PB 218-067

FINAL REPORT

on

INVESTIGATION OF REQUIREMENTS AND PERFORMANCE OF SAFETY CATCHES ON WIRE-ROPE-SUSPENDED, MAN-CARRYING CONVEYANCES IN UNITED STATES COAL MINES

to

PITTSBURGH MINING AND SAFETY RESEARCH CENTER
BUREAU OF MINES
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by

C. H. Larsen, R. A. Egen, and H. A. Cress

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BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
Long Beach Ocean-Engineering Research Facility
965 Harbor Scenic Way
Pier J - Berth 249
Long Beach, California 90802

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16. Abstract This report presents the results of a comprehensive investigation of conveyance arrestment devices (safety catches) in United States coal mines. Availability and use, performance, inspection, maintenance, testing, procedures, and regulatory requirements were investigated. Information was obtained from equipment manufacturers, mine operators, and regulatory-agency personnel, as well as from studies of domestic and foreign mining safety regulations. Traditional mine hoists and commercial elevators for mine use were investigated. Results of this and an earlier study of wire-rope practice in U.S. coal mines show a continued need for conveyance arrestment devices. Only two types have been proved reliable for stopping a conveyance without injuring passengers or equipment. These are elevator overspeed-actuated wedge-clamp safe ties and broken-rope-actuated devices for wooden guides using a single-tooth-dog design developed in Ontario as a braking element. Elevators are widely used in U.S. coal mines, and appear to present no major arrestment problems when using ANSI specifications.

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FOREWORD

This report was prepared by Battelle Memorial Institute, Columbus Laboratories, Columbus, Ohio, under USBM Contract No. H0111810. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of Pittsburgh Mining and Safety Research Center with Dr. Chi-shing Wang acting as the technical project officer.

The report is a summary of the work recently completed as part of this contract during the period May 25, 1971, to May 24, 1972. This report was submitted by the authors on September 27, 1972.

This technical report has been reviewed and approved.

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The authors wish to thank the many regulatory-agency personnel, mining-equipment manufacturers, and mine operators for their cooperation during this program. In particular, the continued interest and assistance of Mr. T. J. Baker, Electrical-Mechanical Engineer of Mines, Ontario Department of Mines and Northern Affairs, is greatly appreciated.

ABSTRACT

The results of a comprehensive investigation of conveyance arrestment devices (safety catches) in United States coal mines are presented. Availability and use, performance, inspection, maintenance, testing, procedures, and regulatory requirements were investigated.

Information was obtained from equipment manufacturers, mine operators, and regulatory-agency personnel, as well as from studies of domestic and foreign mining safety regulations. Traditional mine hoists and commercial elevators for mine use were investigated.

Results of this and an earlier study of wire-rope practice in United States coal mines show a continued need for conveyance arrestment devices. A wide variety of these devices are in use. Only two types have been proved reliable for stopping a conveyance without injuring passengers or equipment. These are elevator overspeed-actuated wedge-clamp (Type B) safeties and broken-rope-actuated devices for wooden guides using a single-tooth-dog design developed in Ontario as a braking element.

Elevators are widely used in U. S. coal mines. When maintained according to American National Standards Institute (ANSI) Specifications A17.1 and A17.2, they appear to present no major arrestment problems.

Of 42 coal-mine hoists used for man transport that were inspected, 30 are in vertical and 12 in inclined shafts. Twenty-four vertical shafts use wood guides; 6 use steel. The 12 inclined-shaft systems use flanged-wheel T-rail guidance. Two wood-guided vertical-shaft systems use the single-tooth Ontario-type dog; the other 22 use multi-toothed wedges, cams, or dogs that have been proved highly unreliable. The arrestment devices in the six steel-guided vertical-shaft systems and in six of the inclined-shaft systems cannot be evaluated because performance data are lacking. The remaining six inclined-shaft systems have no arrestment devices at all.

Of the 36 hoists with arrestment devices, the devices of 16 are never tested, the devices of 10 are actuated periodically with the conveyance at rest, and the devices of the other 10 are actuated periodically with a slow-moving conveyance. Although high speed is as probable as low speed in an emergency and would provide the best test of arrestment capability, no tests are performed in the United States which demonstrate the ability of an arrestment device to stop a loaded conveyance from high speed.

Mine operators indicate little confidence in their conveyance arrestment devices, and manufacturers recognize a need to improve their products. Neither state nor Federal regulations provide a guide to this improvement. Mine operators, manufacturers, and state and Federal regulatory agency personnel would welcome specific guidance.

In view of this, a set of application, design, actuation, stopping-performance, and testing and inspection criteria is presented as a guide to eliminating the inadequacies of these devices. Recommendations are included for improving hoist controls and machinery directly affecting conveyance safety.

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CHAPTER 1

INTRODUCTION AND PROGRAM SUMMARY

INTRODUCTION

PERSPECTIVE

The safe haulage of men into and out of mines has long been of great concern to mining people around the world. Where this is done with vertical- or inclined-shaft conveyances, one or more wire ropes will usually be found as the connective element between the conveyance and the driving machinery. Concern over the fact that these lifelines break has led to the requirement for safety catches on wire-rope-controlled, man-carrying conveyances in some mining countries.

Historically, the name "safety catch" applies to a particular class of conveyance brake. Almost all safety catches require a loss of rope tension for activation. The typical system has toothed elements that are moved into contact with wooden shaft guides by a set of links and shafts driven by a spring that is normally compressed by rope tension. Once activated, these systems can fail to stop or hold the conveyance – the toothed elements can roll over and out of contact with the guides, the guides can be too worn to provide a sufficient bite, the guide-supporting sets, or framework, can be loose and deflect away from the teeth, or the teeth can become filled with wood chips. Commonly, however, accidents occur because of a loss of hoisting control wherein the rope does not break and its tension prevents the safety catches from acting.

Because of the many factors influencing safety-catch operation, there has been much diversity of opinion in the more important mining countries regarding the value of safety catches or other arresting devices. The following official pronouncements and findings illustrate the situation:

1886 – Great Britain – The Royal Commission of Accidents in Mines concluded that no device was a "trustworthy safeguard against accidents".

1902 – Germany – The Commission of the Mining District of Dortmund, Germany, recommended their continued use based on past performance.

1907 – South Africa – The Transvaal Rope and Safety Catch Commission decided to continue their use in vertical shafts.

1909 – Great Britain – The Royal Commission on Mines concluded that it was unable to recommend their use in present form.

1915 – United States – "Rules and Regulations for Metal Mines", Bulletin 75, U. S. Bureau of Mines, required them on man-hoist conveyances and recommended monthly drop testing.

1938 – United States – The Mine Safety Board, Decision 28, recommended their continued use in vertical shafts and slopes.

1948 – United States – The U. S. Bureau of Mines Information Circular 7436, "Safety Catches on Mine Cages and Methods for Testing Them", observed that safety-catch testing as practiced by U. S. mines was unrealistic, and did not clearly demonstrate device performance.

1949 – Canada – "Investigations Regarding the Safety of Hoisting Practice in Ontario Mines", Bulletin 138A of the Ontario Department of Mines, concluded that corrective measures taken since the Paymaster accident of 1945 had greatly improved device performance and reliability.

1953 – United States – The Federal Mine Safety Code for Bituminous Coal and Lignite Mines of the United States, Part I, "Underground Mines", required that cages or platforms used to transport persons had to be equipped with safety catches unless they were also used for hoisting coal.

1957 – West Germany – Removed the requirement for safety catches.

Behind these pronouncements and findings are a multiplicity of accidents, investigations, and mechanical designs for safety catches and other arrestment devices. Nevertheless, there has been an historical tendency to group all arrestment devices into one category and to conclude that all perform similarly. In many cases such generalizing has negatively influenced the development, improvement, and use of conveyance arrestment devices.

Section 314 of Title III of the U. S. Federal Coal Mine Health and Safety Act of 1969 requires that "Cages, 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 such catches shall be tested at least once every two months". Sections 75.1400 and 75.1400-2 of Part 75, Title 30, Code of Federal Regulations, further state that records of these tests shall be made. The simplicity of these regulations is in direct contrast to the complexity of the problems involved.

PROGRAM OBJECTIVES

The Coal Mine Health and Safety Act of 1969 authorizes interim mandatory health and safety standards in the United States and expanded research and development to prevent accidents and occupational diseases in coal mines. In the context of this act, questions arise regarding technological currency of present Federal regulations concerning safety catches. Should they be more explicit in the manner of testing safety catches, in the load conditions under which they must be effective, in defining the word "effective", in indicating who should test and how, or in designating the types of designs that are effective? In accepting Battelle's proposal to answer these questions, the following major objectives were defined:

(1) To determine whether present Federal regulations regarding safety catches are adequate and consistent with the current technological trends in hoisting engineering

(2) To recommend desirable changes in these regulations consistent with improved safety and advancing technology.

PROGRAM SUMMARY

Because of the historical and yet common connotation of the term "safety catch", henceforth this report will use the more general term "arrestment device" in referring to a conveyance-mounted motion-arresting system for use in an emergency.

INFORMATION SOURCES

The information and data used in this program were obtained from mine operators, arrestment-device manufacturers, and Federal and local regulatory agencies (domestic and foreign) as a result of direct contact or written requests. Most of this information and data were obtained during this study (Contract H0111810); the rest was collected during the previous Battelle program for the Bureau of Mines (Contract H0101741), which investigated wire rope practice in underground coal mines and was directed mainly to hoisting.(50)* In this report, the latter program will be called the "earlier" study.

The information sources and the appendices that list or describe them are

(1) Thirty-seven coal mines, five metal mines, and one nonmetal mine (Appendix A)

(2) Seventeen arrestment-device manufacturers and design applications (Appendix B)

(3) Mining regulatory officials (Appendix C)

  (a) Thirteen U. S. Federal
  (b) Twenty-one U. S. state
  (c) Fifteen foreign

(4) Mining laws (Appendix D)

  (a) U. S. Federal
  (b) Thirty-six U. S. state
  (c) Eighteen foreign federal or local.

Much information has been derived from technical papers collected during this program and the earlier study. These papers and reports have been abstracted, annotated, and presented topically in the Bibliography. Not all are specifically referenced in this report.

* Bibliography item number.

Accident reports, particularly those that carefully analyze circumstances and events, can be a superb source of information. Regrettably, few complete reports of hoisting accidents involving arrestment devices were located. Data representative of the types of accidents uncovered are presented in Appendix E.

RESULTS

Worldwide regulation of arrestment devices illustrates the positions maintained throughout the historical safety-catch debate. One major position asserts that arrestment devices are unnecessary, if not detrimental, to safe hoisting practice, and therefore are not required. The rationale is that the safest hoisting can be assured by an intensive program of hoist-rope and machinery inspection and maintenance. The other major position maintains that good hoist-rope and machinery practice notwithstanding, accidents still occur in which arrestment devices could save lives, and therefore these devices are necessary. This group further argues that since these devices are necessary, their use should be well regulated. One minor faction believes that arrestment devices are desirable but does not require their use. The other minor faction requires the use of arrestment devices, but provides few other regulations. The U. S. is a member of the last group.

The 37 coal mines visited during this and the earlier program cover the spectrum of man-hoisting practice in U. S. coal mines. Observation and study of the machinery and the inspection and maintenance practices in use indicate that it is highly desirable to continue to require arrestment devices on mine hoists for man transport.

Observation and study also indicate that both the devices and the inspection and testing practices in use are woefully inadequate.

Of the 42 hoists used for man transport at the mines visited, 30 (72 percent) are vertical-shaft systems. Of these 30, 24 (80 percent) use wooden guides. Of these 24 wood-guide systems, 22 (91^{+} percent) are equipped with arrestment devices using braking elements that have been tested and proved highly unreliable. The braking elements tend either to lose their braking ability because they clog with wood chips, or to develop very high braking forces that damage equipment and injure passengers.

The six remaining vertical-shaft hoists inspected use steel guides. The 12 inclined-shaft hoists inspected are flanged-wheel-on-rail guided; six are not equipped with arrestment devices. Reliability of the arrestment devices in the six steel-guide vertical-shaft systems and the six inclined-shaft systems is unknown because performance data do not appear to exist. Were such data available, the vertical-shaft systems could be judged on the basis of criteria developed in Canada (Chapter 3). No performance criteria for inclined-shaft arrestment devices have been found.

An arrestment device must be tested periodically if reliability is to be expected. The arrestment devices on 16 of the 36 hoists inspected (vertical and inclined shafts) are never tested. On ten others, these devices are periodically tested only for their ability to actuate, that is, for their ability to move the braking elements into contact with the guide or rail. On the remaining ten hoists, the arrestment devices are subject to a type of dynamic test that can demonstrate, at best, the ability of the brakes to stop a slow-moving conveyance, and, at worst, their ability to "catch" a standing conveyance

if the hoist rope should fail. No U. S. coal (or noncoal) mines are known at which dynamic tests are performed to demonstrate the ability of the arrestment device to stop a rapid-moving loaded (or unloaded) conveyance.

The braking elements – those components directly interacting with the guides or rails – proved to be highly unreliable on wooden guides are of the multitooth-wedge, cam, and "dog" varieties. A single-tooth "dog" has been developed in Ontario, Canada, that has proved highly reliable and amenable to design using equations empirically developed from test data. These data relate to British Columbia fir guides. The shear and hardness properties of this fir are similar enough to the pine guides widely used in U. S. coal mines to permit use of the design equations, at least initially. Two U. S. coal-mine arrestment devices inspected use a single-tooth "dog" of the Ontario type.

The single-tooth Ontario-type "dog" currently appears to be the best braking element for arrestment devices for wood-guided vertical- or inclined-shaft conveyances. The free-fall dynamic testing techniques (Chapter 3) that Ontario formulated in the course of developing its single-tooth "dog" (Chapter 3) would provide the performance data currently lacking for vertical-shaft steel-guided conveyances, and, appropriately modified, would provide these data for inclined-shaft arrestment devices. These data would also provide a basis for verifying or formulating qualitative performance requirements, as well as for indicating design modifications necessary to achieve them.

Man hoisting in U. S. coal mines is not performed exclusively with traditional mine-hoisting equipment. It is estimated that there are also over 100 elevators in use and more can be expected, all with cage arrestment devices. These elevators, like their above-ground counterparts, are designed, built, and installed according to a distinct set of specifications developed by the elevator industry and its suppliers (American National Standards Institute A17. 1 and A17. 2); these specifications also cover inspection, testing, and maintenance. Commonly, elevators at coal mines are inspected, tested, and maintained by elevator manufacturers or service organizations under contract to the mine operator. This study has uncovered nothing to indicate that there are major problems with coal-mine elevator arrestment devices maintained according to ANSI standards.

With respect to traditional hoisting systems, mine operators generally have little confidence in their arrestment devices and would welcome specific guidance. Arrestment-device manufacturers generally recognize the need to improve their products and would also welcome specific guidance. State laws provide no guidance, being only slightly more specific than Federal law. State officials aware of the problems with arrestment devices would also welcome specific guidance. Federal law states little beyond requiring the use of arrestment devices, and Federal inspectors contacted would appear to welcome specific guidance also.

In view of this situation, the present Federal approach to regulating arrestment devices should be modified to reflect present technological capability, to promote its use, and to provide a base for technological advancement. This conclusion applies as well to metal and nonmetal mines.

It is also concluded that the capabilities and reliability of U. S. coal-mine (and noncoal-mine) arrestment-device practice could be most expediently improved with a series of specific requirements, either written into the law or, preferably, into a separate governing code specified by law. These requirements should define design, performance, inspection, and testing criteria in as much detail as current technology permits, but without limiting engineering solutions or the application of technology from other fields. They should also provide a base for the general advancement of arrestment-device technology. Recommendations for these and other requirements are presented in Chapter 6.

CHAPTER 2

FUNCTIONAL REQUIREMENTS FOR ARRESTMENT DEVICES

INTRODUCTION

The design process associated with producing an arrestment device, as with any mechanism, should be guided by a set of explicit functional requirements. In addition to stating the basic function (i.e., to stop the conveyance), these requirements must define when and how the stop is to be made. When to stop requires defining actuation requirements, i.e., the emergency conditions under which the arrestment device should actuate. How to stop refers not to the mechanisms used but to performance requirements, i.e., the kinetic (force-time) or kinematic (motion-time) characteristics of the stop.

ACTUATION REQUIREMENTS

To determine actuation requirements, it is necessary to examine the entire mine hoist as a single machine or system. To do otherwise is to run the risk of neglecting some component or characteristic that may have a strong influence on the safety of the conveyance. The functional relationship among control, drive, and brake components currently typical of traditional vertical and inclined-shaft mine hoists is shown in Figure 1. Any arrestment devices associated with the conveyances are excluded from this figure. The solid lines in Figure 1 represent paths for the transmission of large amounts of electrical or mechanical power, while the dotted lines show the transmission of small amounts of power, i.e., information or control signals. It was recognized long ago that any interruption of the main power-transmission path could lead to uncontrolled motion of the conveyance. Thus, most of the control devices of Figure 1 are primarily safety devices.

HOIST-ROPE-RELATED CONSIDERATIONS

Loss of Connection

The basic purpose of the hoist system is to control the motion of the conveyance. This requires constant knowledge of its position, speed, and direction of motion. Figure 1 shows no conveyance motion or position data are directly fed back to any of the control components associated with the motor, brakes, drum, etc. Addition of the omitted conveyance-mounted arrestment devices would not change this condition. All of the control features, except the brake-clutch interlock and slack-rope safety, sense the rotation of the drum, the drum shaft, or the drive wheel of friction hoists. This assumes that conveyance motion is directly proportional to drum motion, a valid

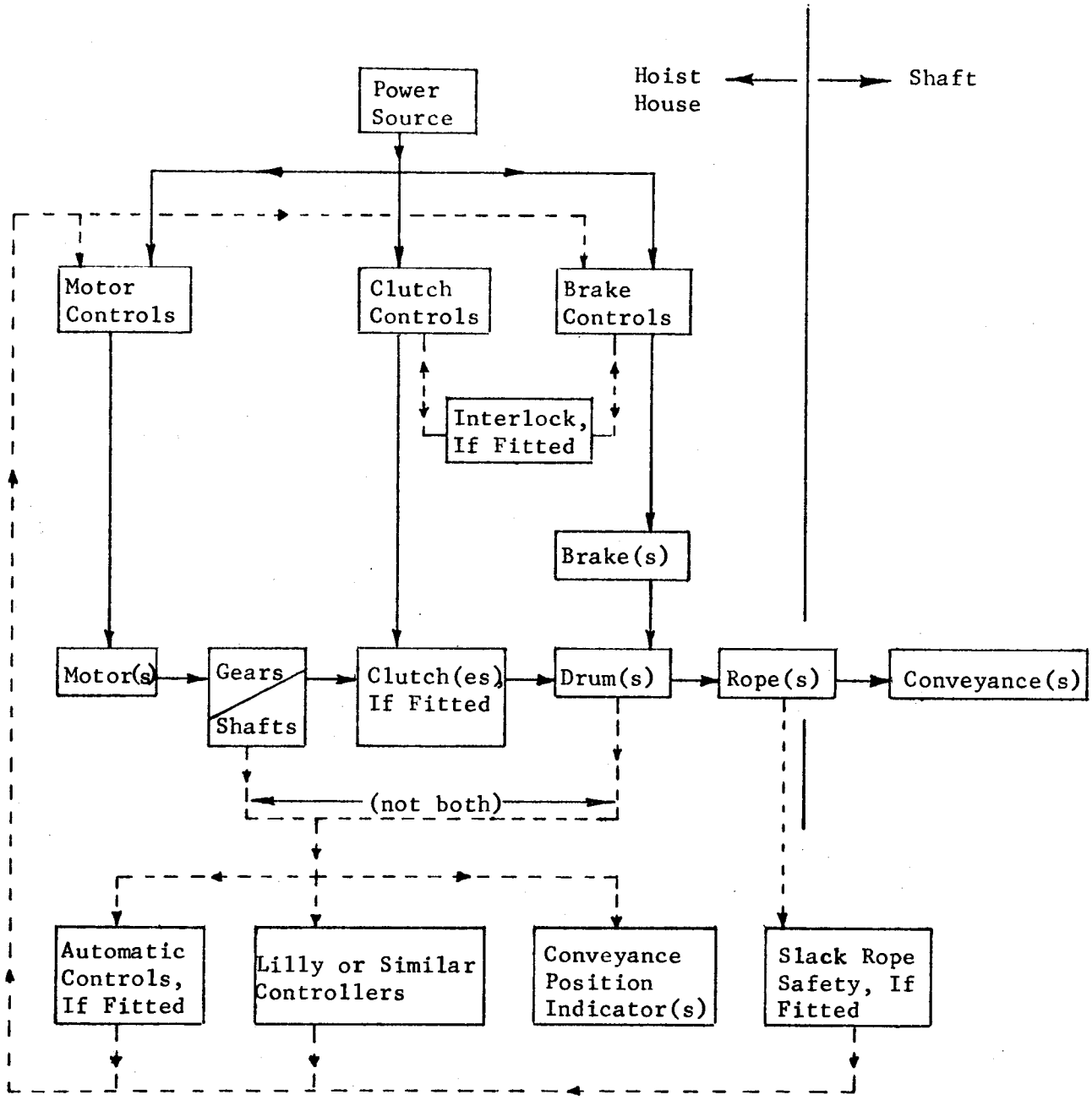


FIGURE 1. FUNCTIONAL RELATIONSHIPS AMONG CONTROL, DRIVE, AND BRAKE COMPONENTS TYPICAL OF U. S. MINE HOISTS

assumption as long as the hoist rope is tensioned by the weight of the conveyance. (Because the hoist rope is a spring, however stiff, conveyance motion is never exactly proportional to drum rotation. This dynamic behavior, most noticeable during stopping and starting, is of secondary importance at this point in the discussion.) Any loss of mechanical connection between drum and conveyance is, therefore, definitely an emergency condition requiring protection at the conveyance. The historic concern for a broken rope is obvious. In addition, hoist ropes have pulled out of their fittings (see Appendix E, Table E-1, Item 5), and the fittings themselves have occasionally failed. This study has not discovered any accidents traced to drum-end rope-terminal failures, but the result can be the same as in the two cases just mentioned.

Slack Rope

Conveyance motion is not determined solely by the tension in the hoist rope. Gravity, guideway resistance, and wind (though usually negligible) also govern. If any of these forces reduce hoist-rope tension enough to cause a slack rope, direct control of the conveyance is not assured.

Vertical Shafts

In vertical-shaft hoists, loss of hoist-rope tension or the development of slack usually means that the descending conveyance has slowed or is stopped, either because of tight guides or some other shaft obstruction. This is definitely a sign of an abnormal condition.

If the descending conveyance has slowed but continues to move, it may eventually pass the slowing obstruction. If it does, it will then free fall until the slack is taken up, at which point it will either be brought up short or the rope will snap. The first case, a rapid deceleration, may cause injury and equipment damage. The second case, a broken rope, requires arrestment-device actuation. In either case, stopping the conveyance under a slack-rope situation has merit. Shutting down the hoist is also desirable, if only to keep the hoist rope from kinking.

If the descending conveyance has been stopped by an obstruction, there is still merit in being able to actuate an arrestment device to assure that the conveyance remains stationary while the obstruction is being cleared (provided the conveyance cannot first be hoisted clear of the obstacle).

There is an additional danger from a slack rope which does not necessarily affect the conveyance responsible for the slack. If the hoist continues to run, rope will begin to pile up somewhere. Since the majority of vertical-shaft hoists are either counterbalanced-conveyance or single-conveyance-counterweight systems, rope slack or piling can have serious consequences. In one instance, the slack spilled into an adjacent compartment and fouled the ascending conveyance (see Appendix E, Table E-1, Item 2). The conveyances were combination skip-cages of the dump variety. In fouling the ascending cage, the slack rope destroyed or damaged the dumping mechanism; the cage tipped and dumped the men down the shaft. It is not obvious that arrestment-device actuation under slack-rope conditions can prevent such an accident; the endangered cage is not connected to the slack rope. The arrestment device on the endangered cage

could be actuated by the slack associated with the slowed or stopped cage using rather complex electronic equipment. Complexities notwithstanding, this approach appears impractical because the arrestment device on the ascending cage would have to be powerful enough to stall the hoist motor. Were this feasible, there is the additional danger of breaking the hoist rope. Again, however, there is clear value to shutting down the hoist when a slack-rope condition occurs.

Many vertical-shaft coal-mine hoists have slack-rope detectors designed to shut down the hoist. These detectors are installed between headframe and hoist. If enough rope is hanging in the shaft, its weight can keep the rope tight between headframe and hoist, even though the rope is slack at the conveyance. Thus, this type of slack-rope detector cannot provide general conveyance protection.

Inclined Shafts

In inclined-shaft systems, loss of hoist-rope tension or the development of slack can occur naturally because of changes in pitch of the shaft, total load on the conveyance, conveyance speed, or load on or connected to the conveyance. Slack can also develop if a conveyance hits an obstruction, encounters tight guides, or derails (where flanged-wheel and T-rail guidance is used). Thus, a loss of rope tension or the development of slack, apart from complete loss of connection, is not always a sign of an abnormal condition.

If an inclined-shaft hoisting system uses counterbalanced or counterweighted conveyances, the potential for disaster from a slack rope can be much the same as for vertical shafts. Even where a single uncounterbalanced conveyance shares a shaft with skips or conveyors, there is potential danger from rope piling up. Again, it seems that the best protection would be hoist shutdown if the rope goes slack. Because slack can occur naturally and is not always a sign of an abnormal condition, the major problem in accommodating potential slack-rope problems in inclined shafts lies in discriminating between natural and abnormal slack conditions.

Conveyance derail in inclined shafts is a common problem where flanged-wheel and T-rail guidance is used. Conveyance-mounted arrestment devices that brake against the rail are useless if the conveyance derails. Nor does there seem to be any clear value in actuation by a slack rope if several conveyances are coupled and one or some derail or the lowest hits an obstruction. The slack could develop too late to prevent the cars still on the track from colliding with the others.

Discussion

Arrestment-device actuation in the event of a slack-rope condition would not appear to accommodate a wide variety of possible accidents.

From what has been presented with respect to vertical- and inclined-shaft hoists, it seems that the basic problems lie in detecting an obstacle in advance of a collision and discriminating between a normal and abnormal slack-rope condition, followed by hoist shutdown. This can be done automatically, but not with state-of-the-art hoist-control equipment. It is possible with state-of-the-art controls technology in general, but because of the cost and complexity of the equipment, it will probably not be applied soon.

Since the conveyances being considered are for man haulage, the use of man as part of the control circuit must be considered. In the case of vertical shafts, men riding a slowed or stopped descending cage would probably be first and most aware of the problem. If they could initiate hoist shutdown, the chances of an ascending cage being hauled into a slack rope would be much diminished. In inclined shafts, commonly more lighted than vertical ones, the men riding the conveyance might be able to detect an obstacle in advance and should be able to discriminate between a normal and an abnormal slack-rope condition. Again, the probability of an accident should be reduced if these men could initiate hoist shutdown.

Manual hoist shutdown from the conveyance appears not only desirable but achievable. Battelle has seen such capability achieved with a rope strung the length of a slope that automatically shuts down the hoist when pulled. An arm or a hand could be injured or lost in using this system, and the problem of applying the idea to vertical shafts is recognized. Electronic control is definitely possible, however. Several years ago a Canadian manufacturer offered an electronic voice-communication system for use between cage and hoist house that used the hoist rope as a signal conductor. The system was taken off the market for lack of interest.(54) Another Canadian manufacturer is transmitting data along a hoist rope from a cage-mounted accelerometer to a recorder located topside.* South Africa has achieved this capability also.(43) Were a system designed to transmit a signal continuously along the hoist rope and to shut down the hoist when the signal is absent, the system would also shut down the hoist in the event of a complete loss of mechanical connection between the conveyance and the hoist – also a desirable action.

If it is desirable to use man on the conveyance as part of the hoist-control system to initiate hoist shutdown, it is necessary to consider providing him the opportunity to actuate the conveyance arrestment device manually. Were such capability provided without providing for concurrent hoist shutdown, an accidental or inadvisable manual actuation of the arrestment device on a descending cage could have the same ramifications as a descending conveyance sticking in the guides or striking an obstacle (Appendix E, Table E-1, Item 10). The one exception is the case of an uncounterbalanced single-compartment hoist system – the typical coal-mine inclined-shaft hoist.

Conclusions

In view of the foregoing, it is concluded that a slack-rope situation is not a prime condition for actuation of an arrestment device. Should such actuation occur merely because the device is designed to actuate in the event of a broken rope, for example, it would not appear to cause a problem in and of itself. However, hoist shutdown from the conveyance seems to be the only readily achievable solution to preventing some of the hoisting accidents caused by a slack rope.

It is also concluded that a manual capability at the conveyance for actuating the conveyance-mounted arrestment device is an alternative to shutting down the hoist only in the case of single-compartment uncounterbalanced hoist systems, e.g., those typical of inclined-shaft coal-mine hoist installations.

Finally, it is concluded that the most comprehensive protection against problems arising from a conveyance sticking in the guides or hitting an obstacle would be to provide for manual hoist shutdown from the conveyance concurrent with manual actuation of the arrestment device on the same conveyance.

*Private communication.

MOTOR-BRAKE-CONTROLS CONSIDERATIONS

Hoisting accidents have occurred for reasons not stemming from a loss of proportionality between drum rotation and conveyance motion (that is, from a broken or slack rope). To determine actuation requirements for arrestment devices under these circumstances, the motor-brake-drum or hoist-house portion of the system of Figure 1 must be considered in detail.

Except for the components related to automatic control of normal operation, the control features associated with the motor and brakes are essentially safety devices designed to prevent the conveyance from traveling faster and farther than is desired. In most hoist operations, "faster than desired" is relative to position of the conveyance in the shaft. For purely economic reasons related to size of motor, power plant, and brakes, it is desirable to have lesser operating speeds toward either end of the shaft. Thus, the historic function for safety devices in hoist speed control has been to limit the maximum hoisting speed. It is not uncommon in newer vertical-shaft systems to find safety control devices that also limit the less-than-maximum speeds desired toward both ends of the shaft. Generally all these safety devices are known as "overspeed" controls.

Traveling farther than desired can also be relative to position of the conveyance in the shaft in multilevel operations. In general, the greatest concern is with the top and bottom of the shaft, and safety devices concerned with this are known as "overwind" and "underwind" controls or, collectively, "overtravel" controls. The greater problem is overwind, since a conveyance pulled into the headframe stands a good chance (if the rope breaks) of free-falling to the bottom of the shaft, in addition to any damage it may do along the way. Underwinding involves lowering a conveyance directly against the bottom of the shaft.

Overspeed

Every overspeed device observed during this and the earlier study has been associated with either Lilly[58] or similar controllers or main-shaft-driven tachometer generators.

Lilly and Similar Controllers

As indicated in Figure 1, these devices monitor drum speed either directly at the drum or indirectly somewhere along the drive shaft, with the vast majority monitoring drive-shaft speed. The point where drum speed is sensed is itself worth discussing.

Point of Monitoring Drum Speed. If drum speed is monitored from the shaft and the drum disconnects from the shaft, an overspeed condition will not be detected and the overspeed controller will probably be useless unless the unloaded motor itself overspeeds. Where clutches are not fitted, such a disconnect almost certainly implies a broken shaft. This is rare, but it has happened with disastrous results (see Appendix E).

Clutches have been observed on a few coal-mine hoists. Some are of the positive-engagement type (toothed) and some are of the friction-band type. They exist despite the fact that regular hoisting operations do not require them. Clutches of either type are common to noncoal-mine hoist systems. It is highly desirable (when not required) to interlock the clutch and brake actuators so that one or the other is always engaged. With such interlocking, overspeed control is usually assured, even though the clutch is between the drum and the point on the shaft where drum speed is being monitored. In the event of a clutch failure, however, all is probably lost unless, as with a broken shaft, the suddenly unloaded motor overspeeds enough to actuate the overspeed controls. No instance of failure of a positive-engagement clutch has been uncovered in this or the previous wire-rope study. However, in February, 1971, a failure of an old Lane friction-band clutch initiated a limestone-mine hoisting accident in which four were killed (see Appendix E, Table E-1, Item 16). One clutch of this type observed on a coal-mine hoist is said to slip occasionally, particularly when starting heavy loads. Thus, the point where drum speed is monitored can affect the reliability of the overspeed control system.

Use of Monitored Drum Speed. Lilly and similar controls are normally gear driven so that some shaft in the controller is rotating at or proportional to drum speed. An attached governor, usually of the ball type, shuts off the power to the motor and applies the drum brakes when the allowed maximum speed is exceeded. If the mechanical controller components, the brake controls, and the brake itself function properly, Lilly and similar overspeed controllers are highly effective.

However, in what seems to be a typical accident, these devices did not function properly. An overspeed condition developed near the top of a shaft. The overspeed controller sensed the problem and provided a signal to a valve that was designed to depressurize the hydraulic system used to release the brakes. Though the signal was provided, the valve stuck. The brakes remained off, the conveyance went into the headframe at speed, the rope broke, and, fortunately, the conveyance jammed in the guides rather than falling down the shaft. In this case, the overwind controls also failed. This accident points out a general problem with safety controls: Safety controls that are rarely used are more prone to malfunction because of corrosion and accumulated grime than components that are used often. There are two possibilities for improving the reliability of these components:

(1) Actuate them periodically.

(2) Provide redundancy – use two or more components, in series or parallel as the case requires, to increase the probability that one will function.

It is convenient at this point to discuss drum brake operation. For safety reasons, these brakes are typically power released, gravity applied and are very reliable. Design differences are slight regardless of manufacturer. However, this study has uncovered a case of failure of the components anchoring the brake to the floor; the brakes did not work when needed (see Appendix E, Table E-1, Item 9). In another case the brake shoe apparently failed in fatigue. This case, as well as those mentioned in regard to drum shaft and clutch failure, points out another general problem: Basic mechanical components subjected over long periods of time to cyclic loads well below strength

limits are prone to fatigue failure. Increased reliability is obtained only by close, periodic inspection of critical components. Ultrasonic or magnetic-particle inspection techniques should be used when in doubt.

Tachometer Generators

Tachometer generators driven by the main shaft or drum have been observed which provide an electrical signal proportional to drum speed in control of automated hoists. It has not been determined to what extent, if at all, this speed signal is used in electrical overspeed control circuits. Potential advantages in its use involve ease of manipulation of signal and provision of some fail-safe control features. As mentioned, a drum-shaft or clutch failure could result in loss of drum-motion signal used for overspeed control. (Within mechanical controllers, a failure of gearing or shafting or ball-governor levers also can result in the loss of control signal.) An additional degree of safety-control reliability would be provided if a sudden loss of drum-speed signal would shut off the hoist motor and apply the brakes. Similarly, if no drum-speed signal were presented several seconds after the machinery were started, a system shutdown would be desirable. Such a fail-safe contingency is relatively simple to provide electrically.

Otherwise, where a tachometer-generator signal is used as a Lilly or similar controller uses a mechanical speed signal, all the previously mentioned problems can occur.

Overtravel – Overwind and Underwind

Three kinds of overtravel controllers are known to be used on mine hoists: Lilly or similar controllers, conveyance-actuated limit switches near the top and bottom of the shaft, and tapered guides at the top and bottom of the shaft.

For overtravel control, Lilly and similar controllers use the same rotary motion that is used for speed control. In this case, the rotary motion drives cams or is converted to linear motion by additional components. Switches and/or valve actuators are positioned at the points on the cams or linear-motion elements that represent the desired upper and lower limits of conveyance travel. When these switches or valves are actuated, the motor power is shut off and the brakes applied. The main motor-brake controls and mechanical components involved are those used in controlling overspeed. Thus, overtravel controls are essentially prone to the same operational problems as overspeed controls.

Overtravel controls using limit switches placed in the shaft are potentially more reliable because they involve the conveyance directly, bypassing the potential mechanical problems with controller, shaft, clutch, and drum components. (Earlier it was stated that there is no motion feedback from the conveyance to the motor-brake control components of traditional mine hoists. Use of shaft-mounted limit switches for overtravel control is the only known exception.) When actuated by the conveyance, the limit-switches shut off the motor and apply the brakes. Typically, limit switch overtravel controllers and Lilly or similar overspeed controllers actuate the same circuit

breakers and hydraulic pressure-relief valves. As stated, if these breakers and valves are normally unused and are not periodically actuated or are not redundant, they may not work when actuated.

In the course of this and the earlier study (particularly in the latter), several overwind incidents were uncovered. All occurred on hoists equipped with overwind safety-control devices.

Tapered guides at the top and bottom of a shaft are an interesting solution to overtravel control. They eliminate the need to rely on the proper functioning of a series of mechanical components. Their use is rare but worthy of greater consideration.

RESPONSE TO HOISTING DYNAMICS

Earlier it was stated that all hoist safety controls rely on the motion of the conveyance being proportional to the rotation of the drum or drive wheel. It was further stated that because hoist ropes act like springs, the motion-rotation relationship is never quite proportional. This dynamic behavioral aspect is a natural characteristic of the physical system and is most noticeable in vertical shafts and more prominent the deeper the shaft. This behavior results in rope tensions that vary positively and negatively about the value which exists when the conveyance is not moving or when it is moving at constant speed. This dynamic behavior also results in conveyance speeds that vary positively and negatively about the value indicated at the drum. These variations are greatest during acceleration and deceleration. Arrestment-device actuation should not occur as a result of these dynamic variations in speed or rope tension.

DISCUSSION

To finalize actuation conditions for a conveyance-mounted arrestment device, there is value in focusing on indications of abnormal operation that could be sensed at the conveyance. The following indications seem sufficient for consideration:

(1) Broken hoist rope or other loss of connection between conveyance and drum

(2) Development of hoist-rope slack, apart from loss of connection (resulting from tight guides, derailment, shaft obstacles)

(3) Overspeed

(4) Overtravel, primarily overwind.

All hoisting accidents uncovered in this and the earlier study that were caused by failures or abnormalities in the hoist-system machinery and controls, excluding malfunctioning arrestment devices, exhibited at least one of these four conditions. If a

conveyance-mounted arrestment device could protect the conveyance against these conditions, hoisting safety would be greatly improved.

The first two listed indications of potential problems appear to require action at the conveyance; the latter two can be accommodated by the hoist controls that are usually required – provided they are reliable. However, it has been shown that in the typical hoist installation, these controls are not highly reliable. Thus, providing overspeed and overtravel reaction capability at the conveyance would provide a measure of redundancy that would increase reliability.

The mining community must understand that, in the best hoist system, there are potential failures against which no arrestment device can prevail. For example, the failure of conveyance guides over even a fairly short distance would probably make it impossible to control or stop a conveyance. Similarly, with traditional flanged-wheel T-rail guidance typical of most slopes, if a conveyance derails, its arrestment device is of no value.

It has been stated that the development of rope slack and conveyance overtravel are abnormal conditions which, though sensible at the conveyance, do not appear to be conditions for arrestment-device actuation. A manual capability at the conveyance for shutting down the hoist appears far more desirable.

Broken-rope (loss of connection between conveyance and drum) and overspeed conditions remain as practical candidates for automatic actuation requirements. Both are valid. However, it should be recognized that in the event of a broken rope or other loss of connection between conveyance and drum, the conveyance will fall and its speed will soon be beyond the rated maximum hoisting speed. Thus, in order of desirability, for comprehensive protection overspeed is first, followed by actuation in the event of any loss of connection between conveyance and drum.

In conclusion, it must be noted that though drum-hoist systems have been discussed throughout, all conclusions and suggestions apply equally well to friction-drive (Koepe) hoists. It should also be noted that elevators used in mine applications are friction-drive hoists.

SUMMARY

Requirements for Automatic Actuation of Conveyance-Mounted Arrestment Devices

Degree of Desirability	Condition
1st	Conveyance overspeed
2nd	Broken rope or other loss of connection between conveyance and drum (drum hoists), or in the case of friction hoists, conveyance and counterweight, or two conveyances
No actuation	Changes in conveyance speed or rope tension resulting from the dynamic behavior of the rope-conveyance (spring-mass) system during periods of acceleration and deceleration.

Additional Desirable Capability Within State-of-the-Art Controls Technology

Degree of Desirability	Capability
1st	Manual capability at conveyance for hoist shutdown and arrestment-device actuation
2nd	Manual capability at conveyance for hoist shutdown
3rd	Manual capability at conveyance for actuation of conveyance-mounted brakes in the case of single-compartment, uncounterbalanced hoist systems (typical inclined-shaft systems).

Suggestions for Increasing the Reliability of Hoist Machinery and Safety Devices

(1) Safety-control components that are normally actuated only when something goes wrong are prone to malfunction because of corrosion and accumulated grime. Increased reliability can be achieved through

   (a) Periodic actuation

   (b) Redundancy of critical components.

(2) Basic mechanical components (shafts, levers, etc.) subjected to cyclic loading well below strength limits over a long period of time are prone to fatigue failure. Increased reliability can be achieved through close, periodic inspection of critical components. Ultrasonic or magnetic-particle inspection techniques are valuable aids.

Suggestions for Future Development

(1) Automatic shaft obstacle detection at the conveyance with subsequent hoist shutdown and/or conveyance arrestment

(2) Automatic hoist shutdown if conveyance arrestment device actuates

(3) Greater use of solid-state electronic components in hoist safety controls, with the addition of loss-of-signal shutdown capability.

PERFORMANCE REQUIREMENTS

Two areas of device performance are of interest.

(1) Performance during stop

(2) Performance after stop.

PERFORMANCE DURING STOP

Though the arrestment device will be used for emergency situations, it does not follow that the emergency stop should be made as rapidly as possible. The more rapid the stop, the greater the stresses on both men and equipment. Clearly, some limits must be considered for both.

Human Considerations

Human tolerance to acceleration depends on body position. Normally acceptable human acceleration limits are more than enough to stop a mine conveyance adequately. However, accelerations well below human tolerance levels can cause great discomfort and in some cases injury. Both should be avoided if possible.

Vertical Shafts

Table 1 indicates the duration and magnitude of accelerations associated with some common and not-so-common human experiences. The elevator emergency deceleration applies to a downward-moving cage, and the passenger is assumed to be standing. When the 2.5-g deceleration (2.5 times the acceleration due to gravity) is applied to the cage, a passenger effectively weighs 3.5 times his normal weight (2.5 g plus the 1 g that is his normal weight).

TABLE 1. APPROXIMATE DURATION AND MAGNITUDE OF SOME ACCELERATIONS

Vehicle	Activity	Acceleration[a]	
		Duration, seconds	Magnitude, g
Elevator	Average acceleration in "fast service"	1-5	0.1-0.2
	Comfort limit for acceleration		0.3
	Emergency deceleration		2.5
Train	Normal acceleration and deceleration	5	0.1-0.2
	Emergency stop (braking from 70 mph)	2.5	0.4
Automobile	Normal stop	5-8	0.25
	Quick stop	3-5	0.45
	Emergency stop	3	0.7
	Crash (potentially survivable)	<0.1	20-100
Aircraft	Normal takeoff	>10	0.5
	Catapult takeoff	1.5	2.5-6
	Crash landing (potentially survivable)		20-100
	Seat ejection	0.25	10-15
	Parachute opening at 40,000 ft	0.2-0.5	33
	Parachute opening at 6,000 ft	0.5	8.5
	Parachute landing	0.1-0.2	3-4

(a) Acceleration of the system.

If wind and guideway resistance are neglected, and if the cage is descending at 1500 ft/min, a 2.5-g deceleration will stop the cage in 0.31 sec in a distance of 3.9 ft. If the deceleration were 1 g, the man would feel twice as heavy, the stopping time would be about 0.77 sec, and the stopping distance about 9.8 ft. It should be noted that the initial velocity of 1500 ft/min chosen for these examples is about 300 ft/min faster than the maximum any state permits for hoisting in coal mines, and about twice as fast as the maximum permissible speed in most coal mines.[50] If the initial speed were 750 ft/min, these stopping times would be halved and the stopping distance reduced to 1/4 of the above values. (The 1500 ft/min speed was chosen to encompass known noncoal-mine hoisting speeds.) Thus, achieving a relatively short stop in a vertical shaft is easily consistent with acceptable human tolerance to acceleration.

It is necessary to consider whether a conveyance brake must modulate its braking force to account for the difference between a fully loaded cage and a cage with only one man aboard. To approach this problem in a general way, the following definitions are presented:

W = weight of empty cage, lb

w = weight of one man, lb

n = maximum allowable number of men carried, or full man load

$W'_m = \ell_m W$ = weight of cage plus capacity man load, expressed as a multiple of the empty cage weight, lb

$\ell_m = \left(1 + \frac{nw}{W}\right)$ = man-load factor

$W'_e = \ell_e W$ = weight of cage plus equipment or supply load, expressed as a multiple of the empty cage, lb. (This applies where the cage is also used to hoist equipment and supplies.)

$\ell_e = \left(1 + \frac{W_e}{W}\right)$ = equipment-load factor where W_e = weight of equipment

$F_b = XW'_m$ = arrestment-device braking force, expressed as a multiple of the total weight of the cage and its full man load, lb, where by necessity the multiplier $X > 0$

g = gravitational constant, ft/sec^2

a_i = acceleration of cage and load, ft/sec^2,

where

$i = m$ refers to full man load

$i = e$ refers to equipment load

$i = 0$ refers to empty cage.

Taking "down" positive, and neglecting conveyance-guide friction and wind resistance, the cage accelerations for the conditions of interest are:

Cage with full man load

$$a_m = \frac{\ell_m W - X(\ell_m W)}{\ell_m W} g = (1-X)g \quad . \tag{1}$$

Empty cage

$$a_0 = \frac{W - X(\ell_m W)}{W} g = (1-X\ell_m)g \quad . \tag{2}$$

Cage with equipment load

$$a_e = \frac{\ell_e W - X(\ell_m W)}{\ell_e W} g = \left(1 - X\frac{\ell_m}{\ell_e}\right) g \quad . \tag{3}$$

It is being assumed that the arrestment device is designed to apply a fixed retarding force and that this force is designed for a cage with a full man load. Rather than write Equation (2) for the case of one man aboard, it has been assumed that an empty cage behaves as if it carried one man.

Assume that the braking force is sufficient to provide a -1-g acceleration (i.e., 1-g deceleration) to the cage with its full man load. Thus, from Equation (1)

$$a_m = -1g = (1-X)g, \text{ or } X = +2 \quad .$$

That is, the braking force F_B must be equal to twice the weight of the fully loaded cage.

Substituting the value for X in Equation (2) for the empty cage, or for the cage with one man, yields

$$a_0 = (1 - 2\ell_m)g \quad . \tag{4}$$

Obviously, the acceleration obtained depends upon the man-load factor. While this varies among coal-mine conveyances, the following example should be applicable:

W = 20,000 lb

n = 15 men

w = 200 lb.

Thus,

$$\ell_m = 1 + \frac{15 \times 200}{20,000} = 1.15 \quad ,$$

or the full man load is equivalent to 15 percent of the weight of the empty cage.

In this case, Equation (4) yields

$$a_0 = 1 - (2 \times 1.15)g = -1.30\ g \quad .$$

Thus, a fixed braking force designed for 1-g deceleration with the full man complement would not result in an excessive deceleration load on one man riding alone.

Earlier it was stated that a deceleration of 2.5 g should not lead to injury to a standing man. Using Equation (4) to determine what ℓ_m might be if -2.5 g were a limit yields

$$-2.5\ g = (1-2\ell_m)g, \quad \text{or} \quad \ell_m = 1.75 \quad .$$

For this example, the brakes could be designed for 1-g deceleration with a total man load as much as 75 percent of the weight of the empty cage, or a full complement of 75 men, without causing undue deceleration loads on one man riding alone in the cage.

Next, the case of lowering a piece of equipment is examined where

$W = 20,000$ lb (empty cage)

$\ell_m = 1.15$ as before

$X = 2$ as determined earlier

and now

$\ell_e = 2$, that is, the equipment weighs as much as the cage.

From Equation (3)

$$a_e = \left(1 - 2\,\frac{1.15}{2}\right) g = -0.15\ g \quad .$$

Thus, in this case, where the brakes are designed to stop the cage with a full man load with a deceleration of 1 g, a piece of equipment weighing as much as the cage could, at least theoretically, be stopped, but the stopping time and distance would be increased by a factor of about seven.

The previous numerical examples show what a conveyance arrestment-device designer would have to consider in designing his brake. Though the process is somewhat iterative, it is simple enough. He must know

(1) Empty conveyance weight, W

(2) Maximum number of men to be hauled, n

(3) Weight of heaviest piece of equipment to be hoisted.

The designer could then quickly determine whether he would subject any man to undue deceleration forces, and could reduce or increase his braking force accordingly. Knowing the values of deceleration, he could easily determine stopping distances and times, assuming a stop from some initial hoisting speed, v_o:

$$t_s = \frac{v_o}{a} \text{ sec, stopping time}$$

$$S_s = 1/2 \frac{v_o^2}{a} \text{ ft, stopping distance.}$$

Since an adequate stop consistent with human tolerance is no problem, it is now necessary to determine what deceleration limit to use in a performance criterion. As Table 1 shows, the 2.5-g deceleration is typical of an elevator emergency stop. No such figure is available from tests on U. S. vertical-shaft mine hoists. Ontario, however, has made extensive tests and has concluded that 3 g is desirable maximum. (With a 3-g deceleration, a man would feel four times heavier.) Lacking any other substantiated limit as a guide, it is suggested that a 3-g deceleration limit be used.

Finally, in framing a performance specification, the speed from which a stop is to be made must be defined, since overspeed actuation is the most desirable approach. An overspeed governor can provide an actuation signal when the speed has increased by 5 to 15 percent of the permissible maximum. At worst, 15 percent overspeed would increase the stopping time by a factor of 1.15 and the stopping distance by a factor of 1.32. Since stopping times on the order of 1 second and stopping distances on the order of 10 feet are readily achievable, a stopping time 15 percent greater and/or stopping distance 32 percent greater is of no concern. Though this discussion centers on arrestment devices, the previous comments apply equally well to the overspeed governor mounted on the hoist. Since these governors are generally required by law, they must be accommodated; a conveyance device that responds to overspeed should do so at an overspeed slightly higher than that of the hoist overspeed controller. To assure, however, that the actual overspeed of conveyance-device actuation does not lead to excessive stopping times and distances when the device is designed to stop the conveyance from rated maximum speed, it seems advisable to specify that the speed at which actuation is effected should not be greater than, say, 1.25 times the rated maximum hoisting speed.

Thus, the following conveyance-mounted arrestment-device performance criteria are suggested:

> In vertical-shaft applications, conveyance-mounted arrestment devices must be capable of stopping a descending conveyance from the rated maximum hoisting speed without subjecting a man to a deceleration greater than 3 g whether the conveyance is carrying one man or its rated man load.
>
> If overspeed activates the device, the speed at which it actuates must not be greater than 1.25 times the rated maximum hoisting speed for the system, nor less than the overspeed for which the hoist overspeed control will actuate.

Inclined Shafts

The human aversion to riding backward has long posed problems in preventing injuries in emergency stops and head-on collisions. It is well known that if people

could be induced to ride backward, the seat back would provide body support that would permit higher deceleration forces with less likelihood of injury. The problem with facing forward is that, without seat and shoulder belts or other restraints, it is easy to send a man flying forward. Multipassenger vehicles that have all seats on the same floor level generally provide a seat back fairly close ahead. Inclined-shaft man cars can be more dangerous because of their stairstep design.

In all the inclined-shaft man cars observed during this program and the earlier study, men face downslope in a conveyance designed to place the seat bottoms more or less horizontal in the steepest part of the shaft. The seat bottoms are typically flat and smooth. The designs of these man cars vary from providing nothing in front of the man, to part of the seat back in front of him, to the steel top of the car. No seat belts have ever been seen, though some open-top cars do provide a handrail running down the center.

Regardless of cause, it is apparent that it would be relatively easy to throw a man into a steel roof or completely off some man cars when making a rapid downslope stop for any reason.

The following arguments in support of a deceleration limit for arrestment devices on inclined-shaft conveyances become practically academic in view of the importance of the design of the car. A complete discussion of the safety aspects of the design of man cars is beyond the scope of this program; however, two obvious solutions come to mind: the use of seat and/or shoulder belts, or car designs that make the men face up-slope. The first would lead to psychological problems and the second to much equipment replacement. Short of either, many downslope-facing cars could be modified to give a man a better chance.

Table 1 shows that an automobile emergency stop from 70 mph (6160 ft/min) produces a deceleration of about 0.7 g. Any driver recognizes that an "emergency stop" will send unrestrained passengers and baggage flying forward. Even with seat belts, such a stop will bend the body and could easily cause head injuries. An appropriate limit to horizontal deceleration for men facing downslope is difficult to determine. Using 0.7 g and the 0.45 g typical of a "quick" automobile stop (see Table 1) and computing the equivalent deceleration parallel to the slope and the corresponding times and distances for stopping provides the data shown in Table 2.

TABLE 2. STOPPING TIMES AND DISTANCES FOR AN INCLINED-SHAFT CONVEYANCE AS A FUNCTION OF SHAFT INCLINATION AND ASSUMED LIMITS FOR THE HORIZONTAL COMPONENT OF ACCELERATION

Assumed Limit, a_{horiz}	$a_{slope} = \frac{a_{horiz}}{\cos \theta^*}$		Time to Stop (from 1500 ft/min), sec		Stopping Distance, ft	
	$\theta = 45°$	$\theta = 12°$	$\theta = 45°$	$\theta = 12°$	$\theta = 45°$	$\theta = 12°$
.7 g	~1 g	~.7 g	.78	1.1	9.7	14
.45 g	~.64 g	~.45 g	1.2	1.7	15	21

* θ = Inclination angle, measured from horizontal.

These data assume an initial velocity of 1500 ft/min as in the discussion of vertical-shaft hoists. In this case, however, this speed is probably easily twice that of the maximum speeds for the majority of coal-mine slope hoists. Again, with an initial speed of 750 ft/min, the above times would be halved and the stopping distance 1/4 of the values indicated.

A 0.45-g limit on the horizontal component of deceleration would, theoretically at least, provide adequately short stops and should be less likely to lead to human injury than a 0.7-g stop. Nevertheless, because of man-car design, there is still no assurance that a 0.45-g horizontal component of deceleration will not send downslope-facing men flying out of their seats. British work in this area indicates that an average deceleration of about 0.15 g parallel to the slope in shallow slopes causes no discomfort to downslope-facing men.[8] There are so many unknowns regarding the design aspects of both the cars and brakes involved in these data that Battelle hesitates to recommend this value. The principal difficulty is that where rail brakes are used, the coefficients of friction between brake shoe and rail can vary widely with environmental conditions. Recommending a low deceleration limit is likely to result in no stop at all under slippery rail conditions.

The question of a brake modulating to account for load differences between full man load and one man aboard is applicable to inclined as well as vertical shafts. The acceleration equations of interest are

Car with full man load

$$a_m = (\sin\theta - X)g, \text{ parallel to slope} \qquad (5)$$

Empty car (or one man aboard)

$$a_o = (\sin\theta - X\ell_m)g, \text{ parallel to slope} \qquad (6)$$

Horizontal component of acceleration

$$a_{horiz} = (\cos\theta)a_i \ , \qquad (7)$$

where

θ = degree of shaft inclination from horizontal

i = m or o

and all other terms are as defined earlier.

The ramifications of a fixed braking load have been examined in this case also. They are the same as for vertical shafts; a modulating braking force does not appear necessary.

In conclusion, the following performance specifications are suggested:

> In inclined-shaft applications, conveyance-mounted arrestment devices for use on cars in which the men face down the shaft must be capable of stopping a descending conveyance without subjecting a man to a horizontal component of deceleration greater than 0.45 g, whether the conveyance is carrying one man or its rated man load.
>
> The condition of actuation in the event of overspeed actuation, presented in the previous section on vertical shafts, applies here also.

It is recognized that there is no assurance that a 0.45-g horizontal component of deceleration will not lead to injury in view of man-car designs. The 0.45-g value should be tested and replaced by a more realistic value if necessary.

Structural Considerations

It was stated at the beginning of this section that both men and equipment are subjected to stresses during an arrestment and that limits for both must be considered. Since people are more fragile than hoisting equipment, it is logical that the vertical- and inclined-shaft conveyances and arrestment devices be capable of withstanding at least the deceleration limits established for people.

Since it has been suggested that a conveyance arrestment device induce no more than a 3-g force on a man, all structural components should also withstand a live load of 3 g. This situation can be stated in either of the following equivalent ways:

(1) Design dead load = 1 g; design live load = 3 g; total design load = 4 g

(2) Design safety factor of 4 based upon maximum static load - men and cage.

The use of the term "safety factor" in the second statement is somewhat regrettable because it does not account for the unknowns involved – the classic job of a safety factor. In this case, the unknowns include impact forces and the effects of fatigue or corrosion in reducing structural strength. There are few guidelines in this area. A safety factor of at least 2 applied to the maximum known loads would appear to be a minimum. Thus, to account for unknowns with respect to Statements (1) and (2):

(1a) Total design loads for stress calculation: 4 g x 2 = 8 g

(2a) A design safety factor of 8 based upon maximum static load.

Great Britain and Ontario use a safety factor of 10 based upon maximum static load for the design of the devices connecting the hoisting rope to the conveyance. Ontario regulations require the safety factor of 10 on all rope-attachment components, conveyance-frame members, and all other parts affecting the structural integrity of the conveyance. To be consistent with the previously recommended performance specification, as well as with the long-established static-load safety factor of 10 in use in Ontario and England, the following is suggested:

In designing man-carrying conveyances and conveyance-mounted arrestment devices, the stress computations should be based upon a load of at least 2.5 times the maximum total load anticipated during a stop brought about by the conveyance-mounted arrestment device.

It should be noted that the above-suggested design specification does not necessarily mean that a safety factor of 10 (based upon the total anticipated maximum static load) will apply. A safety factor of 10 will apply only where a 3-g deceleration is used. It should be further noted that in suggesting "at least 2.5 times", a designer has the freedom to strengthen a component further if other considerations require it.

The suggested criterion has not differentiated between vertical and inclined shafts. Even though lower decelerations are needed to stop inclined-shaft conveyances in general, the above criterion is logically consistent when applied to both vertical- and inclined-shaft conveyances.

PERFORMANCE AFTER STOP

When an arrestment device has been actuated, the conveyance will probably stop somewhere other than at its normal loading-unloading station. The next action probably will involve either someone getting to the men aboard or their getting out. Subsequently, the hoist will have to be returned to its normal operating condition. Thus, some consideration must be given to how long the arrestment device should hold the conveyance where it stops, and, then, how it should be released.

Holding

The most desirable requirement appears to be that the arrestment device be capable of indefinitely holding the conveyance where it stops. Such action is usually automatically assured by systems using stored mechanical energy to apply the brakes. Theoretically, since the stopping force is greater than the holding force, there should be no doubt about holding indefinitely so long as no components fail.

Indefinite holding is not so readily assured with systems using stored hydraulic, pneumatic, or electrical energy to apply the brakes. With hydraulic or pneumatic systems, there is always the danger of leaks and a pressure loss. With electrical energy, there is the eventual depletion of the charge when a battery is used.

To achieve high reliability, stored hydraulic, pneumatic, and electrical energy systems will generally require more maintenance than stored mechanical energy systems. There is no reason to rule against them on these grounds; however, there is good reason to require such systems, particularly battery-powered ones, to be supplemented by braking devices that can be applied manually, for example, to assure that once stopped, the conveyance does not eventually move again.

Therefore, it seems highly desirable to require that, having actuated and stopped the conveyance, the arrestment device must be capable of indefinitely holding the

conveyance where stopped. Where the design of the arrestment device does not automatically assure this, additional manually operated components should be provided for this purpose.

Release

An arrestment device that can hold indefinitely automatically assures that some positive action is required for release. While a system can be designed to release itself when "normal" hoisting conditions are reestablished, it may be desirable in many cases to design for manual release at the discretion of the persons in charge. As will be described in the next chapter, most vertical-shaft arrestment devices will release only after the cage is hoisted a short distance. When they do release, they usually reset themselves automatically. This has merit in vertical shafts because reestablishment of control with the hoist is probably the simplest and safest way to release the arrestment device. Inclined-shaft conveyances, however, are generally more accessible and thus more manageable. To require that their arrestment devices be released by moving the conveyance with the hoist could hinder rescue or clean-up operations. Thus, requiring conditions under which a brake can be released does not appear necessary.

Releasing a brake does not necessarily mean that it must go from fully on to fully off. A brake that could be infinitely adjusted manually between these settings would provide a capability for lowering a conveyance without using the hoist. However, were such adjustable-release capability provided, it should be designed to assure that the brake applies full force when actuated.

SUMMARY

Stopping Performance

A conveyance-mounted arrestment device should be capable of stopping a descending conveyance from the rated maximum hoisting speed without subjecting a man to

(1) A deceleration greater than 3 g for vertical shafts

(2) A horizontal component of deceleration greater than 0.45 g for inclined shafts

whether the conveyance is carrying one man or its rated man load.

If overspeed is the actuating condition, the conveyance overspeed at which the arrestment device actuates should not be greater than 1.25 times the rated maximum hoisting speed, nor less than the overspeed at which the hoist overspeed control actuates.

Note: The 0.45-g deceleration figure above should be validated in view of the designs of the slope man cars typically in use.

Holding Performance

An arrestment device should be capable of indefinitely holding the conveyance where it stops. Where device design does not automatically assure this, additional manually-operated components should be provided.

Release Performance

Where an arrestment device is designed to permit a manual, variable release for lowering the conveyance in the absence of normal hoist control, this capability should not prevent the device from developing its full force when actuated.

Design Criterion

In designing arrestment devices and man-carrying conveyances, the stress computations should be based upon a load of at least 2.5 times the maximum total load anticipated during a stop brought about by the arrestment device.

CHAPTER 3

REVIEW AND EVALUATION OF ARRESTMENT-DEVICE TECHNOLOGY AVAILABLE TO U.S. COAL MINES

INTRODUCTION

In this discussion of arrestment devices, emphasis is given to those commonly used in U. S. coal mines. For completeness, devices used in various U. S. nonmetal and metal mines and in foreign practice are also described. These are of value to understanding the alternatives open to U. S. coal-mine operators.

Mine-conveyance arrestment devices in use in the United States and throughout the world encompass a wide variety of mechanisms. Regardless of appearance, individually or in groups these mechanisms exist to perform at least one of the following functions:

(1) Braking

(2) Actuation

(3) Sensing and discriminating.

The braking elements interact with the guides or rails and are responsible for the conversion of energy required for stopping the conveyance.

The actuation components move the braking elements into contact with the guides or rails and, in some designs, also provide and transmit power necessary for developing the braking forces.

The sensing and discriminating components monitor some variable (e.g., conveyance speed), compare it to a built-in limit, and provide a signal that allows the actuation components to work when this limit is reached.

While it is possible to categorize arrestment devices mechanically according to the above basic functions, this review is categorized in terms of the guide systems to focus attention on the problems the guides present. This arrangement also helps to define the operational and developmental problems that have occurred with arrestment devices.

The discussion is presented in two major sections, traditional mine-hoisting systems and elevators. The distinction is necessary because elevators are designed, built, inspected, and maintained according to a distinct set of specifications developed by the elevator industry. No similar set of specifications exists for traditional mine-hoisting equipment.

VERTICAL SHAFTS – WOODEN GUIDES

General Description

Figures 2 and 3 illustrate two conveyance arrestment devices commonly used in vertical-shaft wood-guide hoisting systems. Figure 2 shows a multitoothed-wedge device, and Figure 3 a single-tooth dog device. The wedge and the dog are the braking elements. It is common to describe arrestment devices by referring to the type of braking element used. Both devices can also be called "broken-rope" devices. A loss of rope tension from any cause will lead to actuation. To Battelle's knowledge, all arrestment devices used in U. S. vertical-shaft wood-guide hoist systems actuate by loss of hoist-rope tension. Finally, both devices can be called "safety catches" in the most accurate, historic sense of the term.

The devices are shown fully released in Figures 2 and 3. The hoist rope attaches to the upper end of the draw bar. The draw bar is not rigidly attached to the conveyance, but is free to move vertically. The weight of the conveyance is transmitted to the draw bar through the compression spring. Under normal conditions, the weight of the conveyance compresses the spring until a positive stop is encountered.

The braking elements are connected to a series of links and levers for wedge devices (Figure 2), or shafts and cranks, for dog devices (Figure 3). These are, in turn, connected to the draw bar. With the spring compressed, the braking elements are clear of the guides.

With a loss of hoist-rope tension, the compression spring is free to extend. In so doing, it pulls the wedges or rotates the dogs into contact with the guides.

These devices almost universally have two braking elements per guide, as shown in Figures 2 and 3. Generally, the actuating links or shafts are designed to equalize the movements of the four braking elements to minimize differences among the braking forces developed by each of them.

While the braking and actuating components are fairly distinct in these devices, note that the compression spring serves double duty: it is the sensing and discriminating element, as well as part of the actuation system.

During and after a stop, the conveyance is supported by the brake elements. The devices of Figures 2 and 3 are both released by reapplying hoist-rope tension. As the tension is reapplied, the draw bar compresses the spring, and the links and shafts reverse their motion. During this time, the conveyance is raised until the brake elements are clear of the guide, at which point the weight of the conveyance is again fully supported by the hoist rope, and the device is automatically reset.

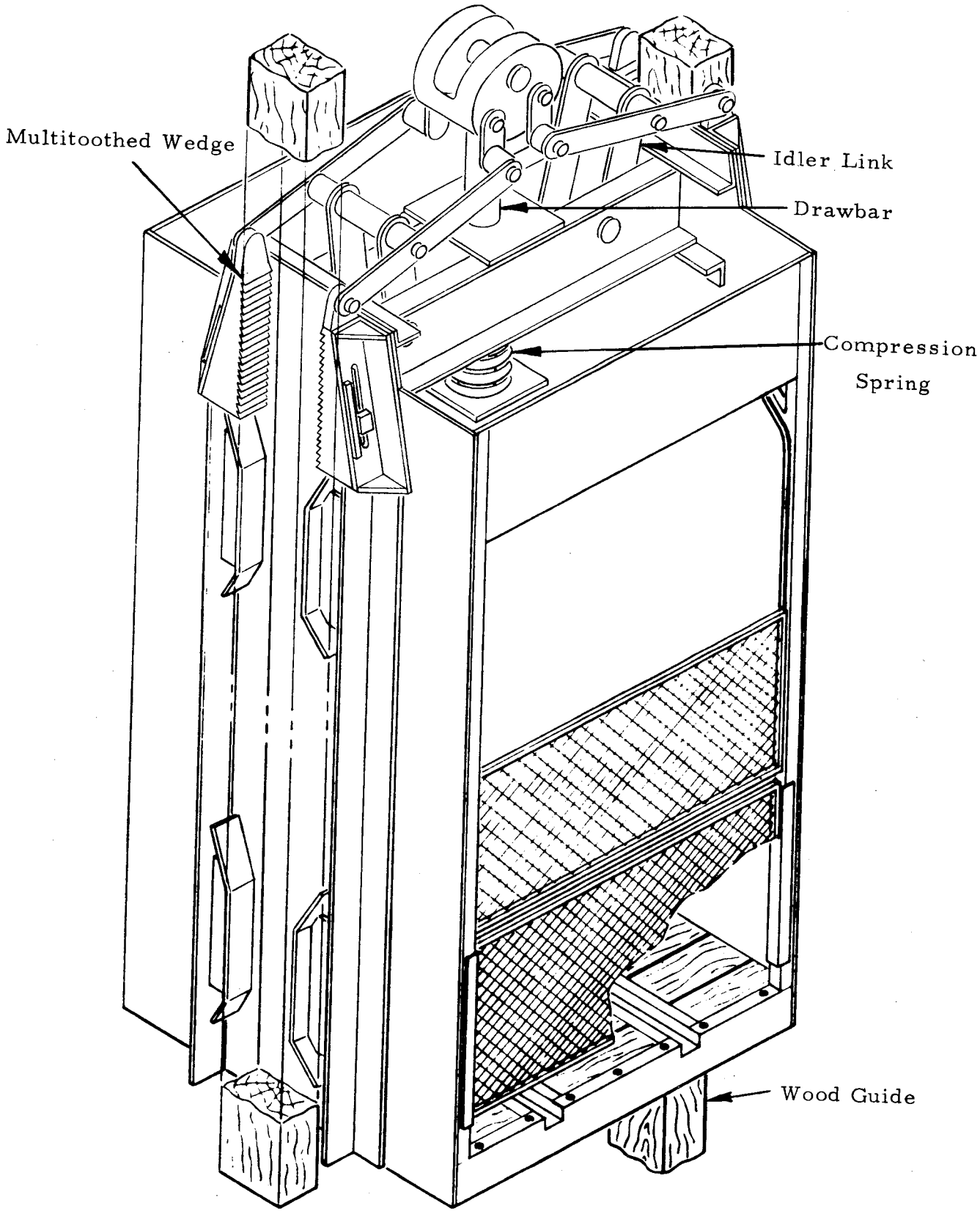


FIGURE 2. CONVEYANCE EQUIPPED WITH A MULTITOOTHED-WEDGE ARRESTMENT DEVICE

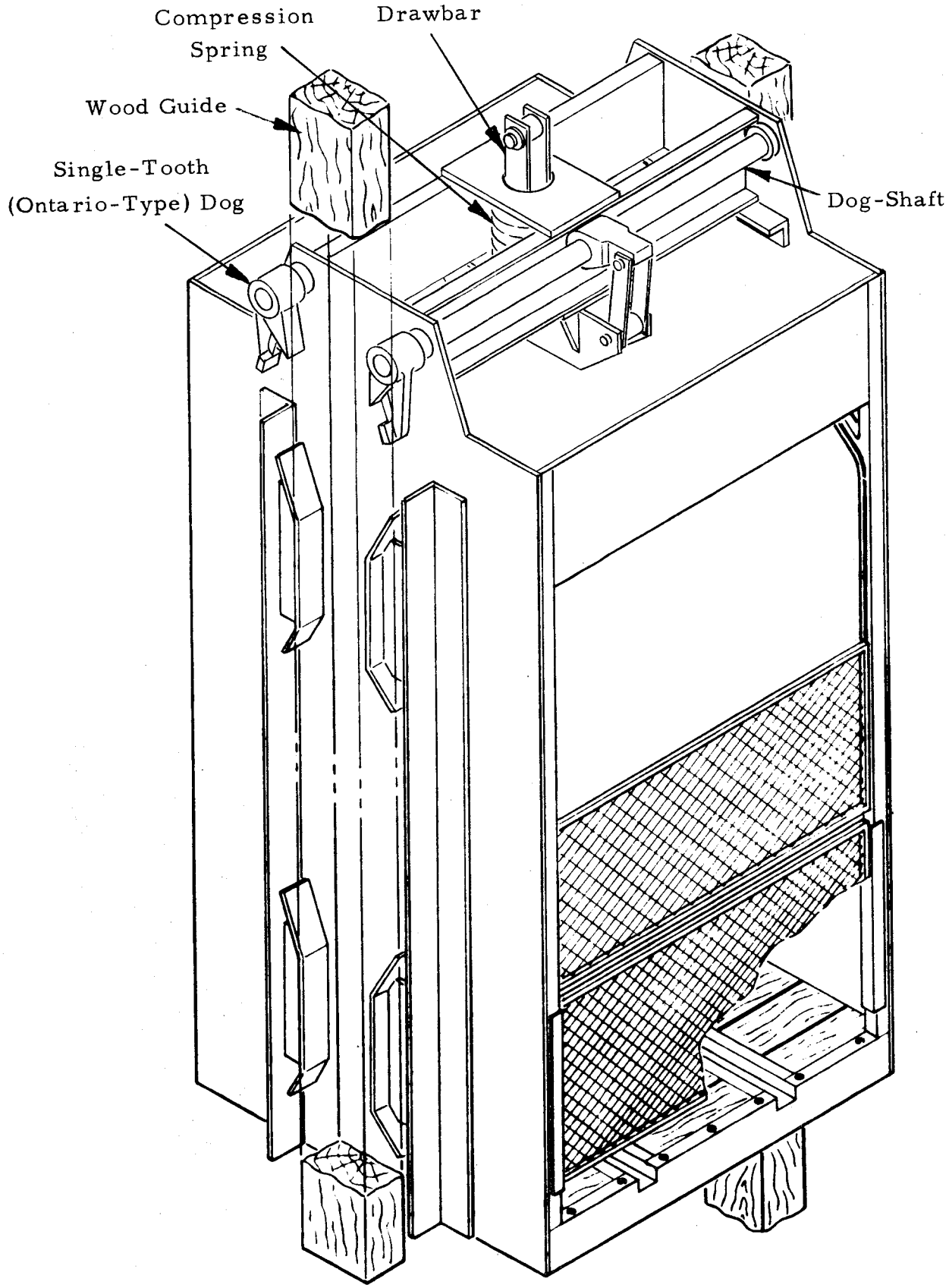


FIGURE 3. CONVEYANCE EQUIPPED WITH A SINGLE-TOOTH-DOG ARRESTMENT DEVICE

Antitrailing-Rope Linkages

Because the application of hoist-rope tension releases the arrestment devices shown in Figures 2 and 3, many have been concerned about a hoist rope breaking some distance from the conveyance. Under these circumstances, the argument goes, the compression spring must overcome the inertia of the rope segment still attached to the conveyance. In addition, if the trailing-rope segment snags or whips against the structure framing the shaftway, it could prevent the movement of the compression spring, thereby preventing actuation of the brakes. This concern was (and still is, in some quarters) practically universal because actuating linkages all work more or less like those of Figures 2 and 3.

Out of this concern grew a series of actuation-linkage designs known as "antitrailing-rope mechanisms", one of which is shown in Figure 4 applied to a single-tooth-dog device very similar to that of Figure 3. (In fact, actuation is identical to that of Figure 3.) However, once the brake is actuated, a reapplication of rope tension may reverse the motion of the actuation shafts and links but will not rotate the dog out of engagement with the guide because of the slot in the link attached to the dog shaft. The dogs can be disengaged only by raising the conveyance.

With the conveyance stopped and hoist-rope tension reapplied in the normal fashion, the compression spring returns the links and shafts to their ready-to-actuate position. At this point, the weight of the conveyance is transferred from the dogs to the hoist rope. However, the dogs are still in their fully engaged position. As the conveyance moves upwards, the force of the small secondary spring becomes sufficient to rotate the dogs to their ready-to-actuate position.

Braking Elements

The braking elements most commonly used with vertical-shaft wood-guide arrestment devices are shown in Figures 5 and 6. Figure 5 illustrates "cam" and "wedge" elements, including the multitoothed wedge previously shown.

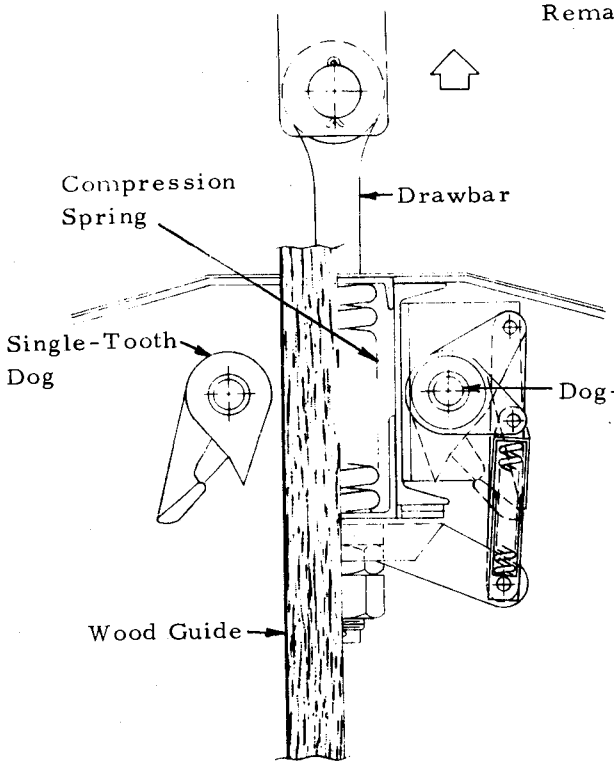
The design of these elements can inherently lead to different performance characteristics. Once the teeth of the cams or wedges engage the guides and produce a drag force, the cams or wedges press more and more tightly against the guides. With cams, the pressure induced on the guides is limited only by the deformation of the guides and the strength of the cam teeth unless there is a limit in the actuation linkage. With wedges, the pressure on the guides is limited only by the deformation of the guides and the deformation of that part of the conveyance-mounted structure which backs up the wedges.

The dogs of Figure 6 are all designed to achieve and maintain a specific position after engaging the guides. Designs (a), (b), and (c) in Figure 6 achieve this positioning with the wear pads that ride against the surface of the guide. Design (d) is limited in its rotation by stops on the actuation shafts and links. Though designs (c) and (d) have multiple teeth, the smaller ones (those that first engage the guide) are provided to assist the engagement of the large bottom tooth.

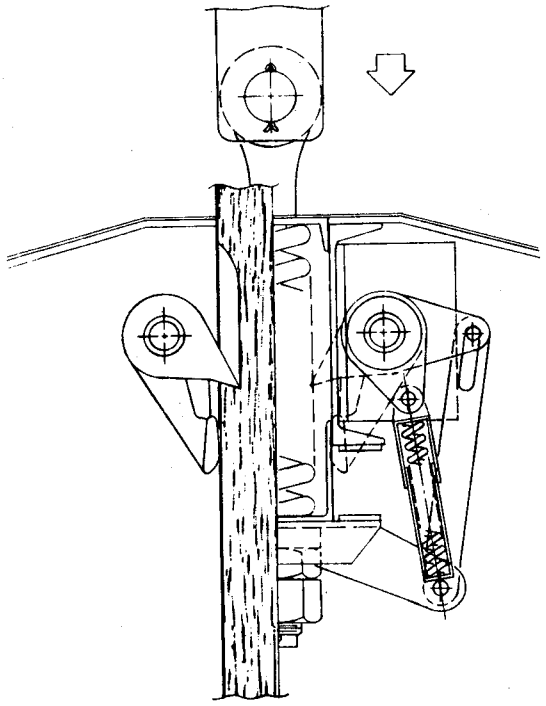
Remarks:

The moment about the dog-shaft axis caused by action of the dog against the wooden guide during arrestment is far greater than the opposing moment provided by the secondary spring causing the dogs to remain engaged even when drawbar tension is re-applied.

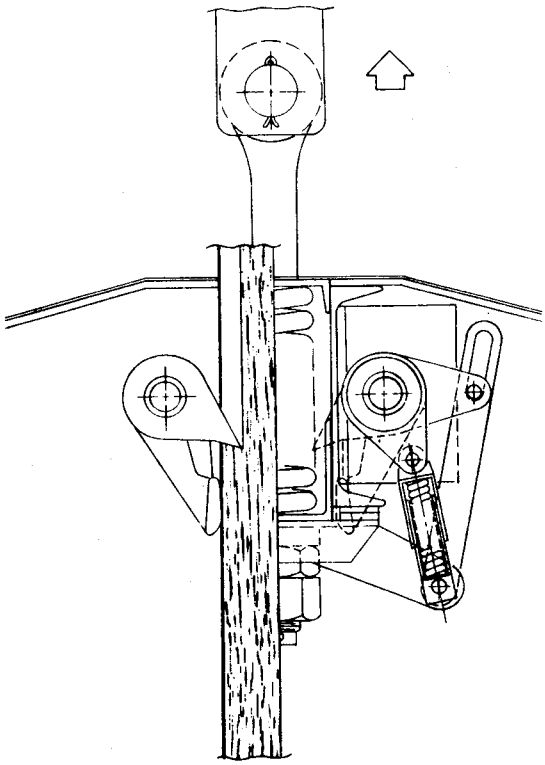
This device cannot be released until the conveyance is translated upward a sufficient distance to roll the dogs out of engagement with the guides. When this is done, the secondary spring and slotted link cause the dogs to return to the normal released position.



a. Normal Released Position
(Drawbar Bottomed, Compressing Spring)

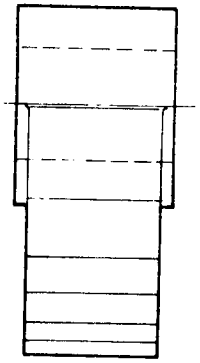


b. Actuated Position
(Drawbar Extended by Compression Spring)

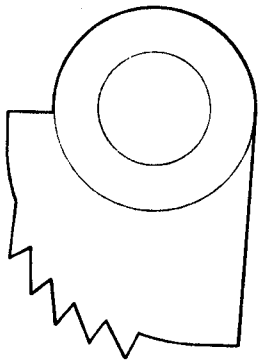


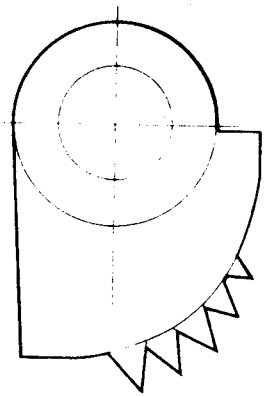
c. Rope Dragging Position
(Drawbar Bottomed)

FIGURE 4. A SINGLE-TOOTH-DOG ARRESTMENT DEVICE EQUIPPED WITH ANTITRAILING-ROPE FEATURES

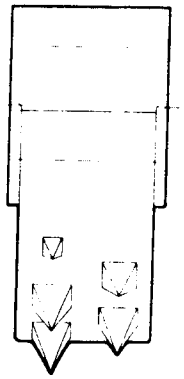


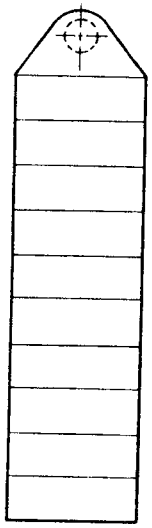
a. Multitoothed Cam



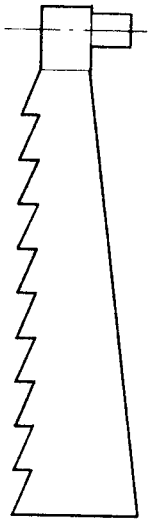


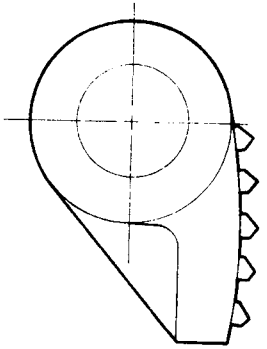
b. Multitoothed Cam





c. Multitoothed Wedge





d. Multitoothed Cam

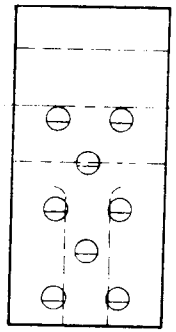
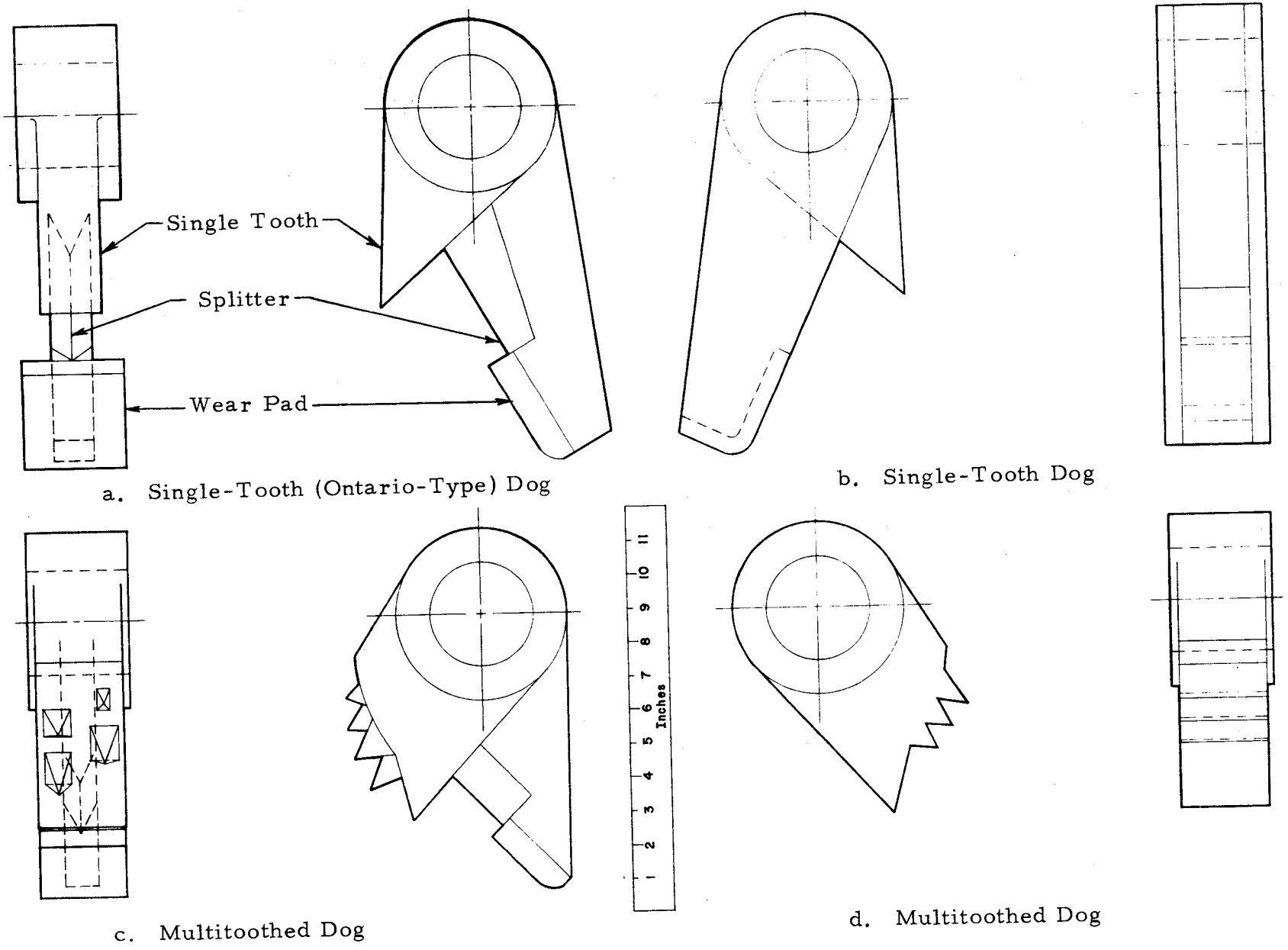


FIGURE 5. CAM AND WEDGE BRAKING ELEMENTS



a. Single-Tooth (Ontario-Type) Dog

b. Single-Tooth Dog

c. Multitoothed Dog

d. Multitoothed Dog

FIGURE 6. SINGLE- AND MULTITOOTHED-DOG BRAKING ELEMENTS

While the cam and wedge elements provide a braking force through friction, pressure, and ripping of the wood (the primary intent is difficult to determine although the odds are in favor of ripping), the single-tooth and multitoothed dogs are designed to provide a braking force by removing wood like a chisel or plane.

Performance

The performance of conveyance-mounted arrestment devices in vertical-shaft wood-guided hoist installations has been a topic for debate, criticism, and studies for well over 70 years. Reliable performance data, however, are obtained only by careful observation of a multitude of tests. No such extensive tests have ever been conducted in the United States. Furthermore, since World War II, there has been only one general investigation of the behavior of arrestment devices in the world as far as Battelle can determine. This program was initiated by the Ontario Department of Mines and Northern Affairs as a result of the Paymaster Mine hoisting accident of 1945 (16 killed). The program involved the problems associated with hoist-rope selection and replacement, as well as "safety catches", and is a continuing effort. Battelle believes this to be the most definitive study of safety catches yet made.

Inadvertent Actuation

Inadvertent actuation, or "accidental dogging", is almost always traceable to one of four sources – brake element design and guide clearance, too-strong or too-weak compression springs, the peculiarities of some antitrailing-rope linkages, and hoist deceleration. Brake elements as a source of inadvertent dogging will be treated later.

In Chapter 2 it was stated that an arrestment device that actuates in the event of a loss of tension must not confuse the dynamic behavior of the rope-conveyance (spring-mass) system with a broken rope. A too-stiff spring that is not always fully compressed can do just this. On the other hand, a too-weak spring cannot provide enough force to engage the braking elements, particularly if there is a trailing rope segment.

Ontario's study has confirmed the rule of thumb that a compression spring requiring a load of from 0.3 to 0.5 times the empty conveyance weight to fully release the brakes appears to be adequate in the majority of cases.[23] Ontario is still investigating this problem, particularly for very heavy and very light conveyances in deep shafts.

Ontario also experimented with antitrailing-rope devices. These devices were required after the Paymaster accident, but concurrent developments with single-tooth dogs soon showed that devices using these dogs could actuate and arrest a conveyance so quickly that a trailing rope no longer presented a problem (in vertical shafts). As time went on, however, many incidents of accidental dogging occurred with some of these antitrailing-rope devices, incidents that involved considerable damage to the wood guides. Currently their use is optional.

Rapid hoist deceleration as a source of inadvertent actuation illustrates the need to consider the performance of the entire hoist installation as a single machine, i.e., as a system, as was done earlier in developing arrestment-device functional requirements. Rapid hoist deceleration will amplify the dynamic variations in hoist-rope tension. If a conveyance were being hoisted upward at 750 ft/min in a vertical shaft, and

if for any reason the rope tension would suddenly go to zero at the conveyance, the conveyance would theoretically travel another 2.4 ft before gravity alone would reverse the motion. For 1500 ft/min, the distance traveled would be 9.7 ft. These travel distances are indicative of a kinetic energy capable of reducing the hoist-rope tension enough to cause a broken-rope arrestment device to actuate if the hoist were very rapidly decelerated or stopped, as could occur during a rapid application of the hoist brakes.

When discussing arrestment-device stopping performance criteria, it was stated that there are compelling reasons not to have the device stop the conveyance as rapidly as possible. The more rapid the stop, the higher the stresses on men and machinery. There are similar reasons not to design hoist brakes to stop the hoist as rapidly as possible. Such a stop could damage equipment and injure men on a descending conveyance, and actuate a broken-rope arrestment device on an ascending one.

Device actuation under these conditions may not of itself cause further problems, but, depending upon device design, actuation can lead to unnecessary guide damage and delay the resumption of normal operations. L. O. Cooper has investigated the relationship between hoist deceleration and the onset of accidental dogging.[12] W. V. McKnight collected data indicating that accidental dogging would probably occur on most of Ontario's hoists during an emergency stop of the hoist.[18] Since McKnight's paper was printed (1966), Ontario has issued a directive limiting hoist decelerations at the conveyance (see Reference 12). It seems highly desirable to likewise limit U. S. hoist decelerations, particularly in inclined shafts where conveyance designs can contribute to injury.

Fouling. Arrestment devices such as those of Figures 2 and 3 have failed to actuate because they were fouled by foreign objects such as rocks, bolts, or tools. This can be prevented by including a protective sheet-metal cover as part of the device. Such covers are usually not provided. Corrosion must not be overlooked as a fouling mechanism. If linkages are not periodically tested, corrosion can cause problems. The role of continued inspection and preventive maintenance should be clear. Good inspection and maintenance would eliminate such failures to actuate in all but the rarest of cases.

Stopping Performance

The manner in which an arrestment device stops a conveyance depends primarily on the design of the braking element and the condition of both the braking element and the wooden guide.

Braking Element Design. A series of tests were conducted in Ontario to determine the performance of arrestment devices. The devices used braking elements similar to those shown previously. The tests were not performed in a laboratory, but in the shafts where the arrestment devices were installed. In all tests, the arrestment devices were actuated after a fully loaded conveyance had reached its rated maximum hoisting speed in a free fall.

Eighty-four tests showed that[10]

Multitoothed wedges, cams, and dogs often

(1) Developed deceleration forces in excess of 3 g, the highest being 187 g

(2) Broke or damaged actuation linkage and guides where high deceleration forces developed

(3) Developed unacceptably low or zero deceleration forces because the teeth became clogged with wood chips.

Single-tooth dogs with engagement-assisting teeth (Figure 6c)

(1) Required large actuating-shaft rotation

(2) Easily fouled the guides during normal operation.

Single-tooth, wood-splitter design dogs (Ontario-type, Figure 6a)

(1) Consistently provided a fairly constant braking force independent of initial conveyance velocity.

Figure 6b shows a single-tooth dog with open center that is untested. It is probable, however, that the central passage would easily become clogged with wood chips.

Wood-guide damage caused by a multiple-toothed dog similar to that of Figure 6d is shown in Figures 7 and 8. This damage results from the development of a very high deceleration force. Severe crushing and splitting is evident. The stopping distance is virtually zero. In this case, the arrestment-device components were apparently strong enough to withstand the forces developed, though it is not known whether the conveyance was damaged.

The behavior of the single-tooth Ontario-type dog is illustrated in Figures 9 and 10. Figure 9 shows how the wood splitter directs the wood spoil away from the cutting edge, thereby preventing clogging. Figure 10 shows what the Ontario dog does to the guides. Notice the generally uniform slot but no other damage.

As a result of these and continuing tests, there are sufficient data to permit design of a single-tooth Ontario-type dog for the deceleration desired. Empirical equations have been developed that relate the arrestment force to tooth width, projection into guide, and the angle between the leading edge of the tooth and the guide surface. This predicted force correlates well with test results. These empirical equations are presented and discussed in Appendix G.

Maintenance Considerations. Corrosion can inhibit the performance of single-tooth dogs. The cutting edges are most critical and must be filed periodically or otherwise sharpened to assure development of the intended braking force.

FIGURE 7. WOOD-GUIDE DAMAGE CAUSED BY MULTITOOTHED DOGS

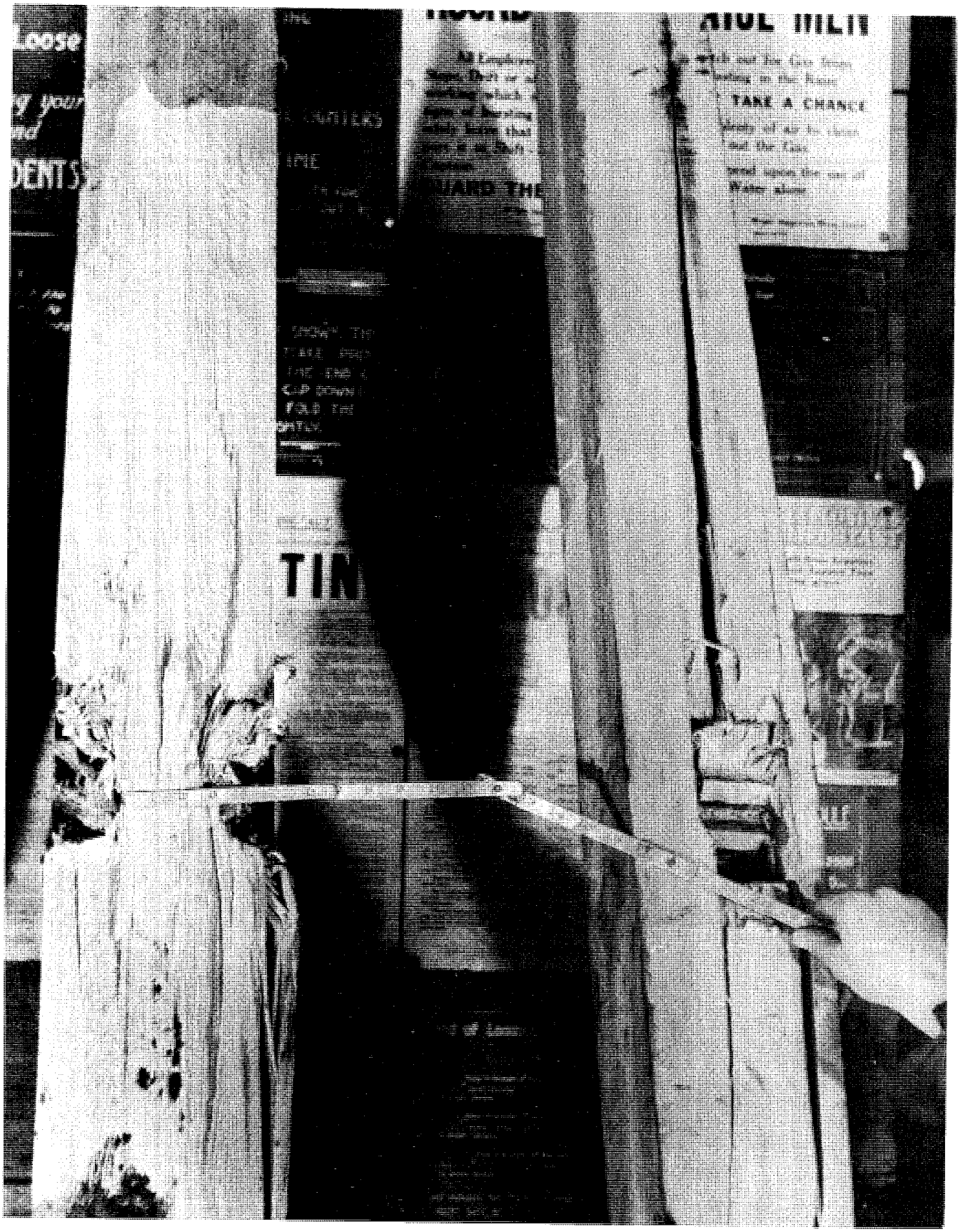


FIGURE 8. WOOD-GUIDE DAMAGE CAUSED BY MULTITOOTHED DOGS

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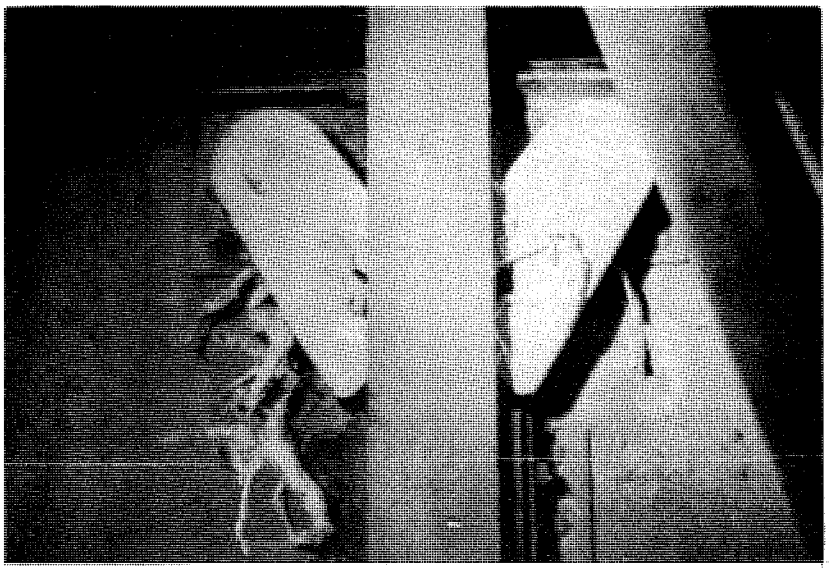


FIGURE 9. EFFECT OF WOOD-SPLITTER FEATURE OF SINGLE-TOOTH ONTARIO-TYPE DOG

FIGURE 10. GUIDE-SLOTTING EFFECT OF SINGLE-TOOTH ONTARIO-TYPE DOG

Internal deterioration and guide-surface wear also strongly affect performance. Figures 11 and 12 show what can happen when the guides become rotted. Figure 11 shows portions of a rotted guide after removal. When the tooth engaged and snapped the wear pad against the guide, the pad embedded itself. The force on the pad caused the whole dog to rotate 180 degrees through the guide, bending and twisting the dog shafts, and breaking the dog (Figure 12).

Guide-surface wear alone can lead to arrestment-device failure. If the wear becomes too great, a braking element will not engage. Wedge- and cam-type elements often automatically compensate for wear, but this good aspect of their performance does not overcome their generally unreliable braking performance. The design of the Ontario dog provides a fair degree of compensation for guide wear. The wear pad controls the degree of rotation and will always seek the guide surface. The tooth length is sufficient to permit engagement over a reasonable range of shaft rotation. Thus, engagement is assured unless guide wear is too great. Furthermore, as the pad travels farther, the leading edge of the tooth becomes more nearly perpendicular to guide surface. Test data show that the more nearly perpendicular, the greater the retarding force. Single-tooth dogs whose shaft rotation is limited by shaft stops rather than a pad against the guide cannot compensate for guide wear.

The structures supporting the guides must be maintained so they are strong enough to resist the forces applied during arrestment. Several arrestment-device failures have been caused by weakened guide structures that allowed the guide to deflect away from the braking elements.

Comments on the Ontario Dog. The Ontario-dog design, the single-tooth, wood-splitter, wear-pad combination shown in Figure 6a, is almost universally used in Ontario. The other designs used are similar in their use of a wood splitter and wear pad, but differ in the tooth. They use two teeth side-by-side in what might be called a split single-tooth arrangement, or two teeth, one vertically displaced slightly from the other, but still separated by the wood splitter. In action, these dogs produce two parallel grooves in the guide. While their performance meets requirements (to be discussed in the chapter on regulatory requirements), Ontario officials have reported that they would prefer the use of the single-tooth design.

Some United States manufacturers of conveyance arrestment devices are now using the Ontario-type dog. Others are almost unaware of its existence and performance capabilities.

VERTICAL SHAFTS - STEEL GUIDES

General Description

Steel guides come in a variety of shapes. Those observed in this and the earlier study (primarily in U. S. coal mines) have been railroad-like rails, wire ropes, and, in one instance, pipes. Rails predominate.

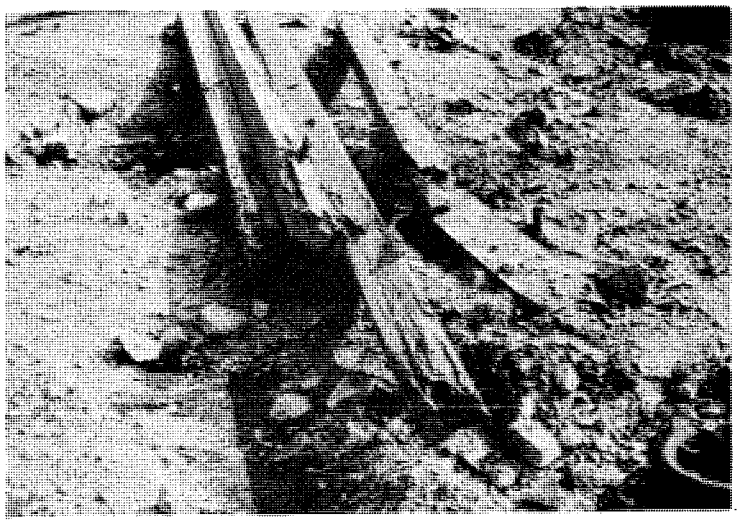


FIGURE 11. ROTTED GUIDES THAT CAUSED AN ARRESTMENT-DEVICE FAILURE

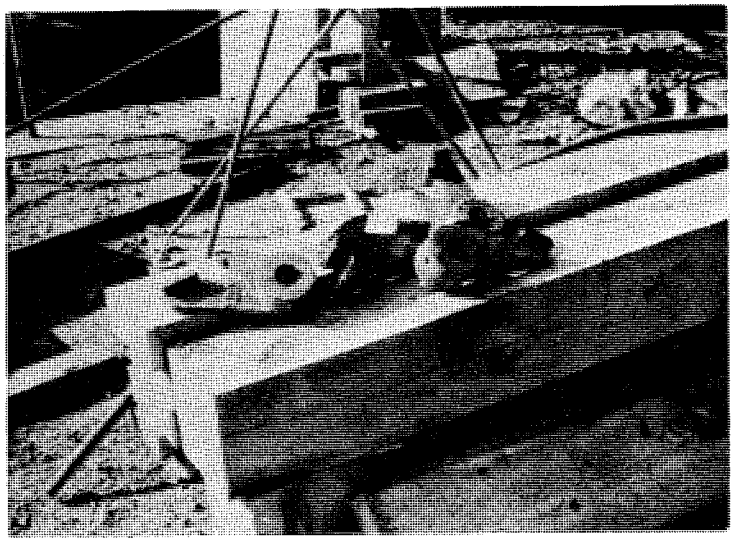


FIGURE 12. SINGLE-TOOTH DOG BROKEN IN ENGAGEMENT WITH A ROTTED GUIDE

Rail Guides

All of the hoists inspected in this category use arrestment devices similar to the broken-rope device shown in Figure 2. All use a multitoothed wedge, the variations being in the actuation components. There is no intent to deform the guide with the braking element, as with a wooden guide. A frictional braking force is intended.

Wire-Rope Guides

A broken-rope arrestment device for wire-rope guides is shown in Figure 13. Sensing and actuating components are very similar to the broken-rope devices of Figures 2 and 3. However, this device is equipped with a horizontal spring that limits and equalizes the load applied to the braking elements.

The braking elements are, in essence, one half of a guide sleeve. During normal operation they function as part of the upper conveyance guide sleeves. When actuated, these elements move toward the fixed half sleeve, squeezing the rope between them. The surface in contact with the rope is smooth.

"No Dogs" Arrestment Device. The "No Dogs" arrestment device is shown in Figure 14. It is included here because it uses wire ropes. Though Figure 14 shows wood guides, any type could be used.

The safety ropes are anchored in the headframe (or atop an incline), reeved about the capstan drums, and extend to the shaft bottom where they are tensioned by weights. The capstan drums are equipped inside with conventional automotive-type shoe brakes. These brakes can be independently actuated electrically with a battery-powered solenoid, or mechanically. The electric and mechanical actuators are controlled by separate overspeed governors, with the governor controlling the electric actuation set for a lower actuation speed. The mechanical actuators also operate in the event of a loss of rope tension.

In addition, the mechanical actuators can be operated manually for actuation and release. The latter feature permits passengers to lower themselves.

Pipe Guides

Though not seen, a noncoal-mine vertical-shaft hoist is reported to use two pipes to guide a man cage, one on each side. These pipes also serve as conduits for air and water. The device is a "broken-rope" safety actuating much like those already presented. The braking element is assumed to be similar to that used on wire-rope guides.

One unique pipe-guide system is the four-man emergency hoist shown in Figure 15. The pipe is centered, and the rope is somewhat off center. With loss of hoist-rope tension, the cam plate is cocked against the pipe by the tension spring. Once brought into contact with the pipe, the plate arrangement is self-energizing.

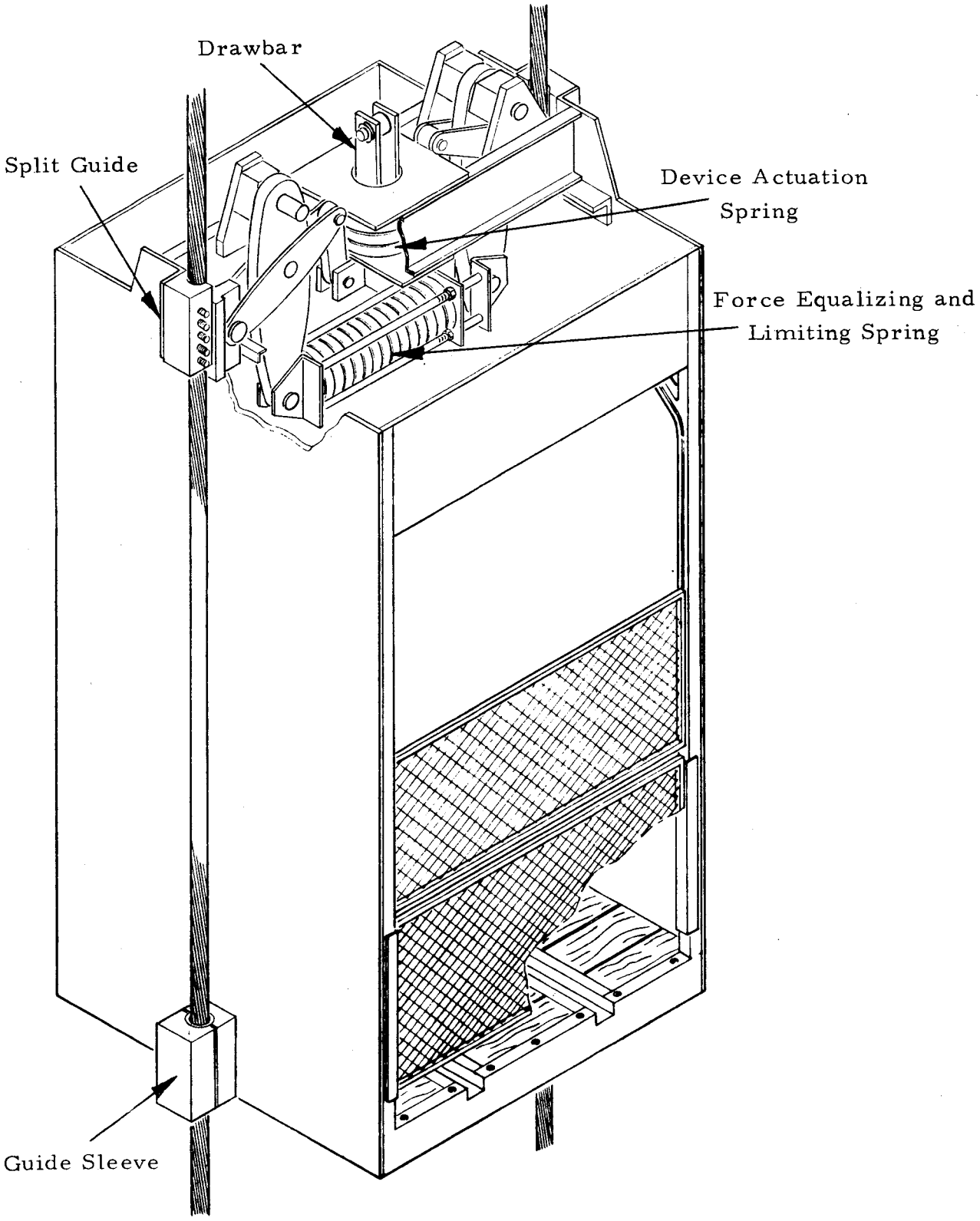


FIGURE 13. CONVEYANCE EQUIPPED WITH A BROKEN-ROPE-ACTUATED ARRESTMENT DEVICE FOR WIRE-ROPE GUIDES

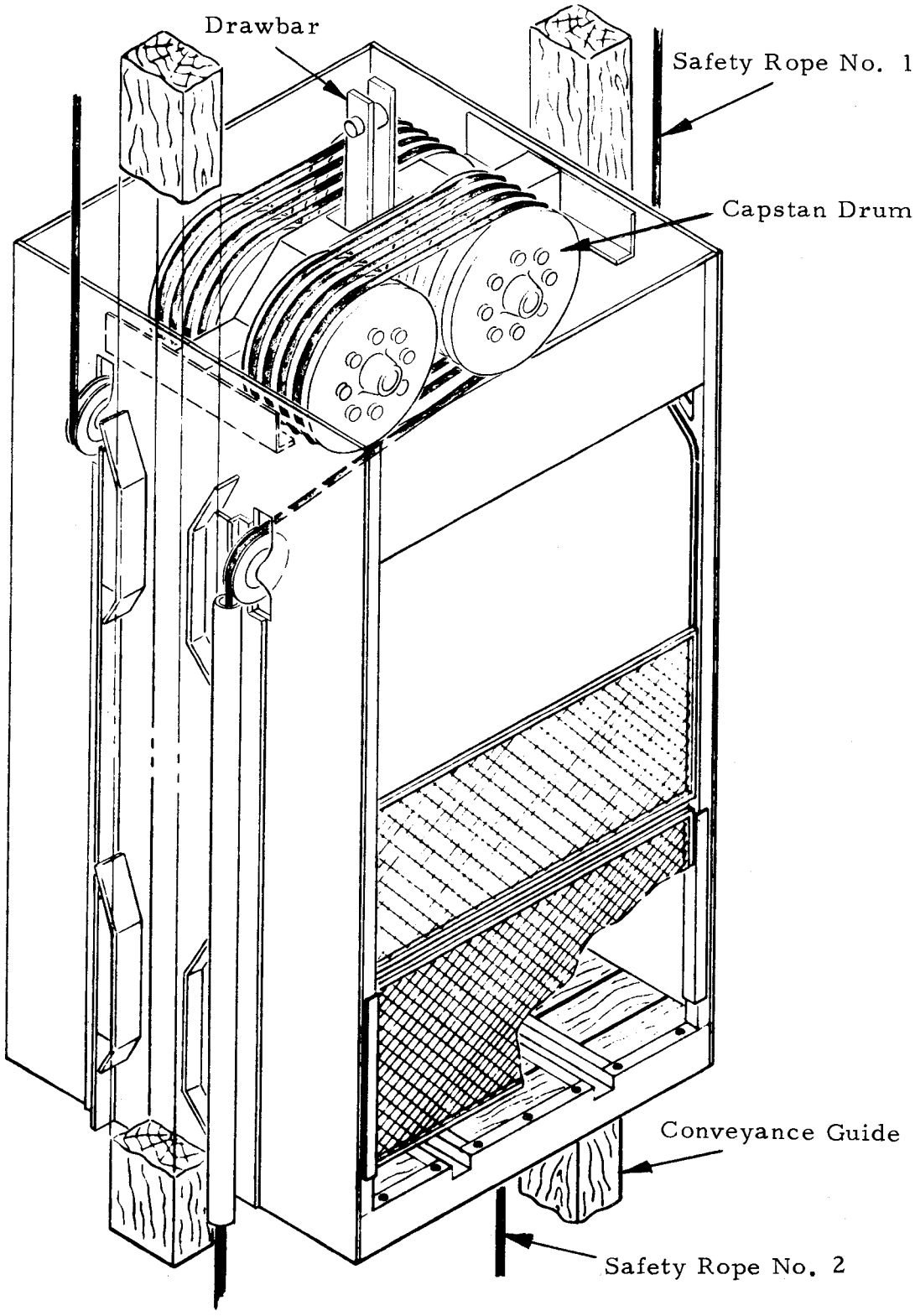


FIGURE 14. CONVEYANCE EQUIPPED WITH A "NO DOGS" ARRESTMENT DEVICE

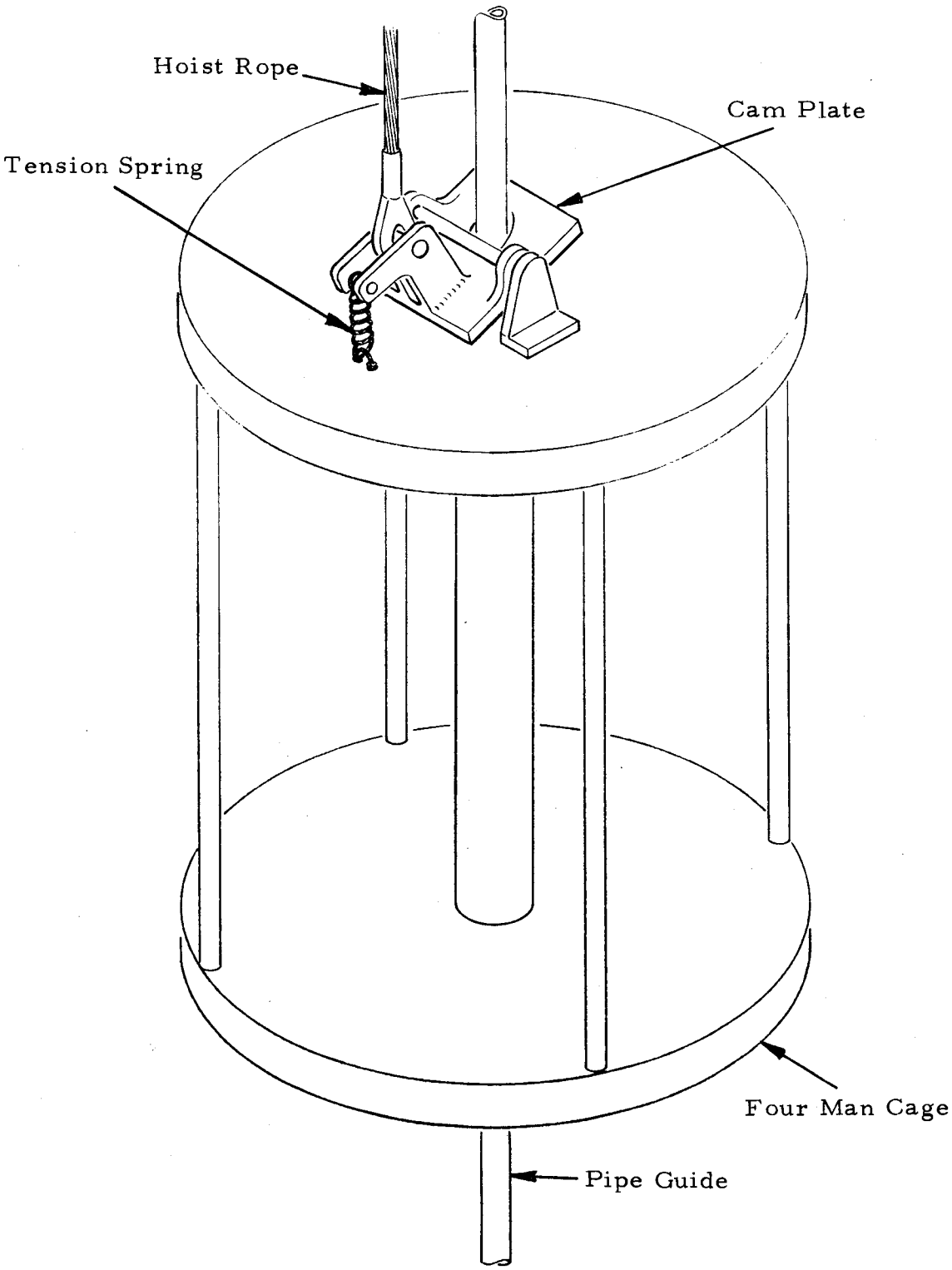


FIGURE 15. PIPE-GUIDE ARRESTMENT DEVICE FOR A FOUR-MAN-CAGE EMERGENCY HOIST

Performance

Little information is available on the performance characteristics of any of these vertical-shaft steel-guide systems. No test data related to stopping behavior under simulated "emergency" conditions have been found.

The sensing and actuating are similar to those arrangements discussed for wooden guides. It is inferred that they are prone to the same actuation difficulties and remedies.

In stopping, all these devices must contend with variations in the frictional characteristics of the guide and brake-element materials under the wide variety of surface conditions typically present in a mine environment. While no data for frictional coefficients between steel and steel have been found for a mine environment, it is expected that they could easily run from 0.1 to 0.3. Such variation could lead to deceleration forces changing either way by a factor of 3.

Performance data for the wire-rope guide and the auxiliary safety-rope systems, as well as information on what these devices do to the rope would be of value. Unless careful attention has been given to the behavioral aspects of wire rope in designing these systems, there is a good possibility for extensive rope damage, particularly from the "No Dogs" device. The concern is not for rope damage alone, but for possible rope failure during an arrestment.

The one quantitative datum obtained relates to the "No Dogs" arrestment device that uses auxiliary safety ropes. It is stated that tests have shown the device to develop decelerations in the range 5.5 g to 6.0 g. The test procedures are unknown and the decelerations developed seem unnecessarily high.

INCLINED SHAFTS

General Description

Many inclined-shaft (slope) arrestment devices in the United States use combinations and variations of the braking, actuating, and sensing mechanisms previously discussed.

Most, if not all, U. S. slope-hoist conveyances use flanged-wheel T-rail guidance. The arrestment devices studied either brake against the running rail ("track" brakes), against an auxiliary guide of some sort, or against the ties.

Track Brakes

One form of track brake manufactured in the United States is the "magnetic track brake". The steel brake shoe is part of an electromagnet. When energized, the shoe is pulled against the top surface of the running rail with a force limited only by current supply and heat-dissipation problems. Car-mounted batteries supply the magnetizing

current. A man-carrying conveyance equipped with magnetic-track brakes is shown in Figure 16.

Typically, these brakes are actuated by an overspeed governor and a reversal-of-direction sensor, and can also be manually applied or released. The reversal-of-direction sensor is an interesting feature. The intended direction of travel is set manually with a push button. Contrary motion immediately applies the brakes. This feature might seem unnecessary in view of the overspeed feature also present. However, the manufacturer warns that the coefficient of friction varies with rail-surface condition and conveyance speed, and therefore the braking force will not necessarily remain constant. Thus, stopping an ascending conveyance just when it begins to descend has merit. The system is recommended for slopes up to 18° from the horizontal.

Another U. S. manufacturer supplies a slope man-haulage system that uses spring-set, air-released track brakes on all cars. The brake shoes are multitoothed steel wedges. When actuated, springs push the shoes against the top surface of the rail. The contact force is limited by the weight of the vehicle. Air for release is supplied by a reservoir on a separate car that is always coupled to the downslope end of the train. Separation of the train actuates the brakes. In addition, the reservoir-carrying car has a manually operated air-dump valve.

Two British systems are very similar to the above – track brakes on all cars, with a "master" car containing the automatic controls and the brake-release power supplies. The major difference between these and the U. S. system is that the British have the brakes rigidly attached to the car frame, and the car suspension system permits lowering and raising the car body relative to the wheel axles. The total brake-shoe pressure is the weight of the car and passengers. The brake shoes have composition linings reported to have a coefficient of friction of 0.5 under dry, clean surface conditions. The car bodies can be raised mechanically, hydraulically, or pneumatically. Various options for brake-shoe arrangements are also available. Brake actuation is controlled by an overspeed governor, manually, and, optionally, by train separation. Satisfactory operation on grades up to 18° is reported for both designs.

The German "Bulli-Truck" system uses tubes in place of the conventional rails. The running gear is designed to prevent derailing. The braking elements clamp around the tubes. They are spring-applied, hydraulic-pressure released, and controlled by an overspeed governor.

Another nonrail track system is the Coolie Car, developed in the late 1800's and widely used throughout Europe.[24, 25] Again, a train consists of at least one special car that carries a hydraulic supply system for releasing the brakes. The braking elements are flame-resistant elastomer-tired wheels that also serve to prevent derailing. Each car has two fully articulated bogies or trucks, one of which is shown in Figure 17. Brakes are applied by train separation, an overspeed governor, or manually. The design is said to be effective on slopes up to 45° from the horizontal.

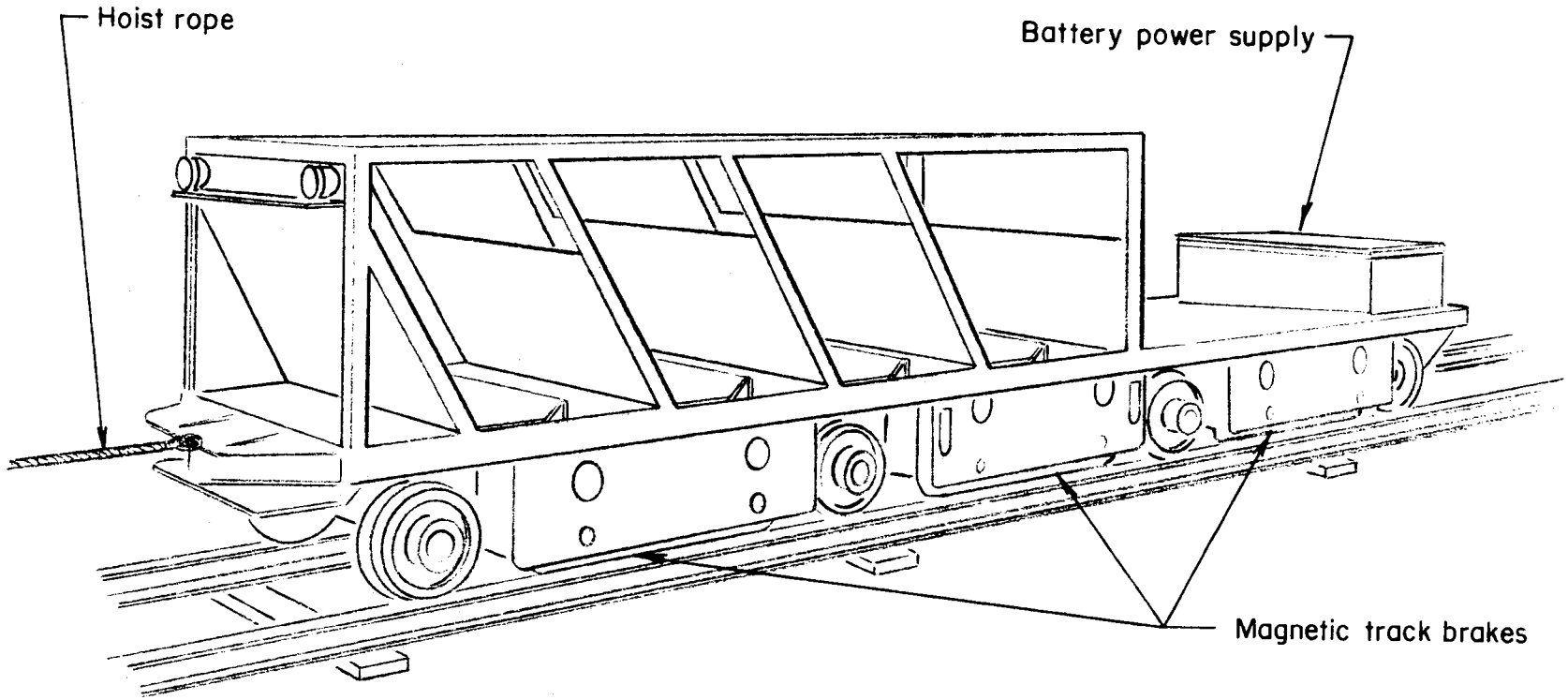


FIGURE 16. SLOPE MAN CAR WITH MAGNETIC TRACK BRAKES

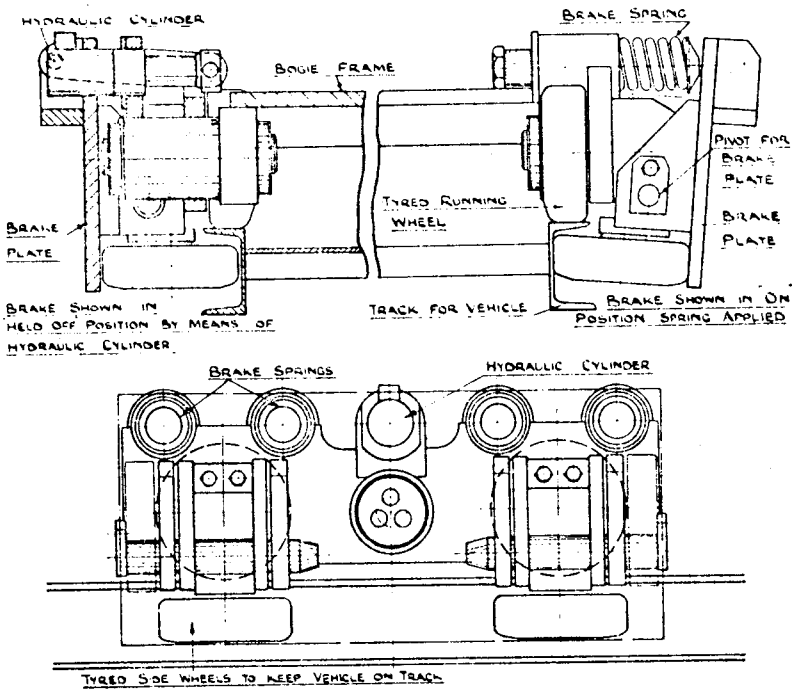


FIGURE 17. DIAGRAM SHOWING OPERATING AND BRAKED POSITIONS OF COOLIE CAR WHEEL ASSEMBLIES

Auxiliary Guide Brakes

Two arrestment systems using an auxiliary guide for braking have been observed applied to conventional flanged-wheel-and-rail slope hoists used for man haulage.

One uses a wooden guide bolted to the ties on the track centerline. Multitooth-dog braking elements engage each of the vertical sides of the guide. Except for some mechanical details, the system is like those discussed for vertical-shaft wood-guide systems. The brakes actuate only with loss of rope tension.

The other system seen uses one side-mounted wire-rope guide for braking and is very similar to the "No Dogs" system described earlier. The rope is reeved over capstans equipped with spring-applied band brakes. As in the "No Dogs" device, the friction between rope and capstans limits braking force, and the system can damage the wire rope through bending. This system is also actuated only by a loss of hoist-rope tension. A man-car equipped with this device is shown in Figure 18. It is reported that the car is normally side tracked, but can be quickly reeved for use during shift changes.

Buck Hooks and Drags

A Buck hook is a rake-like device connected to the up-slope end of a conveyance and to the hoist rope. Normally held clear of the track by the tensioned hoist rope, it drops when the rope goes slack or breaks. Buck hooks stop or slow a conveyance by snagging on the ties.

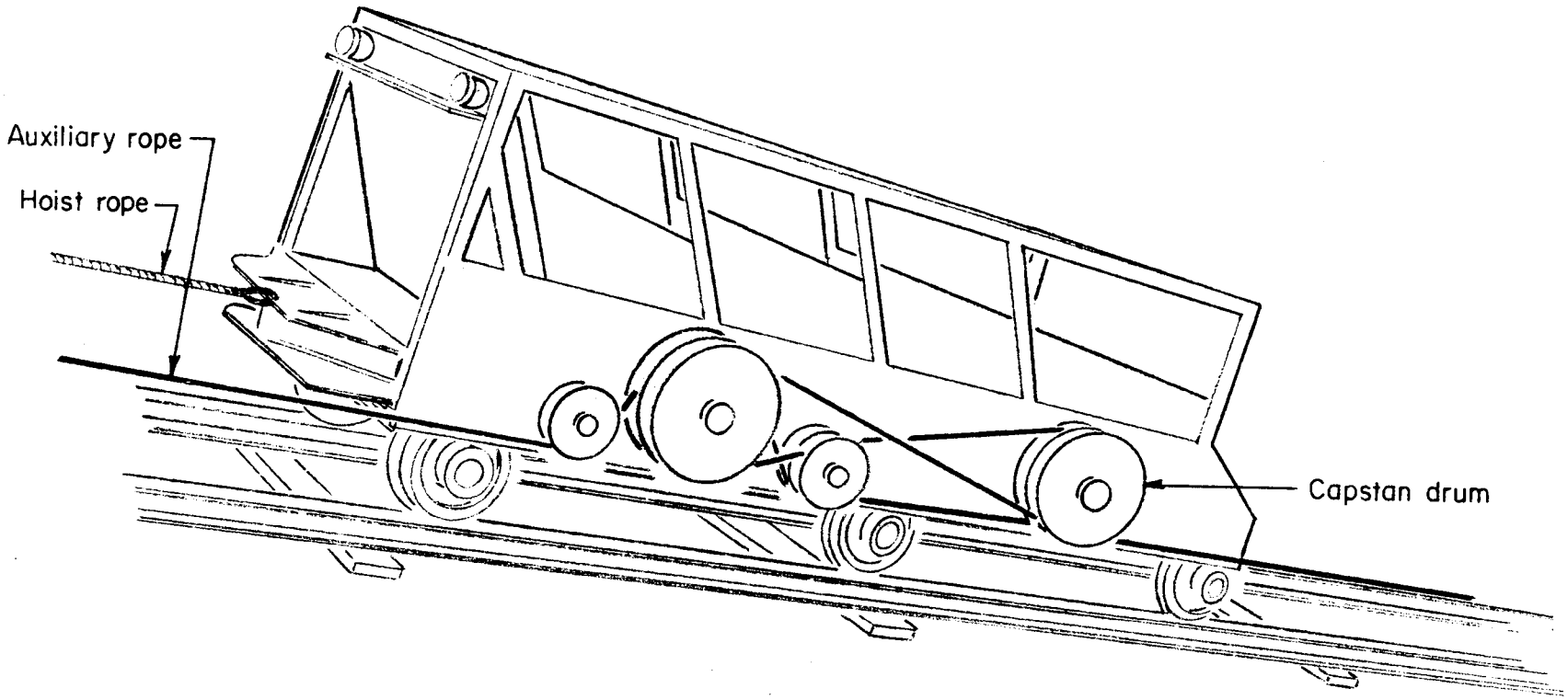


FIGURE 18. SLOPE MAN CAR WITH AUXILIARY-ROPE ARRESTMENT DEVICE

A drag is a bar of steel hinged at one end to the down-slope end of a car. The other end drags along against the ties. They are used only for up-slope travel, being raised clear during descending trips. In use, they are intended to stop or derail a car if it should attempt to run down-slope.

Performance

As with vertical-shaft, steel-guide arrestment devices, no quantitative data related to the performance of any of these inclined-shaft devices have been found.

It is doubtful that actuation, manually or by an overspeed governor, consistently presents problems that cannot be remedied by maintenance or minor design changes. For broken-rope-actuated devices, however, there is concern for the sensitivity of the devices to loss of rope tension. As stated, loss or reduction of hoist-rope tension can occur naturally because of changes in slope pitch or operating speed. Furthermore, because of rope drag, a rope's breaking far from the conveyance may still exhibit a fair amount of rope tension at the conveyance.

Also, as mentioned earlier, the coefficient of friction between the brake shoes and the rails or rope guides will probably vary considerably because of environmental conditions. Of concern are the possibilities of no stop at all under poor conditions, and human injury in a sudden stop under good conditions.

British manufacturers of slope systems could supply no performance data, but did say their systems met British requirements. As far as Battelle can determine, they do not deal with such variables as permissible deceleration or stopping distances.

Sparking

All arrestment devices discussed previously for vertical-shaft steel-guided conveyances, and many inclined-shaft devices just discussed, use steel braking elements acting on steel guides. Braking with steel on steel can produce sparks, but no one questioned during this study could confirm or deny the production of sparks, for example from a magnetic track brake on a slope conveyance.

It is not clear that sparks in hoist shafts constitute the hazard presented by sparks at or near the mining face. Many shafts have downcast ventilation. Many upcast-ventilated shafts are very damp. Since the question of sparking in hoisting shafts involves aspects of mining well beyond the scope of this study, Battelle defers to the Bureau of Mines, but recommends a careful analysis.

TESTING

It is apparent that the performance of an arrestment device is affected by many design, physical, and environmental factors. Only by observing the behavior of the device under conditions simulating those for which it was designed can the design itself be proved, both when new and with use.

Tests of arrestment devices fall into two categories – static and dynamic. As the names imply, the conveyance is either at rest or moving when actuation occurs. Several types of dynamic tests are made, their differences being in manner of actuation and conveyance speed at actuation.

Static Tests

The object of a static test is to determine whether the actuation components are free to function and whether they do so in the desired manner.

A static test of a vertical-shaft conveyance is usually conducted with the conveyance chaired at or set on beams across the collar. The hoist rope is slacked with the hoist and the subsequent behavior of the arrestment device observed. (As stated, all known U. S. vertical-shaft arrestment devices actuate with loss of rope tension.) If the braking devices (wedges, cams, or dogs) come into contact with the guides quickly, the device is pronounced satisfactory.

A static test would provide an excellent opportunity for checking the load characteristics of the compression spring of broken-rope safeties. A tensiometer placed between the draw bar and the rope-end fitting would show the load required to compress it. Any developing weakness could be observed in the results of periodic tests.

Static tests of inclined-shaft vehicles that actuate with loss of rope tension can easily be made by blocking the car and easing off the hoist. Where they can be actuated manually, the car need not even be blocked.

Magnetic track-brake cars are known to be statically tested using manual actuation. Brake-shoe motion is observed and the magnet excitation current is observed on the ammeter installed permanently on the car for this purpose. If the current is too low, circuit or battery problems are indicated.

It is necessary to reiterate that such tests indicate actuation capabilities only. A successful actuation test is sometimes misinterpreted as proof of the ability of the device to stop the conveyance.

Dynamic Tests – Vertical Shafts

Two types of dynamic tests of vertical-shaft conveyances are common – "drop" tests and "free-fall" tests. In a "drop" test, the arrestment device is actuated at the same instant that the conveyance is disconnected (dropped) from a suspension rope (not always the hoist rope). In a "free-fall" test, the arrestment device is not actuated until the dropped conveyance reaches some prescribed speed in a free fall.

Drop Tests

Two methods are commonly used: simulated dropping through rapid hoist action, and actual dropping using a trip hook.* The basic procedure for each follows:

Drop Testing Method 1: Rapid Hoist Acceleration

(1) Mark the position of the conveyance in the shaft.

(2) Rapidly lower the conveyance with the hoist until the conveyance is stopped by the arrestment device.

(3) Measure the distance the conveyance traveled.

Drop Testing Method 2: Trip-Hook Release

(1) Lift the conveyance to the headframe.

(2) Block the shaft at the collar with beams covered with straw bales or rubber tires.

(3) Rest the conveyance on the beams, slack the hoist rope, and install the trip hook.

(4) Raise the conveyance 3 to 5 feet above the collar and mark its position.

(5) Tether the hoist rope.**

(6) Release the trip hook.

(7) Measure the distance the conveyance traveled.

The procedures for Drop Test Method 2 are illustrated in Figure 19. While the tests can be made with an empty conveyance, it is preferable to load it to its rated man-load.

With Method 1, actuation occurs only if the hoist can accelerate fast enough. (If it can, there are very good reasons to reduce the acceleration or to assure against its use in normal operation. To be able to put a descending cage into a free fall is dangerous to men and very hard on the equipment, particularly with a counterweighted or counterbalanced conveyance.) Where actuation can be effected by this method, the speed of actuation is affected by the inertia of the hoist rope. At best, this test simulates a rope break some distance from a static or slowly moving conveyance. Method 2 closely simulates a loss of connection near a static conveyance.

For the emergency conditions simulated, the results indicate

(1) Whether the sensing and actuating components can work and engage the braking elements

*A trip hook is a releasable hook installed between conveyance draw bar and hoist-rope end fitting.

**To prevent the rope from recoiling.

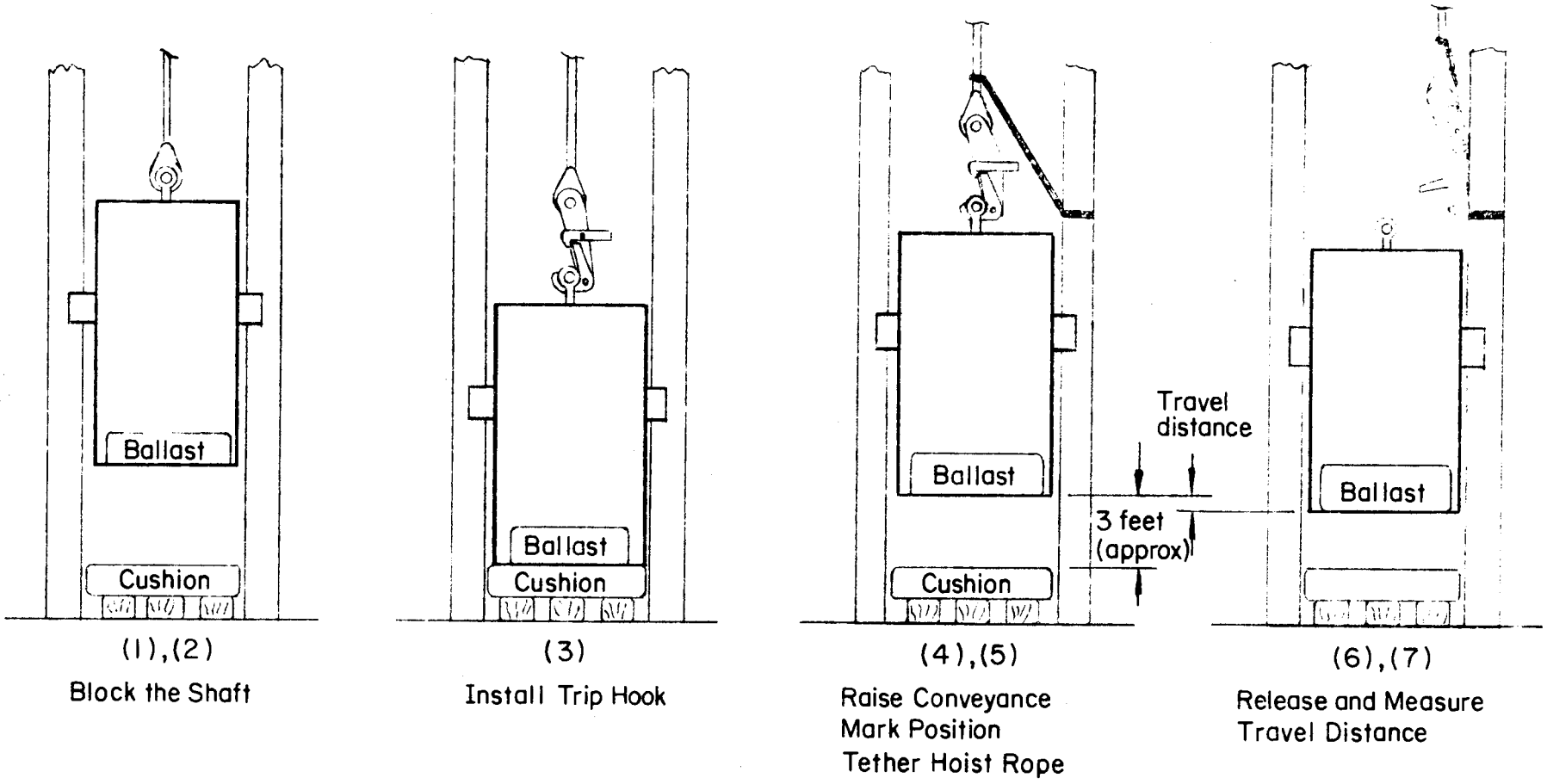


FIGURE 19. DROP TEST METHOD 2: VERTICAL SHAFT

(2) Whether the brakes can stop a very slowly moving conveyance (preferably fully loaded)

(3) Whether the brakes can statically support the conveyance (again, preferably fully loaded)

(4) Whether the guides and their supports in the test area can withstand the forces developed during the stop of a slowly moving (fully loaded) conveyance

(5) Whether the performance capability is deteriorating, for example, because of wear and corrosion, by comparing the data for conveyance travel for successive drop tests.

It is incorrect to assume that acceptable performance demonstrated in these tests would occur anywhere in the shaft and, particularly, that it would occur for a rapidly moving conveyance.

Drop tests with steel-guide systems cause no significant damage to the guide surfaces.

Drop tests with wooden guides result in varying degrees of wood removal. Where performance is satisfactory, little wood is removed, and then only over a very short distance. Performing the tests above the shaft collar or the highest unloading station permits relatively easy replacement of the guide section if necessary. If the guides are not replaced, care should be taken when repeating the test to assure that the braking elements do not engage the wood guide at the same location.

Free-Fall Tests

The basic procedure for a free-fall test is as follows:

(1) Lift the conveyance to the headframe.

(2) Block the shaft at the collar with beams covered with straw bales or rubber tires.

(3) Rest the conveyance on the beams and install the trip hook.

(4) Raise the conveyance an appropriate distance above the collar and mark its position.

(5) Tether the hoist rope and install the lockout plate (to be discussed).

(6) Release the conveyance.

(7) Measure

  (a) Distance conveyance falls to point of engagement of braking elements (free-fall distance).

  (b) Distance conveyance travels after engagement of braking elements (braking distance).

These procedures are illustrated in Figure 20.

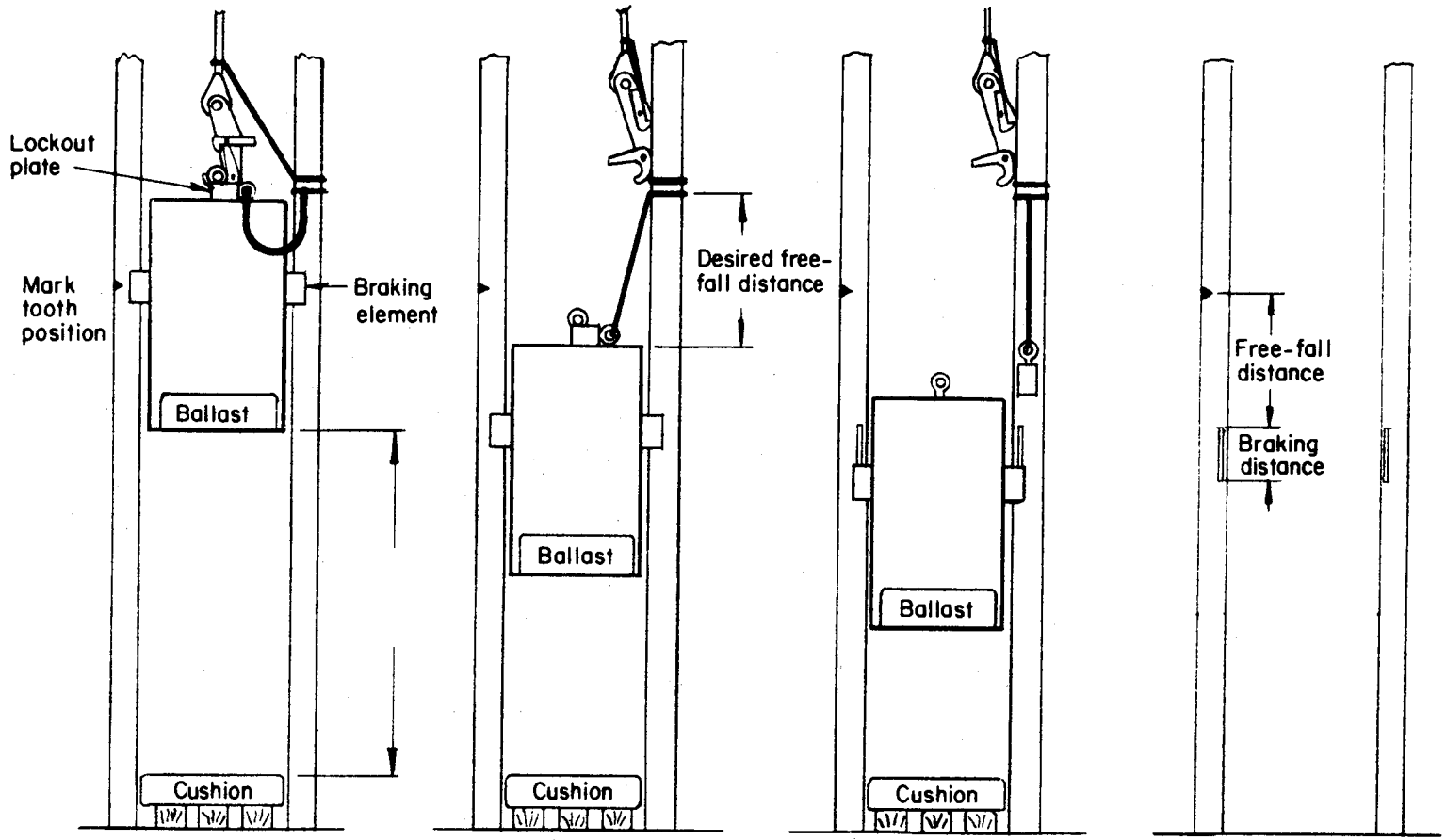


FIGURE 20. FREE-FALL TEST: VERTICAL SHAFT

The purpose of this test is to observe the performance of the arrestment device when stopping a rapidly moving conveyance. This is achieved by allowing the conveyance to free fall after release until its speed reaches a desired value, at which point the lockout plate pulls free, permitting brake actuation.

As in drop tests, the trip hook disconnects the conveyance from the hoist rope. The lockout plate prevents the arrestment device from actuating until it is removed. This plate is typically removed with a chain or wire rope attached to the guides or framing. This rope must be long enough to permit the conveyance to reach the desired speed before actuation of the arrestment device. Its length is determined by calculating how far the conveyance must free fall to reach the desired speed.

$$\text{Free-fall distance in ft} = \frac{(\text{desired velocity in ft/sec})^2}{64.4 \text{ ft/sec}^2} .$$

Since arrestment devices vary in design, so do arrestment-device release hooks. Usually, they are homemade; sometimes the functions of "trip" and "device release" can be combined into one piece of equipment.

Since there is room for error in computing the length of the release-hook rope, measurement of the distance from release to engagement of the braking elements permits calculation of conveyance speed at the time of actuation. Since conveyance speed at actuation is determinable, the average deceleration developed can also be computed:

$$\text{Average deceleration in ft/sec}^2 = \frac{(\text{conveyance velocity at "actuate" in ft/sec})^2}{2 \times \left[\begin{array}{l}\text{distance conveyance travels} \\ \text{after brake engagement in ft}\end{array}\right]} .$$

The results of a free-fall arrestment test of a fully loaded conveyance stopped from rated maximum hoisting speed will indicate

(1) Whether the brakes will stop the conveyance under conditions that closely simulate the worst dynamic conditions for an arrestment

(2) The deceleration force applied by the brakes

(3) Whether the guides and their supports in the test area can withstand the maximum braking forces ever likely to be applied

(4) Whether the maximum performance capability of the device is deteriorating (by comparison of data from successive tests).

In a good system, free-fall tests should result in no significant damage (if any) to steel guides. Tests on wooden guides can be expected at least to groove the guides over the stopping distance.

Regardless of conveyance weight or maximum speed, the sum of the free-fall distance and the stopping distance for decelerations tolerable to human beings will probably be a maximum of about 20 ft. For the majority of United States mine conveyances, distances on the order of 10 ft or less should be expected – assuming, of course, the arrestment device works well.

Ontario developed free-fall testing procedures as part of its investigation of arrestment devices for use with wooden guides. A conveyance is ballasted to its full man rating and braked from rated maximum hoisting speed. The technical results of these tests were presented earlier. An indication of the general improvement of arrestment-device reliability over the first 4 years of this effort is given in Table 3.

TABLE 3. [ONTARIO] FREE-FALL TEST RESULTS, 1945, 1947, AND 1948[9]

	1945 (Feb.-Oct.)	1947	1948
Number of Companies Participating	42	39	57
Number of Tests Conducted	84	184	320
Percent [of Arrestment Devices] Classified as Good or Fair	46.5	87	93.1
Percent [of Arrestment Devices] Classified as Poor	53.5	13	6.9
Subdivision of Poor Tests:			
Percent That Hit Bulkhead at Collar [Failed to Stop]	11.9	5.4	4.3
Percent That Had Stopping Rate Over 3 Gravities	41.6	7.6	5.6

A very complete guide for conducting free-fall tests has been published by the Ontario Department of Mines and Northern Affairs.[1] A specific form is filled out for each test. The data included provide all the information necessary for a realistic estimate of the ability of the device to perform in an emergency. Where corrective action is taken or required, the data provide a quantitative basis for comparing the effects of changes.

The test record form used in Ontario is shown in Figure 21. The data recorded were taken by Battelle at the time of the test. To summarize, a 2155-lb loaded conveyance was stopped from 1638 ft/min in 4.5 ft. This is equivalent to a deceleration of 2.57 g, which is within the 1- to 3-g range generally considered acceptable. As a graphic demonstration, six raw eggs on the conveyance floor were undamaged by the stop.

The conveyance and arrestment device involved had been tested in 1951 when it was first placed in service, but at another mine. At that time three successive tests yielded decelerations of 2.54 g, 2.59 g, and 3.00 g. The 0.46-g range of these data represents an 18 percent variation of the applied arrestment force. Such a spread would be more significant were it to occur for a lower desired arrestment force, since it might result in failure to stop a conveyance. A further stopping-performance criterion is suggested:

> For vertical-shaft applications, a conveyance-mounted arrestment device should be capable of stopping a fully loaded conveyance from rated maximum hoisting speed with at least a deceleration of 1 g.

Mine AGNICO MINES LTD Date 7-20-71 Test No. 4

Shaft 96 SHAFT Compartment _____ Type of Conveyance _____

Maximum Hoisting Speed 1500 ft/min. Conveyance No. 991R

Weight of Conveyance - C = 1155 lbs. Maximum Material Load - R = 3000 lbs

Maximum man-load 8 Men at 175 lbs = 1400 lbs

Load on Conveyance During Test = L = 1000 lbs. (Should = Max. Man-load)

Total Load Decelerated - W = L + C 2155 lbs

Distance Before Dogs Engaged = S 11.6 ft

Distance After Dogs Engaged = S_1 4.5 ft

Speed When Dogs Engaged = $V = 8\sqrt{S}$ = 27.3 ft/sec 1638 ft/min

Deceleration = $A = \frac{V^2}{2S_1}$ 82.8 ft/sec/sec

Deceleration in Terms of Gravity = $\frac{A}{G} = \frac{S}{S_1}$ 2.57 (SEE REMARKS) G

Initial Spring Tension — lbs

Spring Tension as Percent of Weight of Conveyance — Percent

Type of Dog SINGLE TOOTH (E. LONG TYPE G) Furnish Drawings of Dog and Mechanism

Do Dogs Compensate for Wear? YES Anti-Trailing Rope Mechanism? YES

Did Dogs Turn Over, Out of or Through Guides? No

Did Dog Teeth Fill Up with Spoil from Guides? No

Were Dog Mechanism, Dogs, or Dog Shafts Damaged During Test? No

Width of Dog Teeth 3/4 INCH Penetration of Tooth 7/8 INCH

Angle of Dog Teeth to Vertical 82° Degrees

Total Effective Tooth Area Scoring Guide Timbers = T = (3/4)(7/8)(4) = 2.625 Square Inches

Average Resistance of Wood = $F = W\left(\frac{S}{S_1} + 1\right)$ 2155(3.57) = 7693 lbs

Average Resistance of Wood = $\frac{F}{T}$ 2931 Pounds Per Square Inch

Ratio of $\frac{\text{Total Wood Resistance}}{\text{Total Maximum Load}} = \frac{F}{C+R}$ 1.85

(NOTE: This ratio should not be less than one if protection is required for maximum material loading)

Size of Guides (actual) 3 1/2 x 4 1/2 Original Size SAME

Guide Material SPRUCE Number of Guides 2

Condition of Guides NEW

REMARKS TEST COMPLETED SATISFACTORILY. THIS CONVEYANCE WAS ORIGINALLY TESTED 1-5-51 WHEN INSTALLED AT ANOTHER MINE. AT THAT TIME THE DECELERATIONS FROM THREE TESTS WERE 2.54, 2.59, 3.0.

SIGNED CHARLES H. LARIEN AUTHORITY _____

FIGURE 21. ARRESTMENT DEVICE FREE-FALL TEST FORM, ONTARIO DEPARTMENT OF MINES AND NORTHERN AFFAIRS

Dynamic Tests – Inclined Shafts

Though static actuation tests are performed with inclined-shaft arrestment devices, Battelle knows of no one who dynamically tests them, routinely or otherwise.

It would seem a straightforward matter to adapt any of the previously discussed dynamic tests to broken-rope, inclined-shaft arrestment devices. It would even be simpler to adapt them where overspeed actuation is involved. One modification is suggested, however: inclined-shaft systems should be tested for good and bad rail and/or auxiliary-guide surface conditions to determine the maximum and minimum braking forces developed.

It is further suggested that buck hooks and drag devices not be tested but eliminated in favor of one of the other inclined-shaft devices discussed.

OPINIONS OF ARRESTMENT-DEVICE MANUFACTURERS

United States manufacturers of arrestment devices appear to be well aware of their problems and have definite opinions of what is needed to improve them.

Arrestment-Device Actuation and Performance

Several manufacturers feel that actuation criteria should be broadened. Historically, arrestment devices have been actuated by loss of hoist-rope tension, but some manufacturers believe that overspeed protection at the conveyance would also be desirable. Actuation in the event of a broken rope does not necessarily mean that a "broken-rope" device must be used. Since a conveyance usually quickly "overspeeds" after a rope breaks, a device actuating in an overspeed situation would do as well.

Equipment manufacturers generally think that a prerequisite to improved arrestment-device performance is the establishment and enforcement of uniform performance standards. They would prefer to have these standards prescribe the minimum limits of acceptable operation in some definite manner.

Arrestment-Device Testing

Equipment manufacturers believe that proper testing is fundamental to assuring and maintaining effective device performance. Most agree that mine-site testing of arrestment devices is essential and most recognize that the extent of current testing in coal mines is inadequate. They recognize that the most realistic test would be arrestment while the conveyance descends at rated speed with the rated load and, therefore, recommend this as a test condition. Additional testing is necessary to assure that the original performance is maintained. Most agree that this could be accomplished by a combination of dynamic and static testing.

Design Data

The design of conveyances and associated arrestment devices is a custom business. Identical conveyances are seldom used in two separate mines. Most companies base their new designs for wood guides on Ontario test data. In general, they aim for decelerations between 1 and 3 g over the spectrum of possible conveyance loads, but the conveyances are rarely tested before shipment.

Where steel guides are used, manufacturers point out the problems resulting from the variability of the friction coefficient between braking surfaces and the lack of test and design data. In addition, test and design data are lacking for wire-rope guides.

Shaft Design

Some manufacturers indicated a desire to see some form of standardization in shaft and slope layout. Standardized compartment designs are considered highly desirable. Manufacturers often claim that there is insufficient room in the compartment for installation of a suitable arrestment device.

ELEVATORS

GENERAL DESCRIPTION

Initially, the elevator industry used broken-rope-actuated arrestment devices similar to those used in mines. These were replaced with devices actuated by an overspeed governor because the industry felt they provided greater protection to the passengers. One elevator manufacturer contacted notes that while "...there have been very few cases where a safety has operated because of broken hoist ropes...", there have been "...many cases where a safety has operated because of an overspeeding car". Another manufacturer commented that only approximately one out of eight elevator incidents requiring conveyance arrestment is caused by rope breakage. The rest typically involve hoist machinery difficulties which lead to an overspeeding car.

There are only three types of elevator arrestment devices in use today – Type A, B, and C. All essential design features, performance standards, and inspection, maintenance, and testing procedures for each type are prescribed by the American Standard Safety Code for Elevators (ANSI A17.1) and the American Standard Practice for the Inspection of Elevators Manual (ANSI A17.2).

The three types of "safeties", as the elevator industry calls them, differ only in braking elements and immediately associated components. The overspeed governor, its placement within the system, and the manner by which it initiates actuation are practically identical regardless of which safety is used.

Type B (Wedge-Clamp) Safeties

The typical elevator emergency arrestment system using a Type B safety is shown in Figure 22. The governor rope and the conveyance are connected by a mechanism that transmits a driving force to the governor rope, but will disconnect from the conveyance if the force required to drive the rope exceeds a particular value. The safety actuating rope is also connected to this mechanism, and is always connected to the governor rope. In normal operation, governor-rope motion is directly proportional to conveyance motion. In descending, if conveyance speed exceeds the governor setting*, the rope clamp on the governor actuates and stops the governor rope. The force required to drive the governor rope now exceeds the capacity of the conveyance-governor-rope connecting mechanism, and the latter disconnects from the conveyance. In a descending mode, the actuating rope attached to the stationary governor rope immediately begins to unreel from a drum that is beneath the car and part of the safety. The rotating drum turns a shaft that has right- and left-hand threads on its outer ends. Threaded on the shaft ends are nonrotatable nut-like elements that have a wedge-shaped outer surface. As the shaft turns, these wedge elements move toward the drum, spreading the part of the brake clamp that touches them and clamping the outer part of the brake clamp against the conveyance guide rails. The clamping force increases with conveyance motion until the tension in the governor rope exceeds the capacity of the governor-rope clamp. At this point, the governor rope slips and the braking force of the safety remains constant thereafter. The governor-rope clamp on the governor is set to permit the rope to slip before it breaks.

In ascending, if the conveyance overspeeds, the governor does not actuate, and thus the safeties cannot stop the conveyance.

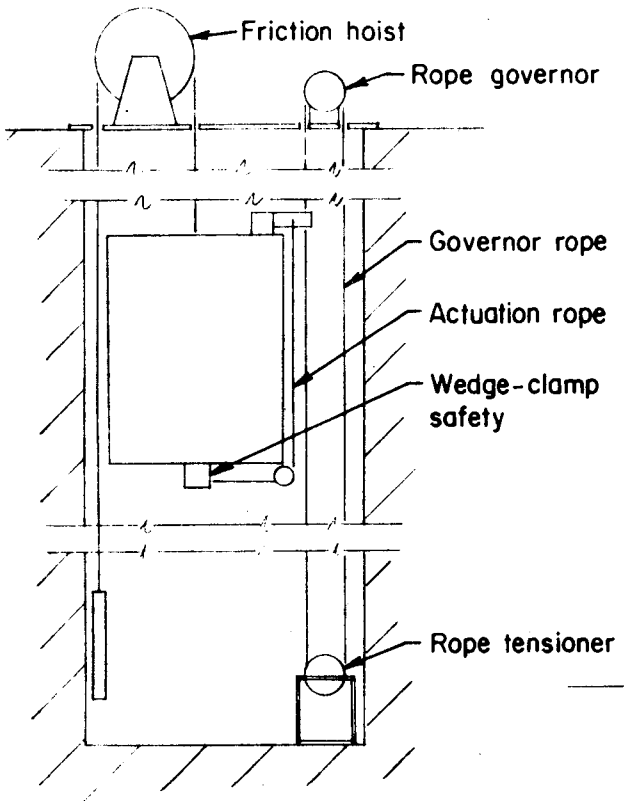
Type A (Instantaneous) Safeties

Type A safeties are also called "instantaneous" because they are designed to develop a very high braking force. Roll and eccentric operated Type A safeties are illustrated in Figure 23. The rest of the system is like or similar to that shown for Type B. After actuation, the braking force is developed by the roll or cam being wedged further into place by friction and conveyance motion. The force developed is limited to some extent by friction and the shapes involved, but to a larger extent by the deformation and strength properties of the components.

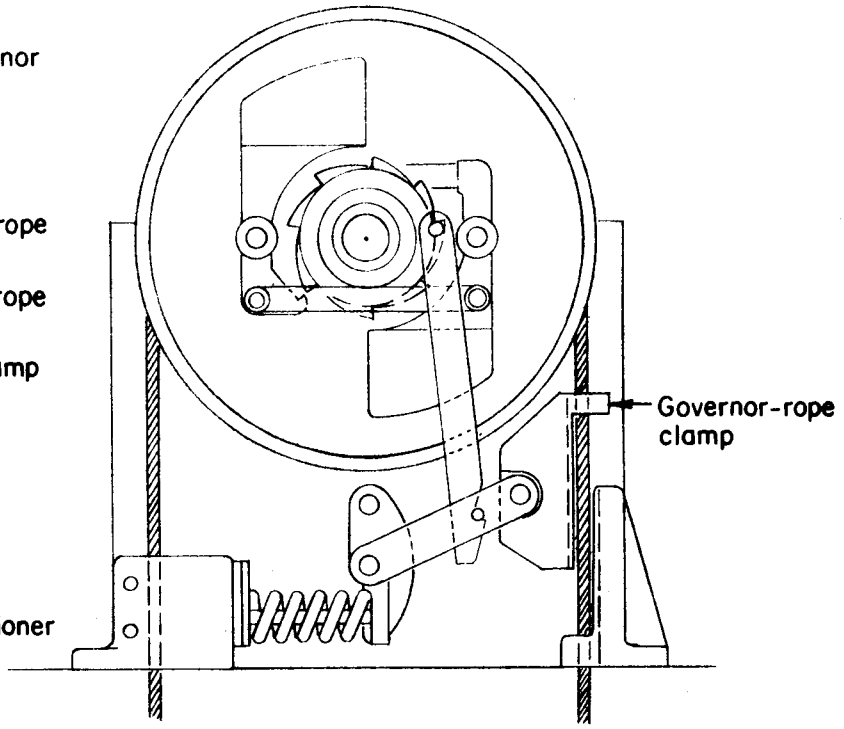
Type C Safeties

Type C safeties are the same as Type A safeties as far as the braking elements are concerned, but incorporate hydraulic buffers (shock absorbers) between the conveyance and the braking element to reduce the force on the conveyance. Two versions of Type C safeties are shown in Figure 24.

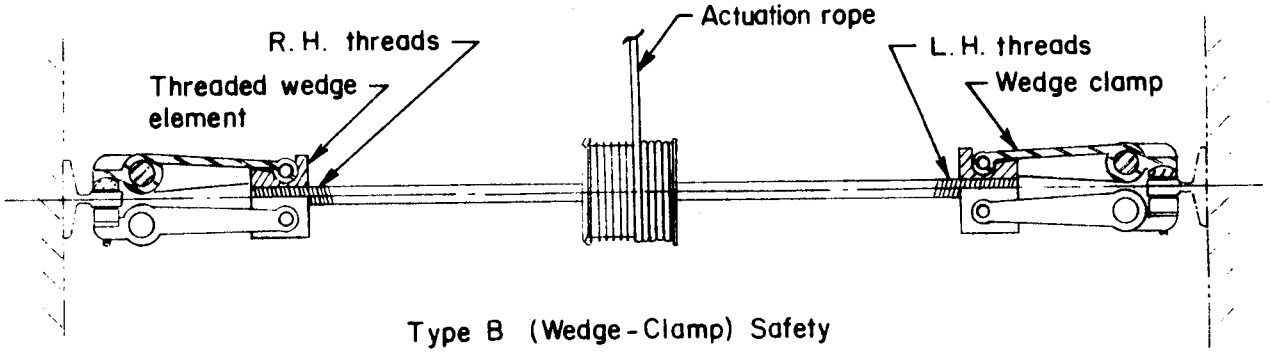
*The ANSI code requires this setting to be at least 115 percent of the rated car speed. Maximum limits are also required, but vary with type of safety (ANSI A17.1, Table 206.2a).



Elevator Schematic



Rope Governor



Type B (Wedge-Clamp) Safety
Plan View

FIGURE 22. ELEVATOR EMERGENCY ARRESTMENT SYSTEM USING A TYPE B SAFETY

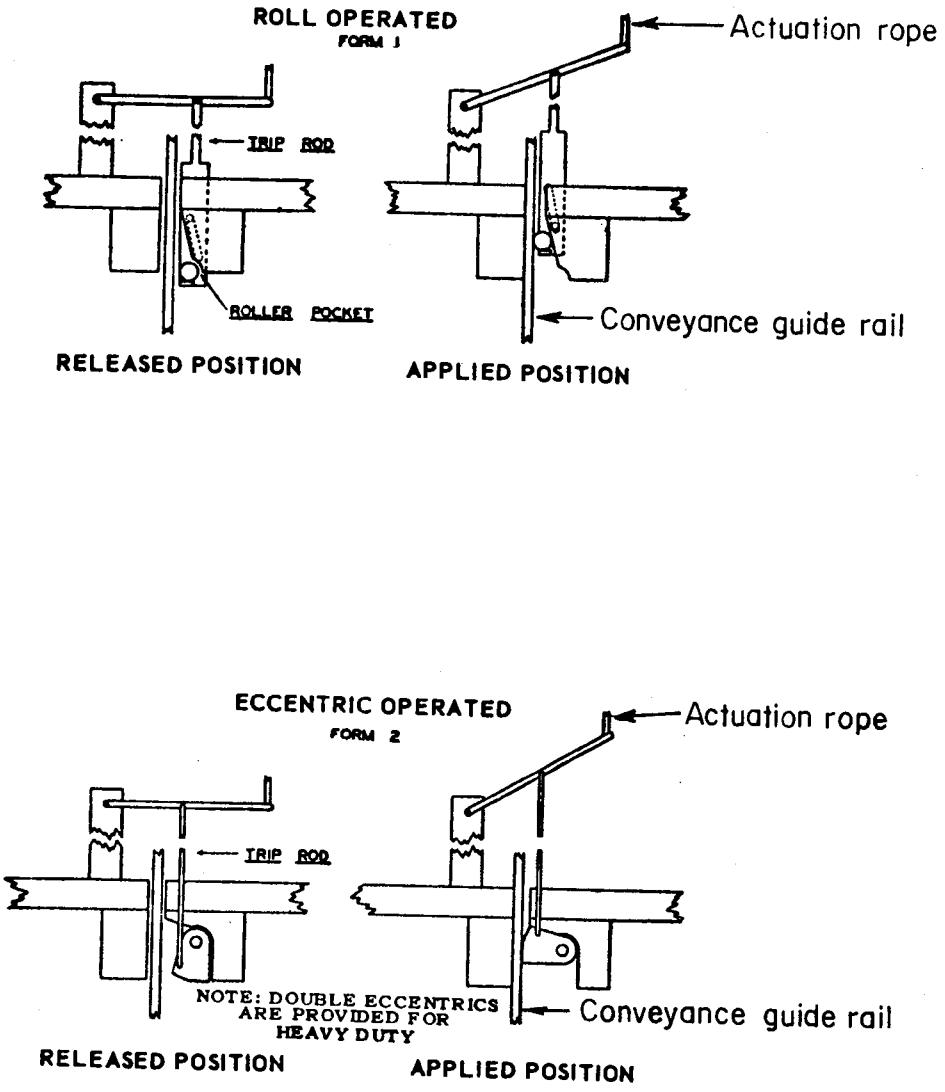


FIGURE 23. ELEVATOR TYPE A INSTANTANEOUS SAFETIES, ROLL AND ECCENTRIC OPERATED (ELEVATION VIEWS)

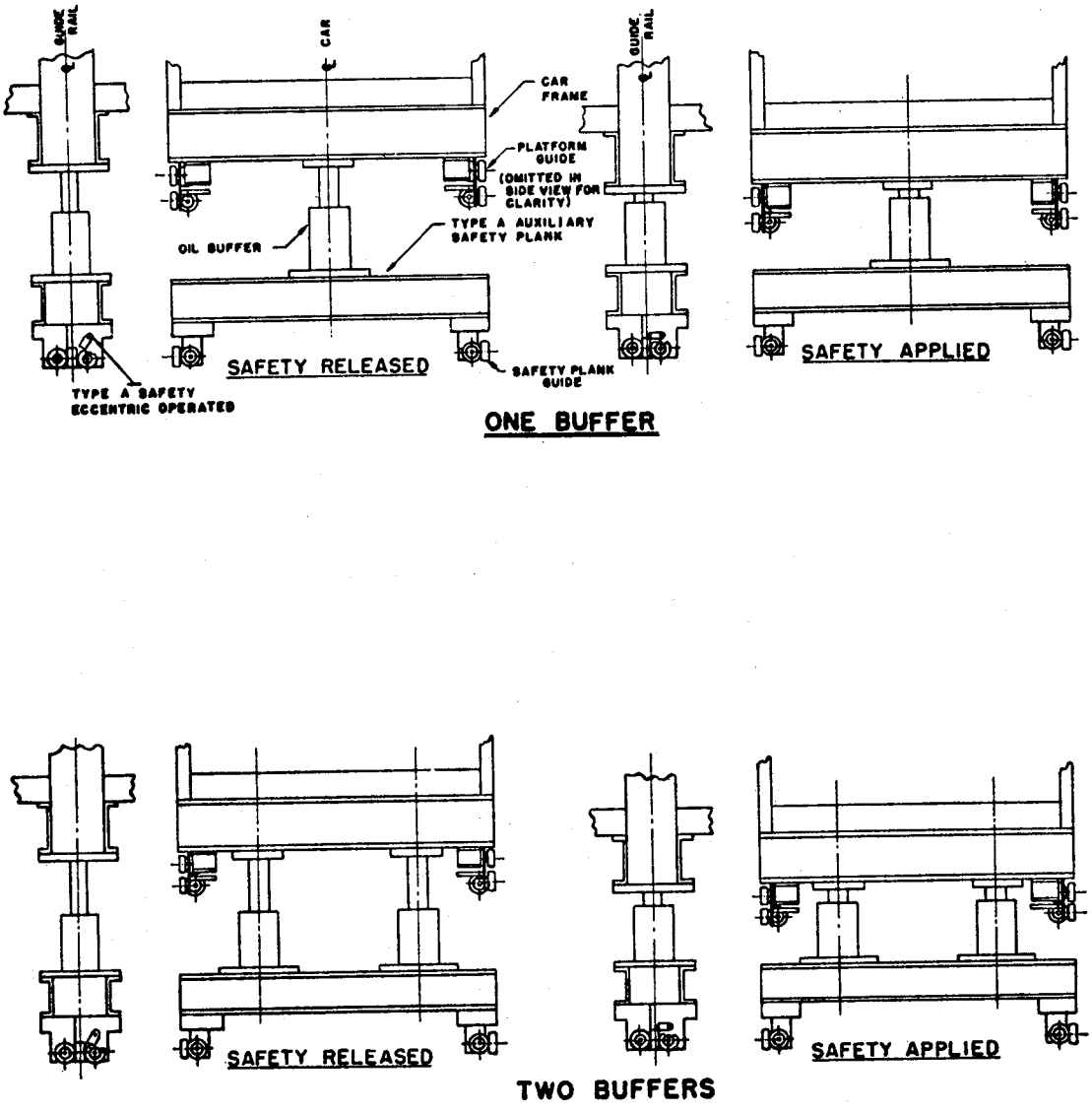


FIGURE 24. ELEVATOR TYPE C SAFETY (ELEVATION VIEWS)

PERFORMANCE

The governing ANSI specification (ANSI A17.1) states that Type B safeties are suitable for all intended maximum car speeds, but must stop the car within the following maximum and minimum distances:

$$S_{maximum} = \frac{V^2}{81444} + 0.84 \text{ (ft)}$$

$$S_{minimum} = \frac{V^2}{231840} + 0.4 \text{ (ft)} \quad ,$$

where

$S_{maximum}$ = maximum stopping distance, ft

$S_{minimum}$ = minimum stopping distance, ft

V = governor-tripping speed, ft/min (maximum conveyance speed).

The divisors of V^2 are equivalent to decelerations of 0.35 g for $S_{maximum}$ and 1.0 g for $S_{minimum}$. It is inferred, therefore, that the elevator industry finds decelerations ranging from about 0.35 g to about 1.0 g to be acceptable and desirable performance for any initial conveyance speed and weight when Type B safeties are used.

Type A safeties are restricted to cars with rated speeds not over 150 ft/min. It is expected that this speed is selected to limit the deceleration forces developed by these "instantaneous" devices. What average or maximum decelerations occur in practice has not been determined.

Type C safeties are limited to speeds not over 500 ft/min. The specification also states that these systems must not develop an average deceleration greater than 1 g at the conveyance.

The braking forces for Types A, B, and C safeties (at the conveyance) and single-tooth Ontario-type dogs on wooden guides are qualitatively compared as a function of conveyance travel after actuation in Figure 25 to illustrate differences among braking-force characteristics.

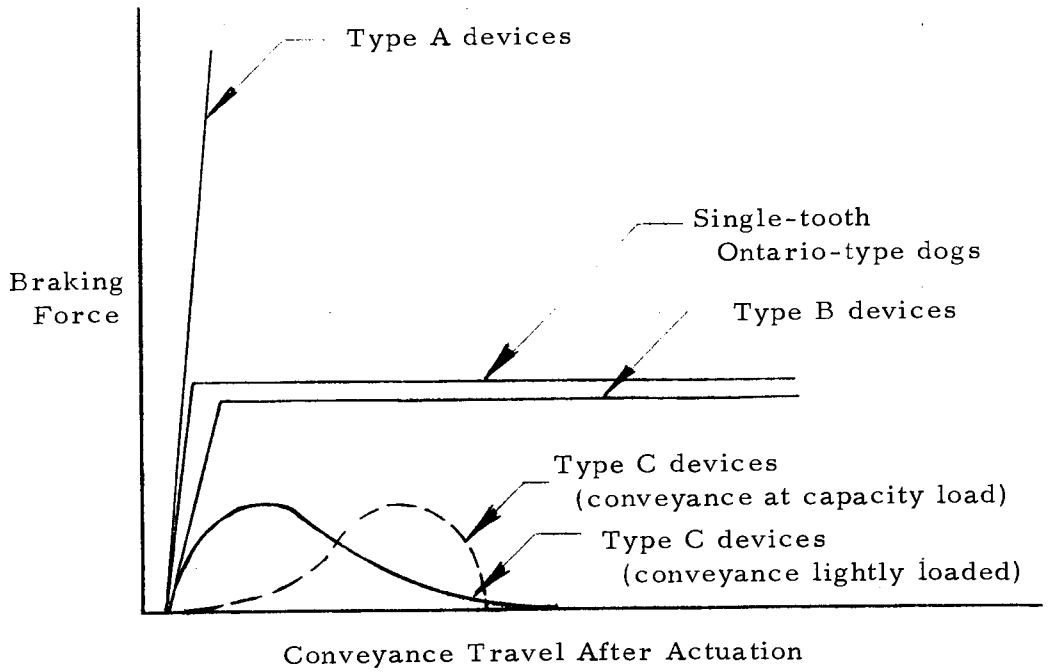


FIGURE 25. COMPARISON OF BRAKING FORCE VERSUS CONVEYANCE TRAVEL AFTER ACTUATION FOR ELEVATOR SAFETIES AND THE SINGLE-TOOTH ONTARIO-TYPE DOG

INSPECTION, MAINTENANCE, AND TESTING

Elevator inspection, maintenance, and testing procedures are stipulated by ANSI A17.1 and A17.2.

These specifications require that safeties, governors, and buffers be inspected in detail at least once a year. At that time, safeties must be actuated and performance observed with the empty car moving slowly. Other gear is to be inspected at least once every 3 months. What to look for and what to do are generally carefully specified.

After installation but prior to use, ANSI A17.1 requires that an elevator be inspected and tested to determine whether all parts conform to the specifications and whether the safeties function as required. A similar inspection and test must be made following major equipment alterations. Safety performance is tested by running at speed, tripping the governor manually, and observing stopping distances, etc. The car must be ballasted for the rated man load.

APPLICATION OF ELEVATOR ARRESTMENT TECHNOLOGY TO TRADITIONAL MINE-HOISTING SYSTEMS

The elevator arrestment technology just discussed differs fundamentally from traditional mine-hoist arrestment technology in two concepts. One is in sensing an emergency, and the other the development of braking forces. The former relates to actuation, and the latter to performance. The following discussion concerns the concepts primarily; their mechanical realization is the prerogative of the design engineer.

Actuation

If Figure 1 (Functional Relationships Among Control, Drive, and Brake Components Typical of U. S. Mine Hoists) and Figure 22 (Elevator Emergency Arrestment System Using a Type B Safety) are compared from a control-system viewpoint, it is seen that the governor rope continuously provides conveyance position, speed, and direction-of-motion data independent of any of the controls associated with the drive machinery. Though the governor rope provides this information, the governor is designed to utilize the speed data only. In discussing arrestment-device functional requirements, it was noted that traditional hoist-control systems do not obtain conveyance-motion data by directly observing the conveyance, but do so indirectly by observing drive-shaft or drum motion. (The one exception is overwind and underwind controls actuated by shaft-mounted limit switches.)

In a control system when a positive signal from any of a number of devices is required, these devices are generally best paralleled. Where lack of a signal from any of a number of devices is required, these devices are generally best distributed in series. Fundamentally, the elevator emergency sensing system and part of the arrestment-device actuation system parallel the motor-brake equipment, whereas typical vertical-shaft mine hoists have these functions serially distributed. Thus, if the traditional hoist overspeed control fails, conveyance overspeed protection is lost.

The elevator approach includes two independent parallel overspeed sensors, one driven by the conveyance and one driven by the shaft or drum. This approach is inherently more reliable.

The elevator governor-rope approach is applicable to traditional vertical-shaft hoist systems. It is recognized that shaft depth leads to problems; however, application of the governor-rope principle – conveyance speed monitored directly from or at the conveyance – is limited only by the designer's ingenuity.

One designer is developing an arrestment device for inclined shafts that will actuate when the conveyance overspeeds but otherwise closely resembles the vertical-shaft broken-rope arrestment devices previously described.

Braking Performance

The most generally useful and applied elevator safety is the Type B. It develops a braking force that increases with conveyance travel until a limit is reached or the

conveyance has stopped. This principle may provide a solution to accommodating the variations in coefficients of friction induced by the mine-shaft environment. For example, a conveyance brake might be designed to initially apply a contact force which, under clean, dry surface conditions, would provide the desired deceleration. After an appropriate time or travel distance, the brake contact force might then slowly increase to the value which, under wet, greasy surface conditions, would provide the desired deceleration. This modulating behavior might be mechanized with electric-current control in magnetic track brakes, with hydraulic dampers (dash pots) in mechanical and hydraulic systems, and pneumatic dampers in pneumatic systems. In any case, such behavior should be mechanized in a fail-safe manner; failure of the modulator should result in more than the minimum brake application.

SUMMARY

ACTUATION

Actuation in the event of loss of hoist-rope tension, conveyance overspeed, and manual command is common. The majority of vertical-shaft systems are loss-of-tension actuated. Inclined-shaft systems are most commonly overspeed actuated, but may also have loss-of-tension and manual capability.

Mechanically, no particular mode of actuation appears preferable, since all appear to be adequate. Compression springs are often used to actuate braking in vertical-shaft systems responding to loss of rope tension. To compress these springs to the ready-to-actuate configuration, a force equal to from 0.3 to 0.5 times the weight of the empty conveyance has been found to provide satisfactory engagement of single-tooth dogs, while avoiding actuation from the dynamic variations in hoist-rope tension.

The hoisting-system considerations of Chapter 2, however, indicate that overspeed is preferred as the primary actuation mode, since it covers more situations that can lead to uncontrolled conveyance motion.

Actuation in the event of reversal of direction, a capability of one domestic line of magnetic track-brake arrestment devices, has merit where the braking force developed depends upon surface coefficients of friction which can vary considerably. A reversal-of-direction mode of actuation would apply the brakes while the kinetic energy of the vehicle is still low, thus minimizing the effects of friction variations.

BRAKING

Vertical Shafts, Wood Guides

The single-tooth Ontario-type dog appears to be the best available braking element for use with wood guides. Using empirical equations developed from actual

stopping performance data, this dog (Figure 6a) can be designed for a desired braking force. Predicted and developed braking forces agree quite well.

Multitoothed wedges, cams, and dogs have been proved highly unreliable. The braking forces developed by these elements are generally unpredictable. The forces are either high enough to cause damage or, because of clogging with wood chips, too low to stop a conveyance.

Vertical Shafts, Steel Guides; and Inclined Shafts

The best devices for these applications are unknown because no performance data have been found for any of the devices known to be used. On the basis of one isolated case of manual actuation of an inclined-shaft magnetic-track brake (to be discussed later), it is suspected that braking forces can be high enough to cause injury.

INSPECTION, TESTING, AND MAINTENANCE

A dynamic test wherein the arrestment device is actuated when the fully loaded conveyance is traveling at its rated maximum hoisting speed is the best way to determine the capability of the device to perform its intended function.

A dynamic test wherein the arrestment device is actuated when the fully loaded conveyance is released from rest is a good indicator of changes in the overall performance characteristic of an arrestment device.

Actuating the arrestment device with the conveyance at rest is the simplest way to determine the performance capability of the actuation components. Performing this test frequently, daily for example, carefully inspecting and maintaining the braking elements, and maintaining the actuation components in accord with the results of the actuation tests is the best way to achieve a high degree of functional reliability.

CHAPTER 4

ARRESTMENT-DEVICE APPLICATION AND PRACTICE IN UNITED STATES COAL MINES

RELATIONSHIP OF OBSERVED AND INDUSTRY-WIDE PRACTICE

Overall, vertical- and inclined-shaft mines are a significant factor in the production of bituminous coal in the United States. These mines produce 35 percent of the coal mined, although they account for only 3 percent of the total number of mines. They also employ 28 percent of all bituminous-production personnel. These data are pictorially presented in Figure 26.

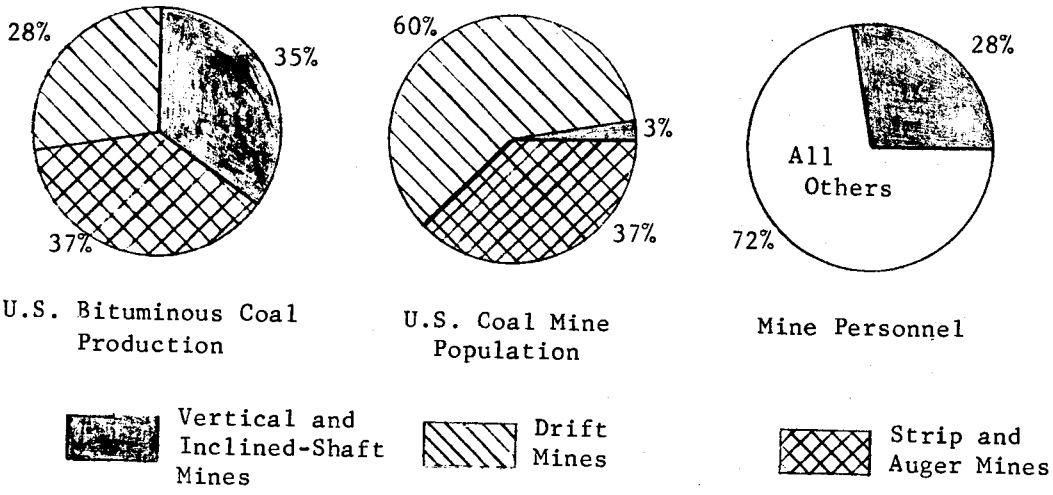


FIGURE 26. SIGNIFICANCE OF VERTICAL- AND INCLINED-SHAFT MINES TO PRODUCTION OF BITUMINOUS COAL IN THE UNITED STATES

(Based on 1970 and 1971 Keystone Coal Mine Directory Information.)

Tonnage mined per year is a fairly consistent indicator of the technological and operational proficiency that one could expect to find at an underground mine. Using this indicator, Table 4 has been prepared to show how representative of industry are the practices that have been observed during this and the earlier study. Listed are all the vertical- and inclined-shaft hoisting installations known to Battelle, as well as those that were inspected.

Of the 47 hoisting installations inspected, 42 are used to hoist men, though not necessarily exclusively. Some systems hoist coal or supplies as well.

TABLE 4. DISTRIBUTION OF VERTICAL- AND INCLINED-SHAFT COAL-MINE HOISTING INSTALLATIONS

Range of Yearly Production, tons	Vertical-Shaft Hoists		Inclined-Shaft Hoists	
	Known	Inspected[a]	Known	Inspected[a]
0 - 400,000	13	5	20	3
400,000 - 800,000[b]	16	7	30	6
800,000 - 1,200,000	15	6	20	4
1,200,000 - 1,600,000	9	4	6	3
1,600,000 - 2,000,000	3	1	7	3
2,000,000 - 3,000,000	5	3	9	2
3,000,000 - and up	0	--	1	0
Totals	61	26	93	21
Percent of Totals	100	43	100	23

(a) Includes visits during Contracts H0101741 and H0111810.

(b) Some of the mines visited in this category have been larger producers but are currently being phased out.

TRADITIONAL MINE HOISTS

DESCRIPTION OF ARRESTMENT DEVICES IN USE

Of the 42 hoists used for man transport, 36 are equipped with conveyance-mounted arrestment devices. Those not equipped are all inclined-shaft hoists. The devices inspected are described in Table 5.

Of the 42 hoists inspected, 30, or 72 percent, are used in vertical shafts. Of these 30, 24 (80 percent) operate with wooden guides. While there is no assurance that 80 percent of all vertical-shaft coal-mine hoists use wooden guides, there is no doubt that wooden guides predominate.

Of the 12 inclined-shaft hoists used for man transport, 50 percent had no conveyance arrestment devices.

Attempts were made during this program to determine whether underground rope haulage of men occurs in stopes or raises in United States coal mines, and, if so, what types of arrestment devices are used or necessary. It is concluded, however, that this practice has been abandoned. The last mine to have underground rope haulage in the pitching seams of Alabama has recently ceased operations.

TABLE 5. DESCRIPTION OF ARRESTMENT DEVICES INSPECTED – TRADITIONAL MINE HOISTS

Shaft/Braking Guides	No. of Hoists Equipped	Braking Element Used	Actuation Conditions
Vertical shaft/wood guides	12	Multitoothed wedge	Loss of hoist-rope tension
	6	Multitoothed cam	Ditto
	4	Multitoothed dog	"
	2	Single-tooth dog (Ontario type)	"
Subtotal	24		
Vertical shaft/rail guides	5	Multitoothed wedge	"
Pipe guides	1	Smooth shoe (1/2 of split guide bushing)	"
Subtotal	6		
Inclined shaft/rail	2	Smooth shoe, magnetically applied	Loss of hoist-rope tension, overspeed, direction reversal, manual
Auxiliary wood guide	1	Multitoothed dog	Loss of hoist-rope tension
Auxiliary wire rope	1	Band brake on rope capstan	Ditto
--	2	Drags	Conveyance reversal during up-slope travel: no down-slope travel protection
Subtotal	6		
Total	36		

INSPECTION, MAINTENANCE, AND TESTING PRACTICE

Inspection and maintenance practices are basically inseparable; testing is a tool for both. These practices range from good to poor to nonexistent. The testing practices routinely applied to the 36 hoist installations inspected are summarized in Table 6.

TABLE 6. SUMMARY OF TESTING PRACTICE WITH ARRESTMENT DEVICES INSPECTED

Shaft Configuration	Number of Hoists Equipped	Number of Installations				
		Static (Actuation) Testing	Dynamic Testing			No Testing
			Drop Method 1[a]	Drop Method 2[b]	Free Fall	
Vertical	30	9	3	7	0	11
Inclined	6	1	–	–	–	5
Totals	36	10	3	7	0	16

(a) Hoist accelerated.
(b) Cage released from hoist rope.

Arrestment devices never tested seldom appear to be maintained. The arrestment devices on one vertical-shaft double-conveyance hoist were so covered with moss that the components were barely recognizable. Others appeared to be very rusty. The one case of static testing in an inclined shaft involved the manual actuation of magnetic track brakes.

The U. S. Bureau of Mines has recommended[3]

(1) That the linkages of arrestment devices be "manipulated" daily to assure proper functioning, and

(2) That a drop test be made bimonthly.

These recommendations are obviously not uniformly followed.

DISCUSSION

Of the 24 vertical-shaft wood-guide hoist systems equipped with conveyance arrestment devices (see Table 5), 22, or almost 92 percent, use braking elements that have been shown to be highly unreliable. Where dynamic drop tests are performed by Method 2 (cage released from hoist rope), the reported stopping distances in wood guides vary from an inch or so to several feet. If all brakes were designed to provide the same deceleration, the stopping distances in these drop tests should be about the same. Allowing a range of 3 in design deceleration, the stopping distances should range no more than a factor of 3 or so. The reported stopping distances, however,

ranging from an inch or so to several feet, represent a range of developed deceleration of at least 20. In the event of a broken hoist rope during operation, for example, any of these 22 conveyances equipped with the proved unreliable braking elements could be expected to go to the bottom or to stop with such suddenness that damage and injury would occur.

The typical performance of inclined-shaft arrestment devices has yet to be determined. One case illustrating what might be expected is worth reporting. Two inspectors, the mine superintendent, and his maintenance foreman were being lowered in a car equipped with magnetic track brakes. One inspector asked if the track brakes had ever been tested. In response, the superintendent manually actuated the brakes. The car stopped, but each man received minor cuts and bruises.

OPINIONS OF MINE OPERATORS

Among the coal-mine operators contacted, there is a general concern for the ability of installed arrestment devices to stop a loaded conveyance from speed in an emergency.

One operator of a vertical-shaft man hoist that uses multitoothed-wedge braking elements expressed the fervent hope that he never have an emergency requiring his arrestment devices to work. He strongly doubts they could stop the conveyance and thinks they would do extensive damage in the attempt. Furthermore, he is adamantly opposed to dynamic free-fall tests for the same reasons.

Another operator of a similar hoist indicated he was considering replacing his multitoothed wedges with single-tooth dogs of the Ontario type, a change which Battelle strongly encouraged.

Yet another operator stated that drop testing had been abandoned because the arrestment devices caused damage to both guides and conveyance.

Some operators concerned for arrestment-device capability and requirements of law have complained of a lack of available workable arresting equipment.

ELEVATORS

There are probably well over 100 elevators in mine applications in the United States. At least a dozen have been seen in coal mines, and seven were closely inspected during this program and the earlier study. All those inspected used the Type B, wedge-clamp safety. One used for hoisting 30 men at 900 ft/min has been in service in Pennsylvania for 32 years without problems.

Coal-mine elevators are often inspected and maintained by elevator manufacturers or elevator-service companies under contract to the mine operator. All work is in accord with the ANSI A17.1 and A17.2 specifications. Though Battelle has learned of cases where the safeties have actuated in emergencies (in one case all six hoist ropes

failed), none appear to have failed to stop the conveyance as designed. Elevators and the contractual approach to inspection and maintenance would appear to rid the miners of some man-hoisting problems. Currently, elevators are limited to hoisting depths of about 1500 ft, a depth, however, that includes the vast majority of U. S. coal mines.

CHAPTER 5

REGULATORY REQUIREMENTS FOR CONVEYANCE-MOUNTED ARRESTMENT DEVICES

INTRODUCTION

United States Federal mining safety regulations and the safety regulations of 29 states and nine foreign countries were studied to determine the extent of prevailing requirements for conveyance-mounted arrestment devices. The regulations studied are listed by title in Appendix D.

The following presentations and discussions of these regulations deal with what is written. In many cases, the law empowers regulatory officials to provide additional guidance in the use of arrestment devices when requested or when they consider it necessary. To cover this aspect of governmental regulation in detail is beyond the scope of this study.

U. S. FEDERAL REQUIREMENTS

SUMMARY OF REQUIREMENTS

U. S. Federal requirements are summarized in Table 7.

TABLE 7. SUMMARY OF U. S. FEDERAL REGULATIONS APPLICABLE TO CONVEYANCE ARRESTMENT DEVICES

Application				When Required			Actuation Criteria				Initial Approval			Periodic Testing							Inspection	
Coal Mines	Metal/Nonmetal Mines	Vertical Shafts	Inclined Shafts	Personnel Hoisting	Product Hoisting	None Required	Emergency	Broken Hoist Rope	Overspeed	Not Defined	Qualification Tests	By Direction	None Required	Free-Fall Test	Drop Test: Loaded	Drop Test: Empty	Actuation Test	Required But Not Defined	None Required	Record Maintained	Visual Examination	Record Maintained
		X	X	X			X					X						2M[a]		X	D[b]	X
		X	X			X[c]																

(a) M = Monthly.
(b) D = Daily.
(c) Except for crossheads in shaft-sinking operations.

DISCUSSION

Application Criteria

Federal law is explicit in requiring arrestment devices for man haulage in both vertical and inclined shafts. The devices that may be used are "safety catches or no less effective devices approved by the Secretary". No exceptions appear to be granted.

Actuation and Performance Criteria

Actuation "in an emergency" is called for. Performance would seem to be covered by the phrase "which act quickly and effectively".

Inspection and Testing Criteria

Inspection is to be daily and testing "at least every two months". No procedures are specified for either. Bureau of Mines Form 6-1494, "Record of Daily Inspection of Hoisting Equipment", requires a check mark (✓) if "safety catches" are in safe operating condition, and "if unsafe conditions are noted, state action taken". Testing is covered by "Tests of safety catches (every two months)" and an indication of when the previous test was made.

OPINIONS OF FEDERAL REGULATORY PERSONNEL

The Federal regulatory officials contacted have little to say regarding conveyance arrestment devices. In general, there is little awareness of their performance capabilities and the problems they can and have caused. There was, however, a general interest in Battelle's study.

U. S. STATE REQUIREMENTS

SUMMARY OF REGULATIONS

Twenty-nine states have laws regulating coal, metal, and nonmetal mining. The sections of these laws regulating conveyance arrestment-device application and practice are summarized individually by state in Table D-1 of Appendix D. In Table 8 below, these regulations are further summarized for all 29 states according to coal and noncoal mining. The regulations for the seven top bituminous-coal-producing states are also presented in Table 8. The noncoal laws are presented for comparison only, and are not discussed below.

TABLE 8. SUMMARY OF U. S. STATE REGULATIONS APPLICABLE TO CONVEYANCE ARRESTMENT DEVICES

Details of Law / Laws	Application				When Required			Actuation Criteria				Initial Approval			Periodic Testing							Inspection	
	Coal Mines	Metal/Nonmetal Mines	Vertical Shafts	Inclined Shafts	Personnel Hoisting	Product Hoisting	None Required	Emergency	Broken Hoist Rope	Overspeed	Not Defined	Qualification Tests	By Direction	None Required	Free-Fall Test	Drop Test: Loaded	Drop Test: Empty	Actuation Test	Required But Not Defined	None Required	Record Maintained	Visual Examination	Record Maintained
Coal Mining																							
All States - Number	25		25	15	25	0		7	8	0	10	1	7	18	0	0	2	3	11	10	7	16	10
% Total			100	60	100	0		28	32	0	40	4	28	72	0	0	8	12	44	40	28	64	40
Top Seven Producers - No.	7		7	4	7	0		2	0	0	5	0	4	3	0	0	0	0	3	4	3	5	2
% Total			100	57	100	0		29	0	0	72	0	57	43	0	0	0	0	43	57	43	72	29
Noncoal Mining																							
All States - Number		23	23	9	23	0		4	14	0	5	1	7	16	0	0	3	3	9	9	4	14	7
% Total			100	39	100	0		17	61	0	22	4	30	70	0	0	13	13	39	39	17	61	30

DISCUSSION

Application

All state coal-mining safety regulations require arrestment devices for man-hoisting in vertical shafts, but only 60 percent require arrestment devices when hoisting men in inclined shafts. Similarly, only four of the top seven coal-producing states require arrestment devices on slope conveyances for men.

Neglecting shaft-sinking hoists, there appear to be no exceptions granted on the basis of type of hoist or guides, except in Indiana where multirope hoists are exempt. Excluding elevators, multirope mine hoists are almost always Koepe-type friction hoists.

Actuation and Performance Criteria

Ten of the 25 states with coal-mining safety regulations do not specify conditions under which an arrestment device should actuate. Seven require actuation in an "emergency", while eight others require actuation in the event of a broken hoist rope. In practice, the broken-rope criterion usually leads to the use of a broken-rope device, although it allows use of an overspeed device because the latter can respond to the overspeed condition that usually follows a broken rope.

Performance criteria may or may not be considered to exist in state law. Certainly no deceleration limits are provided. Usually the wording involves such terms as "stop and hold" or "hold". "Hold" alone is poor since less braking force is required to "hold" than to "stop".

Five of the seven top-producing states have no actuation criteria at all. The two that do require actuation "in an emergency".

Inspection and Testing Criteria

One state requires an acceptance or qualification test for initial approval of arrestment devices. A few require some sort of approval (undefined), but 72 percent require none. Of the seven top producers, four require some approval, but no qualification tests.

Periodic testing of some kind is required by 15 (60 percent) of the states, but only seven (25 percent) require records be kept. Of these 15, only three define tests, these being an acutation test and a dynamic drop test of an empty conveyance. Of the seven top producers, three require testing but define no tests, though records are required.

Where states require arrestment devices on slope conveyances and some kind of testing, it is difficult to determine the extent to which inspection and testing requirements are applied.

The most definitive guidelines for testing are those of Alabama, California, Nevada, and Washington, of which only Alabama is a major coal producer. These guidelines are as follows:

Alabama – "The safety catches of cages, skips, or buckets shall be kept well oiled and in good working order; they shall be tested at least once each month by tying up the cage, bucket, or skip with hemp rope, lowering a few feet of hoisting rope on the top of the cage, skip, or bucket, then cutting the hemp rope, provided that any other method of testing which is equally effective, may be used after securing the approval, in writing, of the Department." (Page 24, Mine Safety Rules)

California – "At least once each work day, the weight on the hoisting rope shall be relieved for activating and inspecting the safety dogs. When deemed necessary by the Division of Industrial Safety, drop tests may be required in the presence of a representative of the Division." (Section 6006-C)

Nevada – "Safety catches should be inspected daily; drop tests should be made at the time of installation. Every two months the cage should be rested on chairs or proper blocking to check the operation or activation of the safety catches by allowing the rope to slacken suddenly." (Section 19-132)

Washington – "The following tests of safety catches on cages shall be made once every six months: The cage shall be secured by passing a heavy hemp rope through the bridle chain ring or link and fastening both ends of the ropes to guides or to diagonally opposite posts of the head frame, drawing the rope taut. A blocking is to be passed below the cage to support same before hoisting rope is taut. The hoisting engineer shall then slack away until the cage is suspended on the hemp rope with at least four feet of the slack hoisting rope on top of it. Everything being in readiness the hemp rope shall be suddenly cut. If the safety catches stop the cage before it rests upon the blocking, the apparatus shall be considered efficient." (Section 64, Coal Mining Law)

Note that only Washington defines acceptable performance.

OPINIONS OF STATE MINE REGULATORY PERSONNEL

Most state regulatory personnel seem generally unaware of the problems with or the shortcomings of arrestment devices currently in use. This may be a result of the general lack of specific inspection and testing requirements in state laws and an even greater lack of requirements for records of either inspection or testing. In some instances, the officials contacted were not certain whether arrestment devices were even required by their states.

Some officials, however, have stated they do not believe that the arrestment devices typically used in their states are very reliable. A few indicated a need for arrestment devices for use with wire-rope guides (in vertical shafts). As stated, Battelle knows of one wire-rope-guide device in use in this country but can obtain no performance data for it. Ontario currently exempts wire-rope-guided conveyances for lack of arrestment devices with proved performance.

Another problem area for some state officials is inclined-shaft conveyances. In one instance, both state and mining company (noncoal) personnel were searching for an arrestment device for an underground, balanced-conveyance hoist used exclusively for man transport. In another case, officials were not sure if a mine was unable or just unwilling to install arrestment devices. Often the problem is simply that an old slope system is incompatible with off-the-shelf arrestment devices.

FOREIGN REQUIREMENTS

SUMMARY OF REQUIREMENTS

Mining regulations or, at least, those portions related to conveyance arrestment devices were requested of 18 foreign countries. Nine countries responded, and their arrestment-device regulatory requirements are summarized in Table D-1 of Appendix D.

The countries not responding were Belgium, Finland, France, Greece, Kenya, The Netherlands, Nigeria, Norway, and Sweden.

The countries responding were Australia, Austria, Canada, Great Britain, Italy, New Zealand, South Africa, Tanzania, and West Germany. There are basically no federal regulations in either Australia or Canada, regulation of mining being a state and provincial prerogative. The three Australian states and eight Canadian provinces listed in Appendix D are those that require arrestment devices.

Great Britain, New Zealand, South Africa, and West Germany do not require conveyance-mounted arrestment devices. Though not requiring them, New Zealand considers their use good practice. Britain, South Africa, and West Germany were long involved in the historic controversy surrounding use of safety catches and no longer require their use.

Italy and Tanzania require arrestment devices in all mining, but only for vertical-shaft man haulage. Both countries require that the devices actuate as the result of a broken hoist rope, but there appear to be no other requirements, such as initial approval for use, periodic testing, or inspection.

The essential features of Australian, Austrian, and Canadian regulatory practices are summarized in Table 9. Of these laws, those of Austria and Ontario are the most explicit and are presented in greater detail below:

Austria – Every conveyance must have a reliable and gradual working gripping device (safety catch) unless hoisted with multirope equipment or riding on wire-rope guides. The device-actuation springs must be factory certificated, and a force-displacement diagram provided.

The devices are to be examined daily for exterior damage or defect. Trained plant inspectors examine the devices weekly. Every 6 months, the devices are to be free-fall tested at rated load. At 1-year intervals the device-actuating springs are removed and a new force-deflection diagram determined; if a noticeable deviation from the original is found, the spring is discarded. Every 3 years, the complete rope-haulage system (safety catches included) is carefully inspected by experts recognized by the Federal Bureau of Commerce, Trade and Industry to determine if replacement of any components is necessary.

Austrian interest in the spring force-deflection relationship is well founded considering the essential role the spring plays in device actuation.

TABLE 9. SUMMARY OF AUSTRALIAN, AUSTRIAN, AND CANADIAN REGULATIONS APPLICABLE TO CONVEYANCE ARRESTMENT DEVICES

Details of Law / Laws	Application				When Required			Actuation Criteria				Initial Approval			Periodic Testing							Inspection	
	Coal Mines	Metal/Nonmetal Mines	Vertical Shafts	Inclined Shafts	Personnel Hoisting	Product Hoisting	None Required	Emergency	Broken Hoist Rope	Overspeed	Not Defined	Qualification Tests	By Direction	None Required	Free-Fall Test	Drop Test: Loaded	Drop Test: Empty	Actuation Test	Required But Not Defined	None Required	Record Maintained	Visual Examination	Record Maintained
Australia																							
Three States	2	3	3	1	3	2	--	0	3	0	--	0	2	0	1	0	0	2	1	0	3	1	1
Austria	X	X	X		X				X						X				D(a)			X	
Canada																							
Eight Provinces	4	6	7	1	8	0	--	0	6	0	2	3	2	3	2	2	3	0	0	4	2	6	2

(a) D = Daily.

Ontario, Canada – (Section 324)* "All cages and skips used for lowering or raising persons in a mine shall comply with the following:

[(1) – (5) Not applicable.]

(6) The safety catches and mechanism shall be of sufficient strength to hold the shaft conveyance with its maximum load at any point in the shaft and shall be of a type the design of which has been approved by the chief engineer.

Such safety catches and mechanism shall not be used until approved by the district electrical-mechanical engineer and such approval shall be based upon test performance.

Such approval shall not be considered until the safety catches and mechanism are found to function satisfactorily under load conditions during such number of tests as are required by the chief engineer, each test to consist of suddenly releasing the shaft conveyance in a suitable manner under maximum loading conditions for persons so that the safety catches will have the opportunity to grip the guides when the conveyance is descending at maximum rated speed.

A report of such tests shall be submitted to the chief engineer.

* See Appendix D, Item 48.

Ontario, (Continued) – (7) Before a shaft conveyance equipped with an approved type of safety catches and mechanism is first used for the purpose of lowering and raising persons, the safety catches and mechanism shall be found to function efficiently according to the requirements of the district electrical-mechanical engineer during a test under the same conditions as set out in Paragraph 6, and a permit for the use of the conveyance for lowering and raising men shall be obtained from the district mining engineer.

(8) A notation of such test shall be entered in the Hoisting Machinery Record Book and two copies of the report shall be sent to the district electrical-mechanical engineer.

(9) A shaft conveyance previously permitted for use by the district mining engineer for the purpose of lowering or hoisting persons on which alterations or repairs to the safety catch mechanism necessary to rectify any distortion of the mechanism from its proven satisfactory position are made shall not be put to such use until the safety catch and mechanism have been found to function efficiently according to the requirements of the district electrical-mechanical engineer during a test made under the same conditions as set out in Paragraph 6, and the district mining engineer has again issued permission for the use of the conveyance for such purpose.

(10) A notation of such test shall be entered in the Hoisting Machinery Record Book and two copies of the report shall be sent to the district electrical-mechanical engineer.

(11) A certificate of load capacity of the conveyance and attachments, which shall include the weight of the tail rope, if any, or other suspended load, shall be obtained from the manufacturer and made available to the district electrical-mechanical engineer."

(Section 361) (1) "The [mine] manager shall depute a competent person or persons who shall examine...

(d) at least once in each day, the safety catches, if any, of the conveyance, to be sure they are clean, sharp and in proper adjustment and working condition;

(e) at least once in every three months, the safety catches of the cage or other shaft conveyance so equipped by testing the same, such test to consist of releasing the empty conveyance suddenly in some suitable manner from rest so that the safety catches have the opportunity to grip the guides, and, in case the safety catches do not act satisfactorily, the cage or other shaft conveyance shall not be used further

Ontario – (Continued)

for lowering or raising men until the safety catches have been repaired and have been proved to act satisfactorily, as referred to in Paragraph 9 of Section 324.

(4) If the district electrical-mechanical engineer deems it necessary, he may, after consultation with the manager, conduct or cause to be conducted specific tests of the safety catches with which a conveyance is equipped."

Ontario regulations for arrestment devices are considerably more definitive and demanding than any others. The requirements for device approval, intitial testing, and periodic testing are explicitly defined. The required reports of the initial free-fall tests are very thorough (see Figure 21), giving the Department of Mines sufficient data to make a reasonable assessment of device performance. Though not specified by law, Ontario restricts conveyance deceleration to between 1-3 g (for vertical shafts). The exact value permitted depends upon the range of conveyance loading as a function of conveyance weight.

Although Britain does not require arrestment devices for man-haulage in vertical shafts, the personal recommendations of engineers of the National Coal Board, Haulage and Transport Section, are as follows for inclined shafts:

Gradient	Braking System Recommendations
Up to 1 in 200	Manual wheel brakes optional
1 in 200 to 1 in 20	Manual wheel brakes required
1 in 20 to 1 in 5	Overspeed track brakes required – conventional linings
1 in 5 to 1 in 3	Overspeed track brakes required – neoprene linings, chevron grooved
Above 1 in 3	Special braking systems required

DISCUSSION

The foreign regulations studied well illustrate the major positions taken in the safety-catch debate. One position maintains that arrestment devices are unnecessary, if not detrimental to safe practice. This stance is taken by proponents of the "good rope theory", which holds that the safest hoisting can be assured by an intensive program of hoist-rope maintenance and inspection. Great Britain and the Republic of South Africa generally subscribe to this theory. The other position, taken by Australia, Austria, and Ontario, for example, asserts that good hoisting-rope practice notwithstanding, conveyance arrestment devices are necessary, and, being necessary, their use and associated practices should be well regulated.

Before 1957, West Germany required conveyance arrestment devices. They were checked daily and statically tested (an actuation test) weekly. The actuation springs were removed and tested yearly. In 1957, the requirement was deleted on the basis of

a study by E. Panitz[19] and the observations of other mining authorities. Panitz's study showed that despite the presence of arrestment devices, between 1901 and 1926, 109 persons died but only 12 were saved through the intervention of a safety device. From 1927 to 1954, 89 died and one was saved. The study also showed an increase in the ratio of accidental actuations to actuations in cases of real emergencies: from 1901 to 1920, the ratio was 0.7; from 1920 to 1930, it climbed to 1.00; from 1930 to 1954, the ratio climbed as high as 2.00.

In 1946, about a year after Ontario's Paymaster accident (16 killed), 45 died at Peine, West Germany, as a result of the failure of the fitting connecting the hoist rope to the conveyance. The conveyance was equipped with safety catches, but they became clogged with wood chips and failed to stop the falling cage. Despite the results of Ontario's work with safety catches for wooden guides, West Germany removed all requirements for arrestment devices in 1957.

Wire-rope guides are used extensively in Europe. As stated, Battelle knows of no arrestment devices proved on wire-rope guides. There is also a trend toward steel guides for which, again, a proved device appears lacking. Increased use of multirope hoists (Koepe friction hoists) in Europe may also be a factor against the use of arrestment devices. The theory is that the greater the number of hoist ropes, the less likely a complete loss of connection. As stated, however, hoisting accidents very often do not result from hoist-rope failures, but from loss of hoisting control.

EVALUATION OF CURRENT U. S. FEDERAL REQUIREMENTS

DISCUSSION AND CONCLUSIONS

As stated in the Introduction, current Federal regulations require that "Cages, 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 such catches shall be tested at least every two months".

This study found that almost 92 percent of the vertical-shaft wood-guided coal-mine man conveyances are equipped with arrestment devices that have been proved to be highly unreliable. It was further found that wood-guided vertical-shaft man conveyances represented 80 percent of all the vertical-shaft coal-mine hoists inspected. The majority of coal-mine operators interviewed have little confidence in their arrestment devices, whether in vertical or inclined shafts, and generally are looking for specific guidance. The manufacturers also generally recognize the shortcomings of their products and are also looking for specific guidance.

The manufacturers say they will make what the miners will buy, and the miners generally say they will buy what the manufacturers will make. Neither is willing or able to take the lead, and it does not appear that a joint effort is forthcoming. Neither can turn to the states because state regulatory officials are too often unaware of the problems with arrestment devices. State laws provide no specific guidance either.

Federal law is definitely no help, being more general than all state laws, and qualified agency personnel have apparently never been found or never given the proper authority.

Previous chapters have shown that a reliable safety catch for wooden guides in vertical shafts exists and is used widely in Ontario where it was developed and on two U. S. coal-mine man-hoists. Where generally unproved devices exist for use with steel guides and wire-rope guides, the means to prove and improve them – testing – also exists. Arrestment devices for use in inclined shafts exist and are occasionally used although, again, their performance in an emergency is unknown because no one tests them under simulated emergency conditions.

The first objective of this study was to determine whether present Federal regulations regarding safety catches are adequate and consistent with the current technological trends in hoisting engineering.

It seems quite clear that the intent of the Federal safety-catch regulations has not been realized. Battelle concludes that the current Federal approach to regulating safety catches should be modified to reflect present technological capability, to promote its use, and to provide a base for advancing hoisting technology.

Further, the most expedient route to improving the capabilities and reliability of conveyance arrestment devices in coal and noncoal mines would be to define design, performance, inspection, and testing criteria in as much detail as current technology permits, without limiting engineering solutions or the application of technology from other fields, while providing for the advancement of arrestment-device technology. It is suggested that these requirements could be more easily modified with experience were there a set of specifications referred to by law.

CHAPTER 6

RECOMMENDATIONS

To promote the use of current arrestment-device technology and to provide for its advancement, it is recommended that the following topics and the ideas expressed for each be incorporated into Federal coal-mining safety regulations, or into a Bureau of Mines specification that by law governs arrestment-device application and use.

APPLICATION CRITERIA FOR ARRESTMENT DEVICES

Arrestment devices must be installed on all wire-rope-hauled conveyances used to transport men in vertical or inclined shafts, and to all shaft-sinking conveyances below which men work.

Exception for consideration:

> Man hoists designated strictly for emergency use for which a comprehensive inspection and maintenance program is established and applied.*

ARRESTMENT-DEVICE DESIGN AND PERFORMANCE CRITERIA

ACTUATION CRITERIA

The arrestment device must actuate

(1) Most desirably, as a result of conveyance overspeed at a speed not greater than 1.25 times the rated maximum hoisting speed and not less than that speed for which the hoist drive overspeed controller is actuated, or

* Since the passage of the 1969 Coal Mine Health and Safety Act, considerable attention is being given to specialized lifesaving equipment for underground emergencies. Included are atypical man hoists for use in air shafts or emergency escape shafts. Some of these emergency man hoists are designed without conveyance guides because guides could be destroyed, making the hoist unusable. Since all known conveyance arrestment devices brake against some kind of guide or stationary member within the shaft, none are usable with these guideless emergency man hoists. Recommending that these hoists be exempt from arrestment devices is not based solely upon the fact that no arrestment devices are currently applicable. The basic reason is that they will probably operate under much different conditions from conventional hoists. Different operating conditions can lead to different design approaches. To require that emergency hoists be governed by the criteria applied to regular hoists is to risk negating valuable and innovative solutions. Further, since these hoists will sit inoperative most of the time, they will require different inspection, testing, and maintenance procedures. Because of this, and because they are relatively new, it is recommended that they not be required to have conveyance arrestment devices at this time. Further, it is recommended that the Bureau of Mines proceed carefully with respect to other current hoisting criteria for this type of hoist until sufficient experience is gained to determine the best criteria.

(2) As a result of a broken hoist rope or other loss of connection between the conveyance and its prime mover or between the conveyance and its counterweight or another conveyance, and

(3) Manually, but only in the case of single, uncounterbalanced conveyances operating in a shaft not shared with other wire-rope-hauled conveyances unless a capability also exists for simultaneously shutting down the hoist from the conveyance.

The arrestment device must not actuate:

As a result of hoist-rope tension or conveyance speed changes resulting from the dynamic behavior of the rope-conveyance system (spring-mass system) during normal hoist operation.

PERFORMANCE CRITERIA

(1) The arrestment device must be capable of stopping the conveyance from the rated maximum hoisting speed without subjecting any man to

(a) An average vertical deceleration greater than 3 g for vertical-shaft conveyances,

(b) An average horizontal component of deceleration greater than 0.45 g for inclined-shaft conveyances,

whether the conveyance is carrying its rated man load or only one man.

In addition to the above limits for maximum deceleration, the device must develop at least

(a) An average vertical deceleration of 1 g for vertical-shaft conveyances,

(b) An average horizontal component of deceleration of 0.15 g for inclined-shaft conveyances.

(2) Having stopped a conveyance under any load up to and including the rated man-load, the arrestment device must be capable of indefinitely holding the conveyance where stopped. Where this capability cannot be assured, additional mechanisms must be provided that can at least be actuated manually.

(3) If the conveyance arrestment device and/or additional holding mechanisms are provided with a manual, variable release capability, the components providing this capability must be designed such that in no case can they prevent the arrestment

device from developing its maximum braking force when actuated in accord with the previously defined criteria.

(4) The arrestment device must be designed

(a) Most desirably to compensate automatically and fully for wear of conveyance guides where these guides are used for braking,

(b) Or to compensate automatically for such wear up to the point where, without compensation, the wear would reduce the developed braking effort by 25 percent.

CONVEYANCE AND ARRESTMENT-DEVICE STRUCTURAL DESIGN CRITERIA

(1) The conveyance and its arrestment device must be designed to withstand a load at least 2.5 times the maximum total load anticipated to be developed in stopping the conveyance from its rated maximum hoisting speed when it is loaded to its rated man capacity.

(2) Arrestment devices should be protected as much as possible against damage or fouling of components by such items as rocks or tools. If this is done with protective shielding, such shielding should be readily removable or openable to permit inspection and maintenance of the shielded components.

(3) The conveyance should be designed to minimize possibilities for human injury from structural components during any stop. Furthermore, conveyances, particularly for inclined shafts, should be designed or equipped to prevent men from being thrown out or off during any stop.

(4) It is suggested that in addition to the above structural design criteria, an additional criterion be written in the usual manner covering such requirements as good workmanship, suitable materials, and choice of a design that is simple and rugged and requires a minimum of maintenance.

ARRESTMENT-DEVICE TESTING AND INSPECTION CRITERIA

(1) To qualify for use in man hoisting, a conveyance and its arrestment device must be tested after initial installation in the shaft where it is to be used, to determine the ability of the arrestment device

to perform in accord with the actuation and performance criteria given above when the conveyance is ballasted to its rated man capacity. No conveyance may be used for man hoisting until its arrestment device has demonstrated its ability to perform in accord with the above-recommended criteria. (The free-fall test procedures in Chapter 3 provide a guide for conducting this test, even though they are written specifically for vertical shafts and devices actuating as a result of a broken rope.) This qualification test must be witnessed by a Federal inspector or his authorized representative. A permit or certificate of acceptance should be issued to the operator by the Bureau of Mines after successful completion of the qualification test. It should be displayed at or near the topside conveyance loading station.

(2) After initially qualifying for use in accord with Step (1), the conveyance and its arrestment device must be requalified for use every 5 years or when directed, in accord with Step (1).

(3) The conveyance and its arrestment device must be dynamically tested in accord with Drop Test Method 2 or by some equivalent method* with the conveyance ballasted to its rated man capacity at the time of the qualification test (Step (1)) and once every 3 months thereafter or when directed. If the trimonthly test results show an increase or decrease in stopping distance greater than 50 percent of that obtained from this test at the time of the qualification tests, the conveyance must be withdrawn from man-hoisting service until the source of the excessive variation has been determined and remedial action taken.

(4) With the conveyance chaired or otherwise prevented from moving, the arrestment device must be actuated daily to determine whether the actuation mechanism can bring the braking elements into contact with whatever they are designed to brake against. If not, the conveyance must be withdrawn from man-hoisting service until the source of difficulty has been determined and remedial action taken.

(5) The conveyance and its arrestment device must be dynamically tested as in Step (3) following any in-service actuation before man hoisting resumes. The results of this test are to be evaluated as if they were the results of the trimonthly dynamic tests of Step (3).

(6) If a conveyance used for man hoisting is out of service for more than 6 months or is transferred to a different shaft, or if modifications, major repairs, or replacement of major components of the arrestment device are made that could affect the strength of components or the overall performance of the device, the

* Experience may show that it is equally or more convenient to dynamically test some arrestment devices according to the free-fall test procedures recommended for Step (1) (or an equivalent method). Where this is the case, much is gained, for the qualification test is the better indicator of the maximum capability of an arrestment device.

conveyance (and arrestment device) must be regarded as newly installed and qualified for use according to Step (1).

(7) If a conveyance used for man hoisting is out of service for more than 1 month, it must be dynamically tested in accord with Step (3) before being put back into man-hoisting service.

(8) Where arrestment devices are spring actuated and/or applied, a load-deflection curve for the spring(s) noting amount of deflection in the ready-to-actuate position must be supplied by the arrestment-device manufacturer at the time of delivery. At the time of re-qualification of the conveyance and its arrestment device (every 5 years), but before actual testing, the actuator spring(s) must be removed and a new load-deflection curve established. If the load to compress the spring(s) to the ready-to-actuate position is less than 75 percent of the load originally necessary for this degree of compression, the spring must be replaced.

(9) The components of the conveyance and its arrestment device must be visually but thoroughly inspected for damage and deterioration at the time of the trimonthly dynamic tests (before the tests are made) and after any in-service actuation. The condition of all moving parts, particularly pinned connections and bearings, should be noted. Similarly, the condition of the braking element, particularly any cutting edges, should be noted.

(10) The arrestment device should be completely disassembled and inspected every 5 years before requalification testing, noting damage and degree of deterioration as in Step (9). Parts should be replaced when reliability is doubtful. Before reassembly, all components should be cleaned and greased and repainted where appropriate.

(11) Detailed records of all dynamic and static actuation tests must be made. One copy must be available at or near the hoist and one copy must be sent to the appropriate Bureau of Mines Office.

(12) Detailed records of all inspections must be made and copies distributed as in Step (11). Recommendations for record forms are presented in Appendix F.

EXCEPTION FOR CONSIDERATION

It is recommended that elevators designed, built, installed, maintained, and tested in accord with ANSI (American National Standards Institute) A17.1 and A17.2 be exempt from the foregoing design, performance, testing, and inspection criteria.

HOIST-SYSTEM CONSIDERATIONS

The conveyance and its arrestment device represents only one portion of the hoist system. Because of this, safe hoisting of men cannot realistically be solely delegated to the arrestment device. There are aspects of conveyance control that cannot be accommodated by current arrestment-device technology. It is even questionable whether they ever should be, using overtravel-overwind and underwind as examples.

With this in mind, the following topics and associated ideas are recommended for serious consideration.

HOIST-BRAKE PERFORMANCE CRITERIA

If deceleration limits for arrestment devices are to be considered to prevent human injury and equipment damage, then logic requires that the maximum forces developed by hoist brakes be limited for the same reasons. It is recommended that a hoist-brake performance criterion be adopted for hoists used to transport men. Where men only are hoisted, the deceleration limits recommended for arrestment-device performance would be logically sufficient for hoist-brake performance.

If the hoist is also used to transport supplies and equipment, this performance criterion may lead to stopping problems when heavy equipment or supply loads are being hoisted. The facts of this case have not been determined, since the topic is beyond the program scope. However, hoist-brake performance for this case is critical to hoisting safety and should be studied.

HOIST-CONTROL-COMPONENT ACTUATION TEST

It is recommended that

(1) All hoist safety-control features, such as overspeed, overwind, underwind, slack rope, loss-of-power shutdown, hoist-brake deadman control, and clutch-brake interlocks, must be actuated weekly. If any fail to function and the hoist is used to transport men, man hoisting must cease until remedial action is taken.

(2) Records of the above actuation tests must be kept at or near the hoist and made available to Bureau of Mines inspectors or their representatives.

ABNORMAL HOISTING INCIDENT REPORT

It is recommended that any accident or abnormal incident that occurs during hoisting operations on hoists or elevators used to transport men – particularly those that involve arrestment-device actuation – be described in a report noting in detail the sequence of events, cause(s), results, and performance of safety controllers, including conveyance arrestment devices. One copy of this report should be kept at or near the hoist and one forwarded to the designated Bureau of Mines Office.

ADDITIONAL HOIST-CONTROL FEATURES

It is strongly recommended that the Bureau of Mines encourage the development, use, and, eventually, the requirement for

(1) A capability for manually shutting down the hoist (motor off, brakes on) from conveyances used to haul men, regardless of what other safety features and mechanisms be installed.

The technology needed to achieve this exists – electrical transmission of signals along the hoist rope, for example, is a demonstrated fact.

(2) A capability for automatic shutdown of the hoist in the event of a loss of conveyance speed- and position-control signals while the hoist is running.

These signals, usually obtained by monitoring drum or friction drivewheel motion, are used by hoist overspeed and overtravel controllers. Typically, loss of these signals means complete loss of the overspeed and overtravel protection features. This capability should be readily achievable with automatically and manually controlled hoists using off-the-shelf components.

Current arrestment-device and hoist-control technologies are at least theoretically capable of protecting the conveyance in almost every kind of abnormal situation. However, an obstacle in the shaft cannot now even be theoretically accommodated by this technology. A very possible obstacle in a two-compartment shaft (and one that has led to disastrous results) is the hoist rope from the adjacent compartment when a descending conveyance jams in the guides. Thus, as a relatively long-range goal, it seems highly desirable to encourage the development and use of a capability for automatic shutdown of the hoist if a conveyance approaches a shaft obstacle.

ARRESTMENT-DEVICE TEST AND EVALUATION FACILITY

It is recommended that the Bureau of Mines consider constructing a facility for testing arrestment devices under speed, load, and guide conditions typical of those the

devices may meet in service. This facility and its tests would not supplant the tests recommended earlier, but would provide manufacturers an opportunity for testing and evaluating arrestment devices being developed or modified. It could also be used in establishing braking-element design data for various types of guides. Such a facility could be quite simple and need not duplicate actual shaft dimensions and configurations.

FIELD APPLICATION OF ARRESTMENT DEVICES

Only two conveyance arrestment-device systems can be recommended on the basis of their proved ability to perform: the elevator wedge-clamp safety (Type B) actuated by an overspeed governor acting on steel T-rail guides, and Ontario-type single-tooth dogs actuated by compression springs released by a loss of hoist-rope tension and acting on wood guides. The elevator devices conform to ANSI design and performance specifications which, though somewhat different from those recommended in this report, are an acceptable alternative for elevators. The Ontario-type single-tooth dogs can perform as recommended earlier.

Other arrestment devices that appear to warrant consideration are magnetic track brakes and auxiliary rope devices. Though their exact performance capabilities are as yet unknown, they seem to offer possible solutions to needs not easily met by elevator or single-tooth broken-rope devices.

Any arrestment device currently in use that can meet the recommended design and performance criteria could, of course, be used. The reader is reminded, however, that the multitoothed cams, dogs, and wedges in use on many wood-guided vertical-shaft hoists have already been proved highly unreliable. Arrestment devices in use in coal-mine inclined shafts are essentially unproved; testing is required to determine which are satisfactory or what modifications are necessary to achieve good performance.

It should also be remembered that any combination of proved devices or components that can perform as recommended is also a good solution. For example, Ontario type single-tooth dogs and a wood guide or two could be applied to inclined shafts. Likewise, the magnetic track brake systems found in inclined shafts, if proved, may have application to vertical-shaft steel-guided conveyances.

In general, the requirements for an arrestment device will probably not be met by "stock" equipment. Many installations will require custom engineering and some equipment may have to be replaced or modified. Much will depend upon how far all persons involved are willing or able to go. For example, no inclined-shaft hoist seen precludes applying a good conveyance arrestment device. But all are flanged-wheel T-rail-guided and, hence, still prone to derailment. There are stock inclined-shaft guidance systems that are antiderailing; in many cases it should be possible to engineer modifications to existing rail systems to reduce the chances of derailment.

BIBLIOGRAPHY

TEST PROCEDURES

(1) Baker, T. J., "Free-Fall Testing of Mine Hoisting Conveyances in Ontario", Department of Mines and Northern Affairs, Ontario (May, 1963).

This extension of a paper first published in 1958 presents arrestment-device test procedures for use at Ontario Mines. Ontario law calls for free-fall testing of new conveyances and drop testing at 3-month intervals. The paper provides a step-by-step plan for testing acceptable to the Department of Mines. It discusses significant test parameters and how they can affect test results. A report is included indicating the extent to which test data are recorded. The paper concludes with a discussion of device design considerations and current equipment trends.

(2) Hicks, H. Brodie, "Safety and Welfare – Test Those Dogs!", Canadian Mining Journal, pp 790-791 (November, 1945).

Hicks comments on the impetus supplied by a hoisting tragedy to the improvement of designs and testing techniques. Commenting on investigations conducted after the 1945 Paymaster accident, the paper notes that previous arrestment-device designs and test criteria were faulty. "More severe tests have now shown that this standard method (a drop test) is inadequate and fails to show up defects of major importance under operating conditions."

(3) Walker, W. D., Jr., and Stahl, R. W., "Recommended Procedures for Mine Hoist and Shaft Installation, Inspection, and Maintenance", United States Department of the Interior, Bureau of Mines, Information Circular 8031, 16 pp (1961).

Safety-catch use is recommended for man-carrying conveyances "if at all possible". Daily actuation to assure proper functioning and bimonthly drop tests to assure continued stopping capability are recommended.

(4) "Safety Catches on Mine Cages and Methods of Testing Them", United States Department of the Interior, Bureau of Mines Information Circular 7436 (February, 1948).

This paper reviews arrestment-device practice in the United States drawing heavily from the results of Ontario studies. It concludes that as of 1948 methods used for testing mine-cage safety catches were not realistic because they did not approach the limits of normal operation.

(5) "Testing Safety Catches on Mine Cages at Some Eastern Bituminous Coal Mines", United States Department of the Interior, Bureau of Mines, Information Circular 7290 (1944).

(6) "Testing Safety Catches on Mine Cages, Lake Superior District", United States Department of the Interior, Bureau of Mines, Information Circular 7325.

These two papers detail devices and test equipment used in two U. S. mining regions. Descriptions of equipment from 24 mines are included. Observations are noteworthy

since they were written before the general availability of data on the Ontario Paymaster accident. For example, "when safety catches are tested with an empty cage, the success of the test can give a false sense of security as to the effectiveness of the safety catches" (5), or "drop tests, as conducted, are believed to be adequate and sufficient to insure the proper functioning of the safety catches in an emergency" (6).

TEST DATA

(7) Baker, T. J., "Hoisting Safety in Ontario Mines", with reference to The Mining Amendment Act, 1970, Ontario Department of Mines and Northern Affairs, Kirkland Lake, Ontario (April, 1971).

Baker reviews hoisting safety in Ontario and presents some of the factors that can cause a need for arrestment-device actuation.

(8) Blellock, J. D., "Man Riding Underground with Particular Reference to the Weetslade Colliery Installation", The Mining Electrical and Mechanical Engineer, pp 275-286 (May, 1964).

A subheading, "Retardations", provides some information on suitable rates of deceleration for inclined-shaft arrestment devices. It reports that retardations of man-carrying conveyances on shallow inclines should be on the order of 4 to 6 ft/sec^2 since this has been found to cause no undue discomfort to persons facing forward or backward.

(9) Stothart, A.B.C., "Mine Conveyance Safety Dogs", The Canadian Mining and Metallurgical Bulletin, pp 675-677 (December, 1950).

Stothart discusses progress in arrestment-device performance since the Paymaster accident of 1945, noting the improvement in free-fall test results from 1945 to 1948.

(10) "Investigations Regarding the Safety of Hoisting Equipment and Hoisting Practice in Ontario Mines", Ontario Department of Mines Bulletin 138, including Appendix II (1947).

(11) "Investigations Regarding the Safety of Hoisting Practice in Ontario Mines", Ontario Department of Mines Bulletin 138A (1949).

These two reports are the product of a most exhaustive investigation of a mine hoisting accident. Safety catches at mines throughout Ontario were uniformly tested and found to be seriously deficient; test results are found in these reports. The final report (11) relates that device design improvements effected in Ontario after the Paymaster accident of 1945 greatly improved device performance and reliability.

DESIGN DATA

(12) Cooper, L. O., "Slow Braking of Mine Hoists", The Engineering Journal, Montreal, pp 15-17 (January, 1952).

Cooper derives a relationship for the onset of inadvertent dogging resulting from rapid stopping of the hoist. The equation, which ignores frictional damping, says the stopping time must be limited as follows:

$$T > \frac{2u}{g} \cdot \frac{W_c + \frac{W_r}{2}}{W_c - S} ,$$

where

T = stopping time of hoist, sec

u = maximum hoisting speed, ft/sec

W_c = weight of cage, lb

W_r = maximum weight of rope, lb

S = safety dog spring tension, lb.

For example, for an 800-ft shaft, conveyance maximum speed of 1500 ft/min, 1-1/8-in.-diameter fiber core rope (2.13 lb/ft), 8750 lb cage weight, and 3000 lb spring tension, the stopping time must be greater than 2.6 seconds. Considering damping, the time could be somewhat shorter. The equation can also be inverted to determine spring sizes for an existing system response.

(13) Cooper, L. O., "Some Notes on the Design of Safety Dogs", Canadian Mining and Metallurgical Bulletin, Montreal, October, 1948, also in Transactions of the Canadian Institute of Mining and Metallurgy, Volume 51, p 252 (1948).

(14) Kilborn, R. K., "Improved Cage Safety Catch Developed at Canadian Mine", Engineering and Mining Journal, pp 68-70 (March, 1947).

(15) Lancaster, A. W., "Mine Cage Safety Dog with Predictable Deceleration", Canadian Mining Journal (November, 1946).

Cooper, Kilborn, and Lancaster discuss the effects of various guide materials and tooth shapes. They introduce a technique for determining the forces required to move a single-tooth dog along a guide, permitting the prediction of device performance as a function of tooth size.

(16) Corey, E. D., "Safety Aspects of the Koepe Hoist", 1958 National Safety Congress, Mining Industry, pp 31-33.

Corey explains the basic features of a Koepe hoist system. Jammed conveyances upset the required force relationship across the friction wheel, causing slipping of the rope. Well designed hoists are equipped with relays or switches to shut off the

hoist motor in the event of rope slippage. Tapered guides are recommended at each end of the shaft to decelerate the conveyance in the event of overtravel. Safety dogs are recommended, though the likelihood of rope or linkage failure might seem remote.

(17) Crook, A. E., "Safety Aspects of Winding Apparatus in Mines", Presented at the Thirty-Ninth National Safety Congress and Exposition of the National Safety Council, Chicago, Illinois (October 8-12, 1951).

Crook reports on safety-catch practice in several countries, but feels that existing designs are not satisfactory for application in Britain. The British have long placed emphasis on proper hoist and rope maintenance as a substitute for arrestment-device use. They do, however, use safety appliances at the headframe to catch the conveyance in the event of overwinds.

(18) McKnight, W. V., "Testing Gravity-Operated Mine Hoist Braking Systems", The Canadian Mining and Metallurgical Bulletin (June, 1966).

McKnight presents data supporting Cooper's contention (12) that hoist deceleration rates should be limited. Emergency deceleration data presented indicate that dogging would probably occur during most hoist emergency stops. Since this paper was printed, a directive of Ontario's Chief Engineer of Mines now limits the deceleration rate, measured at the conveyance, to

(a) "16 feet per second per second, or

(b) the retarding-rate produced by gravity plus an acceptable proportion of the brake effort available to the drum or drums in motion."

The deceleration rate limitations need not apply wherever the hoist-rope velocity is less than 5 ft/sec.

(19) Panitz, E., "Die Zweickmassegkeit der Fangvorriehtungen bei der Seilfahrt (Evaluation of Safety Catch for Men Hoisting)", Gluckhauf, pp 969-972 (August, 1957).

(20) Smith, W., "Operating Ideas, Pneumatic Guides Provide Smoother Skip Travel", Engineering and Mining Journal, 147, 4, pp 106-107 (April, 1946).

Smith reports that replacing skid-type guide shoes with pneumatic tires reduces maintenance costs and results in smoother overall hoisting operation. The decreased guide wear and the lower friction achieved should also enhance arrestment-device performance by reducing conveyance bounce tendencies.

(21) Staley, W. Westley, Mine Plant Design, McGraw Hill (1949).

Staley provides the only known textbook approach to arrestment-device design. Deriving much of his data from the Paymaster studies, he presents techniques for designing safety dogs with predictable deceleration chiefly based on Lancaster's (15) idea. Though this chapter on safety-catch design is the most complete known, it is misleading, including incorrect statements and unclear data that can be misunderstood. For example, a calculation presented for

deriving dog-shaft diameters is valid only for dogs that impart no torsion to the shaft. Cam-type dogs with linkage stops would impart torsion to the shaft and the calculations would be meaningless. Comments on acceptable guide-wear and trailing-rope effects are not well founded.

(22) Details of Practical Mining, Chapter 9: "Cages", McGraw-Hill Book Company, Inc. (1916).

This book correctly identifies an important arrestment-device consideration still often overlooked, namely, that arrestment devices should apply a gradual braking action not provided by typical multitoothed-cam devices. The writer urges against use of such devices since they "act so quickly as to tend to injure the men riding on the cage and to tear out the guides. It is also likely to fill with wood and possibly thus become inoperative".

(23) Mining Engineers' Handbook, Edited by Robert Peele, Third Edition, John C. Wiley and Sons, Inc., New York (1941), "Hoisting Plant, Shaft Pockets and Ore Bins" (W. M. Weigel).

This handbook includes some general comments on safety catches for vertical shafts in the section on "Cage Details". Most of the equipment shown, though still used in the coal industry, is outmoded and their arrestment devices have been proved ineffective. The safety-catch philosophy presented is also outmoded. For example, it states that, "if (the) cage is descending (at the time of actuation) the shock is great; and if moving rapidly it is doubtful whether any safety device could hold, because momentum of cage and load would either break the safety gear, or strip guides from the shaft timbers". The "shock" developed which results in the subsequent breakage of the safety gear is a function of the device's design and can be reduced to an acceptable level. The handbook also indicates that the force stored in the mechanical springs for activating the safety catches should be from 0.33 W for small cages to 0.10 W for large cages, where W is the empty cage weight. The purpose of the spring, however, is dual in that to actuate the device it must also accelerate the trailing rope. The mass of the trailing rope will increase with cage size and with the trailing length and, therefore, the size of force necessary for suitable operation also increases with cage size and possible trailing length. In general, it is desirable to store as large a force as possible consistent with the rates of conveyance acceleration so that the conveyance does not bounce on the spring during normal operation, resulting in inadvertent dogging. This is usually possible with spring force ratios of 0.33 to 0.5. No useful information is included for application to inclined-shaft operations.

EQUIPMENT

(24) Blellock, J. D., "New Developments in Man Riding Underground", The Mining Electrical and Mechanical Engineer, pp 311-315, date unknown.

(25) Blellock, J. D., "Some Aspects of Underground Haulage and Transport", The Mining Electrical and Mechanical Engineer, pp 179-186, 199-211 (September, 1968).

Mr. Blellock provides a review and analysis of five man-carrying systems used in Europe. Reference (24) compares the Hunt-Rider, Ski-Lift, Brently Monorail, Becorit Monorail, and Coolie Car with respect to important system parameters. Reference (25) provides a follow-up to the previous paper, giving additional information on the Coolie Car.

(26) Curth, Ernest A., "Causes and Prevention of Transportation Accidents in Bituminous Coal Mines", Bureau of Mines Information Circular 8506 (1971).

Curth comments on transportation safety at U. S. mines with some general observations on safety catches.

(27) Takaoka, S., Tatsuta, H., Shibata, Y., Kobayashi, H., "On the Development of Arresting Apparatus of Runaway in Winding Slope", Government Resources Research Institute Report – Mining and Safety, Volume 15, No. 10, in Japanese (1969).

Rail friction-type arrestment devices were studied for use in inclined shafts. A new rail-clamp device was developed and its performance analyzed. Of special interest is a table of test data for arrestments initiated during ascent and descent. Arrestments during ascent generated a 0.6 g maximum acceleration, while during descent caused a maximum of 2.7 g. The table also indicates how much time lag exists between detection and the development of initial arresting forces.

The rail-clamp device is very similar in effect to the wedge-clamp devices used in elevators, with the action of the rope governor being replaced by an air actuator powered by a conveyance-mounted air tank and controls.

(28) Troften, Einar, Reprint of publication for Chemistry, Mining, and Metallurgy, entitled, "Litt om personbefordring i sjakter" (in Norwegian), with translation (1956).

Troften discusses four types of safety devices for use in inclined shafts. Two are for slopes up to 25° and are similar to the "buck hook" in that the stopping force is developed by a raking effect against the rail ties. The devices are prevented from interfering with normal operation by hoist-rope tension. Another, for 25° to 50° slopes, applies clamping pressure to the rail web and also prevents derailing. However, the braking force relies upon gravity and decreases as the angle of inclination increases. The fourth, for 50° to 70° slopes, is similar.

(29) Mine Plant, Chapter 14, American Institute of Mining and Metallurgical Engineers (1938).

The chapter includes illustrations of many conveyances and arrestment devices used in U. S. mines.

(30) "Safety Device for Incline Skip", Canadian Mining Journal, Montreal, p 57 (January, 1963).

A new safety device for inclines to 40° has been invented and patented in South Africa. The device consists of two friction-pad brakes mounted on the conveyance that can act on the track rails when actuated by a conveyance-wheel-driven governor. It is not clear to what extent the device relies upon gravitational force or whether derailment would be possible, rendering the device useless.

ACCIDENT REPORTS

(31) Baker, T. J., "Report on Hoisting Accident", Delnite Mines, Limited, 3 pp (February 11, 1963).

Baker reports on a vertical-shaft accident at an Ontario mine. A skip-cage combination dogged while descending. The hoistman continued to lift the opposite conveyance while paying out slack rope to the top of the stopped conveyance. The upward-bound conveyance eventually snagged the rope, resulting in an unscheduled tumbling of its three occupants. No cause for the incident could be verified, though the possibility of a small piece of rock jamming the conveyance or human error seem likely factors.

(32) Baker, T. J., "Report on Hoisting Accident", McIntyre Porcupine Mines, Limited, 2 pp (June 27, 1963).

This report discusses a case in which the controls did not prevent an accident. Brake release prior to the application of power in the proper direction permitted the counterweight to fall.

(33) Baker, T. J., "Report on Hoisting Accident", Silverfields Mining, Limited – Alexandra (March 9, 1964).

A hoist shaft broke, dropping the drum out of position and permitting the cage with a car full of muck to fall to the shaft bottom. The drum fell to the base plate and there permitted the rope to unwind due to the weight of the loaded descending cage. The falling conveyance in this type of accident is not protected by the typical "broken-rope" safety.

(34) Bone, H. J., "Report of Hoisting Accident", Algom Uranium Mines, Limited – Nordic Mine, 4 pp (May 22, 1958).

A conveyance fell approximately 800 ft before arrestment took place during a free-fall test at an Ontario uranium mine. During the test, the conveyance-release mechanism failed, permitting the conveyance to continue its initial free fall. The conveyance and load, with a combined weight of 15, 900 lb, pierced the safety blocking at the collar at about 2, 850 ft/min. Due to vibration, the arrestment devices were eventually actuated about 35 ft above the loading pocket, the conveyance stopping in the water at the shaft bottom. Damage to the conveyance was minimal and the arrestment devices appeared undamaged. Had the devices actuated a few feet sooner, all conveyance damage would probably have been prevented.

(35) Cloete, J. M., Inspector of Machinery (Mines), "Report on the Run-Away Skip Accident in a Hoisting Shaft at the City Deep, Limited, Mine, Johannesburg, on 10th August, 1961", 7 pp.

A conveyance accident on a 36° inclined shaft is discussed. The South Africans, who emphasize wire-rope care as a desirable alternative to arrestment-devices, report that a defective brake caused by poor repair of a previous failure permitted the conveyance to travel out of control 2700 ft. During this period, all 16 occupants were thrown out of the conveyance and fatally injured.

(36) Lazurko, J. J., "Hoisting Incident", Dickenson Mines Limited, No. 2 Compartment (March 19, 1962).

Freezing weather caused an unusual accident at an Ontario mine. Rope lubricant that built up in the head-sheave groove because of extremely low temperatures caused the hoist rope to climb out of the groove. The slack created caused the safety catches to actuate, stopping the conveyance.

(37) Schultz, C. H., "Report of Multiple Fatal Hoisting Accident", U. S. Bureau of Mines Health and Safety Report, Metal and Nonmetal Mine Safety, Western District, Alameda, California, 4 pp (January 26, 1971).

A recent accident at a California limestone mine points out an important limitation of broken-rope safeties. A clutch component failure permitted the arrestment-device-equipped conveyance to fall. Tension in the hoist rope prevented the devices from actuating.

(38) Tenny, Roger L., "Report of Shaft-Hoisting Accident, Detroit Mine, International Salt Company, Inc., Detroit, Wayne County, Michigan", United States Department of the Interior, Bureau of Mines, District F (September 20, 1957).

Successful safety-catch operation occurred at a Detroit salt mine when the hoist rope broke on an ascending conveyance. The wedge-type broken-rope safeties actuated, safely stopping the conveyance carrying six men. No one was injured.

(39) Williams, Fred A., "Report of Transportation (Hoisting) Accident, Ireland Mine, Hanna Coal Company, Division of Consolidation Coal Company, Moundsville, Marshall County, West Virginia", 7 pp (July 29, 1964).

All six elevator ropes failed. The breaks in the corrosion-weakened ropes occurred during descent with one man aboard. The elevator safeties stopped the conveyance without injuring the passenger.

HISTORY OF ARRESTMENT DEVICES

(40) Ingallis, W. R.; Douglas, James; Finlay, J. R.; Channing, J. P.; and Hammond, John Hays, "Rules and Regulations for Metal Mines", Department of the Interior, Bureau of Mines Bulletin 75 (1915).

This bulletin required safety catches on conveyances for hoisting men and recommended drop testing once a month. It warned of problems inherent in the hoisting of men on slopes. Also noted are hoisting accidents from 1910 to 1913.

(41) Vaughan, J. A. (Chief Inspector of Machinery, Mines Department, Union of South Africa), "Safety Catches for Mine Cages", printed about 1912, 19 pp.

Vaughan writes to correct any misunderstandings that might have resulted from the report of the Transvaal Rope and Safety Catch Commission of 1907 of which he was a member. He reports that the "Undeutsch" device tested by the Commission completed all tests successfully, a fact obscured by the conclusions of

the official report. It is worth noting that the Ontario-type dog device, evolved from extensive and costly test work started in 1945, includes the basic features of the Undeutsch device, which are

(a) Actuation by loss of rope tension

(b) Dissipation of kinetic energy by a cutting action on wood

(c) Cage motion during a fall supplements spring action, causing the dogs to penetrate the wood guides

(d) Fixed limit of tooth penetration

(e) Deceleration derived independent of cage velocity.

(42) Wire Rope In Mines, Proceedings of a 1950 Conference of the Institution of Mining and Metallurgy, 828 pp (1951).

This book includes much historical data on safety-catch practices throughout the world and provides insight into many important problems of satisfactory performance. As was the case with the Transvaal Commission report, the conclusions and recommendations for device use recorded on page 798 cannot be supported by the arguments presented earlier in the book:

> "It was clear from the experience and accidents, such as those which occurred at Peine and Paymaster, that arresting devices are not reliable on rigid wooden guides....Although there has been long experience, the construction of a reliable device for rigid guides is not possible by the employment of any present known methods."

These conclusions completely ignore the evidence of existing effective arrestment devices presented by W. O. Tower, Chief Inspector of Mines in Ontario, reported on page 660.

GENERAL

(43) Bellairs, G. ff., and Gericke, M. R., "A Telemetering Instrument for the Measurement of Acceleration and Deceleration of Mine Hoists", The Transactions of the South African Institute of Electrical Engineers, pp 149-183 (June, 1953).

This paper describes an instrument developed in South Africa that measures the apparent change of gravitational forces inside the conveyance in a mine shaft and transmits these quantities electrically along the winding rope to be recorded at the surface.

(44) Craib, S., "Winding From Deep Levels in South Africa", Paper No. D2 presented at the Fourth International Mining Congress 1965, 10 pp (1965).

(45) Gyngell, A. H., "Hoisting Equipment and Shaft Design in Deep-Level South African Gold Mines", The Canadian Mining and Metallurgical Bulletin, 15-25 (January, 1968).

(46) Martin, W., "Shaft Design and Hoisting Equipment for a Deep-Level South African Gold Mine", The Canadian Mining and Metallurgical Bulletin, 26-37 (January, 1968).

Craib, Gyngell, and Martin report on hoisting practice and equipment in South African mines. The papers are of interest because they indicate the hoisting practice in a country that does not require the use of safety catches on man cars.

(47) Ellis, O. W., "Final Report of the Subcommittee on Wire Rope", Ontario Research Foundation, 91 pages plus illustrations (April 2, 1956).

(48) Goldman, D. E., and Von Gierke, H. E., "The Effects of Shock and Vibration on Man", Lecture and Review Series 60-3, U. S. Naval Medical Research Institute, Bethesda, Maryland (1960).

(49) Hendry, W., "Non-Fatal Hoisting Accidents in Ontario Mines 1965-69", Department of Mines, Ontario, Canada, 20 pp.

Hendry presents a clear picture of the extent to which hoisting accidents in Ontario are reported and the information appropriately compiled. His paper identifies five groups of accidents as follows:

(a) Accidents resulting from cage tending errors

(b) Accidents resulting from hoistmen's errors

(c) Accidents resulting from maintenance personnel errors

(d) Accidents resulting from faulty equipment and maintenance

(e) Accidents in which the primary cause is undetermined.

At the end of 1962, there were 166 active shafts serviced by 210 hoists in Ontario. During the 5-year period from 1958 to 1962, there were 15 fatal and 270 nonfatal accidents; in the 5-year period from 1965-1969, there were 15 fatal and 299 nonfatal accidents. This paper is one of the few available that provide a thorough coverage of hoisting incidents in a particular region.

(50) Larsen, C. H., Egen, R. A., Jones, R. D., and Cress, H. A., "Wire-Rope Applications and Practices Associated With Underground Coal Mining in the United States", Battelle Memorial Institute (1971).

This report discusses hoisting practice in U. S. coal mines. It is a detailed study emphasizing the use of wire rope in hoisting installations, pointing out deficiencies in current practices, and recommending new techniques.

(51) Rice, George S., and Hartmann, Irving, "Coal Mining in Europe, A Study of Practices in Different Coal Formations and Under Various Economic and Regulatory Conditions Compared with Those in the United States", United States Department of the Interior, Bureau of Mines Bulletin 414 (1939).

Though dated, this report provides some insight to hoisting needs and applications in Europe.

(52) Tiley, G. L., "The Case for Tower-Mounted Friction Hoists", Engineering/Mining Journal, pp 177-182 (June, 1967).

Tiley's case for tower-mounted friction hoists provides insight into the relative merits of friction and drum hoists. It also discusses important design details for friction hoists, including especially useful safety devices. Arrestment devices are generally not used with a multirope friction hoist in Canada or Europe.

(53) Wilde, D. H., "Effects of Emergency Braking on Multi-Rope Tower-Mounted Friction Winders – Part II", Colliery Guardian, pp 289-297 (February 26, 1965).

Wilde analyzes the effects of emergency braking, which causes conveyance oscillation.

(54) Electronics Division, Canadian Westinghouse Company Limited, "MINECOM Mine Hoist System for Fail Safe Communications Between Hoist Operator and Cage", 4 pp, no date.

This paper details the MINECOM mine-hoist alarm unit, a fail-safe device that transmits a continuous signal from the cage to the surface of the mine shaft along the hoist rope. A small transmitter at the cage emits a constant 150 Kc/s radio-frequency signal. The hoist rope acts as a transmission line, carrying the signal to the headframe, where the signal is picked up by a receiver. One version of the system provides for two-way voice communication. MINECOM was offered to the mining industry by Canadian Westinghouse Company, Limited, for a number of years and, although considerable interest was shown, only a limited number of units were purchased and installed. The product was withdrawn from the market about 1963.

(55) "Haulage and Hoisting", Coal Age, 73, p 172-177 (July, 1969).

This article summarizes hoisting in U. S. coal mines as of 1969. It notes a trend toward elevator equipment at vertical shafts. It claims that there is a trend toward the use of magnetic track brakes actuated by an overspeed device on inclined-shaft conveyances.

(56) "Wood Handbook", Agricultural Handbook No. 72, U. S. Department of Agriculture, pp 70-77 (1955).

(57) Grove, G. W., Ash, S. H., and Ristedt, E. J., "Some Haulage Safety Devices for Use on Grades, Slopes, and Inclined Shafts", United States Department of the Interior, Bureau of Mines, Miners' Circular 43 (1942).

Grove, et al., discuss equipment used in inclined shafts. Though the paper is quite old, it gives a fair picture of conveyance equipment and arrestment devices used currently in U. S. coal mines. "Drags", "buck hooks", and derails in some form are still used. Auxiliary rope devices similar to the "Prockter Safety Car" are also in use. Most of the equipment mentioned in this paper was designed to stop the conveyance without consideration of the effects of high decelerations on the occupants.

(58) Logan Engineering Company, Catalogues and Manuals C-44 and D-44, "The Lilly Hoist Controller – Model C", "The Lilly Hoist Controller – Model D".

APPENDIX A

MINES VISITED

TABLE A-1. COAL MINES VISITED DURING CONTRACT NO. H0111810 – MAN-HOISTING INSTALLATIONS

Location	Mine Name	Type	Approximate Yearly Tonnage	Conveyance	Operator
Alabama	Black Diamond No. 2	Slope/ strip	194,955	Mine car	Black Diamond Coal Mining
	Segco No. 1	Shaft/ slope	1,369,834	Elevator	Southern Electric Generating Co.
	Bessie	Slope/ shaft	453,037	Man cage	U. S. Pipe and Foundry
	Flattop	Slope	462,526	Man car	U. S. Pipe and Foundry
	Mulga	Shaft	1,016,857	Elevator, man car	Woodward Iron Company
Colorado	Lincoln	Slope/ shaft	272,579	Emergency man cage, mine car	Clayton Coal Company
	Imperial	Shaft	59,267	Man cages	Imperial Coal Company
	Eagle	Shaft	249,337	Man cages	Imperial Coal Company
Ohio	Nelms No. 1	Shaft	1,099,000	Man and material cage	Youghiogheny and Ohio Coal Co.
West Virginia	Cranberry	Shaft	268,690	Skip/cage combination	The New River Company
	Lochgelly No. 2	Shaft	293,580	Ditto	The New River Company
	Smith Bros.	Slope	88,700	No man hoisting	Smith Bros. Construction Co.
	Hunter	Shaft/ slope	107,781	Emergency man cage	Smith and Stover Coal Company

TABLE A-2. COAL MINES VISITED DURING CONTRACT H0101741 - MAN-HOISTING INSTALLATIONS

Location	Mine Name	Type	Approximate Yearly Tonnage	Conveyance Type	Operator
Illinois	Orient No. 3	Shaft	2,656,000	Man-materials cage	Freeman Coal Mining Corp.
	Orient No. 6	Shaft	1,810,000	Man-materials cage	Freeman Coal Mining Corp.
	Old Ben No. 21	Shaft	2,179,000	Man-materials cage	Old Ben Coal Corp.
	Old Ben No. 24	Shaft	2,823,000	Man-materials cage	Old Ben Coal Corp.
	Old Ben No. 26	Shaft	2,290,000	Man-materials cage	Old Ben Coal Corp.
Indiana	Kings Station	Shaft	801,000	(a) Skip-cage combination, (b) Emergency cage	Kings Station Coal Co.
Kentucky	Hamilton No. 1	Slope	2,732,000	Mine cars	Island Creek Coal Co.
Ohio	Rose Valley	Slope	1,331,000	Man car	Hanna Coal Company
	Nelms No. 1	Shaft	1,099,000	Man-materials cage	Youghiogheny and Ohio Coal Co.
	Nelms No. 2	Slope	1,036,000	Mine car	Youghiogheny and Ohio Coal Co.
Oklahoma	Choctaw	Shaft	Development tonnage 6,000	Skip-cage combination, emergency cage	Kerr McGee Corp.
Pennsylvania	Renton	Shaft	1,024,018	Man-materials cage	Pittsburgh Coal Co.
	Cambria No. 33	Slope	1,337,000	Man car	Bethlehem Mine Corp.
	Nanty Glo No. 31	Slope	488,000	Man car	Bethlehem Mine Corp.
	Ellsworth No. 51	Shaft	1,082,000	Man-materials cage	Bethlehem Mine Corp.
	Marianna No. 58	Shaft	1,412,000	Man-materials cage	Bethlehem Mine Corp.
	Russellton	Shaft	752,000	Man cage	Republic Steel Corp.
	Newfield	Shaft	623,000	Man cage	Republic Steel Corp.
	Wanamie	Slope	N.A.	Mine cars	Blue Coal Corp.
Virginia	Virginia Pocahontas No. 3	Shaft	N.A.	Man-materials cage, emergency cage	Island Creek Coal
West Virginia	Eccles No. 5	Shaft	553,000	Skip/cage, man cage	Winding Gulf Coal, Inc.
	Eccles No. 6	Shaft	505,000	Skip/cage	Winding Gulf Coal, Inc.
	Dabney Mine	Slope	N.A.	Man car	The Youngstown Mines Corporation
	Olga	Shaft	1,477,700	Man-materials cage	Olga Coal Co.
	Cannelton	Shaft	518,000	Man cage	Cannelton Coal Co.

TABLE A-3. NONCOAL MINES VISITED

Contract H0111810	
Colorado	
Jamestown Mines	Allied Chemical Corporation
Henderson Project Shafts No. 1 and 2	Amax-Climax Molybdenum Co.
Ontario, Canada	
Agnico Mines	Agnico Mines, Ltd.
Kerr Addison Mine	Kerr Addison Mines, Ltd.
Utah	
U. S. and Lark Mine	U. S. Smelting, Refining, and Mining Company
Contract H0101741	
British Columbia	
Texada Mine	Texada Mines, Ltd.
Ontario, Canada	
Hardy Mine, Fecunis Shaft	Falconbridge Nickel Mines, Ltd.
Shaft No. 2	
Strathcona Shaft No. 1	
Creighton: Shaft No. 5	International Nickel
Shaft No. 9	
Slope No. 3	
Tennessee	
U. S. Steel Zinc Mine	United States Steel Corp.

APPENDIX B

ARRESTMENT-DEVICE MANUFACTURERS AND DESIGN APPLICATIONS

APPENDIX B

ARRESTMENT-DEVICE MANUFACTURERS AND DESIGN APPLICATIONS

Table B-1 lists those manufacturers contacted who design and build conveyances and arrestment devices for traditional mine-hoist systems. The table also indicates the reported applicability of the devices, the types of guides on which they can be used, and the actuation modes.

In addition to the mining-equipment manufacturers listed in Table B-1, the following elevator-equipment manufacturers have been contacted:

Contract No. H0111810

Bagby Elevator and Electric Corporation
Birmingham, Alabama

Dover Corporation
Elevator Division
Memphis, Tennessee

Westinghouse Electric Corporation
High Speed Elevator Division
Jersey City, New Jersey

Contract No. H0101741

Haughton Elevator Company
Toledo, Ohio

Otis Elevator Company
Philadelphia, Pennsylvania

TABLE B-1. ARRESTMENT DEVICES – MANUFACTURERS AND DESIGN APPLICATIONS (EXCLUDING ELEVATORS)

Manufacturer	Location	Design Applications: Shaft		Type of Guide			Actuation Mode		
		Vertical	Inclined	Wood	Steel[b]	Wire Rope	Rope Tension Loss	Conveyance Overspeed	Other
Atlas Car and Mfg. Co.	Cleveland, Ohio	x[a]	x[a]						
Card Corporation	Denver, Colorado	x	x	x	x	x	x		
Connellsville Corporation	Connellsville, Pa.	x	x	x	x		x	x	(c)
Dorr-Oliver-Long, Ltd.	Orillia, Ontario, Canada	x	x	x	x		x		
Holmes Bros., Inc.	Danville, Illinois	x	x	x			x		
Robert Hudson (Raletrux) Ltd.	Leeds, England		x		x			x	(c)
Krampe and Co.	Ruhr, Germany		x		x[e]			x	
Lake Shore, Inc.	Iron Mountain, Mich.	x	x	x	x	x	x	x	
Long Airdox Company	Knoxville, Tenn.		x		x			x	(c) (d)
Machinery Center, Inc.	Salt Lake City, Utah	x		x		x	x		
Mayo Tunnel and Mine Equip.	Lancaster, Pa.	x	x	x	x	x	x	x	
Nolan Company	Bowerstown, Ohio	x		x			x		
Safety Lift Corp.	Wheatridge, Colorado	x	x	x	x	x	x	x	(c)
Union Iron Works, Div. of The Coeur d'Arlenes	Spokane, Wash.	x		x	x		x		
Union Iron Works of New Jersey Co., Inc.	Superior, Wisc.	x					x		
Wabi-Iron, Ltd.	New Liskeard, Ontario, Canada	x	x	x	x		x		
D. Wickham and Co., Ltd	Ware, England		x		x			x	(c)

(a) Uses rack and pinion.
(b) Rail or rail-like guides unless otherwise noted.
(c) Manual actuation available.
(d) Actuates with an unscheduled change in direction of travel.
(e) Pipe guides.

APPENDIX C

MINING REGULATORY OFFICIALS CONTACTED

APPENDIX C

MINING REGULATORY OFFICIALS CONTACTED

U. S. Bureau of Mines Personnel

Alameda, California

Howard E. Poland
Metal and Nonmetal Safety Division

Denver, Colorado

George R. Kyler
Donald Hutchison
Robert I. Fujimoto
Health and Safety Technical Support Center

Duluth, Minnesota

R. O. Pynnonen

Pittsburgh, Pennsylvania

Bob Barrett
Eugene Ruttle
John Sulka
George Susko
Steve Gaydor

Mt. Hope, West Virginia

Mr. Cook
Cecil E. Lester

Seattle, Washington

Ken Russell

State Officials

Alabama

Bob Brandon, Division of Safety and Industry, Department of Industrial Relations
Mr. Haynes, Safety Director, City of Birmingham

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State Officials
(Continued)

California

Safety Engineers, Industrial Section, Division of Industrial Safety, Department of Industrial Relations
Robert D. Bailey
Mervin J. Fisk
L. L. McCune
E. A. Brubaker

Colorado

Norman Blake, Deputy Commissioner of Mines, Colorado Bureau of Mines
Donald Haske, Chief Inspector of Coal Mines

Kansas

Rudy Blazic, State Inspector

Kentucky

Mr. Mosgrove, Deputy Commissioner of Mines

Montana

Roy L. Jameson, Safety Director, Industrial Accident Board

Nevada

Harry E. Springer, State Inspector of Mines

New Mexico

William H. Hays, State Inspector of Mines
Joseph D. Longacre, Sr., Deputy State Inspector of Mines

Utah

C. F. Gronning, Commissioner, Industrial Commission of Utah
Robert Peterson, Metal Mine Inspector, Industrial Commission of Utah
George M. Garcia, Metal Mine Inspector, Industrial Commission of Utah

Washington

Robert H. Pierce, Chief Mining and Explosives Inspector, Department of Labor and Industries

State Officials
(Continued)

West Virginia

Paul C. Riley, Deputy Director, West Virginia Department of Mines
Ewell Snuffer, Mine Engineer, West Virginia Department of Mines

Wyoming

Gene Iverson, State Inspector

Foreign Contacts

Australia

A. W. Norrie, Chief Inspector of Mines, Department of Mines, Queensland
A. Y. Wilson, State Mining Engineer, Mines Department of Western Australia
J. H. Burford, Chief Inspector of Mines, Department of Mines, New South Wales

Austria

Dr. Pelzl, Bundesministerium für Handel, Gewerbe und Industrie

Canada

C. M. Barrett, Chief Engineer (Electrical-Mechanical)
J. J. Baker, District Electrical-Mechanical Engineer
Department of Mines and Northern Affairs, Ontario

Great Britain

P. Wood, Head of Shafts and Winding Section, National Coal Board
G. E. Winder, Safety in Mines Research Establishment
J. Marlowe, Safety in Mines Research Establishment

Italy

Mr. Marra, Ministero dell' Industria del Commercio e dell' Artigianato

New Zealand

R. Marshall, Chief Inspector of Coal Mines

Republic of South Africa

T.R.N. Aberdein, Government Mining Engineer

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Foreign Contacts
(Continued)

Republic of West Germany

Mr. Hahn, of LANDESOBERBERG AMT, Nordrhhein-Westfalen
Mr. Heinz Dreyer, Oberbergamt, Clausthal-Zellerfeld

Tanzania

K. N. Cnuze, for the Commissioner for Mineral Resources, Ministry of Commerce and Industries.

APPENDIX D

MINING SAFETY REGULATIONS

APPENDIX D

MINING SAFETY REGULATIONS

Federal

(1) Public Law 91-173 – 91st Congress, S. 2917, also cited as the "Federal Coal Mine Health and Safety Act of 1969" (December 30, 1969).

(2) Public Law 89-577 – 89th Congress, H. R. 8989, also cited as the "Federal Metal and Nonmetallic Mine Safety Act" (September 16, 1966).

(3) Code of Federal Regulations, Title 30 – Mineral Resources, revised as of January 1, 1971, Chapter 1, Subchapters N and O, Parts 57 and 75, respectively.

State

Alabama

(4) Coal Mining Laws of the State of Alabama, as amended 1960, Department of Industrial Relations.

(5) Mine Safety Rules of the State of Alabama, adopted December 15, 1962, Department of Industrial Relations.

Alaska

(6) "Mines Other Than Coal", Regulation 12, 1963 (Section 2550, "Hoisting Equipment"), Division of Geological Survey.

Arizona

(7) "Notice of Proposed Adoption of the Rules of the State Mine Inspector", State Mine Inspector (July 31, 1970).

Arkansas

(8) Mining Laws of the State of Arkansas, printed and distributed by the State Mine Inspector (1962).

California

(9) Mine Safety Orders, effective November 17, 1962, Department of Industrial Relations.

State
(Continued)

Colorado

(10) Coal Mining Laws: State of Colorado, as amended 1966, Department of Natural Resources.

(11) Colorado Mining Laws with Safety and Health Rules and Regulations, Bureau of Mines Bulletin 20 (January 1, 1971).

Idaho

(12) Idaho Mining Safety Code, Section 14, "Shafts, Headframes and Shaft Conveyances", Department of Inspector of Mines.

Illinois

(13) The Coal Mining Act, Department of Mines and Minerals (1969).

Indiana

(14) Coal Mining Laws of Indiana, effective March 8, 1955, Bureau of Mines and Mining.

Iowa

(15) Mining Law, State Mine Inspector (1963).

Kentucky

(16) Laws Governing the Mining of Coal and Clay, Legislative Research Commission (1970).

Maryland

(17) Mining Laws of the State of Maryland, Maryland Bureau of Mines (1950).

Michigan

(18) "Proposed Rules", Section 57.21, "Man Hoisting", Department of Labor (November 6, 1970).

Missouri

(19) Mine Inspection Laws of the State of Missouri, Department of Labor and Industrial Relations (October, 1967).

Montana

(20) Coal Mining Laws of the State of Montana, Industrial Accident Board.

State
(Continued)

(21) Minimum Safety Standards for Mining, Quarrying, Milling, and Smeltering Operations, Bureau of Mines and Geology (August, 1961).

Nevada

(22) Health and Safety Standards for Open Pit and Underground Mines, Mills, Smelters, and Ore Reduction Plants, State Inspector of Mines (July, 1970).

New Mexico

(23) New Mexico Mine Safety Code for All Mines, State Inspector of Mines (1968).

North Dakota

(24) Mining Code and Licensing Laws of the State of North Dakota, Department of Mine Inspector.

Ohio

(25) Mining Laws of Ohio, Department of Industrial Relations (1970).

Oklahoma

(26) Mining Laws of the State of Oklahoma, Chief Mine Inspector (1968).

Oregon

(27) Safety Code for Mining, Tunneling, and Quarrying, effective November 10, 1962, Industrial Accident Commission.

Pennsylvania

(28) Bituminous Coal Mining Laws of Pennsylvania for Underground Mines, Department of Mines and Mineral Industries (1961).

South Dakota

(29) Mine Safety Code for All Mines, Including Quarries and Open-Pit, State Mine Inspector (1967).

Tennessee

(30) Laws and Regulations Governing Mines, and Mining, Department of Labor (1957).

(31) Laws and Regulations Governing Mines and Mining, Title 58, Department of Labor.

State
(Continued)

Utah

(32) General Safety Orders Covering Metal and Nonmetallic Mines, Mills, Smelters, Tunnels, Quarries, Gravel Pits, etc. in the State of Utah, Industrial Commission (July 1, 1963).

Virginia

(33) Mining Laws (Including Oil and Gas) of Virginia, Department of Labor and Industry (1970).

Washington

(34) Coal Mining Laws of Washington, as amended to 1947, Department of Labor and Industries (1966).

(35) Safety Standards for Metallic and Nonmetallic Mines, Department of Labor and Industries.

West Virginia

(36) Mining Laws of West Virginia, Department of Mines (1969).

Wyoming

(37) Wyoming Non-Coal Mining Laws, Office of the State Inspector of Mines (1970).

Foreign

Australia

*New South Wales - J. H. Burford, Chief Inspector of Mines.

*Queensland - A. W. Norrie, Chief Inspector of Mines, "Queensland Mines Regulation Act of 1964-1968".

*Western Australia - A. Y. Wilson, State Mining Engineer.

Austria

*Dr. Pelzl, Bundesministerium für Handel, Gewerbe und Industrie.

Canada

Alberta

(38) The Coal Mines Regulation Act, Department of Mines and Minerals (1966).

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* Information on laws obtained by letter.

Foreign
(Continued)

(39) Regulations and Orders Made Pursuant to the Coal Mines Regulation Act, Department of Mines and Minerals (1966).

British Columbia

(40) Mines Regulation Act, Department of Mines and Petroleum Resources (July 1, 1969).

Manitoba

(41) Regulations Under "The Mines Act", Department of Mines and Natural Resources (1957).

New Brunswick

(42) The Mining Regulations, Section 15, "Drums and Ropes, Counterweights and Sheaves", Department of Natural Resources.

Newfoundland

(43) The Mines (Safety of Workmen) Regulations, 1957, Department of Mines.

(44) The Mines (Safety of Workmen) (Amendment) Regulations, 1959-60-61-63-66, Department of Mines (1967).

(45) Regulation of Mines Act and Amendments, 1960, 1961, and 1966-67, Department of Mines (1967).

Nova Scotia

(46) Coal Mines Regulation Act, Department of Mines (1965).

(47) Canada Labour (Safety) Code: Coal Mines (CBDC) Safety Regulations, Department of Mines (January 14, 1969).

Ontario

(48) Handbook of Requirements Governing the Operation of Mines, Department of Mines and Northern Affairs (1971).

Quebec

(49) "Hoists and Hoisting" (Copy of pending revised regulations), Department of Natural Resources.

(50) Regulations for the Safety and Protection of Workmen in Mines and Quarries, Department of Mines (1960).

Foreign
(Continued)

Great Britain

(51) "Shafts, Outlets, and Roads Regulations", The Law Relating to Safety and Health, Volume I, Mines of Coal, pp 303-327 (1960).

*Mr. G. E. Winder, Safety in Mines Research Establishment.

*Mr. P. Wood, Head of Shafts and Winding Section, National Coal Board.

Italy

*Mr. Marra, Ministero dell' Industria del Commercio dell' Artigianato.

New Zealand

*Mr. R. Marshall, Chief Inspector of Coal Mines, Mine Department.

South Africa

(52) "Amendment of Regulations: Mines and Works Act, 1956 (Act 27 of 1956)", Republic of South Africa Government Gazette, 60 (2741), 172 pp (June 26, 1970).

*T. R. N. Aberdein, Government Mining Engineer, Department of Mines.

Tanzania

*K. A. Cnuze, Ministry of Commerce and Industries.

West Germany

*Mr. Hahn, LANDESOBERBERGAMT NW, Federal Republic of Germany.

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* Information on laws obtained by letter.

TABLE D-1. SUMMARY OF ARRESTMENT-DEVICE REGULATIONS, UNITED STATES AND FOREIGN

REGULATIONS	Application				When Required			Actuation Criteria				Initial Approval			Periodic Testing							Inspection	
	Coal Mines	Metal/Nonmetal Mines	Vertical Shafts	Inclined Shafts	Personnel Hoisting	Product Hoisting	None Required	Emergency	Broken Hoist Rope	Overspeed	Not Defined	Qualification Tests	By Direction	None Required	Free-Fall Test	Drop Test: Loaded	Drop Test: Empty	Actuation Test	Required but Not Defined	None Required	Record Maintained	Visual Examination	Record Maintained
Federal																							
United States	X*		X	X	X			X					X						2M		X	D	X
United States		X	X	X			X																
STATE																							
Alabama	X		X	X	X						X		X						X		X	D	X
Alabama		X	X		X				X					X			X				X	D	X
Alaska		X	X		X				X				X						2W			D	
Arizona		X	X		X				X					X						X			
Arkansas	X	X	X		X				X					X						X			
California	X	X	X	X	X				X					X			R	D				D	
Colorado	X		X	X	X			X						X					3M		X	D	X
Colorado(a,b)**		X	X	X	X				X					X					2W			D	
Idaho	X	X	X		X				X					X					X				
Illinois	X		X	X	X			X						X						X		D	
Indiana(c)	X		X		X			X						X					2M			D	X
Iowa	X	X	X	X	X						X			X						X		D	
Kentucky	X		X	X	X						X		X							X		D	
Maryland	X	X	X	X	X			X						X					2M		X	D	X
Michigan(b,d)	X	X	X	X	X						X			X						X			
Missouri	X		X	X	X				X					X						X		W/2	X
Missouri(b)		X	X	X	X				X				X							X		D	X
Montana	X		X	X	X			X						X					2M		X	D	X
Montana		X	X		X						X			X						X		D	
Nevada(e)	X	X	X		X						X			X			I	2M				D	
New Mexico	X	X	X	X	X				X				X					3M					
North Dakota	X		X		X						X			X						X			
Ohio	X	X	X		X						X		X							X			
Oklahoma	X		X	X	X						X		X							X		D	X
Oklahoma		X	X		X						X		X							X		D	X
Oregon	X	X	X		X				X					X					2W				
Pennsylvania	X		X		X						X			X					2M		X	D	
South Dakota	X	X	X	X	X				X				X						3M				
Tennessee(c)	X		X		X			X						X					2M		X	D	X
Tennessee		X	X		X			X						X					3M		X	D	X
Utah(b)		X	X		X			X	X					X			M						
Virginia	X	X	X	X	X			X						X					M		X	D	X
Washington	X		X	X	X				X					X			6M					D	X
Washington		X	X		X				X				X							X		D	X
West Virginia	X		X		X						X		X							X			
Wyoming(b)		X	X		X				X					X					2W			D	

*Legend on page D-8.

**Footnotes on page D-8.

TABLE D-1. (Continued)

REGULATIONS	Application				When Required			Actuation Criteria				Initial Approval			Periodic Testing							Inspection	
	Coal Mines	Metal/Nonmetal Mines	Vertical Shafts	Inclined Shafts	Personnel Hoisting	Product Hoisting	None Required	Emergency	Broken Hoist Rope	Overspeed	Not Defined	Qualification Tests	By Direction	None Required	Free-Fall Test	Drop Test: Loaded	Drop Test: Empty	Actuation Test	Required But Not Defined	None Required	Record Maintained	Visual Examination	Record Maintained
Foreign																							
Australia																							
New South Wales[b]		X	X		X				X				X					M			X		
Queensland[f]	X	X	X	X	X	X			X				X		R			X			X	X	X
Western Australia	X	X	X		X	X			X				X						D		X		
Austria[g]	X	X	X		X				X						6M				D		D		
Canada																							
Alberta	X		X		X				X					X						X			
Br. Columbia	X	X	X		X						X			X		Y	M				W		
Manitoba	X	X	X		X				X					X		M					W		
New Brunswick		X	X		X						X	X								X			
Newfoundland		X	X		X				X				X							X	W		
Nova Scotia	X			X	X				X				X							X	D	X	
Ontario		X	X		X				X			X			I		3M				D		
Quebec		X	X		X				X			X			I		3M				W	X	
Great Britain	X	X	X	X			X																
Italy	X	X	X		X				X														
New Zealand[h]	X		X	X			X																
South Africa	X	X	X	X			X																
Tanzania	X	X	X		X				X														
West Germany	X	X	X	X			X																

(a) For vertical shafts >50 feet deep, inclined 45° from vertical.
(b) Multirope hoisting systems excepted.
(c) Conveyances for both men and muck excepted.
(d) For slopes inclined ≥ 30° from horizontal; drags used for slopes < 30° in inclination.
(e) Requirement for use is implied but not specifically called out.
(f) Shafts using steel guides or slopes are excepted.
(g) Use on rope guides excepted.
(h) Use not required by law but considered good practice.

Legend
X - Applicable
D - Daily
W - Weekly
M - Monthly
R - As required
I - Upon installation.

APPENDIX E

HOISTING ACCIDENT DATA

APPENDIX E

HOISTING ACCIDENT DATA

Data on hoisting accidents at U. S. mines appear generally unavailable. Apparently, accident data are not consistently recorded unless a fatality occurs. Inquiries to state and Federal officials have yielded little information, and some of the data obtained are lacking in specific detail.

Figure E-1 shows the distribution of fatal transportation accidents in U. S. coal mines from 1956 to 1966.[26] Only 12 hoisting-associated fatalities were recorded, and, of these, only five involved falling conveyances. Although the five conveyance accidents represent less than 1 percent of all coal-mine transportation fatalities for that period, the transportation of men in rope-hauled conveyances does have great potential for multiple-fatality accidents. Fifty-man cages are commonly used, and much higher-capacity man cages will probably be used as mines go deeper. One metal mine in the U. S. is installing two 116-man cages.

Table E-1 lists some examples of hoisting accidents that have occurred in various parts of the world. The list is not all-inclusive, but exemplary of accidents that have occurred and will probably occur again under similar circumstances. Many of these accidents resulted from causes other than hoist-rope failure.

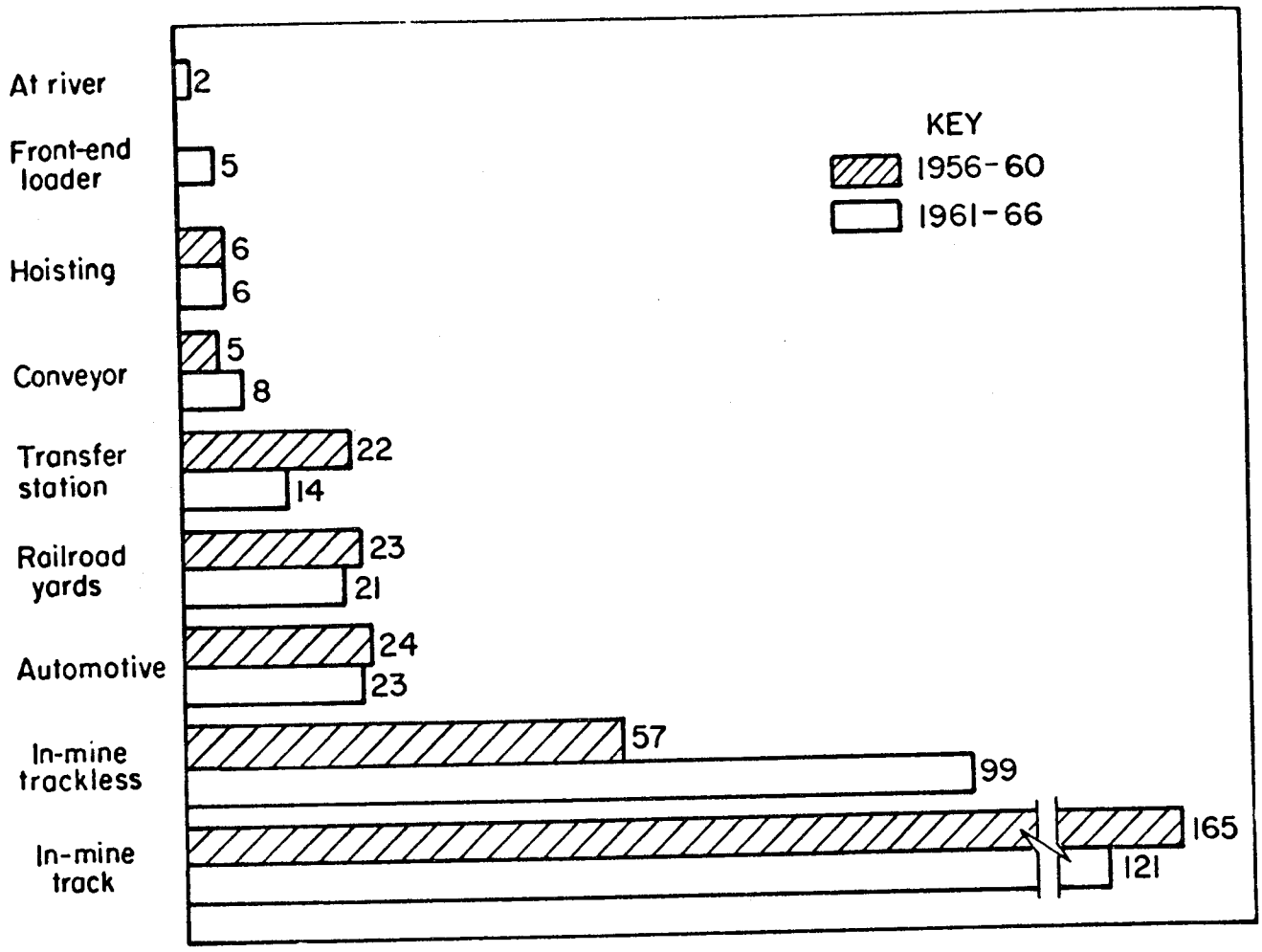

FIGURE E-1. TYPES OF MINE TRANSPORTATION INVOLVED IN FATAL ACCIDENTS, 1956-1966[26]

TABLE E-1. HOISTING ACCIDENTS

Cause	Result	Location	Date
1. Equipment failure – loose bolt	Protruding bolt head on drum fractured the hoist rope, multitoothed cam safety catches became choked with wood spoil, cage fell 1200 ft to bottom of shaft. All 23 occupants were killed.	Jack East Gold Mining Corporation, Ltd., Republic of South Africa	1907
2. Tight guides	A descending cage stuck in the shaft. The ascending cage fouled in the slack rope created by the stopped cage and became overturned. Six men were killed and four injured.	Wolhuter Deep Gold Mining, Republic of South Africa	1907
3. Falling rock	The impact of falling rock snapped the hoist rope. The conveyance fell, killing ten persons.	Vogelstruis Estates and Gold Mining Company, Republic of South Africa	1910
4. Broken hoist rope	The arrestment device was rendered ineffective by clogging with wood spoil. The conveyance fell, killing 16 men.	Paymaster Consolidated Mines, Ltd., Ontario, Canada	1945
5. Hoist rope pulled free from the end fitting at the conveyance	The arrestment device was rendered ineffective by clogging with wood spoil. The conveyance fell, killing 45 men.	Peine, Germany	1946
6. Accidental actuation of the arrestment device	A small rock fouled the arrestment-device linkage, preventing the dogs from returning to their proper position after conveyance chairing.	Sylvanite, Ontario, Canada	1948
7. Fouling in shaft	It is believed that a 7-ft length of drill steel fouled the conveyance, forcing two of four arrestment-device dogs to become inverted 180° and causing them to split and score the guides for 1725 ft.	Kerr-Addison, Ontario, Canada	1949
8. Broken hoist rope	The arrestment device actuated successfully, stopping the conveyance and the six occupants.	Detroit Mine, Michigan	1957
9. Equipment failure – loose brake soleplates	Loose soleplates reduced the hoist braking capability, permitting a conveyance to run down the inclined shaft 2700 ft. Sixteen men were killed.	City Deep, Ltd., Republic of South Africa	1961
10. Accidental actuation of arrestment device	The arrestment device accidentally actuated on a descending conveyance. The ascending conveyance fouled in the slack rope created by the stopped conveyance. The occupants of the ascending cage were badly shaken up.	Delnite Mines, Ltd., Ontario, Canada	1962
11. Frozen lubricant in the head-sheave groove	Lubricant from the hoist rope, frozen in the sheave groove, caused the rope to jump the sheave. The slack created caused the arrestment device to actuate immediately.	Dickinson Mines, Ltd., Ontario, Canada	1962
12. Hoistman error	The brake was released at the wrong time, permitting the counterweight to fall a short distance to the shaft bulkhead. No injuries or damage occurred.	McIntyre Porcupine Mines, Ltd., Ontario, Canada	1963
13. Six broken hoist ropes	The arrestment device for the elevator actuated successfully, stopping the conveyance and its one occupant.	Ireland Mine, West Virginia	1964
14. Broken drum shaft	The drum fell onto the base plate and the weight of the loaded cage continued to unwind the rope. Cage went through a bulkhead and was damaged. Apparently no men were aboard.	Silverfields Mining, Ltd., Ontario, Canada	1964
15. Fire at the hoist house	The two hoist ropes were severed by the heat and the two cages fell until stopped by their arrestment devices.	Kidd Copper Mine, Ontario, Canada	1969
16. Fatigue failure of clutch	The clutch-band anchor broke and the drum continued to turn. The conveyance ran to the shaft bottom, killing four men.	El Dorado Mine and Mill, California	1971

APPENDIX F

RECOMMENDED INSPECTION AND TESTING RECORD FORMS

APPENDIX F

RECOMMENDED INSPECTION AND TESTING RECORD FORMS

In recommending requirements for arrestment devices and hoist controls, it is stated that these requirements should also provide a basis for promoting application of technology and for improving the technology involved. Qualitative and quantitative data are that basis.

In this program, as well as in the earlier study, Battelle often found it difficult to obtain the kinds of qualitative and quantitative data necessary for engineering judgments. What few records are available are generally too qualitative, if not just check lists. Such records are fine for guiding a man in his inspection and maintenance duties. But as a source of information about mechanical performance, such records are generally useless. They do not provide information about performance inadequacies and problems or what components make up the machine and how they determine the limits of its performance capabilities.

In attempting to formulate meaningful record forms for arrestment-device inspection and testing, it became obvious that such forms would overlap somewhat the present "Report of Daily Inspection of Hoisting Equipment", Bureau of Mines Form 6-1494 (March, 1970), and thereby add to rather than subtract from the general problem.

Furthermore, it became obvious that there are several aspects of hoisting safety that are currently unregulated. Hoist-drive machinery acceleration and deceleration, and hoist-rope selection, inspection, and replacement are two noteworthy examples. Elsewhere in the mining world these aspects have been recognized as significant and regulated to the extent that developing technology permits. Thus, consideration was given to accommodating the regulation of these aspects in this country at some hopefully not-too-distant date.

After much consideration of the problems and needs, the following changes and additions are recommended:

(1) Change the cover of present Form 6-1494 as edited in Figure F-1.

(2) Change the format of the pages in present Form 6-1494 as edited in Figure F-2a or F-2b.

(3) Provide a folder with a spring-clip binding with the cover format shown in Figure F-3.

(4) Provide the following forms for insertion as needed into the folder of Item (3) above:

   (a) Record of Arrestment-Device Inspection and Testing: Dynamic Test (see Figure F-4)

   (b) Record of Arrestment-Device Inspection and Testing: Qualification Test (see Figure F-5)

(c) Record of Arrestment-Device Inspection and Testing: Equipment Description (see Figure F-6)

(d) Record of Weekly Actuation Tests of Hoist Safety Controls (see Figure F-7)

(e) Record of Abnormal Hoisting Incidents (see Figure F-8).

Retaining copies of Items (3) and (4) at or near the hoist would provide a ready source of data for continually assessing arrestment-device performance and hoist-control problems, and for investigating and assessing hoisting accidents on the spot.

Copies of Items (3) and (4) filed with the Bureau of Mines would permit the above assessments to be made without further references or travel in the majority of cases. They would also permit easy general evaluations and comparisons for many hoisting installations, a task impossible now but basic to the advancement of hoisting technology in general and arrestment devices in particular.

The forms for Figure F-4, Dynamic Test, and Figure F-5, Qualification Test, are intended to be used for vertical and inclined-shaft conveyances. The Dynamic Test is patterned after Drop Test Method 2 (see Chapter 3), but since inclined-shaft conveyances cannot be "dropped", the name "drop test" was not used for fear of misinterpretation. The Qualification Test carried out in a vertical shaft with a broken-rope-actuated arrestment device would follow the procedures of the free-fall test of Chapter 3. But since the idea of testing an arrestment device at speed has equal value in inclined shafts, again the name "free-fall test" has not been used.

The recommended forms for the Dynamic and Qualification Tests state only the goal and basic method under "Test Procedures". The Drop Test Method 2 and Free Fall Test procedures of Chapter 3 can be directly applied in vertical-shaft systems for arrestment devices that actuate because of a broken rope, for example. These procedures do not specifically apply to devices that actuate from overspeed or for inclined-shaft systems. It is not practical to formulate test procedures for the possible combinations of arrestment devices and shaft and conveyance configurations. They would be many and it is feared they would be taken as gospel. Battelle believes that as long as the stated goal under Test Procedures (Figures F-4 and F-5) is met in a manner consistent from test to test, the particular method is not important. The method must be described, however, so that test results can be properly evaluated. Thus, it is believed that particular test methods are best developed in the field. With experience, it is probable that a few methods will evolve that will be sufficient for the great majority of cases. Then, perhaps, is the time to codify test methods.

It is necessary to discuss the suggested "Evaluation" of a Dynamic Test presented in Figure F-4. The data taken are

(1) Distance Conveyance Traveled from Release to Engagement of Braking Elements, S_A

(2) Distance Conveyance Traveled from Engagement of Braking Elements to Stop, S_B

(3) Distance Conveyance Traveled from Release to Stop, S_T.

This test involves a slowly moving conveyance. Because relatively little kinetic energy is involved, the braking distance, S_B, may be very short. Because of natural variations in physical properties of the braking elements or guides or because of different environmental conditions from one test to another, this short braking distance can be expected to vary significantly from test to test even though the maximum performance capability of the arrestment device has not changed.

It is quite possible in many cases that the distance from release to braking-element engagement, S_A, will be a significant portion of S_T. This distance is an expression of device actuation time. Depending upon test methods and actuation mode of the device, a fraction of a second difference in actuation time may produce a significant change in S_T.

In general, the total travel distance, S_T, in a Dynamic Test can vary significantly without meaning that the maximum performance capability of the device has changed. Thus, it has been recommeded in Figure F-4 that S_T can vary from 1/2 to 1-1/2 times the S_T from the initial Dynamic Test. This range is strictly a Battelle judgment; as field experience is gained, this range should be revalued if necessary.

The evaluation criteria for the Qualification Test suggested in Figure F-6 are based upon the recommended arrestment-device performance criteria and need no further comment.

and Testing

Report of Daily Inspection of Hoisting Equipment

Company _____

Mine _____

Insert → Shaft _____

Location _____

Post Office **County** **State**

FIGURE F-1. RECOMMENDED CHANGES IN COVER OF PRESENT BUREAU OF MINES FORM 6-1494

F-5

DAILY AND TESTING

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~~ Conveyance Arrestment Device Actuation. _____
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~~ _____ (delete)

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 F-2a. RECOMMENDED MINIMAL CHANGES IN PAGES OF PRESENT BUREAU OF MINES FORM 6-1494

DAILY AND TESTING
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.~~

INSERT→ INSPECTION:

1. Visual examination of hoist ropes. _____

2. Rope fastenings, alignment, and lubrication. _____

~~3. Safety catches.~~ _____

3. ~~4.~~ Examination of cage, platform, elevators, etc. _____

4. ~~5.~~ Head sheaves, flanges, bearings, lubrication. _____

5. ~~6.~~ Ride top of cage or elevator to check guides buntons, power wires, etc. _____

6. ~~7.~~ Overwind, overspeed, and automatic stop controls. _____

7. ~~8.~~ Anchorage of hoist; check for loose bolts, etc. _____

INSERT→ TESTING AND INSPECTION:

11. ~~9.~~ Cage, platform, skip, bucket, or cars position indicator. _____

12. ~~10.~~ Signal systems. _____

8. ~~11.~~ 3 wraps of rope around drum; fastening to spoke, etc. ← place before ~~"Testing...."~~ in numerical order _____

10. ~~12.~~ Cage operated one round trip before men transported ← place before ~~"Testing...."~~ in numerical order _____

9. ~~13.~~ Landing gates or doors. ← place before "Testing ..." in ~~numerical order~~ _____

INSERT→ 13. Conveyance Arrestment Device Actuation and Inspection _____

~~14. Tests of safety catches. (every two months)~~

~~Previous test made~~ _____ ← (delete)

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 F-2b. RECOMMENDED MAXIMAL CHANGES IN PAGES OF PRESENT BUREAU OF MINES FORM 6-1494

F-7 and F-8

REPORT OF SPECIAL INSPECTION AND TESTING
OF HOISTING EQUIPMENT

Company _____

Mine _____

Shaft _____

Location _____
Post Office County State

FIGURE F-3. RECOMMENDED COVER FORMAT FOR ADDITIONAL FOLDER

RECORD OF ARRESTMENT DEVICE INSPECTION AND TESTING: DYNAMIC TEST

Company _____

Mine and Location _____

Shaft _____ ☐ Vertical ☐ Inclined

Compartment _____

SHAFT REGION WHERE TEST WAS PERFORMED:

_____

INSPECTION PRIOR TO TEST (Note Condition Under "REMARKS")

DYNAMIC TEST NO. _____

- ☐ Initial Qualification Test
- ☐ Trimonthly
- ☐ After In-Service Actuation
- ☐ Return to Service After 2 Months Disuse
- ☐ OTHER (Describe)

_____

Date _____

BASIC TEST PROCEDURES

Goal: Actuation of arrestment device when conveyance is moving slowly.

Basic Method: Release conveyance from rest. If arrestment device does not automatically actuate either immediately or very soon because of release or because the conveyance begins to move, do what is necessary to assure that it does so. What method is finally selected should be used henceforth so that the results of this test indicate variations in arrestment device performance, rather than variations in test method. Describe methods used under REMARKS.

TEST DATA

CONVEYANCE TEST LOAD: _____ lb = M
(Try for Equivalent of Maximum Man Load, M_O, on Equipment Description Sheet)

DISTANCE CONVEYANCE TRAVELED FROM RELEASE TO ENGAGEMENT OF BRAKING ELEMENTS = _____ ft = S_A (1)

DISTANCE CONVEYANCE TRAVELED FROM ENGAGEMENT OF BRAKING ELEMENTS TO STOP = _____ ft = S_B (2)

(NOTE: Either or both of these distances may be small and therefore not measurable with great accuracy. Do what is possible.)

DISTANCE CONVEYANCE TRAVELED FROM RELEASE TO STOP = _____ ft = S_T (3)

EVALUATION Not Necessary for Initial Dynamic Test

S_A is basically a measure of actuation time. If actuation is not automatic, changes in S_A may be due to test methods.

S_B is basically a measure of braking element performance.

S_T from Initial Dynamic Test = _____ ft = S_{TO} (4)

Ratio $\frac{S_T \text{ (Item 3)}}{S_{TO} \text{ (Item 4)}}$ = _____ = R (5)

		Check Which
If R (Item 5) is greater than 0.5 but less than 1.5,	Test is SUCCESSFUL	☐
If R (Item 5) is less than 0.5,	Test is CONDITIONALLY SUCCESSFUL	☐

Review previous Dynamic Test Data to determine if S_A or S_B or both have decreased to make R less than 0.5. If S_A has decreased, look for changes in actuation mechanisms or test method. If S_B has decreased, look for changes in brake elements, guides, or brake force-producing mechanisms. These changes may also be due to expected natural variations. However, if the previous Dynamic Test was "Conditionally Successful" (☐Yes, ☐No), or if the next Dynamic Test is "Conditionally Successful", there may be a change in the performance characteristics of the arrestment device. If there have been three "Conditionally Successful" Dynamic Tests in a row (☐Yes, ☐No), a Qualification Test may be in order. Inspect guides, devices, and test method for possible explanations and note under REMARKS.

FIGURE F-4. RECOMMENDED FORMAT FOR RECORD OF ARRESTMENT DEVICE INSPECTION AND TESTING: DYNAMIC TEST

If R (Item 5) is greater than 1.5, Test is NOT SUCCESSFUL

Review previous Dynamic Test data to determine if S_A or S_B or both have increased to make R greater than 1.5. If S_A has increased, look for changes in actuation mechanisms or test method. If S_B has increased, look for changes in braking elements, guides, or brake-force-producing mechanisms.

Determine Source of Problem
Take Remedial Action
Repeat Dynamic Test
} Describe Under "REMARKS"

REMARKS

[SIGNATURES]

Retain One Copy; Send One Copy to _____

F-11

RECORD OF ARRESTMENT DEVICE INSPECTION AND TESTING: QUALIFICATION TEST

Company _____

Mine and Location _____

Shaft _____ ☐ Vertical ☐ Inclined

Compartment _____

SHAFT REGION WHERE TEST WAS PERFORMED: (Also Indicate Shaft Inclination if not Vertical)

_____

INSPECTION PRIOR TO TEST (Note Condition Under REMARKS)

QUALIFICATION TEST NO. ____

☐ Initial
☐ Requalification
  ☐ 5-year
  ☐ Return to Service After 6 mo. Disuse
  ☐ Shaft Transfer
  ☐ Modification, Repair, or Replacement
☐ Other (Describe)

Date _____

BASIC TEST PROCEDURES

Goal: Actuation of Arrestment Device when Conveyance is Traveling at its Rated Maximum Hoisting Speed.

Basic Method: Release conveyance from rest. If arrestment device does not automatically actuate at or near maximum rated speed, do what is necessary to assure that it does so. Describe methods used under REMARKS.

Rated Max. Hoisting Speed _____ ft/min = V_0
Conveyance Weight _____ lb = C
Rated Man Load _____ lb = M_0
Rated Material Load _____ lb = E

} See Equipment Description Sheet

TEST DATA

Conveyance Test Load: (Try for M_0 above) = _____ lb = M

Total Load Decelerated = C+M = _____ lb

Distance Conveyance Traveled from Release to Braking-Element Engagement = _____ ft = S_1 (1)

Try to make $S_1 = \left(\frac{V_0}{481.5}\right)^2 \frac{1}{\sin\theta}$ if actuation is not by overspeed

θ = shaft inclination angle measured from horizontal

(NOTE: $\sin\theta = 1$ for vertical shafts)

Distance Conveyance Traveled from Engagement to STOP = _____ ft = S_2 (2)

EVALUATION

Speed at Engagement $V_m = 481.5\sqrt{S_1 \sin\theta}$ = _____ ft/min (3)

Average Deceleration in Direction of Travel: $\bar{A} = \frac{S_1}{S_2}(\sin\theta)\ g$ = _____ g (4)

Average Horizontal Deceleration: $\bar{A}_H = \bar{A}\cos\theta$ = _____ g (5)
(For Inclined Shafts Only)

Average Braking Force: $\bar{F}_B = (C+M)\left(\frac{S_1}{S_2} + 1\right)\sin\theta$ = _____ lb (6)

Average Deceleration for One Man Aboard: $\bar{A}_0 = \left(\frac{\bar{F}_B}{C} - \sin\theta\right)\ g$ = _____ g (7)

Average Horizontal Deceleration for One Man Aboard: $\bar{A}_{HO} = \bar{A}_0 \cos\theta$ = _____ g (8)
(For Inclined Shafts Only)

Ratio $\frac{\text{Average Braking Force}}{\text{Total Material Force}}$: $\bar{R}_E = \frac{\bar{F}_B}{(C+E)\sin\theta}$ = _____ (9)

FIGURE F-5. RECOMMENDED FORMAT FOR RECORD OF ARRESTMENT DEVICE INSPECTION AND TESTING: QUALIFICATION TEST

FOR VERTICAL SHAFTS

		Check Which
If $\bar{A}$ (Item 4) is greater than 1.0 g and less than 3.0 g AND $\bar{A}_0$ (Item 7) is less than 3.0 g,	Test is	SUCCESSFUL ☐
If $\bar{A}$ and $\bar{A}_0$ are not as above,	Test is	NOT SUCCESSFUL BECAUSE OF ☐ $\bar{A}$ ☐ $\bar{A}_0$ ☐ See "ACTION"

FOR INCLINED SHAFTS

If $\bar{A}_H$ (Item 5) is greater than 0.15 g and less than 0.45 g AND $\bar{A}_{HO}$ (Item 8) is less than 0.45 g,	Test is	SUCCESSFUL ☐
If $\bar{A}_H$ and $\bar{A}_{HO}$ are not as above,	Test is	NOT SUCCESSFUL BECAUSE OF ☐ $\bar{A}_H$ ☐ $\bar{A}_{HO}$ ☐ See "ACTION"

FOR ALL SHAFTS

If $\bar{R}_E$ (Item 9) is less than 1.0, brake will not stop conveyance with rated material load aboard or attached

RATED EQUIPMENT LOAD CAN BE STOPPED? ☐ Yes ☐ No

ACTION

Determine Source of Problems, Take Remedial Action, Repeat Qualification Test } Describe Under "REMARKS"

REMARKS

[SIGNATURES]

Retain One Copy; Send One Copy to_____

RECORD OF ARRESTMENT DEVICE INSPECTION AND TESTING: EQUIPMENT DESCRIPTION

Company _____

Mine and Location _____

Shaft _____ ☐ Vertical ☐ Inclined

Compartment _____

ARRESTMENT DEVICE AND RELATED EQUIPMENT DESCRIPTION

☐ At Initial Qualification Test

☐ Notice of Changes or Modifications Only

Date _____

ARRESTMENT DEVICE

Date Installed _____ Mine Ident. No. _____

☐ New ☐ Used

Actuation Modes: ☐ Loss of Rope Tension, ☐ Conveyance Overspeed, ☐ Manual
☐ Other (Describe) _____

Actuated With: ☐ Springs ☐ Battery
☐ Other (Describe) _____

Braking Element Type _____

Does Device Compensate for Guide Wear? ☐ Yes ☐ No

Manufacturer _____ Mfg. Model No. _____

NOTE: Attach copy of device drawings and spring load-deflection curve(s), noting ready-to-actuate deflection(s) if springs are used.

CONVEYANCE

Date Installed _____ Mine Ident. No. _____

☐ New ☐ Used

Use: ☐ Men ☐ Supplies ☐ Equipment ☐ Product (Name) _____

Type: ☐ Cage ☐ Skip-Cage Combo ☐ Other (Describe) _____
☐ Dump Type

Manufacturer _____ Mfg. Model No. _____

Max. Rated Hoisting Speed: _____ ft/min = V_0	Max. Man Capacity: _____ Men
Conveyance Weight: _____ lb = C	Max. Man Load:
Max. Material Capacity: _____ lb = E	___ Men X 200 lb = _____ lb = M_0

BRAKING GUIDES

Date Installed _____

Material _____

Construction if Wire Rope

Shape and Dimensions When New

Guide Layout Looking Down Shaft

INCLINED SHAFTS ONLY

Minimum Inclination From Horizontal _____

Maximum Inclination From Horizontal _____

Majority of Shaft is Inclined _____

FIGURE F-6. RECOMMENDED FORMAT FOR RECORD OF ARRESTMENT DEVICE INSPECTION AND TESTING: EQUIPMENT DESCRIPTION

HOIST

Date Installed _____ Mine Ident. No. _____

☐ New ☐ Used

Type: ☐ Friction (Koepe) ☐ Drum

☐ One ☐ Two

☐ Cylindrical ☐ Conical

☐ Other (Describe) _____

Manufacturer _____ Mfg. Model No. _____

Safety Controls Fitted:

☐ Overspeed, Type _____

☐ Overwind, Type _____

☐ Underwind, Type _____

☐ Slack Rope, Type and Where Located _____

☐ Clutch-Brake Interlock Clutches Fitted? ☐ Yes ☐ No

☐ Dead-Man Control

☐ Other (Describe) _____

REMARKS (If Modifications or Changes are Indicated, Give Reasons)

[SIGNATURES]

Retain One Copy; Send One Copy to _____

F-15

RECORD OF WEEKLY ACTUATION TEST OF HOIST SAFETY CONTROLS

Company _____

Mine and Location _____

Shaft _____ ☐ Vertical ☐ Inclined

ACTUATION TEST OF HOIST SAFETY CONTROLS

Sheet No. _____

SAFETY CONTROLS FITTED

- ☐ Overspeed, Type _____
- ☐ Overwind, Type _____
- ☐ Underwind, Type _____
- ☐ Slack Rope, Type and Where Located _____
- ☐ Clutch Interlock Clutches Fitted? ☐ Yes ☐ No
- ☐ Dead-Man Control
- ☐ Other (Describe) _____

ACTUATION TESTS

Items checked above must be actuated manually or otherwise to determine whether they shut off the hoist motor and apply the hoist brakes.

Date	Inspector's Initials	All Actuate Correctly? Yes	All Actuate Correctly? No	REMARKS If ☑ No, Note Item, Problem, and Action Taken

(Continue on Reverse Side)

FIGURE F-7. RECOMMENDED FORMAT FOR RECORD OF WEEKLY ACTUATION TEST OF HOIST SAFETY CONTROLS

Date	Inspector's Initials	All Actuate Correctly? Yes	All Actuate Correctly? No	REMARKS If ☑ No, Note Item, Problem, and Action Taken

Retain One Copy; Send One Copy of Completed Sheet to _____

RECORD OF ABNORMAL HOISTING INCIDENT

Company _____

Mine and Location _____

Shaft _____ ☐ Vertical ☐ Inclined

Compartment _____

ABNORMAL HOISTING INCIDENT

Date _____

SUMMARY

Time _____

Shift _____

At Time of Incident Hoist Was Being Used to:

_____

_____

Equipment Damaged
☐ No ☐ Yes (Describe)

_____

_____

Hoist Safety Controls Failed?
☐ No ☐ Yes (Name)

_____

_____

_____

Men Injured
☐ No ☐ Yes (Describe)

_____

_____

Conveyance Arrestment Device Actuated?
☐ No ☐ Yes (Describe Performance)

_____

_____

CAUSE _____

DETAILED ACCOUNT

(Continue on Reverse Side - Use Additional Blank Sheets if Necessary)

[SIGNATURES]

Retain One Copy; Send One Copy to _____

FIGURE F-8. RECOMMENDED FORMAT FOR RECORD OF ABNORMAL HOISTING INCIDENT

APPENDIX G

BRAKING FORCES DEVELOPED BY SINGLE-TOOTH ONTARIO-TYPE DOGS

APPENDIX G

BRAKING FORCES DEVELOPED BY SINGLE-TOOTH ONTARIO-TYPE DOGS

Arrestment devices usually have been designed to "stop" and/or "hold" the conveyance in the event of rope breakage. Devices so designed work reasonably well for stopping ascending or slowly descending conveyances. However, when required to arrest a conveyance descending at rated speed, the devices often generate high arrestment forces that damage the devices themselves, the cages, the shaft guides, and the associated timbering. In other instances, the devices are rendered ineffective by wood spoil, which clogs the braking elements and reduces the braking force.

The chief shortcomings of such devices are three-fold:

(1) They do not provide for continuous removal of wood spoil from the wood cutting teeth.

(2) They do not properly compensate for continuous guide wear.

(3) They are not sufficiently force limited, the force generated essentially increasing as a function of conveyance speed.

Considerable investigative work to improve arrestment-device performance has been initiated by Ontario. Numerous free-fall tests were conducted (1107 as of 1952) through which the performance of many devices was observed and improvements made. The single-tooth Ontario-type dog is the result of those investigations. While the testing program was led by the Ontario Department of Mines and Northern Affairs, improvements in the performance of the arrestment devices were primarily the responsibility of the manufacturers.

The single-tooth dog developed and endorsed by Ontario's mining regulatory group is shown in Figure G-1 in its position of engagement with a new guide. The tooth is responsible for the braking force. The wood splitter, as the name implies, breaks up and diverts the wood spoil generated by the tooth. The wear pad limits the rotation of the dog and its associated actuation shaft. As the guide wears, the wear pad travels farther before contacting the guide. Thus, with guide wear, the engaged dog would have rotated farther in a counterclockwise direction than shown in Figure G-1. As the guide wears, the tooth penetrates less and the leading edge becomes more nearly perpendicular to the guide surface.

In analyzing the copious free-fall data from Ontario's tests, manufacturers and interested individuals recognized that the chief variables affecting the arrestment force developed are

(1) Tooth width, W, in.

(2) Tooth projection, D, in.

(3) Tooth rake angle, α, degrees

(4) Guide material and condition (wood).

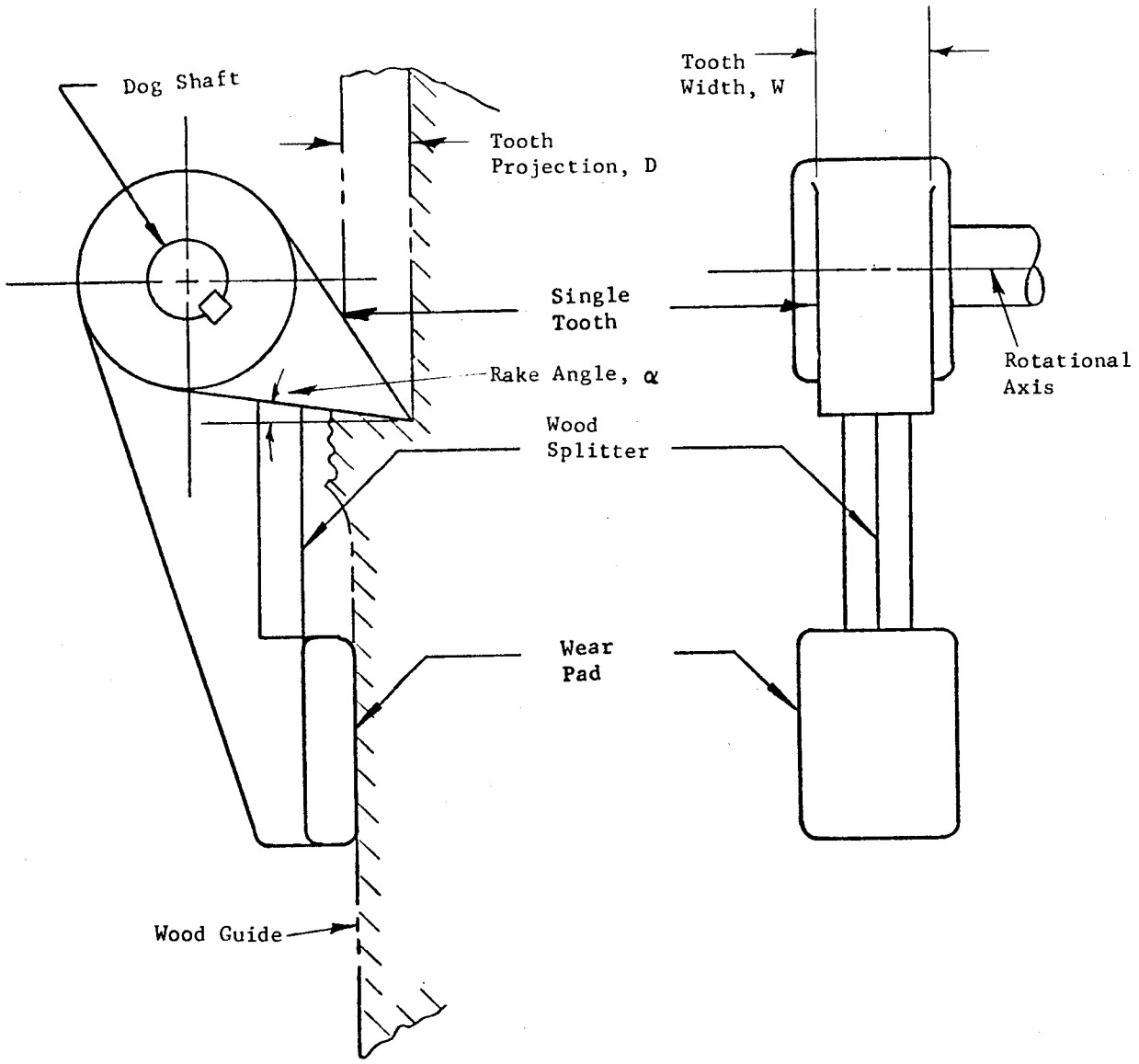

FIGURE G-1. SINGLE-TOOTH ONTARIO-TYPE DOG, SHOWING MAJOR ELEMENTS AND DESIGN PARAMETERS

Conveyance speed at actuation was not found to affect braking force.

One Canadian manufacturer developed the following empirical relationship:

$$F_B = CDW, \text{ lb} \quad , \tag{G-1}$$

where

F_B = braking force developed per tooth, lb

C = constant varying with tooth rake angle as follows:

Rake Angle	C, lb/in.
8°	4000
12°	3500
18°	3000
22°	2500

Another Canadian manufacturer developed the following empirical design equation:

$$F_B = PD + RW \quad , \tag{G-2}$$

where P and R, again, vary only with rake angle as follows:

Rake Angle	P, lb/in.	R, lb/in.
5°	2880	1865
12°	2580	1680
18°	1840	1310
25°	1530	1180

L. O. Cooper, a Canadian mining engineer, developed some force equations for double-tooth dogs.[13] These dogs are much like the single-tooth dog of Figure G-1, except that there are two teeth, side by side, separated by a wood splitter. His equation for an 18° rake angle can be written:*

$$F_B = 1730(DW) + 542(4D + 2W) \quad , \tag{G-3}$$

where D and W apply to one tooth.

Equation (G-1) correlates braking force with the projected frontal area of the tooth, while Equation (G-2) correlates with the parameters that essentially define the cutting edges of the tooth. Equation (G-3) correlates with total projected frontal area (DW) and total cutting edge. In this respect, Equation (G-2) may actually correlate with the total length of the cutting edge by including a factor of 2 in the constant associated with the (D) term.

* Coefficients have been revised from those of Reference (13) in accord with correspondence between Mr. Cooper and T. J. Baker [1] dated 10/22/55.

In Table G-1, the forces predicted by Equations (G-1), (G-2), and (G-3) are compared to forces computed from free-fall test data obtained during Battelle's visit to Ontario. The predictions of Equation (G-2) provide less error (33 percent maximum) than those of Equation (G-1) (90 percent maximum). The predictions of Equation (G-3) are best where comparison is possible, but the equation relates to a double- or paired-tooth dog, while the data relate to a single-tooth dog. This may be purely coincidental and a result of the limited comparison.

All of these equations were derived from data for free-fall tests conducted on guides of British Columbia fir or spruce. British Columbia fir guides predominate in Ontario.

As indicated earlier, guide condition and material were found to be important parameters affecting developed braking force. Some of the error in the predicted forces may result from variations in the condition of the wood guides involved. "Condition" can mean moisture content as well as quality, degree of rot, and wear. The extent to which these factors varied in the tests cannot be determined. In general, dry or frozen guides increase the braking force, whereas highly moist wood reduces it. Local density variations, such as knots, can also affect it. In general, the surface condition of the guides does not appear to have any significant effect.

Although guide material is an important parameter, no free-fall arrestment data exist for southern yellow pine, the most prevalent wood used for guides in United States coal mines. In spite of this, Equation (G-2) (considered the best) may be sufficient, at least initially. It has been determined through a discussion with a taxonomist that British Columbia fir is undoubtably a type of Douglas fir. Table G-2 lists shear, tensile, and hardness data for both Douglas fir and the four known varieties of southern yellow pine. Though the previous empirical design equations do not involve the physical properties of the wood, Battelle believes that hardness affects the initial penetration of the tooth, and that the listed shear and tensile properties govern the braking force in some complex manner.

Except for the slash pine, the pines are fairly similar in their listed properties. Also, except for the shear values at 12 percent moisture content, the first three pines are quite similar to the Douglas firs. Since the first three pines have somewhat higher shear strengths (at 12 percent moisture content), it is expected that Equation (G-2), for example, would predict somewhat lower braking forces than might actually develop.

TABLE G-1. COMPARISON OF ACTUAL AND PREDICTED BRAKING FORCES

Case No.	Tooth Parameters: Projection D, in.	Tooth Parameters: Width W, in.	Tooth Parameters: Rake Angle α, degrees	Guide Material	F_B = Braking Force per Dog, lb: Test F_B[a]	Equation G-1: F_B	Equation G-1: % error	Equation G-2: F_B	Equation G-2: % error	Equation G-3: F_B	Equation G-3: % error
1	1-1/16	1-1/4	12	fir[b]	4630	4648	≃ 0	4841	+5	--	--
2	1-1/16	1-1/4	12	fir	4028	4648	+15	4841	+20	--	--
3	1-3/16	1-1/4	12	fir	4810	5195	+8	5141	+7	--	--
4	1-3/16	1-1/4	12	fir	5896	5195	-12	5141	-13	--	--
5	1-1/8	1-1/4	12	fir	5316	4922	-7	5003	-6	--	--
6	1-3/8	2-1/4	12	fir	7462	10828	+45	7328	-2	--	--
7	1-3/8	2-1/4	12	fir	8065	10828	+34	7328	-9	--	--
8	1-1/4	3-3/4	12	fir	8648	16406	+90	9525	+10	--	--
9	1-1/4	3-3/4	12	fir	11212	16406	+46	9525	-15	--	--
10	1-1/16	1-1/4	18	fir	5359	3984	-26	3592	-33	4127	-23
11	1-1/16	1-1/4	18	fir	5150	3984	-23	3592	-30	4127	-20
12	1	3/4	18	spruce	2563	2250	-12	2823	+10	2788	+9
13	1	3/4	18	spruce	3140	2250	-28	2823	-10	2788	-11

(a) Braking force computed from free-fall test data.
(b) British Columbia fir.

TABLE G-2. SHEAR, TENSILE, AND HARDNESS PROPERTIES OF SOUTHERN YELLOW PINES AND DOUGLAS FIR(56)

	Shear Strength Parallel to Grain, Maximum Strength, psi		Tensile Strength Perpendicular to Grain, Maximum Strength, psi		Hardness Load to Embed a 0.444-in. Ball to 1/2 its Diameter, psi	
Douglas Fir:[a]						
Coast Type (Pseudotsuga menziesii)	1160 (12)[b]	930 (38)	340 (12)	300 (38)	710 (12)	500 (38)
Intermediate Type (P. menziesii)	1130 (12)	890 (48)	340 (12)	300 (38)	600 (12)	450 (48)
Rocky Mountain Type (P. menziesii variety glauca)	1070 (12)	880 (38)	330 (12)	350 (38)	630 (12)	400 (38)
Pine, Southern Yellow:						
Loblolly (Pinus taeda)	1370 (12)	850 (80)	470 (12)	260 (81)	690 (12)	450 (80)
Longleaf (P. palustris)	1500 (12)	1040 (63)	470 (12)	330 (63)	870 (12)	590 (63)
Shortleaf (P. echinata)	1310 (12)	850 (81)	470 (12)	320 (81)	690 (12)	440 (81)
Slash (P. elliotii)	1730 (12)	1000 (66)	570 (12)	400 (81)	1010 (12)	630 (66)

(a) The three types are no longer considered taxonomically distinct.
(b) All numbers in parentheses denote percent moisture content.

THE FOLLOWING PAGES ARE DUPLICATES OF ILLUSTRATIONS APPEARING ELSEWHERE IN THIS REPORT. THEY HAVE BEEN REPRODUCED HERE BY A DIFFERENT METHOD TO PROVIDE BETTER DETAIL.