of this response is shown in Table 11.

TABLE 11. BREAKDOWN OF MINE OPERATOR RESPONSE TO QUESTIONNAIRES

	Response Mechanism Used			Individual Responses
	Letter	Intent-to-Respond Form	Q(a)	
Questionnaire answered	2	3	6	6
Questionnaire relayed elsewhere or intention to respond indicated	1	1		2
No significant use of rope and/or no hoist installations reported		3		3
Company not involved in mining or at least no underground mining	1	1		2
		—		—
		Total	Total	13
		8		

(a) Filled-out questionnaire.

The six filled-out questionnaires included data on 16 hoisting installations plus other rope-application data. These 16 hoist-installation descriptions (from Part II of the questionnaires) represent 20 percent of the total of 79 coal-mine hoist-installation descriptions obtained, the others having been obtained during visits.

Three of the six questionnaires returned were preceded by the return of the intent-to-reply form. Five of the other seven responses were made with this form only. On the basis of these numbers it could be concluded that the intent form was of value. However, the total number of responses being low, it is concluded that the value of such a device has not been sufficiently determined.

The response times are of interest with respect to this questionnaire. The returned intent forms were received within about 2 weeks of the mailing, but the questionnaires returned were spread more or less evenly over a period of 3 months, with the last arriving at the end of March. The majority of responses to the questionnaires to the other groups arrived within 5 to 7 weeks after mailing.

#### Evaluation of Approach to Mine Operators

The low response called for a critical review of the entire approach to the coal-mine operators. This is particularly pertinent not only for its value to others who may be contemplating similar studies but because Battelle has discussed additional programs of a similar nature related to mine hoisting and wire rope use with the Bureau of Mines. These programs would probably make use of visits and questionnaires to mine operators in some manner, but, clearly, the details of the approach should be different.

Visits seemed to indicate that there are two attitudes regarding rope and hoisting problems: one is that there aren't any, and the other is that there are. Many operators with the latter attitude expressed interest in the program and a desire for any results which might help them. Generally, the larger and more progressive companies belong to this group. The visits were primarily to large operators, who sent most of the responses to questionnaires. Perhaps those that did not respond are less concerned with rope problems. Nonetheless, written requests probably should have been shorter, and easier to answer, followed by a more intensive follow-on effort.

It is also clear that many operators are especially busy since the passage of the Coal Mine Health and Safety Act of 1969, both because coal is in great demand and because of requirements of the Act. This is a probable factor.

Some operators visited expressed surprise and a degree of pleasure at someone's searching them out with an interest in their problems as well as with some possibly helpful suggestions for their rope problems. Perhaps the questionnaires alone evoked a somewhat opposite reaction.

There is some sentiment in the coal mining industry objecting to the idea that any real problems will be solved by persons from outside the industry. As far as is known, the visits did not evoke any such sentiment with respect to ropes and hoisting. However, it is a possible reason for the lack of questionnaire response from some operators.

Considering all that has been learned, it is concluded that the questionnaire approach used is not the best approach to the coal mine operators. It is furthermore concluded that, in future survey-like programs related to hoisting ropes and/or ropes in general, the approach to mine operators would be somewhat as follows:

- (1) Operators of apparent interest would be selected from available guides, such as the Keystone Register, on the basis of information presented in such guides. Typical key words for selecting would be "underground mines", "shafts", and "slopes" (This step represents no change in approach.).
- (2) A single-page check list similar to the first page of the mine operators' questionnaire used in this program (see Appendix I) would be sent to all operators selected in Step (1) above. The intent of this questionnaire would be to establish the uses for ropes and/or the existence of slope or vertical shaft hoist installations (This step is different.).
- (3) Returns of interest would be followed up by phone to establish other details and to determine if further contact is necessary and, if so, to explore which option - a visit or a second, more detailed questionnaire - should be used to obtain the data sought in a manner most convenient to the mine operator.

It is felt that the above approach would provide greater overall mine-operator response to written requests for information than occurred in the present program. It appears to anticipate the previously discussed, possible reasons for poor questionnaire response in this program.

In general, written requests and phone calls must be used as much as possible in any program requiring wide coverage if a reasonable response can be expected. Estimates of the costs for the various mechanism are illustrative as shown in Table 12. These estimates were prepared from costs incurred during this program.

TABLE 12. ESTIMATED COSTS FOR VARIOUS INFORMATION GATHERING MECHANISMS USED

Mechanism	Questionnaires and letters	Phone Calls	Visits
Cost/contact	\$25(a) 50(b) (Mine operators only) 175(c)	\$25	\$225

(a) Based upon total number sent.

(b) Based upon total number of responses.

(c) Based upon questionnaire response.

On the basis of all contacts the cost per contact is less for written requests than visits. However, on the basis of mine-operator response to questionnaires, the cost per contact for written requests and visits is about the same. Much more information was obtained on the visits.

These estimates include labor costs and costs for items such as postage, reproduction, rental cars, plane fare, and room and board.

APPENDIXES

APPENDIX A

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## APPENDIX A

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APPENDIX B

DETAILS OF HOIST INSTALLATIONS  
IN SOME U. S. COAL MINES

TABLE B-1. DRUM AND SHEAVE DATA - SHAFT HOISTS

Hoist usage	Mine	Conveyance	Type	Hoist Drum						Head Sheave		Source of information <sup>(1)</sup>	
				Grooving Type	Size (in)	Drum diameter (in.)	D/d	Max. no. rope layers	Min. no. dead wraps	Rope lifters fitted	Diameter		D/d
Coal													
	1 <sup>(2)</sup>	Balanced skips	Cylindro conical	Spiral	1-3/4	84-120 <sup>(3)</sup>	48-69 <sup>(3)</sup>	1	- <sup>(4)</sup>	DNA <sup>(5)</sup>	-	-	V
	2	"	Cylindro conical	Spiral	1-3/4	104-144	59.5-82	1	-	DNA	120	69	V
	3	"	Cylindro conical	Spiral	1-3/4	108-144	62-82	1	-	DNA	-	-	V
	4	"	Cylindro conical	Spiral	1-3/4	108-144	62-82	1	-	DNA	-	-	V
	5	"	Cylindro conical	Spiral	1-1/2	108-	72-	1	-	DNA	144	93	V
	6	"	Friction	Parallel	1-1/2	120	80	1	DNA	DNA	-	-	V
	7	"	Cylindrical	-	1-3/8	84	61	-	-	-	100	72	V
	8	"	Cylindrical	Spiral	2	132	66	1	-	DNA	144	72	V
	9	"	Cylindro conical	Spiral	1-3/8	96-144	70-105	1	-	DNA	144	105	V
	10	"	Cylindrical	Spiral	-	-	-	1	-	-	144	82.25	V
	11	"	Conical	Spiral	1-1/2	72-96	48-64	1	3-4	DNA	144	96	V
	12	"	Cylindro conical	Spiral	2	120-156	60-78	1	-	DNA	144	72	V
	13	"	Cylindrical	Spiral	1-7/8	108	57.5	1-1/3	4	Yes	120	64	V
	14	"	Cylindrical	Spiral	1-7/8	108	57.5	1	3-4	DNA	120	64	V
	15	"	Cylindrical	Spiral	2-1/8	144	67.5	1	3-4	DNA	144	67.5	V
	16	Balanced skip/cage combination	Cylindro conical	Spiral	1-1/2	96-120	64-80	1	3	-	120	80	V
	17	"	Cylindro conical	Spiral	1-1/4	72-96	57.5-77	1	3	-	120	96	V
	18	Skips in balance	Cylindro conical	Spiral	1-7/8	120-	64-	1	3	DNA	120	64	Q
	19	"	Cylindro conical	Spiral	1-5/8	144	88	1	3	DNA	90	55	V
	20	"	Cylindrical	Spiral	2	192	81	1	4	DNA	192	81	Q
Men													
	11	Cage/counter-weight	Cylindrical	-	1-1/4	72	57.5	1	3-4	DNA	144	115	V
	17	"	Cylindrical	-	7/8	96	110	1	-	DNA	60	68.5	V
	21	"	Cylindrical	-	1-1/4	60	48	1	-	DNA	72	58	V
	22	Cage	Cylindrical	LeBus	3/4	36	48	6	-	No	48	64	V
Men and Supplies													
	2	Cage/counter-weight	Cylindrical	-	1-1/4	84	67	1	-	DNA	-	-	V
	3	Balanced cages	Cylindro conical	Spiral	1-1/4	72-108	57.5-86.5	1	-	DNA	-	-	V
	4	"	Cylindrical	Spiral	1-1/4	84	60	1	-	DNA	-	-	V
	6	Cage/counter-weight	Friction	Parallel	1-1/2	120	80	1	DNA	DNA	-	-	V
	8	"	Double conical	Spiral	1-5/8	104-146	64-90	-	-	-	-	-	V
	8	"	Cylindrical	Spiral	1-5/8	100	61.5	1	-	DNA	100	61.5	V
	12	"	Cylindro conical	Spiral	2	120-156	60-78	1	-	DNA	144	72	V
	13	"	Cylindrical	Spiral	1-1/2	84	56	1	4	DNA	96	64	V
	14	"	Cylindrical	Spiral	1-7/8	96	51	1	3-4	DNA	120	64	V
	15	"	Cylindrical	Spiral	1-7/8	96	51	-	4	DNA	120	64	V
	18	"	Cylindrical	Spiral	1-1/2	72	48	1	3	DNA	84	56	Q
	18	"	Cylindro conical	Spiral	1-3/8	95	69.2	1	3	DNA	72	52.4	Q
	20	"	Cylindrical	Spiral	2-1/4	144	64	1	6	DNA	168	74.7	Q
	23	"	Conical	Spiral	1-1/4	60-96	48-77	-	-	-	96	77	V
Material and Coal													
	21	Balanced skips	Cylindro conical	-	1-1/2	84-144	56-96	1	-	DNA	72	48	V
	22	Cage/counter-weight	Cylindrical	Spiral	1-7/8	144	77	1	-	DNA	120	64	V

(1) V - Visit, Q - Questionnaire.

(2) Numbers have been assigned to each mine to permit relating data appearing in other tables in the report.

(3) For cylindro-conical and conical drums the two numbers refer to the small and large ends of the drum.

(4) Dashes indicate that the information was not available.

(5) DNA - Does not apply.

TABLE B-2. DRUM AND SHEAVE DATA - SLOPE HOISTS

Hoist usage	Mine	Con-veyance	Hoist Drum							Track Rollers				Head and Idler Sheaves			Source of infor-mation <sup>(1)</sup>		
			Type	Grooving Type	Size (in.)	Drum diameter (in.)	D/d	Max. no. rope layers	Max. no. dead wraps	Rope lifters fitted	Diameter (in.)	D/d	Spacing (ft.)	Extent of usage	Type	Diameter (in.)		D/d	
Coal	24 (2)	Coal cars	Cylindri-cal	Spiral	1-1/4	72	57.5	3+	6-8	No	(3)	-	-	-	Head	72	57-1/2	Q	
Supplies	3	Cars	"	Parallel	1-1/4	120	96	1	-	DNA <sup>(4)</sup>	-	-	-	-	-	-	-	V	
	11	"	"	-	1-1/4	96	77	1 1/2	10-11	No	12	9.6	10-15	Full slope	Head	96	77	V	
	18	"	"	Parallel	1-3/8	120	87.2	1	3	DNA	18	13.1	Irregular	At crown	Head	96	69.8	Q	
	19	"	"	-	1-1/4	72	57	1	-	DNA	-	-	6&10	-	-	-	-	V	
	23	"	"	LeBus	1-1/2	84	56	4	3	Yes	-	-	-	-	Head	60	40	V	
	25	"	"	Smooth	1-1/4	-	-	4	20	No	8	6.4	8	2 at top	Head	72	57.5	V	
	26	"	"	Spiral	1-1/8	64	56	2	-	No	8	7.1	-	2 at top	Head	20	17.75	V	
	27	"	"	"	Smooth	1-1/4	72	57.5	2+	-	No	6	4.8	-	3 at top	Head	24-30	19.2-24	V
	28	"	"	"	Spiral	1	72	72	-	-	-	-	-	1 at crown	Idler	10	8	V	
	29	"	"	"	LeBus	-	72	-	1+	3	No	9	-	30	Full slope	Head	38	-	V
	30	"	"	"	Spiral	1-5/8	92	56.5	1+	3-4	No	(All worn through)			At switch (vertical)	-	-	-	
	31	"	"	"	Smooth	1	70	70	3	-	No	8	-	-	Full slope	Head	12	7.4	V
	32	"	"	"	-	1-1/8	72	64	3	-	-	None	-	-	-	Head	12	12	V
	33	"	"	"	-	1-1/4	48	38	4-5	-	-	4	3.5	-	Few	Idler(2)	30	27	V
	34	"	"	"	Spiral	1-3/8	72	52.5	3	3	-	None	-	-	-	Head	5	4	V
	35	"	"	"	Parallel	1-3/8	120	87	2	-	-	8	5.82	-	Near top	-	-	-	Q
	36	"	"	"	Parallel	1-1/4	-	-	3 1/2	19	-	10	8	30	Near top	-	-	-	V
	37	"	"	"	Smooth	1-1/4	84	62.2	3	3	-	5	6	50	Full slope	-	-	-	Q
	38	"	"	"	Smooth	1	72	72	3	6	-	36	36	-	At switches (vertical)	-	-	-	Q
	39	"	"	"	Smooth	1	72	72	3	6	-	36	36	-	At switches (vertical)	-	-	-	Q
	40	"	"	"	Smooth	1-1/4	108	86	-	60	-	30	24	-	At switches (vertical)	-	-	-	Q
	41	"	"	"	-	1-1/4	72	57.5	3	-	-	-	-	-	-	-	-	-	V
	42	"	"	"	-	1-1/4	72	57.5	-	-	-	10	8	-	-	-	-	-	V
43	"	"	"	Parallel	1	45	45	2 1/2+	8-10	No	6	6	8-10	At crown	Head	70	70	V	
44	"	"	"	Spiral	7/8	28	32	3	-	No	6	6.85	10	6 at top	Idler	5	5	V	
44	"	"	"	Spiral	7/8	28	32	3	-	No	6	6.85	10	6 at top	Head	30	34	V	
Men and Supplies	24	Cars	Cylindri-cal	Spiral	1-1/4	72	57.5	2 1/2	8	No	-	-	-	17 at crown	Head	36	28.8	V	
	45	Cars	"	Spiral	1-3/4	-	-	2 1/2	-	No	6	3.43	25-30	Full slope	Idler(10)	24	19.2	V	
	46	Man car	"	-	1-1/4	120	98	1 1/2	-	-	8	4.58	1	At switch(vert)	Head	36	20.6	V	
	47	Cars	"	Spiral	1-1/4	72	57.5	2 1/2	8	No	6	4.8	-	-	Head	12	6.86	V	
	48	Cars	"	LeBus	1-3/4	108	62	-	-	-	-	8-18	4.57-	-	-	-	-	-	V
	49	Cars	"	-	1-1/4	48	38.5	-	-	-	-	10.3	15	-	-	-	-	-	V
	49	Cars	"	-	1-1/4	48	38.5	-	-	-	-	36	29	15	-	Head	36	29	V
Men, Supplies and Coal	24	Cars	Cylindri-cal	Smooth	1-1/4	96	77	2	8	No	12	6.85	-	At switch(vert)	Head	12	6.85	V	
	50	Cars	"	Spiral	1-3/4	144	82	-	-	-	-	-	-	-	Idler(2)	8	6.4	V	
50	Cars	"	Spiral	1-3/4	144	82	-	-	-	-	-	-	-	Head	108	62	V		

BATTELLE - COLUMBUS

B-3 and B-4

(1) V - Visit, Q - Questionnaire.  
 (2) Numbers have been assigned to each mine to permit relating data appearing in other tables in the report.  
 (3) Dashes indicate that the information was not available.  
 (4) DNA - Does not apply.

TABLE B-3. HOIST ROPE DATA - VERTICAL SHAFTS

Hoist usage	Mine	Conveyance	No. of ropes	Shaft depth (ft.)	Diameter and construction	Lay	Core	Material	Approx. (1) wt. per ft. (lbs)	Approx. (1) B/S new (tons)	Max. dead load (tons)	Max. total load (tons)	Calculated factor of safety (new)	Hoist drum D/d	Type of attachment	Max. rope speed	Approx. no. trips per day	Typical rope life	Shaft wall conditions	Shaft ventilation flow	Source (2)	
Coal	1	Skips in balance	2	150	1-3/4 - -	Rt. Lang	(6)	-	-	-	11	29	-	48-69	-	-	880	4 yrs.	Very wet	Upcast	V	
	2	"	2	530	1-3/4 - 6x19	X-Lay	Fiber	IPS	-	-	-	10 (live)	-	59.5-82	-	-	650	-	Wet	-	V	
	3	"	2	300	1-3/4 - 6x27	Lang	Fiber	IPS	5.51	136.0	-	-	7(3)	62-82	Poured socket	-	-	Wet	Downcast	V		
	4	"	2	456	1-3/4 - 6x27	Lang	Fiber	IPS	-	-	-	-	-	62-82	-	-	-	-	-	-	V	
	5	"	2	500	1-1/2 - 6x19	Rt. reg.	IWRC	-	4.16	98.9	10	19	5.2	72-?	Thimble and clamps	1200	250	2-1/2 yrs.	-	Upcast	V	
	6	"	4(4)	1300	1-1/2 - -	Rt. Lang(2) Lf. Lang(2)	-	-	-	-	-	30 (live)	-	80	-	850	-	-	Wet	-	V	
	7	"	2	90	1-3/8 - 6x25	-	Fiber	IPS	3.40	85.5	-	-	-	61	-	-	-	-	-	-	V	
	8	"	2	675	2 - 6x30	Lf. Lang	IWRC	IPS	7.55	189.0	-	18	10.5	66	-	1088	-	-	Very wet	Upcast	V	
	9	"	2	250	1-3/8 - 6x25	Rt. Lang	Fiber	IPS	3.40	85.5	-	15	5.7	70-105	-	-	1600	-	-	-	V	
	10	"	2	-	1-3/4 - 6x19	Rt. reg.	Fiber	IPS	5.67	153.0	-	15	10.2	-	-	-	600	-	Dry/lined	Upcast	Q	
	11	"	2	200	1-1/2 - 6x19	Rt. reg.	-	-	-	-	8	15	-	48-64	Thimble and clamps	-	-	Changed every 2 yrs.	Dry	-	V	
	12	"	2	920	2 - 6x19	Rt. reg.	Fiber	IPS	6.72	160.0	-	-	-	60-78	Mod lake Shore wedge	-	-	-	-	-	V	
	13	"	2	804	1-7/8 - 6x27	Rt. Lang	Fiber	IPS	-	-	12	22	-	57.5	Thimble and clamps	1750	580	1/2 yr.	Dry/lined	Downcast	V	
	14	"	2	804	1-7/8 - 6x25	Rt. Lang	Fiber	IPS	5.91	141.0	12	22	6.4	57.5	Thimble and clamps	1500	-	1 yr.	Dry/lined	Heavy downcast	V	
	15	"	2	820	2-1/8 - 6x25	Rt. Lang	Fiber	IPS	7.59	179.0	12	27	6.63	67.5	Thimble and clamps	1250	-	-	Dry/lined	Downcast	V	
	16	Skip-cage combination	2	585	1-1/2 - 6x19	Rt. reg.	Fiber	IPS	3.78	92.0	8	14	6.56	64-80	-	-	-	Changed every 1-1/2 yrs.	Some water	Slight downcast	V	
	17	"	2	285	1-1/4 - 6x19	Rt. reg.	Fiber	IPS	2.63	64.6	8	14	4.6	57.5-77	-	-	-	Changed every 1-1/2 yrs.	Some water	Slight downcast	V	
	18	"	2	300	1-7/8 - 6x19	Rt. reg.	Fiber	PS	5.91	123.0	18	33	3.73	64	Thimble and clamps	700	620	1-1/3 yrs.	Wet/lined	Downcast	Q	
	19	Skips in balance	2	150	1-5/8 - 6x21	Rt. Lang	IWRC	-	4.83	115.0	7	18	6.38	88	Thimble and clamps	450	-	1-1/3 yrs.	Damp	Upcast	V	
	20	"	2	930	2 - Locked coil	Right	DNA	-	9.78	246.0	15	36	6.85	96	Reliance capel	1200	300	2 yrs.	Damp	Downcast	Q	
51	"	2	600	2 - 6x19	Rt. reg.	Fiber	IPS	6.72	160.0	-	-	-	60-78	Mod. lake shore wedge	-	-	-	-	-	Q		
Men	9	Cage and counter-weight	2	-	7/8 - 6x19	Rt. Lang	Fiber	IPS(5)	-	-	-	-	-	-	-	-	-	-	-	-	V	
	11	"	2	-	1-1/4 - 6x19	Rt. reg.	-	-	-	-	-	-	-	57.5	Poured socket	-	20-30	Scheduled for 3 yrs.	Wet	-	V	
	17	"	2	285	7/8 - 6x19	Rt. reg.	-	-	-	-	-	-	-	-	-	-	Emergency use only	-	-	-	V	
	18	"	2	230	1-1/2 - 6x19	Rt. reg.	Fiber	PS	3.78	80.0	4	6.5	12.3	48	Poured socket	1000+	35	Resocket every 3 yrs.	Wet/lined	Downcast	Q	
	18	"	2	488	1-3/8 - 6x19	Rt. reg.	Fiber	PS	3.18	67.5	4	6.5	10.4	70	Poured socket	1000+	100	Resocket every 3 yrs.	Wet/lined	Downcast	Q	
	21	"	2	-	1-1/4 - -	Rt. reg.	-	-	-	-	-	-	-	48	-	-	Emergency use only	-	Wet	Upcast	V	
	22	Cage	1	1400	3/4 - 6x21	Rt. reg.	Fiber	-	-	-	-	-	-	48	-	-	-	-	-	-	V	
	Men and Supplies	2	Cage and counter-weight	2	510	1-1/4 - 6x19	X-Lay	Fiber	IPS	2.63	64.6	15	29	2.22	67	-	-	-	-	Dry	-	V
		3	Cages in balance	2	300	1-1/4 - 6x25	Rt. reg.	Fiber	IPS	2.63	64.6	-	-	10(3)	57.5-86.5	-	-	-	-	Wet	Downcast	V
		4	Cages in balance	2	300	1-1/4 - 6x25	Rt. reg.	Fiber	IPS	2.63	64.6	-	-	-	60	-	-	-	-	-	-	V
6		Cage and counter-weight	4(4)	1300	1-1/2 - -	Rt. Lang(2) Lf. Lang(2)	-	-	-	-	-	30 (live)	-	80	-	850	-	-	Wet/lined	-	V	
8		"	2	-	1-5/8 - 6x19	-	Fiber	IPS	4.44	107.0	-	-	-	64-90	-	-	-	-	Wet	Upcast	V	
8		"	2	600	1-5/8 - 6x19	-	Fiber	IPS	4.44	107.0	-	-	-	61.5	-	-	-	-	Wet	Upcast	V	
12		"	2	800	2 - 6x19	Rt. reg.	Fiber	IPS	6.72	160.0	-	-	-	60-78	-	-	-	-	Dry/lined	Downcast	V	
13		"	2	660	1-1/2 - 6x19	Rt. Lang	Fiber	-	-	-	10	30	-	56	Thimble and clamps	600	-	4-5 yrs.	Dry	Downcast	V	
Men, Supplies and Coal	14	"	2	666	1-7/8 - 6x25	Rt. Lang	Fiber	IPS	5.91	141.0	10	30	4.7	51	Thimble and clamps	500	-	4-5 yrs.	Dry/lined	Heavy downcast	V	
	15	"	2	660	1-7/8 - 6x25	Rt. Lang	Fiber	IPS	5.91	141.0	10	30	4.7	51	Thimble and clamps	600	-	4-5 yrs.	Dry	Downcast	V	
	20	"	2	735	2-1/4 - 6x36	Lang	Fiber	-	-	-	18	48	-	-	Thimble and clamps	600	50	-	Damp/lined	Heavy downcast	Q	
	23	"	2	290	1-1/4 - -	-	-	-	-	-	-	-	-	48-77	Poured socket	-	-	-	Dry	Downcast	V	
	21	Skips in balance	2	450	1-1/2 - 6x25	Rt. reg(1)	Fiber	-	3.78	92.0	9	14.5	6.35	56-96	-	-	1200	1 1/2 yrs.	Dry	Downcast	V	
	22	Cage and counter-weight	2	1400	1-7/8 - 6x25	Rt. reg	IWRC	XIPS	5.91	155.0	15	25	6.2	77	-	-	600	-	-	-	Downcast	V

(1) Obtained from wire rope catalogs.  
 (2) V - Visit, Q - Questionnaire.  
 (3) Indicated by mine operator.  
 (4) Friction hoist.  
 (5) Stainless steel counterweight rope.  
 (6) Dash indicates data not available.

BATTLE - COLUMBUS

B-5 and B-6

TABLE B-4. HOIST ROPE DATA - SLOPE HOISTS

Hoist usage	Mine	Con-veance	No. of ropes	Shaft length	Diameter and con-struction	Lay	Core	Material	Approx. (1) wt. per ft. (lbs)	Approx. (1) B/S new (tons)	Max. (2) dead load (tons)	Max. (2) total load (tons)	Calcu-lated factor of safety (new)	Hoist drum D/d	Type of attach-ment	Max. rope speed (fpm)	Approx. No. trips		Shaft wall con-ditions	Shaft venti-lation flow	Source of infor-mation(3)	
																	Typical rope life	per day				
Coal	24	Coal cars	1	1500	1-1/4 - 6x19	Rt. reg.	Fiber	IPS	2.5	64.4	1.5	5.8	11.1	57.5	Socket	1000	60	Splice at 1/2 yr.	Damp/ lined	Heavy downcast	V	
Supplies	3	Cars	1	1200	1-1/4 - 6x21	Rt. reg.	Fiber	IPS	2.5	64.6	(4)	-	-	96	-	-	-	-	-	-	V	
	11	"	1	600	1-1/4 - 6x21	Lft. reg.	Fiber	-	2.5	64.6	6(wt)	26(wt)	-	96	Poured socket	-	4-5	-	Damp	-	V	
	18	"	1	810	1-3/8 - 6x19	Rt. reg.	Fiber	PS	3.18	67.5	3	53	4.12	87.2	"	500	5	4 yrs.	Damp/ lined	Downcast	Q	
	19	"	1	427	1-1/4 - 6x19	-	Fiber	-	2.5	64.6	-	-	-	57	"	-	-	2 yrs.	-	Upcast	V	
	23	"	1	600	1-1/4 - 6x21	Lft. reg.	Fiber	-	2.5	64.6	6(wt)	26(wt)	-	84	"	-	-	6 yrs.	Dry	Downcast	V	
	25	"	1	3100	1-1/4 - 6x19	Rt. reg.	Fiber	-	2.5	64.6	-	-	-	-	Clamps	600	-	-	Dry	Downcast	V	
	26	"	1	500	1-1/8 - 6x21	Rt. reg.	Fiber	-	2.03	52.6	-	-	-	56	Clamps	-	10-12	1-1/3 yrs.	Damp	Downcast	V	
	27	"	1	-	1-1/4 - 6x19	Rt. reg.	Fiber	-	-	64.6	-	-	-	57.5	Clamps	-	100	-	Damp	Downcast	V	
	28	"	1	375	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	29	"	1	(deep) 700	1 - 6x19	Rt. reg.	IWRC	-	1.76	45.0	-	-	-	72	-	-	-	1 yr.	-	Upcast	V	
																				Damp	Heavy downcast	V
	30	"	1	1200	1-5/8 - 6x21	Rt. Lang	Fiber	-	4.23	107.0	-	30(wt)	-	56.5	-	-	-	1 yr.	Wet	Upcast	V	
	31	"	1	-	1 - 6x7	Rt. Lang	Fiber	-	1.5	39.7	-	-	-	70	Clamps	-	-	-	Damp	Downcast	V	
	32	"	1	950	1-1/8 - 6x19	Rt. reg.	IWRC	IPS	-	-	-	45(wt)	-	64	-	-	-	-	-	-	-	V
	33	"	1	1000	1-1/4 - 6x19	Rt. reg.	-	-	-	-	-	60(wt)	-	38	-	-	-	3/4 yr.	-	-	-	V
	34	"	1	1250	1-3/8 - 6x7	-	Fiber	-	-	-	28.8	70.6	-	52.5	-	-	525	25	1 yr.	Wet/ lined	Downcast	Q
	35	"	1	1200	1-3/8 - 6x21	Rt. Lang	Fiber	IPS	3.03	77.7	-	-	-	87	-	-	-	-	-	-	-	V
	36	"	1	1800	1-1/4 - 6x19	Rt. reg.	-	-	-	-	-	5.5	-	-	Poured socket	400	15	2 yrs.	Wet	Downcast	Q	
	37	"	1	900	1-1/4 - 6x19	-	Fiber	PS	2.5	56.2	-	-	-	62.2	"	200	6	1-2 yrs.	Damp	Downcast	Q	
	38	"	1	720	1 - 6x19	Rt. Lang	Fiber	PS	1.6	36.4	-	-	-	72	"	250	25	2 yrs.	Dry/lined	Downcast	Q	
	39	"	1	720	1 - 6x19	Rt. Lang	Fiber	PS	1.6	36.4	-	-	-	72	"	250	25	2 yrs.	Dry/lined	Downcast	Q	
	40	"	1	2300	1-1/4 - 6x19	Rt. reg.	Fiber	PS	2.5	56.2	-	-	-	86	"	350	40	-	Dry/lined	Downcast	Q	
	41	"	1	1500	1-1/4 - 6x19	Rt. reg.	Fiber	IPS	2.5	64.6	-	11.3	5.7	57.5	-	-	-	-	-	-	-	V
42	"	1	-	1-1/4 - 6x37	Rt. reg.	Fiber	IPS	2.42	61.5	-	-	-	57.5	-	-	-	-	-	-	-	V	
43	"	1	-	1 - 6x19	Rt. reg.	Fiber	IPS	1.60	36.4	-	20-30 (live wt)	-	45	Poured socket	-	-	-	Replace at 1 yr.	Wet	-	V	
44	"	1	-	7/8 - 6x37	-	IWRC	-	1.31	28.6	-	-	-	27-34	-	-	-	1 yr.	Wet	-	-	V	
Men and supplies	24	"	1	1460	1-1/4 - 6x19	Rt. reg.	Fiber	IPS	2.5	64.6	1.45	6.05	10.6	57.5	-	1000	50	Splice at 1/2 yr.	Dry/lined	Downcast	V	
	45	"	1	1800	1-3/4 - 6x27	Rt. Lang	Fiber	IPS	5.51	136.0	-	30(wt)	-	-	-	500	60	1 yr.	Damp	Upcast	V	
	46	Man car	1	1752	1-1/4 - 6x19	Lang	Fiber	IPS	2.5	64.6	-	40(wt)	-	98	-	200 (men)	-	1 yr.	-	-	-	V
	47	Cars	1	1487	1 - 6x19	Rt. reg.	Fiber	IPS	1.6	41.8	-	4.12	10.2	48	Thim-bles and clamps	-	-	3 yrs.	-	-	-	V
	48	"	1	-	1-3/4 - 6x21	Rt. Lang	Fiber	IPS	4.9	124.0	-	-	-	62	Poured socket	1000	-	-	-	-	-	V
	49	"	1	335	1-1/4 - 6x21	Rt. reg.	IWRC	IPS	2.75	69.5	-	50(wt)	-	38.5	-	-	-	-	Damp	-	-	V
	50	Coal cars	1	8100	1-3/4 - 6x21	Lang	-	IPS	-	-	-	-	-	82	-	1700	-	-	-	-	-	V

(1) Obtained from wire rope catalogs.  
 (2) Rope load, unless otherwise noted.  
 (3) V - Visit, Q - Questionnaire.  
 (4) Dash indicates data not available.

BATTELLE - COLUMBUS

B-7 and B-8

APPENDIX C

SAFETY FACTOR AND MAXIMUM SPEED AND ACCELERATION  
RECOMMENDATIONS (REPRODUCED FROM BUREAU OF MINES  
BULLETIN 75, RULES AND REGULATIONS FOR METAL MINES, 1915)

## APPENDIX C

SAFETY FACTOR AND MAXIMUM SPEED AND ACCELERATION  
RECOMMENDATIONS (REPRODUCED FROM BUREAU OF MINES  
BULLETIN 75, RULES AND REGULATIONS FOR METAL MINES, 1915)

TABLE C-1. HOISTING-ROPE SAFETY FACTORS FOR VARIOUS  
 DEPTHS OF SHAFTS

Length of Rope, feet	Minimum Safety Factor for New Rope	Minimum Safety Factor When Rope Must be Discarded	Percentage Reduction
500 or less	8	6.4	20
500 to 1,000	7	5.8	17
1,000 to 2,000	6	5.0	16-1/2
2,000 to 3,000	5	4.3	14
3,000 and over	4	3.6	10

TABLE C-2. PERMISSIBLE HOISTING SPEEDS WHEN SPECIFIED  
 SAFETY FACTORS ARE USED

Length of Rope in Shaft, feet	Maximum Hoisting Speed, ft/min	Length of Rope in Shaft, feet	Maximum Hoisting Speed, ft/min
500 or less	1,200	2,500 to 3,000	2,500
500 to 1,000	1,600	3,000 to 3,500	2,750
1,000 to 1,500	2,000	3,500 to 4,000	3,000
1,500 to 2,000	2,000	4,000 to 4,500	3,250
2,000 to 2,500	2,250	4,500 to 5,000	3,500

TABLE C-3. PERMISSIBLE RATES OF ACCELERATION FOR CERTAIN HOISTING SPEEDS AND SAFETY FACTORS

Speed, ft/min	Maximum Acceleration, ft/sec <sup>2</sup>	Minimum Time of Acceleration in Which to Attain Speed Corresponding, Thereto, sec	Speed, ft/min	Maximum Acceleration, ft/sec <sup>2</sup>	Minimum Time of Acceleration in Which to Attain Speed Corresponding, Thereto, sec
500 or less	4.16	2	2,000	8.33	4
750	4.16	3	2,500	8.33	5
1,000	5.55	3	3,000	8.33	6
1,250	5.95	3-1/2	3,500	8.33	7
1,500	6.25	4			

APPENDIX D

HOIST-SYSTEM INSPECTION SCHEDULE  
PENNSYLVANIA MINE

## APPENDIX D

HOIST-SYSTEM INSPECTION SCHEDULE  
PENNSYLVANIA MINEMan Hoist  
Daily Inspection

1. Cages
  - (a) Cage sides and floor and top
  - (b) Safety dog jaws
  - (c) Dog linkage mechanism
  - (d) Rope socket
  - (e) Rope at socket
  - (f) Safety chains
  - (g) Safety clamp
  - (h) Rope at safety clamp

The rope at the socket and safety clamp is cleaned and lubricated once each week. Once every 60 days, the safety dogs are tested by bringing the cage to ground level. Placing four beams across the shaft through the cage between the floor and the bonnet. With the cage resting on the beams, the socket devis pin is removed and a special trip hook is connected to the rope socket and the cage. The cage is raised two feet off of the beams and the special hook is tripped allowing the cage to drop. A measurement is taken of the distance the cage drops before the safety dogs stop it. The results of this test are recorded on a form provided by the Commonwealth of Pennsylvania, Department of Mines, Bituminous Inspection District. The first copy is sent to the state mine inspector and the carbon copy is kept on file at the mine. A record of this test is also entered in our record book.

2. Rope
  - (a) Inspected as it runs off and on the drum
  - (b) Checked for broken strands. Once every week the rope is calipered for size, and cleaned and lubricated
  - (c) Re-socket every two years
3. Safety devices
  - (a) Overwind
  - (b) Limit switch
  - (c) Overspeed
  - (d) Brakes

4. Drum
  - (a) Drum grooves
  - (b) Lay of rope on drum
  - (c) Safety clamps. Drum groove is gaged every 30 days.
  
5. Bull wheels
  - (a) Lube bearings
  - (b) Check groove. Bull wheel groove is gaged every 30 days.
  
6. Miscellaneous
  - (a) Fire doors are checked every 60 days
  - (b) Each engineer makes a dry run at beginning of his shift before hoisting or lowering men.
  - (c) Ropes are re-socketed every two years.
  - (d) Two men on top of cage inspect shaft, guides, guide bolts, and timbers. Results are recorded in book and signed by those making the inspection.

Coal Hoist  
Daily Inspection

1. Skip
  - (a) Rope socket
  - (b) Safety clamp
  - (c) Safety chains
  - (d) Dogs (or Cams). The rope at the socket is cleaned and greased once every week.
  - (e) Door latches
  - (f) Door hinges
  - (g) Pony wheels
  - (h) Opening of the door
  - (i) Landing plates on skip
  
2. Rope
  - (a) Rope checked as it comes off or goes on drum
  - (b) Check rope on drum
  - (c) Special check of last ten feet that comes off of the drum
  - (d) Special check of last ten feet of rope when played out that does not pass over the bull wheel. The ropes are calipered every 30 days.
  - (e) Re-socket every 500,000 tons
  
3. Safety devices
  - (a) Overwind
  - (b) Limit switch
  - (c) Overspeed
  - (d) Hoist brakes

4. Drum
  - (a) Drum grooves
  - (b) Rope on drum
  - (c) Safety clamps. Drum groove is gaged every 30 days.
5. Bull Wheels
  - (a) Bearing lube
  - (b) Bull wheel groove. Bull wheel groove is gaged every 30 days
6. Miscellaneous
  - (a) Shaft is inspected every 30 days
  - (b) Guides are greased twice weekly
  - (c) A record is kept of all broken wires
  - (d) Fire doors are checked daily
  - (e) Head frame is checked daily
7. The rope is re-socketed every 500,000 tons.

Slope Hoist  
Daily Inspection

1. Barney car to hoist rope
  - (a) Rope socket
  - (b) Rope at socket
  - (c) Clevis
  - (d) Clevis pins. The rope is re-socketed as needed or at least once each year.
2. Barney car
  - (a) Safety chains
  - (b) Safety ropes
  - (c) Bolts and nuts for these chains and ropes
  - (d) Barney car wheels
3. The rope is inspected while making a slow trip as it is wound off or on the drum.
4. The brakes are checked while operating.
5. Safety devices
  - (a) Overwind
  - (b) Safety switch
  - (c) Over speed
6. Every 30 days
  - (a) Safety clamps on drum
  - (b) Drum grooves
  - (c) Caliper rope

APPENDIX E

ELEVATOR ROPES METHOD OF  
BABBITTING WIRE ROPES IN TAPERED SOCKETS

## APPENDIX E

ELEVATOR ROPES METHOD OF  
BABBITTING WIRE ROPES IN TAPERED SOCKETS\*

Where the tapered babbitted type of socket is used, the method and procedure to be followed in making up the fastening shall conform to the following:

- (1) Handling: The rope to be socketed shall be carefully handled to prevent twisting, untwisting, or kinking.

For precautions to be taken in the handling, unreeling, and uncoiling of wire rope preparatory to making up tapered babbitted sockets, reference is made to ASA A17.2, American Standard Practice for the Inspection of Elevators, Appendix 4.

- (2) Seizing of Rope Ends: The rope ends to be socketed shall be served before cutting with seizings in accordance with the following:

- (a) The seizing shall be done with annealed iron wire, provided that other methods of seizing may be used which give the same protection from loss of rope lay.

Where iron wire is used for seizing, the length of each seizing shall be not less than the diameter of the rope.

- (b) For nonpreformed rope, three (3) seizings shall be made at each side of the cut in the rope.
- (c) For preformed rope, one (1) seizing shall be made at each side of the cut in the rope.
- (d) For nonpreformed rope, the first seizing shall be close to the cut end of the rope and the second seizing shall be spaced back from the first length of the end of the rope to be turned in. The third seizing shall be at a distance from the second equal to the length of the tapered portion of the socket.

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\*Reproduced from American Standard Safety Code for Elevators, ANSI, A17.1, as revised through 1970, pp 129-130.

For preformed rope, the seizing shall be at a distance from the end of the rope equal to the length of the tapered portion of the socket plus the length of the portion of the rope to be turned in.

- (3) **Spreading of Rope Strands:** After the rope has been seized, it shall be inserted into the socket through the hole in the small end a sufficient distance for manipulation; and where nonpreformed rope is used, the first two seizings shall be removed. The rope strands shall then be spread apart and, where rope with fibre core is used, the fibre core shall be cut away as close as possible to the remaining seizing.
- (4) **Removal of Grease or Oil:** Grease and oil shall be removed by cleaning the outer surface of the exposed rope strands with a nonflammable low-toxic solvent.
- (5) **Turning in of Rope Strands:** The exposed rope strands shall then be bent, turned in and bunched closely together, with each strand being turned back the same distance. The portion turned in shall have a length of not less than two and one-half (2- 1/2) times the diameter of the rope and such that, when the rope is pulled as far as possible into the socket, the bend of the turned-in strands shall be slightly overflush with the mouth of the tapered socket (large end) and will be visible when the socket has been babbitted. Where rope with steel core is used, the steel core shall be cut off even with tops of the looped strands.
- (6) **Insertion of Bent-In Rope Strands in Socket:** The rope end shall be pulled as far as possible into the socket so that the remaining seizing projects outside the hole at the small end of the socket.
- (7) **Position of Socket Preparatory to Pouring Babbitt:** The socket shall be held in a vertical position with the large end up and the rope held in a position truly axial with the socket. Tape or waste may be wound around the rope at the small end of the socket to prevent the babbitt from seeping through, but it shall be removed after the metal has cooled.
- (8) **Heating of Babbitt:** The babbitt shall be heated to a fluidity just sufficient to char a piece of softwood such as white pine without igniting it. Care shall be taken not to overheat the babbitt sufficiently to damage the rope.
- (9) **Heating of Socket Basket and Pouring of Babbitt:** The rope socket basket shall be heated by a blowtorch flame sufficiently to prevent chilling of the babbitt and to insure that the babbitt when poured will completely fill the basket including all the spaces between the rope strands. Following this, the molten babbitt shall be poured slowly and evenly into the basket until it is filled to a point level with the top of the opening in the large end.

- (10) Inspection of Socket After Pouring: When the babbitt has cooled and the tape at the small end removed, a visual inspection shall be made which shall show that:
- (a) The babbitt is visible at the small end of the socket.
  - (b) The tops of the looped strands of the rope are just visible above the surface of the babbitt. Where rope with steel core is used, the steel core shall also be visible above the surface of the babbitt.
  - (c) The entire loop of any strand is not visible above the surface of the babbitt.
  - (d) No loss of rope lay has occurred where the wire rope enters the basket.

Babbitted sockets which do not conform to the above requirements shall be rejected and the rope resocketed.

APPENDIX F

SOME PROPOSED RULES AND REGULATIONS FOR METAL MINES  
(REPRODUCED FROM BUREAU OF MINES BULLETIN 75, 1915)

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SOME PROPOSED RULES AND REGULATIONS FOR METAL MINES  
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## SECTION 31

## Hoisting

The superintendent of the mine shall establish for each shaft rates of speed for the cages, skips, buckets, or other conveyances that shall not be exceeded in the hoisting or lowering of men, and he shall post a notice of such limitation in a conspicuous place near each hoisting engine; Provided, That the speed so permitted shall not be greater than 500 feet per minute in the case of shafts of less than 500 feet in depth and not greater than 800 feet per minute in the case of shafts between 500 and 1,000 feet in depth and, in shafts of more than 1,000 feet in depth, not more than one-half the speed normally employed in hoisting material; Provided further, That in the case of inclined shafts the classification herein made shall be determined by the measurement on their slope.

The superintendent of the mine shall determine the maximum number of men that in his judgment may safely ride on each cage, skip, bucket, or other conveyance used in the mine under his supervision and shall post in a conspicuous place near each shaft a notice stating the maximum number of persons so permitted to ride and forbidding the carrying of any greater number. At the beginning of each shift the mine foreman or shift boss, or some other responsible person appointed by the superintendent, shall be stationed on the loading platform at the top of the shaft and shall prevent any greater number of men than that permitted by order of the superintendent to enter upon or into any cage, skip, bucket, or other conveyance and shall remain at this station until the last man about to descend the shaft shall have entered the cage, skip, bucket, or other conveyance. And at the end of the shift the man in charge of work on each level of the mine from which men are to be hoisted shall post himself in the station of the shaft at that level and shall prevent any greater number of men than the maximum permitted by the superintendent of the mine to enter upon or into any cage, skip, bucket, or other conveyance and shall remain in this station until the last man to ascend shall have entered upon or into the cage, skip, bucket, or other conveyance.

In every mine operated on two or more levels in which 100 or more men are employed underground and in which the men are hoisted or lowered by cage or other conveyance except a bucket, such cage or other conveyance shall be operated under the charge of a person appointed as conductor, and no person other than this conductor shall give any signal for the movement of the cage or other conveyance.

At every mine in which 100 or more men are employed underground, whenever men are being lowered or hoisted at the beginning or end of a shift, there shall be with the hoisting engineer an extra man competent to operate the engine in an emergency.

In hoisting or lowering men with a bucket, the speed, except in the case of apprehended danger, shall not exceed 200 feet per minute when the bucket is within 100 feet of the surface or 500 feet per minute in any other part of the shaft.

The superintendent of the mine shall be responsible for the enforcement of the provisions of this section.

## SECTION 34

### Hoisting Ropes

It shall be unlawful to use in any mine any rope or cable for hoisting or lowering either men or material when such hoisting or lowering is done by any means other than human or animal power, unless such rope or cable shall be composed of metal wires, with a factor of safety determined as hereinafter set forth: Provided, however, That such metal wires may be laid around a hemp center.

The factor of safety of all such ropes or cables when newly installed in shafts less than 3,000 feet deep shall in no case be less than six and shall be calculated by dividing the breaking strength of the rope, as given in the manufacturers' published tables, by the sum of the maximum load to be hoisted plus the total weight of the rope in the shaft when fully let out.

It shall be unlawful to use any rope or cable for the raising or lowering of men when its factor of safety, based on its existing strength and dead load, shall have fallen below 4.5.

It shall be unlawful to use any rope or cable of the so-called 6 by 19 standard construction for the raising or lowering of men, either when the number of broken wires in one lay of said rope exceeds six or when the wires on the crown of the strands are worn down to less than 65 percent of their original diameter or when the superficial inspection provided for in this section shows marked signs of corrosion: Provided, however, That, when such broken wires are reduced by wear more than 30 percent in cross section, the number of breaks in any lay of the rope shall not exceed three.

The superintendent of a mine shall keep a record of every hoisting rope used at the mine or mines in his charge, noting the length and cross-sectional dimensions of the rope, the construction of the rope, the kind of core, the number of strands, the construction of the strands, the number of wires per strand, the class of steel of which the wires are made, the breaking stress of such steel, the breaking load of the rope, the name and address of the maker, the date of manufacture, the date of purchase, the date when put in use, the designation of the shaft and compartment in which the rope is used, the dates of resocketing, reclipping, reclamping, recapping, and shortening, the length of rope cut off at each such operation, the dates of reversing ends, and the date when discarded. A copy of this record shall be filed with the inspector of mines.

It shall be unlawful to use any hoisting rope after three years from the time of its first installment, irrespective of whether use of the rope in the interval has been continuous or intermittent, unless a piece be cut off from the socket end of said rope and

subjected to an actual breaking test in the laboratory of a responsible rope manufacturer or a testing laboratory of recognized standing and shall be found thus to be above the minimum limit of strength as prescribed in this section.

Every hoisting rope whereof the hook for connecting with the skip, cage, bucket, or other conveyance is made by means of a babbitted or zinc-filled socket must be resocketed at frequent intervals, at least 6 feet of the rope being cut off, and every rope whereof the connection be made by clamps or clips must be reclamped or reclipped with the same frequency as herein specified for sockets, at least 6 feet of the rope being cut off at each time: Provided, That if the expected rope life, based on previous experience, be less than 10 months the resocketing must be done every month, And provided further, That if the expected life be between 10 and 15 months, the resocketing must be done every 2 months; if between 15 and 21 months, the resocketing must be done every 3 months; if between 21 and 24 months, the resocketing must be done every 3-1/2 months; and if over 24 months, the resocketing must be done every 4 months.

When a new hoisting rope is installed, it must be run for at least ten trips under full load before it is used for lowering or hoisting men and, after each resocketing, reclipping, reclamping, or recapping, every rope shall be similarly run for at least four trips before it is used for lowering or hoisting men.

All ropes shall be superficially inspected once in every 24 hours by some competent person designated for that purpose by the superintendent. It shall be the duty of the superintendent to cause an examination to be made whenever a rope is resocketed, reclamped, or reclipped by cutting off from the lower end of such rope a section not less than 6 feet in length and having such section carefully examined both exteriorly and interiorly for corrosion and breaks. If upon any inspection such hoisting rope or cable shall be found to be below the requirements set forth in this section, it shall be disused for such purpose forthwith, and any operator or superintendent using or permitting the use of such hoisting rope or cable for the purpose of hoisting or lowering men thereafter shall be deemed guilty of a misdemeanor and shall be punished as hereinafter provided.

Every rope used for hoisting or lowering men or materials shall be securely fastened to its drum or reel and when in use shall never be fully unwound; at least one full turn shall remain always on the drum or reel. The end of the rope attached to the conveyance in the shaft shall either be securely fastened within a tapered socket or else it shall be bound around an oval thimble and then fastened to itself by such number of clips or clamps as will develop at least 80 percent of the strength of the rope and the rope connection shall be maintained at least at that point of efficiency.

Every hoisting rope shall be treated with oil or some suitable rope compound at least once every month. Such compound shall be chemically neutral and shall be of such consistency as to penetrate the strand and not merely cover the surface of the rope:

Provided, That the terms of this section shall not apply to the hoisting and lowering of men in shafts over 3,000 feet deep: Provided further, That the terms of this section shall not apply to the hoisting or lowering of water or other material in shafts used exclusively for that purpose and whereof no compartment is used for the hoisting or lowering of men. If any shaft exempted by this proviso has a compartment for pipes

or any other purpose than hoisting, and repairs or the attention of men be required in such compartment, hoisting through the shaft must be suspended while the men are in it.

The depth of incline shafts shall be taken as the vertical depth measured from the shaft collar.

APPENDIX G

ONTARIO'S ROPE RECORD FORM



## EXTRACTS FROM MINING ACT

## Section 160 s.s. 264 (a), (b), (c), (d), (e), (f), (g), 273

(264) (a) No hoisting rope shall be used which has not been tested by the Ontario Cable Testing Laboratory and for which a certificate of such test is not in the possession of the user.

(b) No hoisting rope shall be used which is not accompanied by a certificate from the manufacturer giving the following information: name and address of manufacturer; manufacturer's rope number; date of manufacture; diameter of rope in inches; weight per foot in pounds; number of strands; class of core; percentage by weight of lubricant in core; trade name of interior rope lubricant; number of wires in strand; diameter of wires in decimals of an inch; breaking stress of steel of which the wire is made in pounds per square inch; standard torsion test of wires; actual breaking load of rope as provided by clause (a) of this rule; length of rope.

(c) When a rope is put on in any shaft compartment or hoisting way the foregoing data along with the additional following information shall be entered in a book termed the Rope Record Book:

name of party from whom purchased; date of purchase; date put on in present location; identification number of rope; name of shaft or winze and compartment in which rope is used; weight of shaft conveyance; weight of material carried; maximum length of rope in service below sheave; maximum weight of rope in service below sheave; static factors of safety (at conveyance connection and at head sheave with rope fully let out); and date put on and removed from previous locations, if any.

(d) Duplicate copies of such entries shall be forwarded to the Chief Inspector at the time the rope is put on in any location.

(e) The owner or manager shall keep or cause to be kept at the mine a book termed the Rope Record Book in which shall be recorded in addition to the information referred to in clauses (b) and (c) of this rule, a history of the hoisting rope outlining the date on which the rope was first put on, date of shortening, dates and results of breaking tests, date and reason for taking off for

each occasion the rope is put into and taken out of service.

(f) The Rope Record Book shall always be open for inspection by the Inspector.

(g) When a hoisting rope is taken out of service from any shaft compartment, notice to that effect shall be forwarded to the Chief Inspector, giving the date, the reasons for discarding or discontinuing the use of such rope, disposition of rope, and such other information as he may require.

(273) At least once in every six months the hoisting rope shall have a portion not less than eight feet in length cut off the lower end, from a position above the clamps or other attachment. The length so cut shall have the ends adequately fastened with binding wire before the cut is made, to prevent the disturbance of the strands, and shall be sent to the Ontario Government Cable Testing Laboratory for a breaking test. The certificate of such test shall be kept on file and a summary thereof recorded in the Rope Record Book.

## INSTRUCTIONS FOR PREPARATION OF TEST SPECIMENS

The portion of cable sent to the testing laboratory shall be the eight feet above the socket or clamps. This test piece should be kept free from bends and should be shipped in a box or attached by staples to a two-inch board, eight feet six inches in length. The ends should be wrapped in burlap to prevent injury to persons in handling. Before cutting at least two seizings or servings of soft iron wire, each about one and a half inches long, shall be placed tightly upon the rope at a distance apart equal to the length of the test specimen (96 inches). If the ends of wire rope are not properly secured the relation of tensions in the rope will be disturbed. Hence it is most important that proper seizings be placed at each side of any point at which the rope is to be cut. If possible two or three seizings should be employed at each side of a cut. Annealed iron wire should be used, the suitable size being from .054-inch diameter for half-inch rope to .080-inch diameter for rope one inch in diameter and .105 inch for rope two inches in diameter.

Attach a label to each test specimen showing clearly the Rope, Shaft, and Compartment numbers, and the name of the mine.

FIGURE G-2. BACK SIDE OF RECORD

APPENDIX H

EVALUATION OF THE PRINCIPLES AND APPROACHES  
OF THE INSPECTION OF WIRE ROPES BY  
ELECTROMAGNETIC METHODS

APPENDIX H

EVALUATION OF THE PRINCIPLES AND APPROACHES OF THE  
INSPECTION OF WIRE ROPES BY ELECTROMAGNETIC METHODS

by

H. L. Libby

Introduction

Good practice in the use of wire ropes dictates the initial establishment and continuance of good operating conditions and regular maintenance activities. Rope can be damaged by improper use and neglect. Lack of lubrication can result in deterioration caused by corrosion. Improper handling may result in broken or flattened wires. Defects resulting from misuse, lack of proper lubrication and use beyond normal expected life can result in failure.

Wire rope is used in many critical locations where safety of people and property depend upon its integrity. Thus, it is important that periodic inspections be made to assure maintenance of safe conditions. Visual inspection of wire rope may reveal damage to the outer wires, but serious internal defects may exist and yet be missed by such external inspection. Some users of wire rope have supplemented the more usual maintenance procedures and periodic inspections with an electromagnetic nondestructive testing method which gives some information about external and internal conditions without removing the rope from service and without affecting its serviceability.

Activity in the development or application of electromagnetic methods of inspection of wire rope has been greatest in South Africa, Germany, Poland, Belgium, and Canada.

The objective of this limited study is to evaluate the principles and approaches of the inspection of wire rope by electromagnetic methods based upon the study of five immediately available accounts<sup>(1-5)</sup> of the subject. The evaluation and conclusions given and based upon extensive experience in the development and application of electromagnetic nondestructive tests for tubing and rod material. However, it is emphasized that this experience has not included the inspection of wire rope. It is usually not possible to transfer all of the techniques developed in one problem area to another because of special problems encountered in the new area. Thus, it is important that experimental work be performed to check critical points in the evaluation and in the suggested alternative approaches.

Summary and Conclusions

The principles of the dc and ac electromagnetic methods of inspection of wire rope are described. Five available articles related to the nondestructive inspection of wire rope are reviewed.

Both of these general methods are well founded on physical principles which have been applied for many years in the inspection of metal products. The principles differ, and thus there is a difference in the performance of the two methods.

Means to interpret the chart records obtained with the ac method have not been as highly developed as those obtained with the dc method. However, the ac method, with its ability for producing more information about the test object has the greater potential for future development. A general choice between the two methods in the stage of development described in the articles reviewed cannot be made as performance depends upon many factors.

The dc method appears to give best results for the detection of broken wires, whereas the ac method appears most effective in detecting corrosion and wire flattening. The ac method, operating as described at 10 Hz or above would be less effective in the inspection of locked coil ropes as its ability to penetrate the material is less effective than that of the dc method. The dc method was reported to be less effective in the detection of flattened wires than in the detection of corroded wires. The ac method was reported to be ineffective in detecting simple, uncomplicated wire breaks having small separation or gap. Both methods, as described, respond to variations in the magnetic characteristics of the wire. This is advantageous when such variations are a measure of integrity. However, variations in magnetic characteristics may occur without indicating loss of test object integrity.

Future development of these techniques can proceed in several areas. Combining the magnetic saturation technique with the ac method should result in reduction of the ac method's sensitivity to variations in magnetic characteristics of wire rope. This should reduce variations in signals caused by magnetic permeability variations due to cyclic loading, earth's magnetic field, and residual stress. In addition, depth sensitivity would be increased giving special advantage in the inspection of locked coil ropes. In this technique, flaw conditions would be detected mostly by the eddy current effect, and special problems may arise. For example, less difference would be expected to be observed between cross-section loss and contact between wires when the magnetic saturation technique is used.

The use of multifrequency techniques, with or without the magnetic saturation technique, offers a means to increase the amount of information obtained from the electromagnetic inspection. More advanced development could lead toward the automatic interpretation of instrument output signals.

### Basic Principles

Two major electromagnetic inspection methods, one known as the dc method and the other known as the ac method, are available for use in the inspection of wire rope made of electrically conducting ferromagnetic material. The two methods are identified by the dynamics of the magnetizing field used for the inspection. The method using a steady magnetic field is known as the dc method, whereas the method using an alternating field is known as the ac method.

The concept of electromagnetic induction is basic to both inspection methods. Faraday's law of electromagnetic induction associates an electromotive force with the rate of change of magnetic flux threading a circuit. The relationship can be stated by

the equation  $V = - \frac{d\phi}{dt}$  where  $V$  is the emf associated with the flux  $\phi$ . The change in flux can be caused either by the movement of the source of a steady magnetic field as in Figure H-1a (dc method), or by the variation of the strength of the source of the magnetic field as in Figure H-1b (ac method). Thus, in Figure H-1a a steady magnetic field is set up by the direct current flowing in loop 1. A portion of this flux threads loop 2, but as long as this flux does not change no emf is induced in loop 2. However, if there is relative motion between loop 1 and loop 2 resulting in a change in the amount of flux threading loop 2, an emf is thereby induced in loop 2. If loop 1 is replaced with a permanent magnet, similar relationships hold. If loop 2 is replaced with a coil having  $N$  turns, each threaded by magnetic flux  $\phi$ , the emf is  $V = - N \frac{d\phi}{dt}$ .

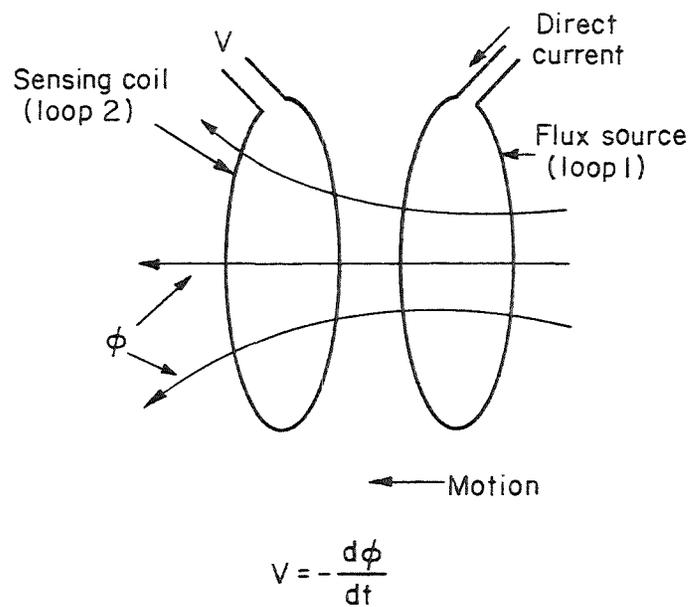
In Figure H-1b, the two loops are fixed in position, and the magnetic flux threading loop 2 varies because of its alternating nature arising from the alternating excitation current in loop 1.

Important features of the two methods are shown in the simplified diagrams in Figure H-2. A single wire with a notch defect is shown as a test object in each case for simplicity. Complicating factors arising from the multiplicity of wires in a rope will be treated separately. It is noted that except for the addition of the test objects and a minor change in coil positions the diagrams are the same as those in Figure H-1.

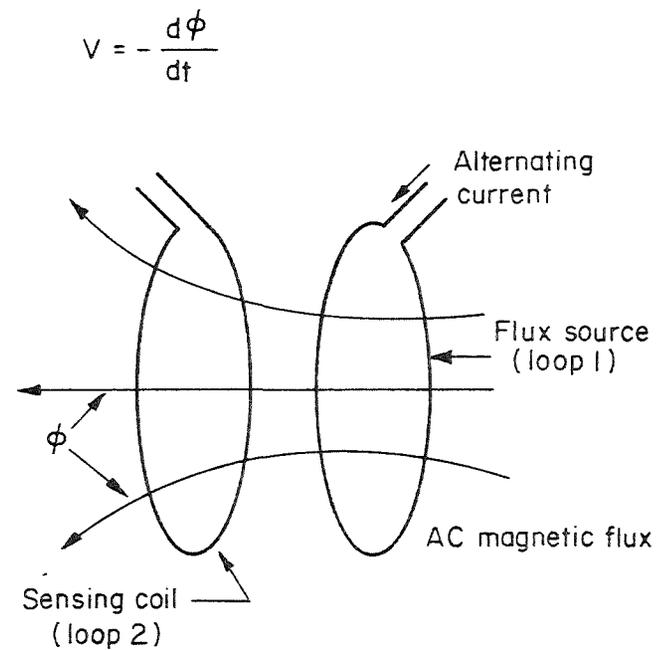
In the dc method depicted in Figure H-1a, the magnetic test object is magnetized by the field of the steady field of the excitation coil. In the example shown this field is established by the direct current flowing in the excitation coil. Alternatively this field may be provided by one or more permanent magnets. If the test object is uniform in cross section and in magnetic characteristics the magnetization produced in it is symmetrical with respect to the coil, and as the test object is moved through the coil no net change occurs in the magnetic flux threading the sensing coil. Thus, no emf is induced in the sensing coil. However, if an irregularity exists, such as the notch shown, the flux is no longer uniform. Leakage flux exists and as this region moves through the sensing coil an emf is induced in the sensing coil. Thus, the presence of the defect can be detected by monitoring the sensing coil emf. The signal observed is proportional to the velocity of the test object. It also varies in a more or less complicated manner with the severity of the defect and strength of the exciting field.

In contrast, the ac method, depicted in Figure H-2b, does not require motion of the test object except as desired for scanning the test object. The alternating excitation current sets up an alternating magnetic flux. This flux, in accordance with Faraday's law, produces an emf within the test object. Eddy currents flow as a result of this emf and set up a secondary alternating magnetic field. This field and the original primary field are monitored by observing the emf induced in the sensing coil. The flow of eddy currents is affected by test object electrical conductivity, diameter, shape, and magnetic permeability as well as by the presence of cracks, porosity and other irregularities. The effect of these variations may be considered as being reflected in the emf's induced in the sensing coil, or alternatively, as affecting the impedance of a coil which is used simultaneously as an excitation coil and sensing coil.

Both views are valid and result, in principle, in the same type of performance diagrams. The eddy current nondestructive inspection method has been very highly developed and is used extensively in the metals industry. (6)

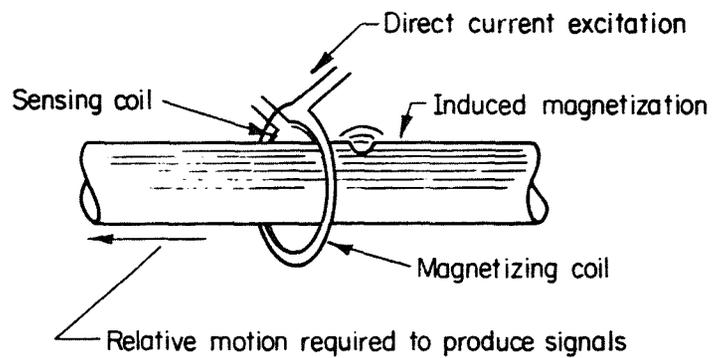


a. Fixed Excitation and Relative Motion Between Loop and Source

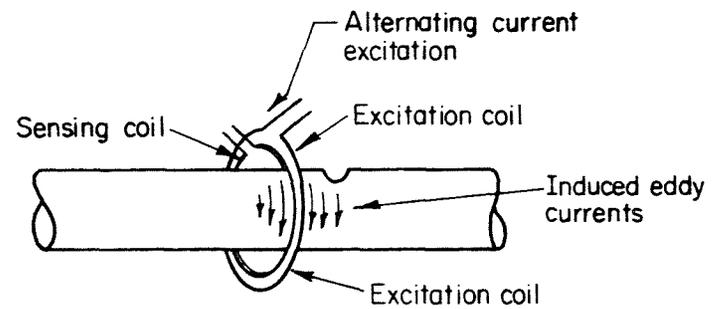


b. AC Excitation. Loop and Source Stationary

FIGURE H-1. FARADAY'S LAW OF ELECTROMAGNETIC INDUCTION



a. DC Method



Relative motion required only to produce desired scanning of test object

b. AC Method

FIGURE H-2. TWO MAJOR ELECTROMAGNETIC TEST METHODS



contains many wires, variations in contact between wires gives an effect similar to conductivity variation. Thus, the change in magnetic permeability and change in conductivity or wire contact variations affect the impedance components differently. The instrument used to analyze the coil output signal can be designed to discriminate between these effects. A change in diameter causes impedance variations approximately along the same locus CD. The relative position of the operating point C also varies with conductivity and operating frequency. Loci for  $\mu d$  for higher values of test object conductivity are shown labeled  $\mu, d, \sigma_2$  and  $\mu, d, \sigma_3$ . The conductivity locus is labeled  $\sigma$ , and the arrow indicates the direction of increasing conductivity. Change in operating frequency also affects this diagram, but this is beyond the scope of the present discussion.

If the test object within the inspection coil is nonferrous, impedance diagrams of the type shown in Figure H-4 apply. The point A represents the empty coil reactance, and the curve labeled  $\sigma$  represents the impedance locus obtained as the electrical conductivity of the test object is increased. Variation in diameter results in impedance loci labeled  $d$ . The particular loci depends upon the value of the conductivity. It appears possible to inspect ferrous wire rope under these conditions by magnetically saturating the rope, making it behave electromagnetically as though it were nonferrous. The effect of wire-to-wire contact may be crucial here for it may differ very little from that of diameter variations. If so, it will be difficult to distinguish between corrosion and loss of wire-to-wire contact.

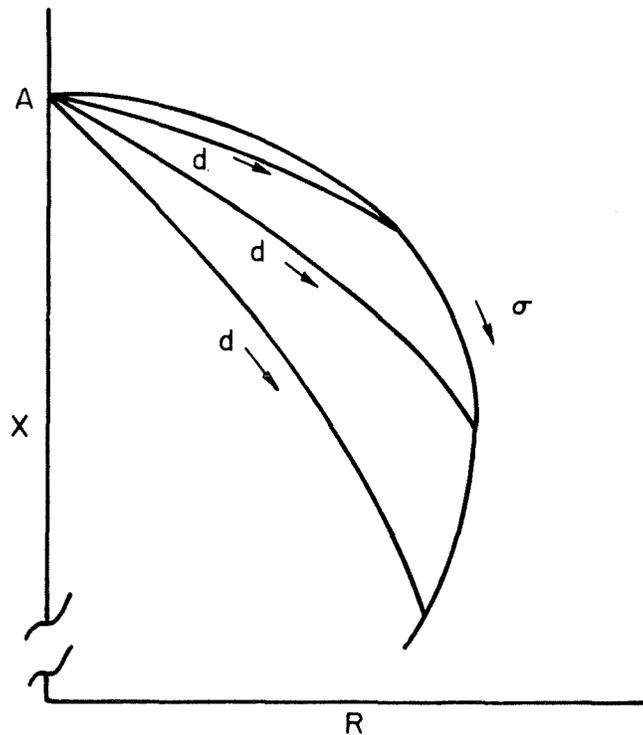


FIGURE H-4. INSPECTION COIL IMPEDANCE LOCI  
NONFERROUS CONDUCTING CORE

The multiparameter eddy current test method developed at Battelle-Northwest has the ability to discriminate between more test variables or parameters than can be done with the conventional single frequency method. For example, whereas a single frequency system can discriminate between two test variables, a two-frequency multiparameter system can discriminate between four variables. The application of such a method to the wire rope inspection problem might give dramatic improvement in discriminating between desired and undesired signals. The potential of this method is shown in a report<sup>(7)</sup> in which signals caused by simulated tube supports made of stainless steel and of iron were discriminated against, permitting the detection of artificial tube defects.

### Review of Related Articles

Lang<sup>(1)</sup> presents a description of the operation and commercial experience obtained with a specific wire rope inspection device which uses the ac method with inspection coil excitation at either 30 Hz (csp) or 80 Hz. He states that the reliability of the type of equipment used has been previously adequately demonstrated in the detection of wire rope metal loss caused by wear and corrosion. It is his stated purpose to present an outline of anomalies and condition found in use of the device in Canada and the United States, to discuss the response of the device to broken wires, and to tests of locked coil ropes.

The device uses a single-turn excitation coil encircling the rope to be inspected. Alternating current flowing in this coil establishes an alternating magnetic field which is modified as a result of the magnetic properties of the wire rope which is fed through the coil. Both the ferromagnetic properties of the rope and the magnetic fields (called secondary fields) set up by eddy currents induced in the rope are included in the "magnetic properties." The changes in the magnetic field are monitored by a sensing or search coil fixed in relation to the excitation coil. The signals developed in this sensing coil are processed by the instrument. Two output channels are provided, called the X and the R channels, and are recorded on a channel recorder. The recording is a continuous record, and, assuming constant rope speed, the position of signals along the chart record are related to the location of corresponding anomalies along the wire rope. The optimum rope speed is specified to be about 200 feet per minute. The speed is stated to be not critical and may have large fluctuations without appreciably affecting the inspections.

The X output trace is stated to respond mostly from loss of metal, but is also affected some by permeability variations and by eddy current variations. The eddy current variations referred to here are caused by varying contact between wires. Corrosion or wear would also give indications on the channel since such conditions result in loss of metal.

The R output trace is stated to be mainly affected by eddy current changes. Such changes may be caused by variation in contact between wires. The presence of sludge on film between the wires can reduce the amount of contact between wires.

Interpretation of signals is aided by having the two channels, "X" and "R", available. For example, changes in the X trace caused by variations in adjacent wire contacts will be accompanied by variation in the R trace. Thus, the use of both channels

may contribute to the interpretation of signals. Lang discusses the problem of broken wires which is of considerable concern. He points out that the type of break determines the response of the instrument to the broken wire. Broken wires accompanied by flattening, plastic wear, peening or signs of abrasions have been detected. In some cases sections of rope with "apparent" missing wires were found. Fatigue conditions in the absence of corrosion or wear are not detected.

Lang presents a series of test results in the form of records of the "X" and "R" instrument channels for a variety of test conditions. The first group, Figures 3 to 6, illustrates the detection of corrosion effects, which in general grow progressively worse between successive tests. Figure 6 shows that three galvanized ropes gave only minor signals, whereas an ungalvanized rope in the same installation produced significant signals and corrosion was observed.

The next group, Figures 7 to 10, illustrates mainly the detection of broken wires, but the correlation here is not as definite as in the case of the detection of corrosion. In several cases the loss of strength of the rope was believed to be greater than the estimates based on the chart record only.

The last group, Figures 11 and 12, shows comparative test results of locked coil ropes using 30 Hz and 10 Hz operating frequencies. In the test of two ropes (Figure 11) estimated loss of strength correlated moderately well with actual loss of strength, with peak estimated strength loss being underestimated about 20 percent. Another test of a locked coil rope (Figure 12) showed poor correlation, the strength loss being underestimated by a factor of about 10.

Lang concludes that electromagnetic wire rope testing is becoming more widespread, that many serious rope defects have been detected by the method, and that a regular program of inspection is desirable. He emphasizes that the limitations of the method must be considered, and that it should be used with a regular maintenance and inspection program for maximum benefit.

Comment. The results of tests reported by Lang show the ac method most effective in the detection of loss of cross sectional rope area, especially that caused by corrosion. Detection of broken wires does occur, but this depends upon other conditions accompanying the break. It appears that customer confidence in the test would be increased if some kind of representative sample rope specimen with known flaws was checked before and after each inspection for comparison purposes. Chart records of such reference specimens would be valuable in establishing credibility.

No mention is made of displaying the signals in an X-Y, vector point, or phasor presentation as in Figure 3 of this report. Such presentations have been found to be useful in aiding the interpretation of eddy current inspection signals obtained in the course of inspecting tubing, rods and wire.

The general lack of penetration of the field into the rope because of the ferromagnetic nature of the rope material presents a special problem. This is especially critical in the case of the locked coil ropes. The tests described using 10 Hz instead of 30 Hz are interesting but are inconclusive. This reduction in frequency increase the standard depth of penetration (plane wave case for bulk material) by a factor of only 1.73.

The test as described responds to variations in wire magnetic permeability, some of which may not necessarily affect rope servicability.

The use of the magnetic saturation technique has been found very effective in the inspection of ferromagnetic materials using the eddy current (ac) inspection method, and might well contribute to the effectiveness of the inspection of wire rope.

Higginson and Butler<sup>(2)</sup> discuss the ac method and the dc method for inspecting wire rope. The dc method is emphasized, with the ac method being treated briefly. The authors point out the need for detecting localized defects of corrosion and broken wires, and the need for the inspection of locked coil ropes. They indicate that the ac method was found to be incapable of detecting localized defects.

The use of differentially wound inspection coils is mentioned. The M. D. 6 instrument which uses a permanent magnet for magnetizing the rope is described briefly. A German instrument is also mentioned which uses a dc coil for magnetization and 4 saddle-type search coils (see discussion in this report of the paper authored by Helmut Crupe). A Japanese equipment is mentioned which uses search coils which are hand wound around the rope at the time of each inspection.

Higginson and Butler discuss the performance of the dc and permanent magnet instruments. Highlights of this discussion are:

- (1) Inspection coil output signals can be analyzed mathematically to aid in their interpretation, but this is tedious.
- (2) Rope having fabricated defects was used to compare various instruments, but the defects differed from the specifications.
- (3) Breaks in wires having gap lengths less than 1 mm cannot be detected.
- (4) Corrosion is indicated by a high general noise level, and severe corrosion can mask the wire break signals.
- (5) Residual magnetism may affect instrument records.
- (6) Little information is available on the correlation between instrument test records and faults found in locked coil ropes.
- (7) Good safety record of wire rope use is cited.

The relationship between length of wire break gap and signal pattern is shown. Also shown are the effects of fault radial position, the effects of coils having large and small diameters, the effect of a short fault and the effect of a long fault.

Comment. The conclusion that the ac technique could not detect localized defects may have been based on use of specific equipment rather than on real basic limitations of the method. This should be checked both analytically and experimentally.

The statement about residual magnetization is pertinent, and demagnetization as suggested should reduce the severity of this problem. (It is noted that demagnetization and magnetic saturation are different techniques.)

The work using inspection coils having different diameters is very good and this approach should be further explored. Altogether, this account shows that the "dc" or magnet-inductive inspection procedure has been highly developed.

Ross<sup>(3)</sup> discusses the use of the M. D. 6 instrument. This paper deals mostly with the operation of the equipment and briefly describes the principle of operation. Again, two coils having different diameters are available and the magnetizing force is provided by a permanent magnet. Sensitivity is claimed to be 0.2 percent of the cross-sectional area of the steel. Calibration charts are used to estimate the severity of the fault and the location of the fault. These charts are supplemented with signal patterns of sample faults as an aid in estimating gap length in the case of broken wires.

Comment. This paper does not give test results to support the statements about its effectiveness. The brief account of the use of calibration charts and sample fault signals is very interesting and again shows that the dc method has been highly developed.

A description of the M. D. 6 instrument<sup>(4)</sup> summarizes its main features. Only those features of dc equipment not previously mentioned before in this report will be given here.

Bronze "slippers" are used to give guidance for the rope to center its position with respect to the inspection coils. A roller running on the rope being inspected provides means to synchronize chart paper speed with rope speed, and provides means to compensate instrument sensitivity for variations in rope speed. The controlled speed range is from 2 to 8 feet per second.

Amplifier gain ratios of 1:32, 1:16, 1:8, 1:4, 1:2, and 1:1 are provided. Use of the equipment on either moving ropes or standing ropes is described.

The need for skill in interpreting inspection results is emphasized. The advantages of the use of calibration charts furnished are stressed. Periodic tests of wire ropes are suggested.

Comment. This is a concise description of the instrument for the prospective purchaser or user.

Grupe<sup>(5)</sup> gives an excellent detailed account of the development of a magnetic inductive procedure for the inspection of wire rope. This method is based on the same principles as the approach identified as the dc method in other papers. He gives an approximate analysis of the magnetic principles. His work was done to overcome disadvantages observed in earlier equipment. Work was done leading to the design of a new magnetizing system and new sensing coils. He showed that by using separated partial coils more information about the location of a flaw could be obtained.

The magnetization and leakage flux of an idealized magnetic test object were studied to give increased understanding of the principles involved in the magnetic-induction inspection method.

He studied the effect of coil width and rope wire break length on observed signals. He made measurements using a bundle of rods containing 91 wires, 2 meters long and 4 mm in diameter. Rope wire breaks were simulated by removing a wire, cutting it, and replacing the two pieces with known separation between the cut ends. The effects of multiple breaks were also studied in this manner. Here he found that under certain conditions some signals cancelled other signals, and suggests that this effect is probably common to other inspection processes. Loss of sensitivity with depth of wire break within the bundle was also studied.

Grupe discusses factors affecting signals not directly related to loss of cross section. He mentions variable air spaces between the wires, change of wire direction, chemical and structural variation in the wires, and effects of tensile loading.

The signal amplitude varies in direct proportion to rope speed, thus it is desirable to automatically control the instrument amplifier gain. A circuit for doing this is described. Means are also described for driving the recorder chart paper from the motion of the rope to assure that the length of any portion of the record is proportional to the corresponding section of rope. Grupe explains that a nondefective rope produces background signals, which he calls the interference level. Wire breaks give sharp signals which may be observed to exceed the background signals. He shows how the sector location of wire breaks can be determined by simple interpretation of the 4 traces obtained from four partial coils.

The presence of rust causes an increase of the interference level. The amount of signal increase depends both on the amount of rust and upon the location of the affected wires. Thus, there is no simple relationship between signals and loss of rope strength. Grupe states that the flattening of wires causes signals which are smoother than those arising from the rest condition. For equal signal (interference level) the weakening (strength loss) is much greater for pressure and abrasion areas than for rust.

Corkscrew distortions are detected using the individual records of the partial coils. Sudden changes in diameter cause changes in the interference level because of the change in coupling between wire and coils. Grupe points out that, whereas interior wire breaks may not always be detected, the method does assure the detection of weakened conditions in the outer layers of wire before the conditions become dangerous.

He emphasizes that the interpretation of the diagrams is difficult, and belongs in the "hands of the expert."

Comment. This is a detailed account of the theory and of experimental investigations of the dc (magnets inductive) method of inspecting wire rope. It is a good source for the stimulation of ideas for further development of the method. It further illustrates that a large amount of effort has been given to the development of the dc method.

Considerations covering the optimum number of times discussed by Grupe should be carefully studied. Further experimental and analytical work is needed here, since his conclusions in this area may be of limited value, probably being a function of the specific equipment which he used.

Discussion

Both of the general methods, the so called ac method and the dc method, described in the articles which have been reviewed are well founded on physical principles which have been applied for many years in the inspection of metal products. Each method requires special operator skills to interpret the instrument output signals or chart records. There appears to have been more work done to provide interpretation aids for the dc test than for the ac test.

The paper by Lang<sup>(1)</sup> on the ac method does not specifically cover the topic of signal interpretation aids, but rather gives the chart records of many ropes and describes the corresponding rope conditions. The papers reviewed do not give any detailed account of the ac theory. These two important areas are possibly treated in other papers not available for this brief study.

The dc method appears to respond best to wire breaks and severe corrosion. It is less reliable for the detection of wire flattening. In contrast, the ac method appears to respond best to corrosion and wire flattening, and is less responsive to simple, uncomplicated, wire breaks. Both methods respond to variations in the magnetic permeability of the wire rope, and these may not necessarily adversely affect the serviceability. The ac method gives indication of electrical contact between wires. This summary of response effects presents an oversimplified picture as rope conditions vary greatly and there is considerable overlap between the performance of the two methods.

References

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- (2) N. Higginson and R. Butler, "Non-Destructive Examination of Steel Wire Ropes", Special Report.
- (3) A. C. Ross, "The Use of the Magnetic Defectograph, M. D. 6", The Canadian Mining and Metallurgical (CIM) Bulletin, p. 425-431, April, 1969.
- (4) Notes on "Varimex" Magnetic Defectograph Type M. D. 6.
- (5) H. Grupe, "Development of a Plan for the Testing of Hoisting Cables by the Magnetic-Inductive Procedure", West German Publishing House/Cologne and Opladen, 1961.
- (6) R. C. McMaster, Ed., Nondestructive Testing Handbook, Vol. 2, Ronald, New York, 1959, pp. 36-1 to 42-74.
- (7) H. L. Libby and C. R. Wandling, "Transformation (Analyzer) Device Using Post-Detector Signal Pattern Rotators for Multiparameter Eddy Current Tester", BNWL-1469, Battelle-Northwest, Richland, Washington, July, 1970.

APPENDIX I

MINE OPERATORS CONTACTED

## APPENDIX I

MINE OPERATORS CONTACTEDCoal Mining Companies Sent QuestionnairesAlabama

Alabama By-Products Corp.  
Maxine Mine  
Maxine

Black Diamond Coal Mining Co.  
Black Diamond No. 3 Mine  
Bessemer

Republic Steel Corporation  
Sayre Coal Mine  
Adamsville

Southern Electric Generating Co.  
SEGCO No. 1 Mine  
Parrish

United States Pipe & Foundry Co.  
Bessie Mine  
Adamsville

United States Pipe & Foundry Co.  
Flattop Mine  
Flattop

Woodward Iron Company  
Mulga Mine  
Mulga

Colorado

C. F. & I. Steel Corporation  
Allen Mine  
Weston

Clayton Coal Company  
Lincoln Mine  
Erie

Imperial Coal Company  
Imperial Mine and Coal Co.  
Erie

Illinois

Bell & Zoller Coal Co.  
Ziegler No. 4 Mine  
Johnston City

Bell & Zoller Coal Co.  
Murdock Mine  
Murdock

Consolidation Coal Co.  
Hillsboro Mine  
Coffeen

Inland Steel Company  
Inland Mine  
Sesser

Peabody Coal Co.  
No. 10 Mine  
Pawnee

Peabody Coal Co.  
Eagle Mine  
Shawneetown

Sahara Coal Company, Inc.  
Sahara No. 5 and 16 Mines  
Harrisburg

Zeigler Coal & Coke Co.  
Spartan Mine  
Sparta

Indiana

Ayrshire Coal Co.  
Thunderbird Mine  
Farmersburg

Iowa

Big Ben Coal Company  
Big Ben Mine  
Chariton

Lovilia Coal Company  
Lovilia No. 4 Mine  
Melrose

Kentucky

Bell & Zoller Coal Co.  
Zeigler No. 9 Mine  
Madisonville

Brownies Creek Collieries, Inc.  
No. 2 Mine  
Balkan

Bubby Coal Company  
No. 9 Mine  
Hazard

Buckhorn Hazard Coal Corp.  
Buckhorn Mine  
Hazard

Cal-Glo Coal Inc.  
No. 1 Mine  
Barbourville

Caperton Coal Co., Inc.  
No. 2 Mine  
Hazard

Carr Creek Fuel Co.  
Hytemp Mine  
Sassafras

Cedar Creek Mining Co.  
Wheelright

Clearbrook Coal Company  
Clearbrook Mine  
Cumberland

Scuddy Tipple  
F & D Coal Co.  
Scuddy

Findley Coal Company  
No. 10 & 11 Mines  
Sibert

Kentucky (Continued)

Jakes Fork Coal Company  
Garno Tipple  
Bulan

John Creek Eikhorn Coal Corp.,  
No. 1 Mine and No. 2 Mine  
Kimper

Johnson Elkhorn Coal Co.  
Johnson Elkhorn Mine  
Garrett

Kentucky Mountain Coal Co.  
Kentucky Mountain Mine  
Manchester

Little Hackney Creek Coal Co.  
Little Hackney Creek Mines  
Mouthcard

Marthann Coals, Inc.  
No. 1 Mine  
Coalgood

Peter Cave Coal Co.  
No. 1 Mine  
Lovely

Pounding Mill Coal Co.  
Pounding Mill Mine  
McCarr

R & T Coal Company  
Mine No. 1  
Pikeville

Sigmon Construction Co.  
Merna Mine  
Coalgood

Thornton Elkhorn Coal Co.  
Lorraine Mine  
Thornton

Webster County Coal Corp.  
Dotiki Mine  
Clay

Whitaker Coal Corp.  
Francis Mine  
Hazard

Kentucky (Continued)

Matthews Mine  
Middlesboro

Belfry Coal Corporation  
Belfry Mine  
Belfry

Ohio

Island Creek Coal Co.  
Vail Mine  
Freeport

Midvale Coal Company, Inc.  
Midvale No. 7 Mine  
Midvale

North American Coal Corp.  
Ohio Division  
Cleveland

Oglebay Norton Co.  
Saginaw  
St. Clairsville

Oglebay Norton Co.  
Norton No. 3 Mine  
Jacobsburg

Peabody Coal Co.  
Sunnyhill No. 9 Mine  
New Lexington

Pennsylvania

Barnes & Tucker Company  
Lancashire No. 25B & D Mine  
Barnesboro

Barnes & Tucker Company  
Lancashire No. 20 Mine  
Barnesboro

Buckeye Coal Co.  
Nemacolin Mine  
Nemacolin

Helvetia Coal Company  
Lucerne No. 6 Mine  
Coral

Island Creek Coal Co.  
Hammer Division  
Tire Hill

Pennsylvania (Continued)

Johnstown Coal & Coke Co.  
Bear Run Mine  
Glen Campbell

National Mines Corp.  
Isabella Mine  
Isabella

North American Coal Corp.  
Pennsylvania Div.  
Conemaugh No. 1 Mine  
Seward

P & N Coal Company, Inc.  
Punxsutawney

Penn Allegheny Coal Co., Inc.  
Allegheny Mine  
Tarentum

Rochester & Pittsburgh Coal Co.  
Indiana

Rushton Mining Co.  
Rushton Mine  
Phillipsburg

Tunnelton Mining Co.  
Marion Mine  
Blairsville

Virginia

Black Diamond Fuel Co.  
Black Diamond Mines  
Conway

Clinchfield Coal Div.  
Pittston Company  
Moss No. 2 Mine  
Dante

Island Creek Coal Co.  
Virginia Pocahontas Div.  
Keen Mountain

Westmoreland Coal Co.  
Stonega Division  
Big Stone Gap

Washington

Palmer Coking Coal Co.  
Rogers Mine  
Black Diamond

West Virginia

Amherst Coal Company  
Paragon Section  
Lundale

B & L Coal Co.  
B & L Tipple  
Lynco

Bethlehem Mines Corporation  
Marion-Barbour Division  
Barrackville

Boone County Coal Corporation  
Mine No. 1  
Sharples

Burning Creek Fuel Corporation  
Number 2G Mine  
Kermit

Consolidation Coal Co.  
Mountaineer Coal Co., Div.  
Fairmont

Consolidation Coal Co.  
Osage

Consolidation Coal Co.  
Ohio Valley Division  
Moundsville

Consolidation Coal Co.  
Rowland Coal Co. Division  
Beckley

Galloway Land Co.  
Dawson Mine  
Clarksburg

Imperial Colliery Co.  
Imperial No. 11 Mine  
Eskdale

Indian Creek Mining Corp.  
No. 1 G Mine  
Morgantown

West Virginia (Continued)

Island Creek Coal Company  
Island Creek Division  
Holden

Moyce Mining Corp.  
Joyce No. 4 Mine  
Clarksburg

Lieving Mine  
West Columbia

The New River Company  
Mt. Hope

Pittsburgh & Redstone Fuel Co., Inc.  
Sun Valley Mine  
Bridgeport

Semet-Solvay Division  
Allied Chemical Corporation  
Bluefield

Slab Fork Coal Co.  
Slab Fork

Smith & Stover Coal Co.  
Hunter Mine  
Whitby

The Snap Creek Coal Co.  
Lyburn

Turner Coal Co.  
Morgantown

Union Carbide Corp.  
Ferroalloys Div.  
Putnam Mine  
Leon

Upshur Coals Limited  
Adrian Mine  
Buckhannon

The Valley Camp Coal Co.  
Northern Division  
Triadelphia

Wyoming

Gunn-Quealy Coal Co.  
Rainbown No. 7 Mine  
Frontier

Coal Mines VisitedIllinois

Orient No. 3 Mine	Freeman Coal Mining Corp. Waltonville
Orient No. 6 Mine	Freeman Coal Mining Corp. Waltonville
Old Ben No. 21 Mine	Old Ben Coal Corp. Sesser
Old Ben No. 24 Mine	Old Ben Coal Corp. Benton
Old Ben No. 26 Mine	Old Ben Coal Corp. Sesser

Indiana

Kings Station Mine	Kings Station Coal Co. Princeton
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Kentucky

Scotia Mine	Scotia Coal Co. Cumberland
Crescent Mine	West Kentucky Division Island Creek Coal Co. Central City
Fies Mine	West Kentucky Division Island Creek Coal Co. Madisonville
Hamilton No. 1 Mine	West Kentucky Division Island Creek Coal Co. Uniontown
Hamilton No. 2 Mine	West Kentucky Division Island Creek Coal Co. Morganfield
Uniontown Mine	West Kentucky Division Island Creek Coal Co. Uniontown

Ohio

Franklin No. 25 Mine	Hanna Coal Co. Cadiz
Rose Valley Mine	Hanna Coal Co. Cadiz
Nelms No. 1 Mine	Youghioghney & Ohio Coal Co. Cadiz
Nelms No. 2 Mine	Youghioghney & Ohio Coal Co. Hopedale
Allison Mine	Youghioghney & Ohio Coal Co. Beallsville
Powhatan Point No. 1 Mine	North American Coal Corp. Powhatan Point

Oklahoma

Choctaw Mine	Kerr McGee Corp. Stigler
Howe Mine No. 1	Howe Coal Co., Inc. Heavener

Pennsylvania

Renton Mine	Pittsburgh Coal Co. Division Consolidation Coal Co. Renton
Harmar Mine	Harmar Coal Co., Pittsburgh Coal Co. Division, Consolida- tion Coal Co. Pittsburgh
Cambria Slope No. 33 Mine	Cambria Division, Bethlehem Mines Corp. Ebensburg
Nanty Glo No. 31 Mine	Cambria Division, Bethlehem Mines Corp. Nanty Glo
Ellsworth No. 51 Mine	Ellsworth Division, Bethlehem Mines Corp. Ellsworth

Pennsylvania (Continued)

Somerset No. 60 Mine	Ellsworth Division, Bethlehem Mines Corp. Ellsworth
Marianna No. 58 Mine	Ellsworth Division, Bethlehem Mines Corp. Marianna
Russellton Mine	Republic Steel Corp. Russellton
Newfield Mine	Republic Steel Corp. North Bessemer
Gateway Mine	Gateway Coal Co. Clarksville
Wanamie Mine	Blue Coal Corp. Ashley

Virginia

Virginia Pocahontas No. 3	Virginia Pocahontas Division Island Creek Coal Co. Keen Mountain
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West Virginia

Eccles No. 5 Mine	Winding Gulf Coals, Inc. Westmoreland Coal Co. Eccles
Eccles No. 6 Mine	Winding Gulf Coals, Inc. Westmoreland Coal Co. Eccles
MacAlpin Mine	Winding Gulf Coals, Inc. Westmoreland Coal Co. MacAlpin
Hampton No. 3 Mine	Hampton Division, Westmore- land Coal Co. Clothler
Hampton No. 4 Mine	Hampton Division, Westmore- land Coal Co. Clothler
Dehue Mine	The Youngstown Mines Corp. Dehue

West Virginia (Continued)

Dabney Mine	The Youngstown Mines Corp. Dehue
Olga Mine	Olga Coal Co., The Youngstown Mines Corp. Coalwood
Cannelton Mines	Cannelton Coal Co., Algoma Steel Corp. Superior

Noncoal Mines VisitedBritish Columbia

Texada Mines, Ltd.  
(Iron Ore)  
Texada Island

Ontario

Hardy Mine Fecunis Shaft Shaft No. 2	Falconbridge Nickel Mines, Ltd. Falconbridge
Strathcona Shaft No. 1	
Creighton Shaft No. 5 Shaft No. 9 Slope No. 3	International Nickel Copper Cliff

Tennessee

U. S. Steel Zinc Mine	United States Steel Corp. Jefferson City
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Letter of Inquiry  
and Questionnaire

Our facility has recently started a research program for the U.S. Bureau of Mines concerning wire rope in coal-mine applications. Our program objectives relate to the service conditions, maintenance and inspection procedures, and replacement criteria for the wire rope. We are currently concentrating on efforts in the area of hoisting applications in underground mines, but, hopefully, not to the exclusion of other important rope applications. In this context we have been talking with hoist machinery manufacturers, state regulatory agencies, and rope manufacturers. We are now beginning to contact mine operators which we recognize as the greatest single source of the knowledge we seek.

We would like to gain an in-depth understanding of problems and practices related to hoisting ropes in U.S. coal mines. Past experience with wire-rope applications and problems has shown us that to gain such an understanding requires us to determine and examine a fair amount of data related to the associated machinery and the environment in which the rope is used. To do this we have chosen to send questionnaires to a large number of operators, following them up with visits where it seems appropriate. Prior to finalizing the questionnaires in format and content, we visited about 15 mines, inspecting the hoisting and other rope applications and talking with operating personnel. We discussed the kinds of data we needed, the general availability of it, rope problems and failures that arise, how long the ropes are used, and typical maintenance and inspection procedures. The enclosed questionnaire was finally formulated in accord with what we learned and what we were led to believe would be acceptable to most mine operators in terms of how much effort would be required to answer the questionnaire.

The questionnaire has two parts: (I) General Information and Procedures; and (II) Engineering Data - Shaft/Slope Hoisting. Some of the general information and procedures questions, Part I, may be covered by operating, maintenance, inspection, etc., procedures or record forms which your company has already printed up. In these cases a reference for this literature after the appropriate question and copies of it would be sufficient and very much appreciated. The engineering data requested in Part II, though comprehensive, require mostly check marks or a few words or numbers as the example indicates.

Our mine visits have shown that the information we seek is not always available from one person or one office. We hope, therefore, that you will distribute or circulate the parts of the questionnaire as you see fit for most efficiently gathering the requested information.

We have enclosed three copies of the questionnaire with the thought that it may make distribution or circulation easier and in the event you would like to retain one for your files.

Please understand that although mine names and locations are requested on the questionnaire, we ask this information solely for our own use. Company and mine names and locations will not be identified with questionnaire answers in our final report.

On various occasions during our mine visits we have been asked for opinions on hoist rope problems. Furthermore we have, on occasion, brought back a piece of hoist rope containing an excessive number of broken wires or a broken strand for closer examination in an attempt to determine the cause of failure. We have often been asked what we will do with the information we get and, if it would be of benefit to the mine operators, could they be informed? We will compare the rope applications and practices data we receive with our knowledge and experience in rope problems and with the information we have received from the other major mining countries of the world from both mine operators and research and development efforts. The comparison should indicate if improvements in U.S. wire-rope practices in mines can be made consistent with safety and longer rope life and what these improvements would involve. We have mentioned to our sponsor the desire of mine operators thus far contacted to learn of the result of our program and we are considering how this might best be done.

We would be very pleased to have your cooperation and assistance in this program and look forward to your reply. If we can provide you with any other information about our program or can be of any assistance to you in any way, or if you have any questions at all, please call me or Mr. Charles Larsen collect.

We thank you for any efforts on our behalf.

Sincerely,



Richard A. Egen  
Senior Project Leader

RAE:mmg  
Encs.

QUESTIONNAIRE TO MINE OPERATORS  
REGARDING USE OF WIRE ROPE  
IN U.S. COAL MINES

Prepared by Long Beach Ocean-Engineering Facility  
Battelle Memorial Institute

(All Answers and Opinions will be Treated as Confidential)

PART I: GENERAL INFORMATION AND PROCEDURES

COMPANY \_\_\_\_\_

ADDRESS \_\_\_\_\_

NAME AND TITLE OF PERSON ANSWERING \_\_\_\_\_

DATE ANSWERED \_\_\_\_\_

\* \* \* \* \*

- (1) Our company operates \_\_\_\_\_ (number) underground mines.
- (2) In these mines, or associated with them, wire ropes are used in (please check as appropriate)
  - (a) \_\_\_\_\_ shaft hoisting: \_\_\_\_\_ men, \_\_\_\_\_ supplies, \_\_\_\_\_ coal
  - (b) \_\_\_\_\_ slope hoisting: \_\_\_\_\_ man trips, \_\_\_\_\_ supply cars, \_\_\_\_\_ coal
  - (c) \_\_\_\_\_ elevators: \_\_\_\_\_ men, \_\_\_\_\_ supplies
  - (d) \_\_\_\_\_ skip, cage, or elevator guidance (guide ropes)
  - (e) \_\_\_\_\_ tail ropes (friction hoists)
  - (f) \_\_\_\_\_ rubbing ropes
  - (g) \_\_\_\_\_ conveyors: \_\_\_\_\_ support, \_\_\_\_\_ belt tensioning
  - (h) \_\_\_\_\_ loader boom swings
  - (i) \_\_\_\_\_ railroad car positioning or retarders
  - (j) \_\_\_\_\_ mine car positioning
  - (k) \_\_\_\_\_ barge positioning
  - (l) \_\_\_\_\_ aerial tramways
  - (m) \_\_\_\_\_ other (please specify) \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(8) If Question 7 is not applicable, please indicate any experience with and/or opinions regarding nondestructive testing or inspection of installed ropes:

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(9) If shaft and slope ropes are strength tested after retirement, please indicate which ropes are tested and by whom:

<u>Rope Tested After Retirement</u>	<u>Tested By</u>
<hr/>	<hr/>

(10) Normally, retired shaft and slope ropes are disposed of as follows:

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(11) Our company \_\_\_\_\_ could \_\_\_\_\_ could not provide sample lengths of retired shaft and slope rope to Battelle for possible detailed inspection and testing for remaining strength. (If  X  could, please indicate how Battelle could obtain the sample.)

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(14) We \_\_\_\_\_ do \_\_\_\_\_ do not think that a visit or a telephone conversation with Battelle project personnel would be more appropriate for obtaining the requested information. (If  X  do, please indicate availability and where and with whom Battelle should meet):

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(15) Comments: \_\_\_\_\_

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PART II

ENGINEERING DATA - SHAFT/SLOPE HOISTING (Check or fill in as appropriate)

COMPANY

MINE NAME	EXAMPLE			
LOCATION				
APPROX. YEARLY OUTPUT (TONS) (If Applicable)	800,000 TONS			
SHAFT NAME/NUMBER	#2			
COMPARTMENT NAME/NUMBER	182			
	* * * * *	* * * * *		

SHAFT

Vertical	✓			
Slope (state degrees from vertical)				

HOISTING ARRANGEMENT

Skip	✓			
Cage				
Skip-cage combination				
Elevator				
Single Conveyance/ Counterweight				
Two Conveyances	✓			
Men				
Supplies				
No. of Loading Points	1			
Maximum Hoisting Depth	520 FT			
Head Sheave Height	80 FT			
Distance Head Sheave to Hoist	100 FT			
Chairs Used?				

ROPE(S) INVOLVED

Use				
Hoist	✓			
Guide		✓		
Rubbing				
Tail				
No. of Ropes Used	2	4		

Description

Manufacturer	XYZ	XYZ		
Diameter	1 1/2 IN.	2 IN.		
Length Used	780 FT	600 FT		
Construction	6x19	1x63		
Material	PLOW STEEL			
Core	HEMP	-		
Flattened Strand				
Round Strand	✓			

ENGINEERING DATA - SHAFT/SLOPE HOISTING (Check or fill in as appropriate)

COMPANY \_\_\_\_\_

MINE NAME	EXAMPLE			
	* * * * *	* * * * *		
<u>ROPE(S) INVOLVED (Cont'd.)</u>				
<u>Description (Cont'd.)</u>				
Lock Coil		✓		
Semi Lock				
Lay (please describe)	RT-REG	RT		
Name of Lubricant Applied	EBONY			
How Often Lubricated	WEEKLY			
<u>Load</u>				
Maximum Dead Load	7TON	-		
Maximum Total	18TON	-		
<u>Miscellaneous</u>				
Maximum Rope Speed(FPM)	900	-		
Number of Trips/Day	~350	-		
Typical Life	19 MOS	4 YRS		
Typical Reason Replaced	WIRE BREAKS	WEAR		
Type of Attachment at Conveyance	SOCKET	-		
Bridle Chains Attached?	YES	-		
Splicing Permitted?	NO	-		
Rope Reversed Periodically?	NO	NO		
<u>HOIST MACHINERY</u>				
Manufacturer	PDQ			
<u>Friction (Koepe) Type</u>				
Tower Mounted				
Ground Mounted				
Drive Wheel Dia.				
<u>Drum Type</u>				
Cylindrical				
Cylindro-conical		✓		
Conical				
Number of Drums	2			
Parallel (2 shafts)		✓		
Single Shaft				
<u>Drum Face</u>				
Plain (Smooth)				
Parallel Grooved				
Helical Grooved (Spiral)		✓		

ENGINEERING DATA - SHAFT/SLOPE HOISTING (Check or fill in as appropriate)

COMPANY \_\_\_\_\_

MINE NAME	EXAMPLE			
	* * * * *	* * * * *	*	
<u>HOIST MACHINERY (Cont'd.)</u>				
<u>Drum Face (Cont'd.)</u>				
Lebus Grooved				
How Often Regrooved?	AS NEEDED			
Face Diameter	9 FT 4 13 FT			
Max. No. Rope Layers	1			
Min. No. Dead Wraps	3			
Rope Lifters Fitted?	-			
<u>Rope Spout</u>				
Number of Clamps	4			
Type of Clamps	CROSBY TYPE			
<u>Controls</u>				
Auto, Manual, Both	BOTH			
Overspeed Control?	YES			
Overwind Control?	YES			
<u>Brakes</u>				
Mechanical (Air or hydraulic actuated)	✓			
Electric (Dynamic or regenerative)	✓			
<u>Head Sheave Diameter</u>				
How Often Regrooved?	12 FT			
	AS NEEDED			
<u>Idler Sheave Diameter</u>				
How Often Regrooved?	NONE			
<u>Track Rollers (Slope Hoists)</u>				
Diameter				
Spacing				
Used Full Slope				
Used Partial Slope (Near top)				
How Often Refaced?				
<u>Vertical Rope Rollers (At Switches)</u>				
Diameter				
How Often Refaced?				

ENGINEERING DATA - SHAFT/SLOPE HOISTING (Check or fill in as appropriate)

COMPANY \_\_\_\_\_

MINE NAME	EXAMPLE			
	* * * * *	* * * * *	* * *	
<u>SHAFT ENVIRONMENTAL CONDITIONS</u>				
Dry				
Damp				
Wet	✓			
Water ph Measurements Made	YES (NEUTRAL)			
Lined				
Partially Lined	✓			
Ventilation Flow				
Neutral				
Upcast	✓			
Downcast				
Heavy				
Moderate	✓			
Light				

APPENDIX J

MINING EQUIPMENT MANUFACTURERS CONTACTED

## APPENDIX J

MINING EQUIPMENT MANUFACTURERS CONTACTED

Allis-Chalmers Manufacturing Company Milwaukee, Wisconsin	Hardie-Tynes Manufacturing Company Birmingham, Alabama
Acushnet Process Co. New Bedford, Massachusetts	Houghton Elevator Company Toledo, Ohio
ASEA Electric, Inc. New York, New York	Huwood-Irwin Corporation Irwin, Pennsylvania
Barber-Greene Company Aurora, Illinois	Ingersoll-Rand Company New York City, New York
The Bowdil Company Canton, Ohio	Jeffrey Manufacturing Company Columbus, Ohio
Brown Boveri Corporation North Brunswick, New Jersey	Joy Manufacturing Company Pittsburgh, Pennsylvania
Coeur d'Alenes Company Spokane, Washington	Lake Shore, Inc. Iron Mountain, Michigan
Coeur d'Alenes Company Wallace, Idaho	Logan Engineering Company Chicago, Illinois
Conco, Inc. Berkeley, Illinois	Long-Airdox Company Knoxville, Tennessee
Clyde Iron Works Duluth, Minnesota	Meyers-Whaley Co., Inc. Knoxville, Tennessee
Connellsville Corporation Connellsville, Pennsylvania	J. S. Murdy Hoisting Engine Co. New York City, New York
Denver Equipment Company Denver, Colorado	Nordberg Manufacturing Company Milwaukee, Wisconsin
Eaton, Yale, & Towne, Inc. Forest City, Arkansas	Northern Engineering Works Detroit, Michigan
Essick Manufacturing Company Los Angeles, California	Otis Elevator Company Philadelphia, Pennsylvania
Fairfield Engineering Company Marion, Ohio	Robbins & Meyers, Inc. Springfield, Ohio

Rotesco, Ltd.  
Don Mills, Ontario

Stephens-Adamson Manufacturing  
Company  
Aurora, Illinois

Sterling Machinery Company  
Los Angeles, California

Superior-Lidgerwood-Mundy  
Corporation  
Superior, Wisconsin 54880

Stearns Roger Corporation  
Denver, Colorado

Vulcan-Denver Corporation  
Englewood, Colorado

Washington Iron Works  
Seattle, Washington

Webster Manufacturing Company  
Tiffin, Ohio

Western Machinery Company  
San Francisco, California

Westinghouse Electric Corporation  
Pittsburgh, Pennsylvania

Letters of Inquiry and Questionnaire

Gentlemen:

The Long Beach Ocean-Engineering Facility of Battelle is under contract with the Bureau of Mines to study the requirements and service conditions for wire rope used in U. S. coal mines. To gain wide coverage from many viewpoints we are contacting machinery manufacturers, wire-rope manufacturers, state regulatory agencies, and a large number of mine operators.

In this study we are concerned with all the wire-rope applications associated with underground coal mining (as opposed to strip and auger mining) even if the use is on the surface. Our concern relates to engineering practice as well as rope handling, maintenance, inspection, and replacement criteria.

We have identified you as a manufacturer of mining equipment which uses wire rope or is associated with it in some fashion. We would be pleased if you could provide us with the following kinds of information:

- (1) Equipment manufactured using or associated with wire rope in coal mines
- (2) The function of the rope (if applicable)
- (3) Typical rope diameters and constructions used or recommended for use (if applicable)
- (4) Typical rope loads (if applicable)
- (5) The ratio of component diameter to rope diameter applied in design in the case of sheaves, rollers hoist drums, friction hoist wheels, etc.
- (6) Rope groove configurations (if applicable)
- (7) Rope maintenance procedures recommended (if applicable).

Where this information is covered by company catalogs or applications literature, copies of them would be sufficient and much appreciated.





(12) Typical machinery and rope inspection procedures followed are:

<u>Inspected Item</u>	<u>What Inspected For</u>	<u>Frequency</u>
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

(13) We would replace or recommend replacement of our mine elevator rope(s) for the following reasons:

<u>Item</u>	<u>Quantitative Reason for Replacement</u>
_____	_____
_____	_____
_____	_____

(14) Normal rope life on our elevators is \_\_\_\_\_

(15) We \_\_\_\_\_ have \_\_\_\_\_ have not replaced ropes because of \_\_\_\_\_ broken wires \_\_\_\_\_ broken strands, \_\_\_\_\_ other \_\_\_\_\_

(16) Where broken wires or strands have occurred the probable cause and/or type of failure is considered to be \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(17) We \_\_\_\_\_ do \_\_\_\_\_ do not maintain records of the service histories of our elevator rope. (If X do, please indicate kinds of data recorded.)

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(18) We \_\_\_\_\_ have, \_\_\_\_\_ have not been involved with strength testing of new or used elevator ropes. (If   X   have, please indicate generally your involvement.)

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(19) Our opinions of or experience with nondestructive inspection of wire rope on our elevators is: \_\_\_\_\_

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(20) We \_\_\_\_\_ do \_\_\_\_\_ do not think that a visit by Battelle project personnel would be more appropriate to a discussion of the above topics. (If   X   do, please indicate so, your availability within the next three or four months, where and with whom Battelle would meet, and whom Battelle should contact to set up such a visit.)

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APPENDIX K

WIRE ROPE MANUFACTURERS CONTACTED

## APPENDIX K

WIRE ROPE MANUFACTURERS CONTACTED

American Chain and Cable, Inc.  
Wilkes-Barre, Pennsylvania

Armco Steel Corp.  
Kansas City, Missouri

Bethlehem Steel Corp.  
Williamsport, Pennsylvania

Bergen Wire Rope Co.  
Lodi, New Jersey

Broderick & Bascom Rope Co.  
St. Louis, Missouri

The Colorado Fuel & Iron Corp.  
(Roebing Wire Rope Engineering)  
Trenton, New Jersey

Hackensack Cable Corp.  
Hackensack, New Jersey

Jones and Laughlin Steel Corp.  
Munch, Pennsylvania

Lowery Brothers  
Chicago, Illinois

Macwhyte Wire Ropes, Inc.  
Kenosha, Wisconsin

Paulsen Weber Cordage Corp.  
Sunbury, Pennsylvania

Pennsylvania Wire Rope Corp.  
Williamsport, Pennsylvania

Rochester Corp.  
Culpepper, Virginia

Sanders' Sons, Inc.  
New Cumberland, Pennsylvania

United States Steel Corp.  
New Haven, Connecticut

Universal Wire Products, Inc.  
North Haven, Connecticut

Wire Rope Corp. of America, Inc.  
St. Joseph, Missouri

Wire Rope Industries of Canada  
Vancouver, British Columbia

Letter of Inquiry and Questionnaire

Dear Sir:

The Long Beach Ocean-Engineering Facility of Battelle Memorial Institute is engaged in a research program concerning the use of wire rope in U. S. coal mines. Of primary concern are rope strength and service life as they relate first, to human safety, and secondly, to the efficient use of the rope as a mechanical component.

As you probably know, the staff of the Long Beach Facility has been gaining experience with and knowledge of the behavior of wire rope and the factors which cause degradation in its strength. A majority of this work has been related to wire rope in marine applications. Battelle is now applying this background to promoting human safety in coal mine service.

Our main area of interest is hoisting, but not to the exclusion of other rope applications associated with underground mining. To achieve our goals a wide coverage of the mining industry is necessary. To do this effectively we have elected to use questionnaires and follow-up visits where appropriate. We recognize that some of our questions may involve considerable detail. Therefore, where standard codes or specifications, Federal, State, and/or local regulations, or printed company catalogs or applications literature cover the requested information, a reference to this literature and copies of them would be sufficient and much appreciated.

Some of our questions relate to possible inadequacies in current rope use and practice in mining. In this context, as an example, we cite USAS M 11.1-1960. In the 10 years since these specifications were issued we feel that more quantitative information must have come to light in such important areas as rope replacement criteria. Thus, some of our questions solicit your thoughts and opinions as to possible advances in guidelines for safe rope use. If you feel that this area cannot be adequately treated by a response to a questionnaire, we would be pleased to have an opportunity to visit with you to discuss current practices and possible future improvements. Please understand that the sources of all such comments and opinions will not be identified at the conclusion of our efforts.

We have enclosed two copies of our questionnaire in the event you may like to retain one for your files.

We look forward to your reply and thank you in advance for any assistance in our efforts.

Sincerely,

Richard A. Egen  
Senior Project Leader

RAE:mng  
Encs.





- (5) In selecting a rope for a given application some rope(s) are more appropriate than others. Battelle would like to know, in general, what guidelines are used in matching the rope characteristics to the various conditions of the application. For example, in hoisting, beyond the more obvious length and strength requirements, how are such rope characteristics as strand shape, locked or semilocked construction, and core material related to shaft conditions or hoisting machinery design or number of rope layers on the drum? It is recognized that this request could involve considerable effort on your part. Please advise as to the most appropriate way for us to obtain this information. Catalog or applications literature might be sufficient.

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- (6) We can and/or do provide the mine operators service, assistance, or recommendations in:

_____	installation of new ropes
_____	inspection of rope
_____	maintenance of ropes
_____	retirement and/or replacement of ropes
_____	testing of rope strengths, new or used ropes
_____	other _____

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- (7) Our typical recommendations, precautions, procedures, etc., for installation of new ropes are as follows (please indicate application):

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- (13) We \_\_\_\_\_ do, \_\_\_\_\_ do not, maintain records of our ropes in mining service. If X do, please indicate the kinds of data recorded (e.g., date of installation, date of removal, reason for removal, condition of rope upon removal, etc.)

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- (14) Our investigations of, experience with, and/or opinions regarding nondestructive, rope inspection devices are as follows:

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- (15) The experimental or development work we have done related to improving service life and/or inspection and retirement criteria for ropes in mining applications is as follows:

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- (16) Our opinions on present wire rope practice, inspection, retirement criteria, etc., regarding possible advances in safety and service life are as follows:

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- (17) We \_\_\_ can \_\_\_ cannot supply samples of ropes retired from coal (or similar) mine service (ropes with some known use history) for possible detailed inspection and testing by Battelle. (If X can, how should Battelle proceed to obtain samples?)

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- (18) We \_\_\_\_\_ do \_\_\_\_\_ do not think that a visit by Battelle project personnel would be more appropriate to a discussion of the above topics. (If X do, please indicate your availability within the next three or four months, where and with whom Battelle would meet, and whom Battelle should contact to set up such a visit.)

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APPENDIX L

UNITED STATES  
STATE MINING REGULATORY AGENCIES CONTACTED

## APPENDIX L

UNITED STATES  
STATE MINING REGULATORY AGENCIES CONTACTED

Alabama

Department of Industrial Relations  
 Safety and Inspection Division  
 Birmingham

Alaska

Department of Natural Resources  
 Mining Branch  
 Juneau

Arizona

Arizona State Mine Inspector  
 Phoenix

Arkansas

State Mine Inspector  
 Fort Smith

California

Division of Industrial Safety  
 Industrial Section  
 San Francisco

Colorado

Department of Natural Resources  
 Denver

Georgia

Department of Mines, Mining,  
 and Geology  
 State Division of Conservation  
 Mining Section  
 Atlanta

Idaho

Inspector of Mines  
 Mining Section  
 Boise

Illinois

Department of Mines and Minerals  
 Inspection Division  
 Springfield

Indiana

Bureau of Mines and Mining  
 Terre Haute

Iowa

State Mine Inspector  
 Mines and Minerals Department  
 Des Moines

Kansas

Department of Labor  
 Mine Branch Inspector  
 Pittsburgh

Kentucky

Department of Mines and Minerals  
 Mine Inspection Division  
 Lexington

Maryland

Department of Geology, Mines, and  
 Water Resources  
 Bureau of Mines  
 Westernport

Michigan

County Mine Inspector  
 Baraga County  
 L'Anse

Dickinson County  
 Iron Mountain

Michigan (Continued)

County Mine Inspector  
Gogebic County  
Bessemer

Houghton County  
Calumet

Iron County  
Crystal Falls

Keweenaw County  
Allouez

Marquette County  
Ishpeming

Ontonagon County  
Mass

Department of Public Health  
Bureau of Safety and Regulation  
Detroit

Minnesota

County Mine Inspector  
Crow Wing County  
Ironton

Itasca County  
Grand Rapids

St. Louis County  
Virginia

Missouri

Division of Mine Inspection  
Mining Section  
Jefferson City

Montana

Montana Bureau of Mines and Geology  
Montana School of Mines  
Butte

Nevada

State Inspector of Mines  
Carson City

New Mexico

State Inspector of Mines Department  
Albuquerque

North Carolina

Division of Mineral Resources  
Raleigh

North Dakota

State Mine Inspector  
Bismarck

Ohio

Division of Mines  
Department of Industrial Relations  
Mining Section  
Columbus

Oklahoma

Department of Chief Mine Inspector  
Oklahoma City

Oregon

Department of Chief Mine Inspector  
Mining Section  
Portland

Pennsylvania

Department of Mines and  
Mineral Industries  
Harrisburg

South Carolina

Division of Geology  
State Development Board  
Mining Section  
Columbia

South Dakota

State Mine Inspector  
Keystone

Tennessee

Division of Mines  
Department of Labor  
Mining Section  
Knoxville

Utah

Industrial Commission  
Mining Section  
Salt Lake City

Virginia

Department of Labor and Industry  
Division of Mines and Quarries  
Drawer V  
Big Stone Gap

Washington

Department of Labor and Industries  
Mining Division  
Seattle

West Virginia

Department of Mines  
Mining Section  
Charleston

Wisconsin

Wisconsin Industrial Commission  
Mine Quarry Section  
Mining Branch  
Madison

Wyoming

State Inspector of Mines  
Mining Section  
Rock Springs

Letter of Inquiry and Questionnaire

The Long Beach Facility of Battelle Memorial Institute is engaged in a research project for the Bureau of Mines, U.S. Department of the Interior, concerning the use of wire rope in U.S. Mines. The primary concern is with rope strength and/or life as it relates, first, to human safety, and secondly, to the efficient use of the rope as a mechanical component. Our principal area of investigation is hoisting ropes in underground mining.

The staff of this Facility has considerable experience with, and knowledge of the behavior of wire rope and the factors which cause degradation of rope strength. This background is now being applied to promoting human safety and to extending the service life of ropes in mine service.

Proper selection of the wire rope and the associated machinery, good usage practices, and good maintenance and inspection programs all contribute to the service life of the wire rope. Affecting all these factors and, possibly, governing them are the laws, regulations, etc., which may be imposed by the state agencies regulating mining activities.

As part of our research project we would like to determine the wire-rope related activities of your state's mining agency. First of all, we would appreciate receiving a copy of your state's mining laws. Secondly, we would be pleased if you would answer the enclosed questionnaire (some of these questions may be covered by the printed laws, if so, please so indicate.) The questionnaire is directed toward your wire rope and related machinery inspection activities, your rope replacement criteria, and your opinions of where advances might be made and what they might be.

We have enclosed two copies of our questionnaire in the event you would like to retain one.

We look forward to your reply and thank you for your efforts on our behalf.

Sincerely,

Richard A. Egen  
Senior Project Leader

RAE:mmg  
Encs.

QUESTIONNAIRE TO STATE AGENCIES  
REGULATING THE USE OF WIRE ROPE  
IN U.S. MINES

Prepared by Long Beach Ocean-Engineering Facility  
Battelle Memorial Institute

(All Answers and Opinions will be Treated as Confidential)

STATE \_\_\_\_\_

NAME OF REGULATORY BODY OR AGENCY \_\_\_\_\_

NAME AND TITLE OF PERSON ANSWERING \_\_\_\_\_

DATE ANSWERED \_\_\_\_\_

\* \* \* \* \*

- (1) State regulations with respect to wire rope installations, use, replacement, etc., are based upon, include, or make use of the following standard codes, specifications, regulations, etc: (Please list if they are not spelled out in the regulations themselves.)

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

- (2) State laws, regulations, etc., apply to the following uses of wire ropes in our state's coal mines:

- \_\_\_\_\_ Hoisting
  - \_\_\_\_\_ hoist rope
  - \_\_\_\_\_ tail ropes
  - \_\_\_\_\_ guide ropes
  - \_\_\_\_\_ rubbing ropes

\_\_\_\_\_ Other (Please List)

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



- (8) Wire rope replacement-criteria items and quantitative limits specified by state law are as follows (e.g., number of broken strands, total or per lay length; amount of wear, diameter reduction; ton-miles; service time):

<u>Item</u>	<u>Quantitative Limit</u>
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

- (9) Our opinions regarding rope retirement criteria, their adequacy, reliability, and how they might be improved to obtain greater safety and usable lifetime are as follows:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

- (10) Our agency \_\_\_\_\_ is, \_\_\_\_\_ is not, directly or indirectly involved with performing strength or life tests on new or retired wire rope for mine service. If X is, please indicate how this is done.

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

(11) Our agency \_\_\_\_\_ is, \_\_\_\_\_ is not, directly or indirectly involved with experimental or developmental efforts directed toward improving rope life or replacement criteria, etc. If  X  is, please describe efforts.

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(12) Our agency \_\_\_\_\_ does, \_\_\_\_\_ does not, maintain records related to service histories of wire rope installations. If  X  does, please indicate the kinds of data which are recorded (e.g., date of installation, date of retirement, rope construction, type of machinery involved, condition of rope upon retirement, reason for retirement, etc.)

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(13) We \_\_\_\_\_ do, \_\_\_\_\_ do not, think that a visit by Battelle project personnel would be more appropriate to obtaining information on the above topics. (If  X  do, please indicate your availability within the next two or three months, where and with whom Battelle would meet and whom Battelle should contact to set up the visit.)

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PLEASE INCLUDE A COPY OF YOUR STATE MINING LAWS AND OTHER PERTINENT PAPERS WITH THE RETURN OF THIS QUESTIONNAIRE.

APPENDIX M

CANADIAN PROVINCIAL REGULATORY  
AGENCIES CONTACTED

APPENDIX M

CANADIAN PROVINCIAL REGULATORY  
AGENCIES CONTACTED

Mines Division  
Department of Mines and Minerals  
Edmonton, Alberta

Mine Inspection and Engineering  
Division  
Mines Branch  
Department of Lands and Mines  
Fredericton, New Brunswick

Coal Inspection Division  
Department of Mines  
Halifax, Nova Scotia

Department of Natural Resources  
Inspection of Mines Service  
Mines Branch  
Quebec, Province of Quebec

Mines Inspection Branch  
Department of Mines and Northern  
Affairs  
Toronto, Ontario

Mines Inspection Division  
The Mines Branch  
Department of Mines, Agriculture,  
and Resources  
St. John's, Newfoundland

Inspection Branch  
Department of Mines and  
Petroleum Resources  
Victoria, British Columbia

Mining Engineering Division  
Mines Branch  
Department of Mines and  
Natural Resources  
Winnipeg, Manitoba

Letter of Inquiry

Gentlemen:

Battelle Memorial Institute is presently under contract to the United States Department of the Interior through the Bureau of Mines to investigate the use of wire rope within the coal-mining industry. The objective of this program is to develop a firm base for formulating new United States Federal coal-mine wire-rope safety standards.

To achieve this goal we desire to learn from other countries' experience with the use of wire rope in mine hoisting.

We would like to obtain from you a copy of the mining laws for your province. We also request any specific information concerning the nondestructive testing and/or recommended inspection practices for mine hoisting ropes in British Columbia. Please provide a name and address for future contact on wire-rope safety and inspection problems.

Your efforts on our behalf will be greatly appreciated.

Yours very truly,

Charles H. Larsen  
Research Engineer

CHL:mmg

APPENDIX N

MISCELLANEOUS CONTACTS

## APPENDIX N

MISCELLANEOUS CONTACTSForeign Research GroupsAustralia

University of New South Wales  
 School of Mining Engineering  
 Kensington (Sydney)  
 New South Wales

England

Institution of Mining Engineers  
 London

Ministry of Power  
 Safety in Mines Research  
 Establishment  
 Central Laboratories  
 Sheffield

National Coal Board  
 Central Engineering Establishment  
 Stanhope  
 Bretby

India

Central Mining Research Station  
 Dhanbad  
 Bihar

Indian Bureau of Mines  
 Nagpur

Italy

Politecnico Di Torino  
 Torino

Japan

Ministry of International Trade  
 and Industry  
 Chiyoda-ku  
 Tokyo

Kenya

Ministry of Natural Resources  
 Mines and Geological Department  
 Nairobi

Nigeria

Ministry of Mines and Power  
 Lagos

South Africa

Department of Mines  
 Pretoria

Sweden

Royal Institute of Technology  
 Institute for Bergteknik  
 Stockholm

Svenska Gruvforeningen (Swedish  
 Mining Association)  
 Stockholm

West Germany

Gesellschaft Deutscher Metallhütten-  
 Und Bergleute E. V. (Society of  
 German Mining and Metallurgical  
 Engineering)  
 Clausthal-Zellerfeld

United States Universities

Colorado School of Mines  
Golden  
Colorado

University of Missouri  
Rolla  
Missouri

Virginia Polytechnic Institute  
Blacksburg  
Virginia

Miscellaneous Sources

American Mining Congress  
Washington, D. C.

Climax Molybdenum Co.  
Western Operations  
Golden, Colorado

Colorado Mining Association  
Denver, Colorado

U. S. Bureau of Mines  
Section of Publications Distribution,  
Region V  
Pittsburgh, Pennsylvania

Mine Inspectors Institute of America  
Pittsburgh, Pennsylvania

Norther Colorado Coals, Inc.  
Denver, Colorado

U. S. Department of Agriculture and  
Forestry Service  
Rocky Mountain Region  
Denver, Colorado

Society of Mining Engineers of AIME  
New York, New York

United States Information Agency  
Washington, D. C.

U. S. Department of Commerce  
Office of Field Services  
Washington, D. C.

APPENDIX O

WIRE ROPE TERMINOLOGY AND CONSTRUCTION

APPENDIX O

WIRE ROPE TERMINOLOGY AND CONSTRUCTION

MULTI-STRAND ROPE

Typical Word Description

Abbreviated: 6X19 W, RT-Reg, FC

Complete: 6X19 Warrington, Right Lay-Regular Lay, Fiber Core

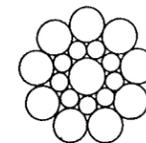
Number of strands

Core Type

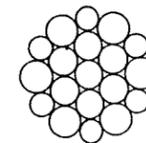
Fiber-hemp or synthetic (FC)  
Independent wire rope (IWRC)

Wire Arrangements  
in Strands

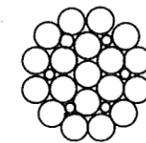
Round Strands



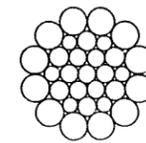
19 wire Seale (S)



19 wire Warrington (W)

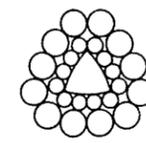


25 wire filler wire (F.W.)

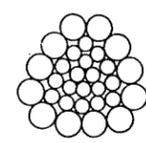


31 wire Warrington Seale

Flattened Strand (FS)



25 wire



30 wire

Lay Configuration

Standard

Available



Right Lay, Regular Lay



Left Lay, Regular Lay



Right Lay, Lang Lay



Left Lay, Lang Lay

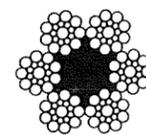
Lay Length

Distance along rope axis in which a strand makes one complete spiral or turn around the rope.

Wire Material

Grades of steel in order of increasing strength: traction, plow (PS), improved plow (IPS), extra improved plow (XIPS)

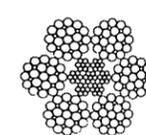
Typical Constructions (Neglecting Lay Terminology)



6X19 Seale, fiber core



6X19 Warrington, fiber core

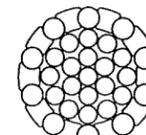


6X25 filler wire, IWRC



6X25 filler wire, fiber core

Single Strand  
Rope



Half-lock



Locked coil



Locked wire