

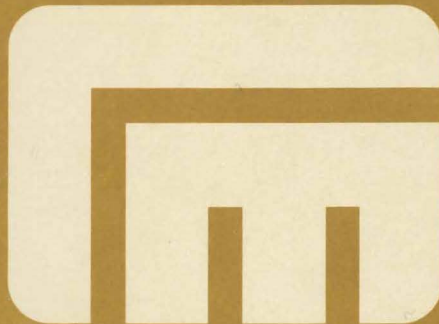


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Coal Mine Escape Hoist
Standards

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Final Report

Coal Mine Escape Hoist
Standards

by
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Under
USBM Contract HO 133020

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The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies of the Bureau of Mines or the U.S. Government. U.S.B.M. Information Circulars, and Reports of Investigations, and American Standards Association specifications and procedures have been used for background and source information and are properly referenced.

FOREWORD

This research program was initiated under the Coal Mine Health and Safety Program of the U.S. Bureau of Mines. The technical project officer was Mr. William Kleysteuber, and the contract administrator was Mr. Joseph Herickes. The program manager at Foster-Miller Associates, Inc. was Mr. Randy Berry.

ACKNOWLEDGMENTS

The successful completion of this program is the result of a team effort involving the engineers and consultants at Foster-Miller, the Mining and Safety Research Center of the U.S.B.M., and the Coal Mine Health and Safety division of MESA.

Messrs. William Kleysteuber and George Susko provided invaluable technical assistance throughout the project and were particularly helpful during the final development of the guidelines.

The nine MESA District Managers generously supplied us with information on emergency hoist locations and the local needs and difficulties encountered by the mines in their districts.

Cecil V. Peake, a consultant for Foster-Miller provided the necessary research into worldwide escape hoist practices.

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SUMMARY

Foster-Miller Associates has developed a set of guidelines to permit hoist manufacturers, mine owners, and MESA mine inspectors to design, purchase, install or inspect a safe and effective Emergency Escape Hoist, as required by the Coal Mine Health and Safety act of 1969.

A series of surveys were carried out to determine:

1. The attitudes and local needs of the MESA District Managers.
2. Current escape hoist installations.
3. Equipment available for future designs.
4. Foreign methods and equipment for mine rescue.

From these survey studies, preliminary guideline objectives were developed.

An investigation into previous research and present standards for hoisting equipment, and the unique requirements of emergency hoists produced a set of precise, straightforward and enforcable guidelines. Continued contact with sources in the mine industry, and the Bureau of Mines provided the "practical" feedback needed to ensure a realistic set of hoist guidelines.

As a parallel effort to the development of the guidelines, a complete design of an acceptable, economic and structurally sound Emergency Hoist was developed. The final design has been based directly on the requirements specified in the guidelines.

1. Introduction

This report is submitted in fulfillment of the requirements of USBM Contract No. HO 133020, "Coal Mine Escape Hoist Standards". Under this contract a research investigation to determine the requirements of emergency hoist systems has been carried out.

1.1 Background

In the tragic history of coal mine disasters, situations have often occurred in which men are trapped below ground because the regular hoist facilities have been disabled. Such disasters have been well documented (3, 4)* and examples of damage to surface installations are presented in Figures 1 to 3. In numerous instances, make shift and jerry-rigged hoisting buckets were used to send rescue teams into the mine to aid in the evacuation of trapped miners. Typical "emergency hoists" are pictured in Figures 4 and 5.

The rapid evacuation of miners under all conceivable mine emergencies such as local power failures, loss of ventilation, mine fires or explosions has become a major concern throughout the mining industry. The Federal Coal Mine Health and Safety Act of 1969 (P. L. 91-173, 83 Stat. 742) contains a provision for the installation of escape facilities in shafts or slopes to permit rapid evacuation in case of emergency. Section 75.1704, as quoted in Appendix A, states that every designated escape shaft deeper than 20 feet shall include a hoist and cage, or similar equipment. No specific technical requirements or standards for the emergency escape hoist exist other than Section 75.1400 - Hoisting Equipment, General of (1).

Several sets of escape hoist guidelines were prepared prior to this research program (Appendix B - D). These guidelines were developed by several of the MESA District Managers for use in their districts and do not represent a uniform enforceable set of hoist requirements; they are not part of the law and hence cannot be used for issuing violation notices. As a result, Foster-Miller Associates was contracted to investigate present emergency hoist installations and equipment, and

*Numbers in parenthesis are references listed in Bibliography.

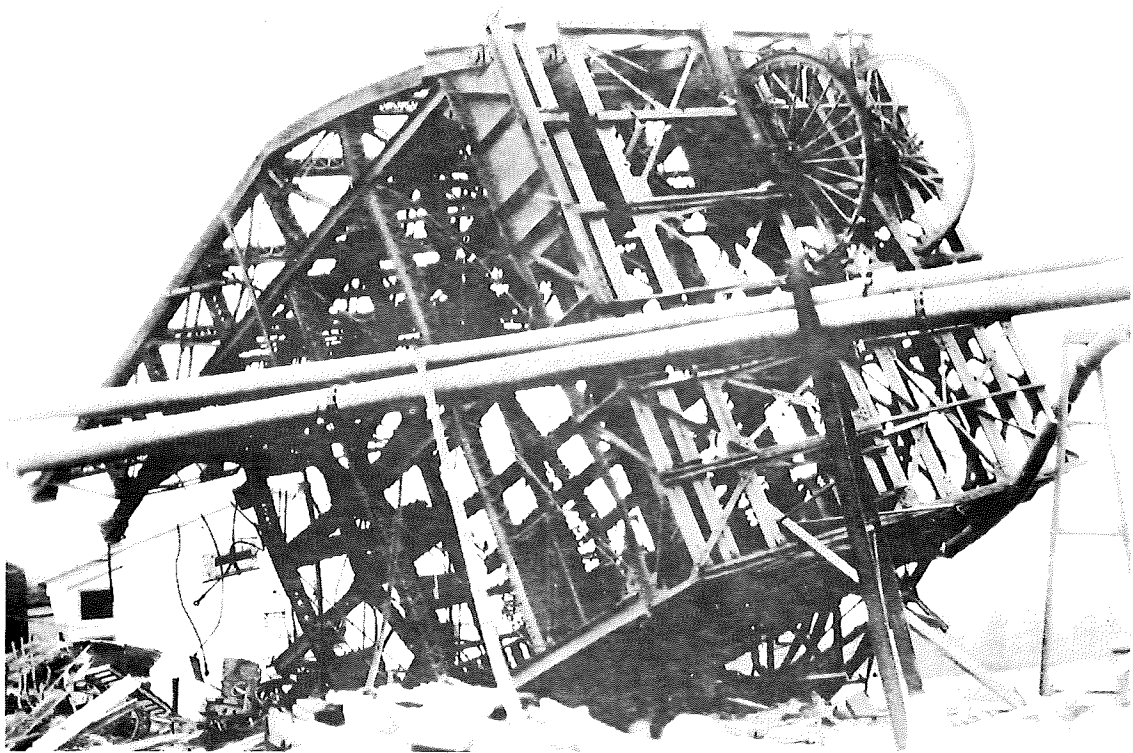


Figure 1. Headframe of Woodward No. 3 Shaft, Edwardsville, Pa., After Explosion, May 26, 1927.

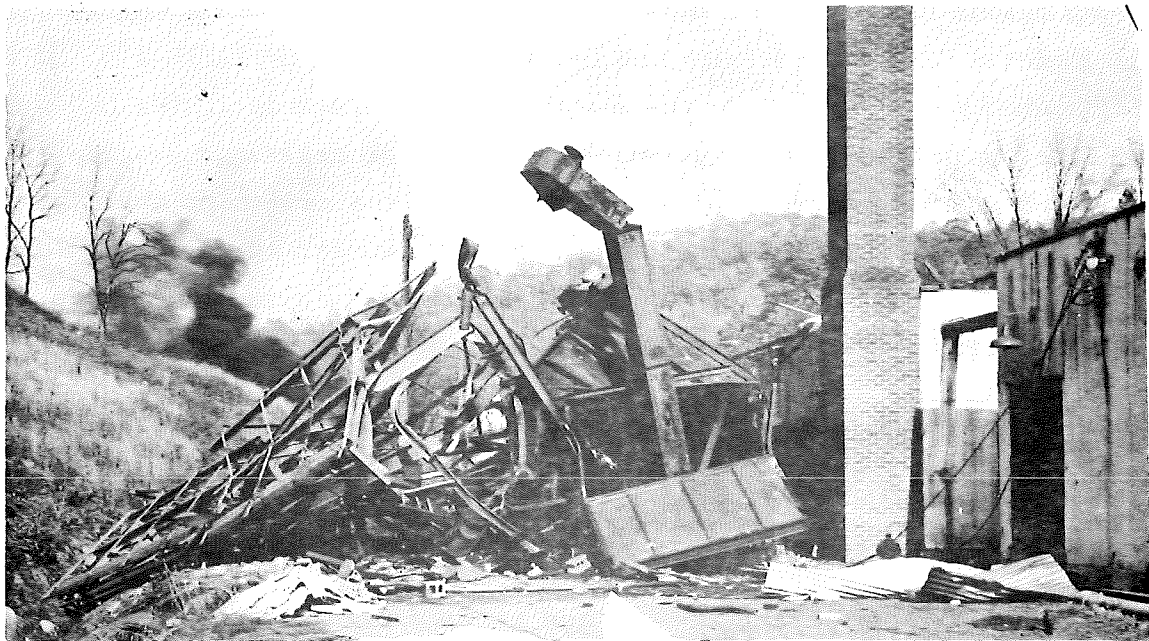


Figure 2. Headframe From Manshaft, Blown From Other Side of Building on Right, Jamison No. 9 Mine, Farmington, W. Va., November 13, 1954



Figure 3. View of Damage to Moore-Shaft Headframe and Truck with Winch and A-Frame After Explosion, Marianna No. 58 Mine, Marianna, Pa., September 23, 1957.

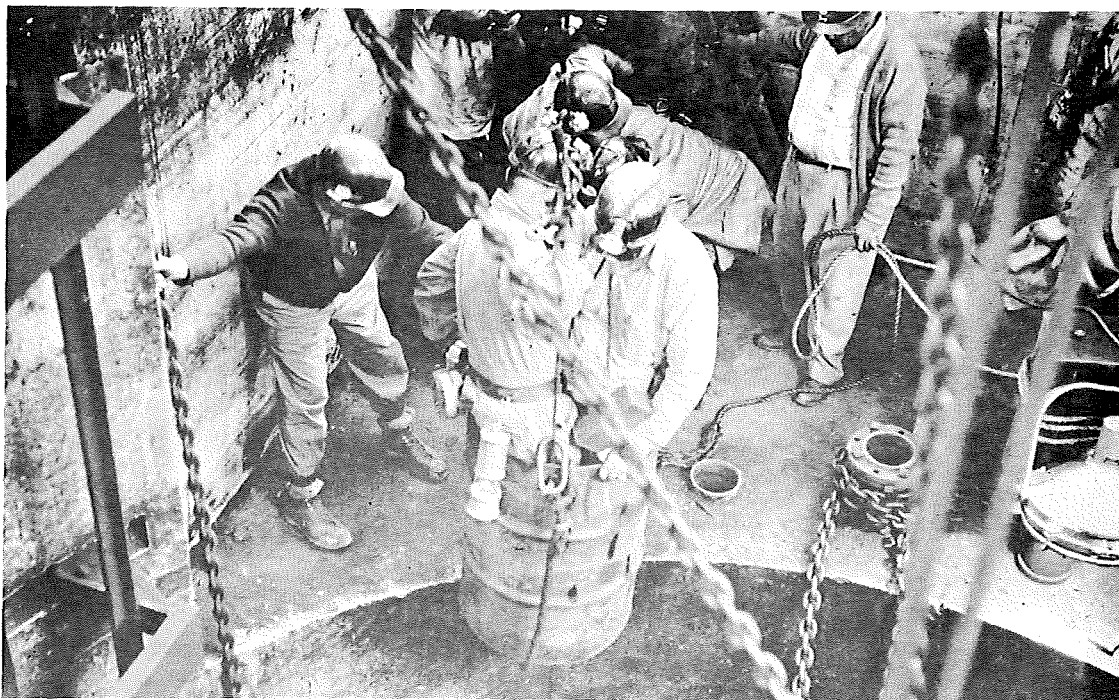


Figure 4. Rescue Officials Preparing to Enter Moore Shaft in Oil Drum Rigged for Emergency Hoisting Following Explosion, Marianna No. 58 Mine, Marianna, Pa., September 23, 1957.

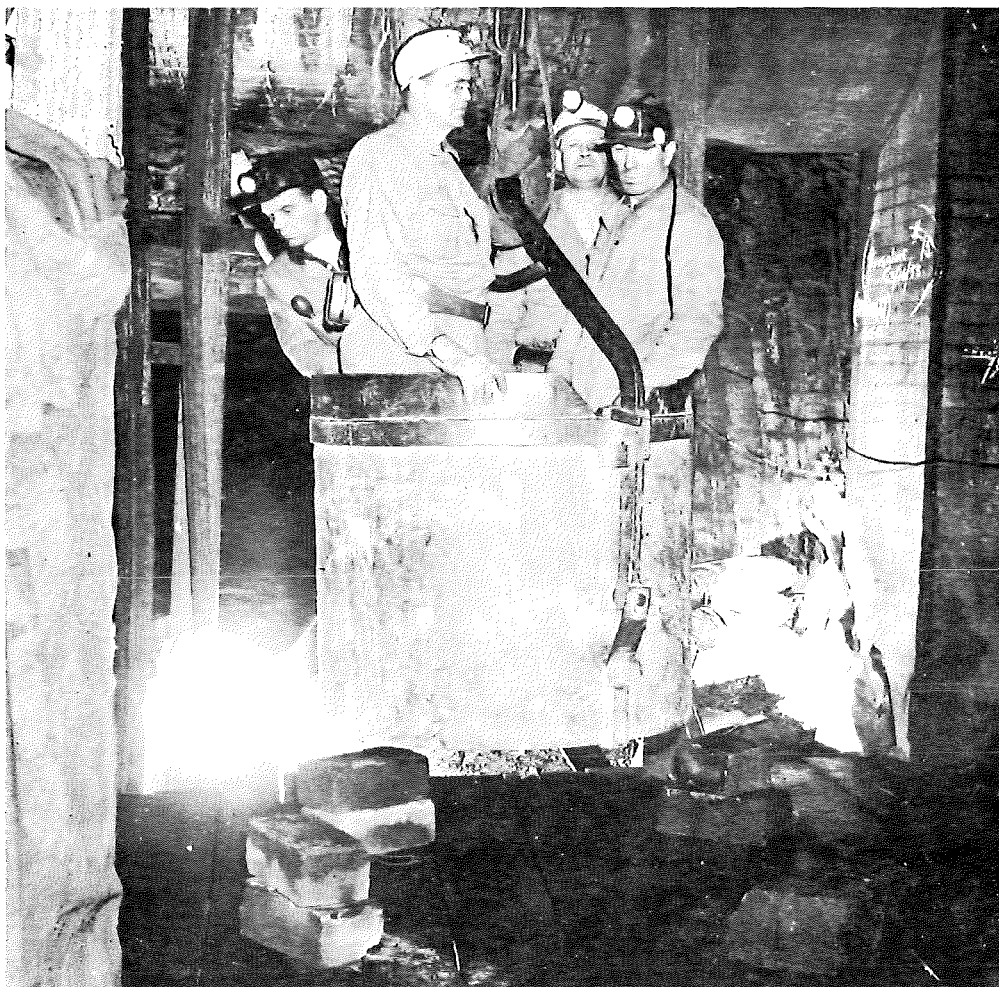


Figure 5. Bottom of Manshaft During Recovery Operations, Jamison No. 9 Mine, Farmington, W. Va.

to develop a detailed set of guidelines for their proper design, operation, and enforcement.

1.2 Contract Objectives

The objective of this contract is to develop guidelines suitable for the selection and evaluation of emergency escape systems and to establish criteria for their safe and reliable installation and operation. These guidelines are based on survey studies, interviews, site visits and in house research into the requirements of an emergency hoist. To illustrate the composition of the proposed guidelines, a design effort is included to evaluate alternative hoisting concepts and recommend an acceptable system.

2. Research Surveys

The investigation into Emergency Hoist installations and practices began with interviews with the Washington office of MESA and the nine MESA District Managers. A survey was made of all currently installed emergency hoists and presented in an Interim Report, "State of the Art for Coal Mine Escape Hoist Standards" (25). A survey of equipment presently available for future hoist designs was presented in the Interim Report, "Equipment Available for Use in Coal Mine Emergency Escape Hoists" (26). A study of methods and equipment used in foreign mine emergencies was carried out to determine what has been done and what is available from foreign sources.

These surveys, interviews, and later site visits provided a general background for the development of the proposed guidelines. The surveys of hoist installations and equipment available are summarized in this section. Conclusions of the interviews with MESA District Managers and the study of foreign methods and equipment are presented fully.

2.1 Survey of MESA District Managers

The first major activity of this program was to visit each of the nine MESA district managers. These visits were conducted to obtain:

An over view of the emergency hoist installations in each district.

An assessment of the particular or unusual escape facilities and requirements of mines in each district.

The opinion of senior MESA field personnel as to what regulations should be formulated to govern the installation and operation of emergency hoists.

An assurance of MESA cooperation relative to the on-site inspection of hoist installations which was to follow.

In most of the districts, FMA personnel interviewed the District Manager and those members of his staff most knowledgeable concerning the emergency hoist installations in that district. The following represents a summary of the views elicited on the design of Emergency Hoists.

2. 1. 1 Hoist Location

A location on intake air is desirable though not essential. Any hoist operating in a fan housing should not interfere with the regular mine ventilation. There was some feeling that hoists in fan housings operate through double air locks to guarantee no disruption to the mine ventilation.

2. 1. 2 Mobility

Some districts did not favor the use of mobile hoists, but all recognized the increased flexibility of a mobile unit. Though mobile units can reach several shafts if needed, a general preference for permanent installations (or permanently stationed mobile units) was expressed. The advantages of accurate hoist control, adjustment, and lack of confusion about where the escape hoist is stationed favored permanent installations.

2. 1. 3 Power Supply

Some District Managers preferred internal combustion engines, citing an unreliable local power supply, while others preferred electric power citing the problems of maintenance and vandalism of I. C. engines in remote locations.

2. 1. 4 Cage Size

No strong feelings existed on a specific or minimum cage size. All requested that at least two men and a stretcher be accommodated and some preferred room for at least four.

2.1.5 Hoist Response Time

Thirty minutes was a generally accepted requirement for getting the hoist operational, though one district considered this time excessive.

2.1.6 Flexibility of the Guidelines Developed

A wide range of opinions on the degree of flexibility of the guidelines was expressed. Some Districts wanted rigid statutes that permit an inspector to enforce compliance, and leave little room for interpretation by the individual District Managers. Others preferred flexible regulations which place most of the responsibility for interpreting and implementing the guidelines in the hands of the District Manager.

2.2 Survey of American Emergency Hoist Installations

A "State of the Art" Survey of existing Emergency Hoist Installations was carried out during the first six months of the research effort and was presented in the interim report "State of the Art Report for Coal Mine Escape Hoist Standards", December, 1973 (25). The primary objective of this survey was to locate, interview and inspect emergency hoists that are currently installed. Ninety installations were identified using three different sources: the survey of the nine MESA District Managers, our contact with hoisting equipment manufacturers, and by direct contact with coal mine operators and industry officials. These installations were studied in detail and mine superintendents and/or mine safety officials were interviewed relative to specific design and construction. Approximately 50% of these installations were selected for on-site inspection. These inspections revealed the problems encountered in large and small mines, shaft depths ranging from 40 feet to 840 feet; hoists operating on intake and return air, through fan housings, and at remote locations. The survey results are presented fully in the Interim Report and are summarized briefly as follows:

2.2.1 Survey Summary

The existing escape hoist installations were categorized by method of construction and component design.

Method of Construction:

1. Units purchased as a complete package --9% of total
2. Modified cranes --15%
3. Units fabricated from standard components --44%
4. "Home-built" units -- usually put together from used
or re-conditioned components --32%

Component Design

1. Power Supply

Self-Contained:	66%*
Outside Utilities:	32%
Unknown:	2%

2. Winch Drive Mode

Hydraulic:	17%
Direct:	70%*
V-Belt:	4%
Unknown:	9%

3. Shaft Type

Intake:	85% *
Return	11%
Escape or Other	4%

*Categories with asterisks include all 24 of the Consol units in northern West Virginia, which amounts to 27% of all installations.

4. Hoist Location

Fixed	92%*
Mobile	8%

5. Bucket Type and Capacity

Type: Open	37%*
Closed	43%
Unknown	20%
Access: Freely suspended over shaft:	47%*
Swings away from Shaft	32%
Secured in shaft	13%
Through explosion doors	7%
Capacity: 1 - 2 men	10%
3 - 4 men	49%*
5 or more	20%
Unknown	21%

6. Communications

Number: At least one installed system	74%*
Two or more systems	18%
None	26%
Type: Standard Mine phones	65%*
Special phones	16%
Whistle, horn, bell	12%
Other	6%

7. Safety Controls on Winch

Overwind	29%
Overspeed	17%
Brake on winch <u>drum</u>	52%*
Dead man switch	8%
Mechanical depth indicator	19%
Guide ropes or rails	12%

*Categories with asterisks include all 24 of the Consol units in northern West Virginia, which amounts to 27% of all installations.

2.2.2 Survey Conclusions

Major objections to the design of present installations lay in the following areas:

1. Lack of adequate safety controls in manually operated units.
2. Inadequate bucket construction.
3. Inadequate landing facilities or safe means for getting out of the bucket.

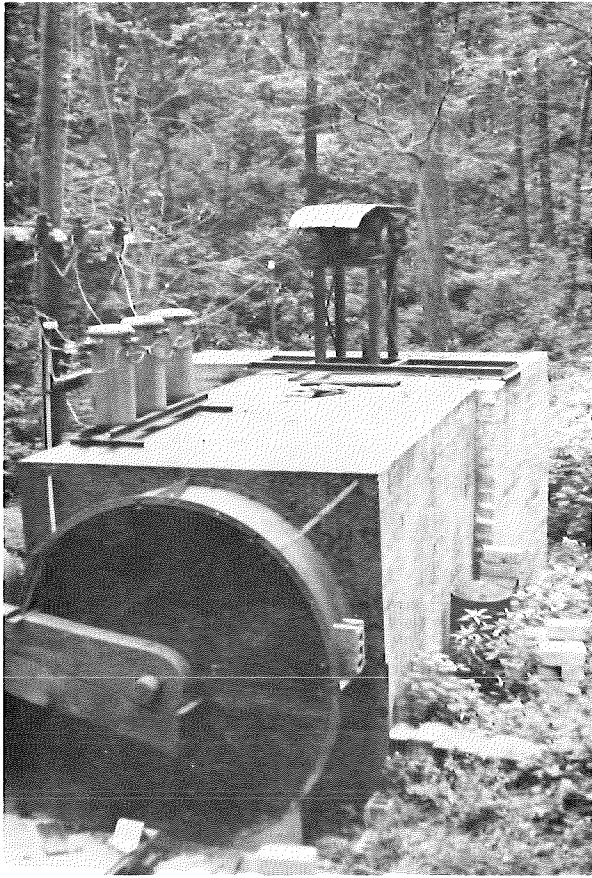
The quality of individual installations varied greatly. Automatic elevators were installed at a few mines, but most "escape hoists" were clearly unsafe, and many were inoperative. Over 90% of the installations visited were unsatisfactory in at least two of these three categories.

This survey indicated that a consistent and uniform set of hoist regulations should be instituted. Variations in the specific guidelines issued by the MESA District Managers has created confusion for the mine operators and potential escape hoist manufacturers. Lack of a coordinated enforcement policy has produced only a small number of hoists which could operate safely and reliably in a mine emergency. Six of the installations visited are illustrated in Figures 6 - 11. The reader is referred to the Interim Report (25) for a detailed description of these and all other current emergency hoist installations.

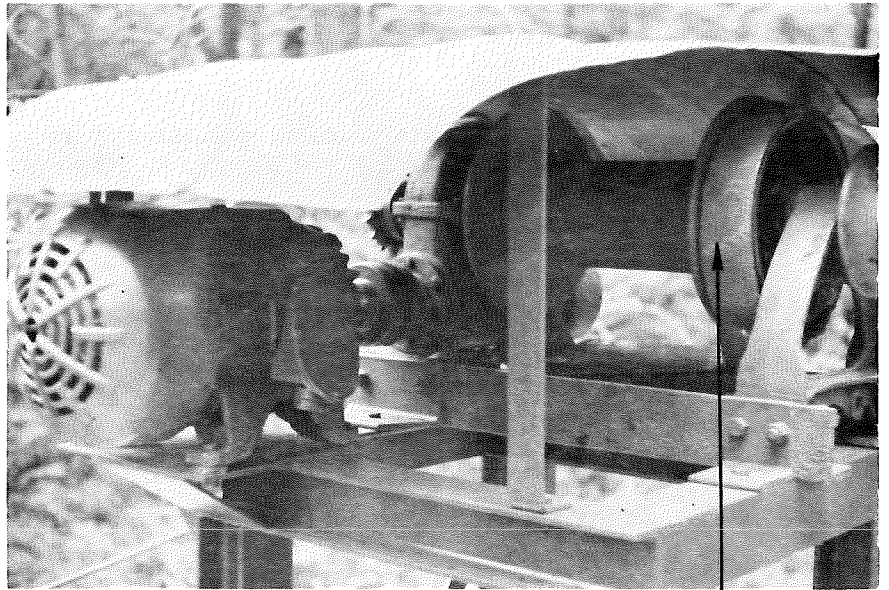
2.3 Survey of Equipment Available for Emergency Hoists

2.3.1 Survey Summary

A survey of the manufacturing industry was performed as a requirement of this research contract and was presented in the Interim Report, Equipment Available for Use in Coal Mine Emergency Escape Hoists, January, 1974 (26).



Return Air Shaft

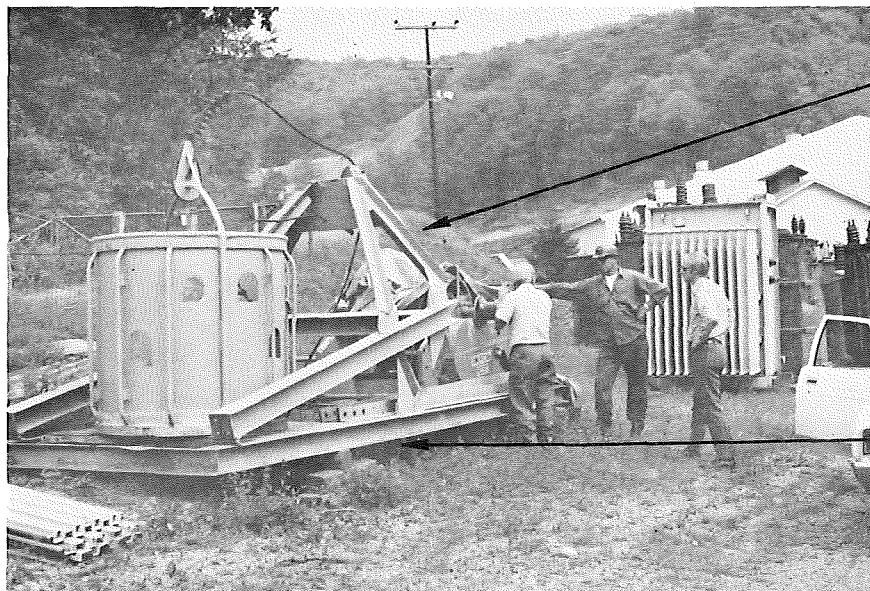


Band Brake

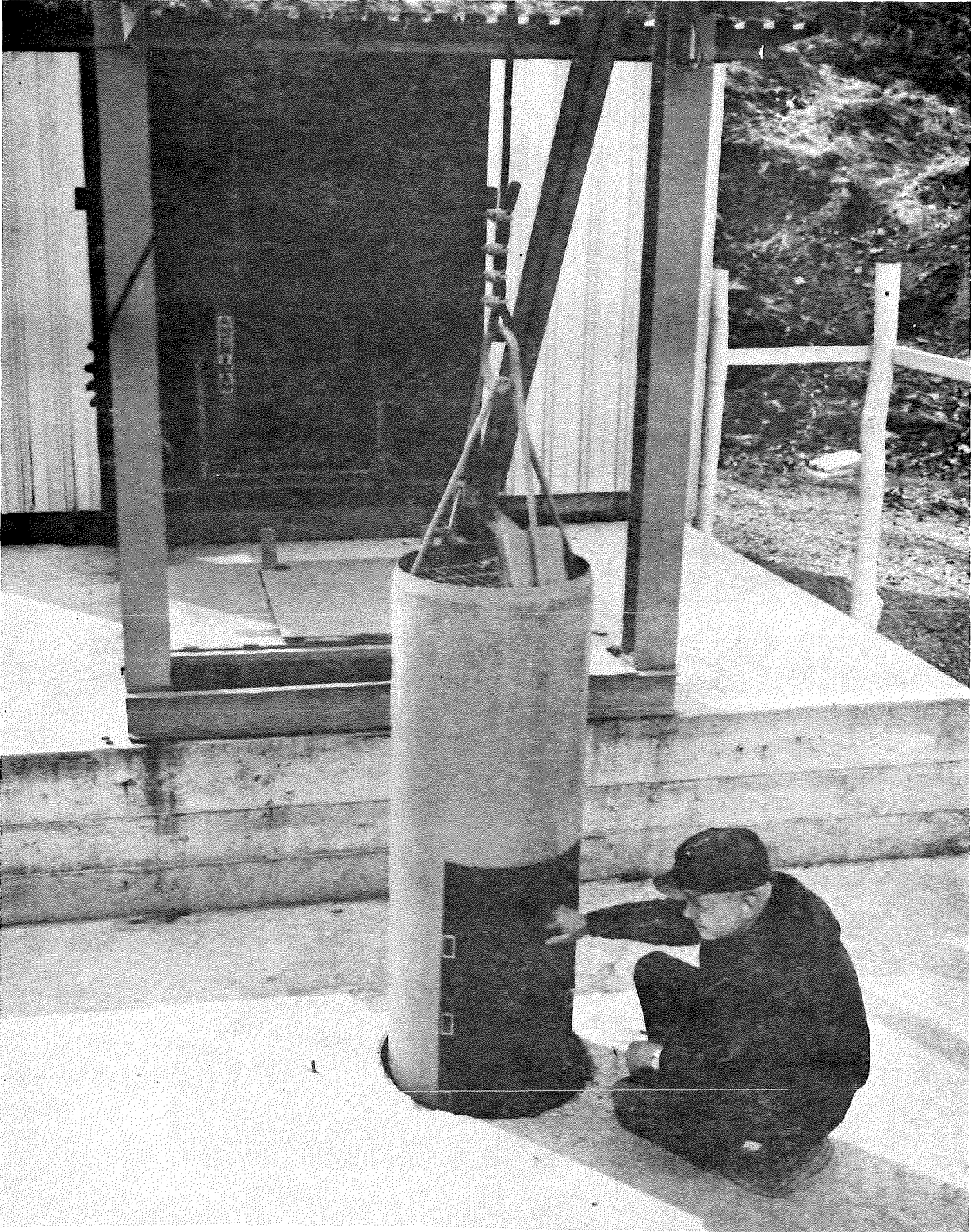
Christopher Fuel Corporation

Christopher No. 5 Mine

Figure 6



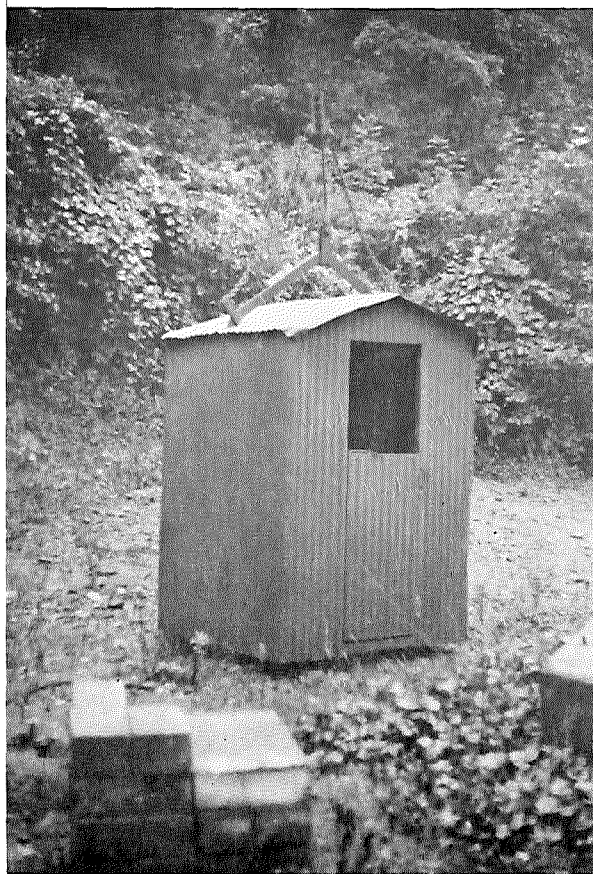
Consolidation Coal Company
Christopher No. 8 Shop, Stand-by Mobile Hoist
Figure 7



Consolidation Coal Company, Christopher Division

Osage Mine (Rescue Shaft)

Figure 8

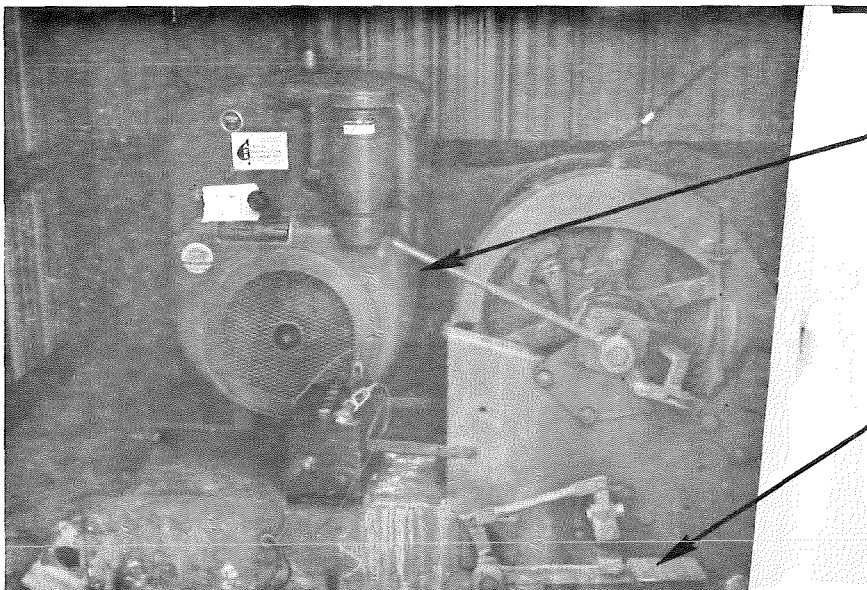
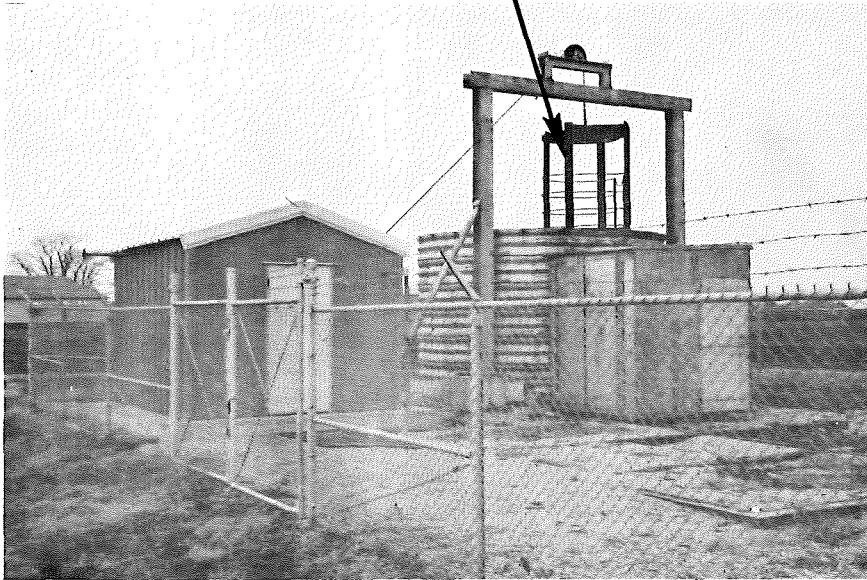


Eastern Associated Coal Corporation

Federal No. 1 Mine

Figure 9

Bucket Over Shaft



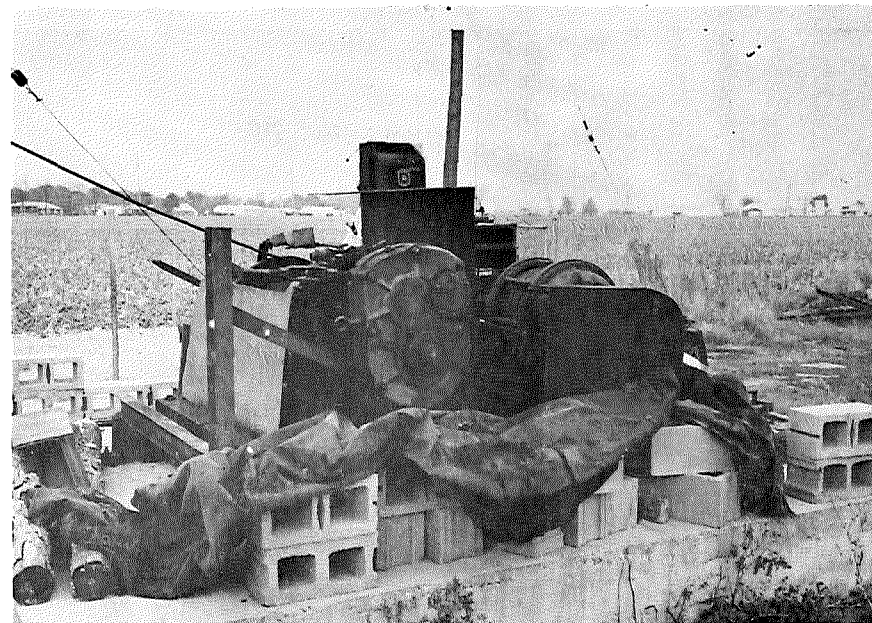
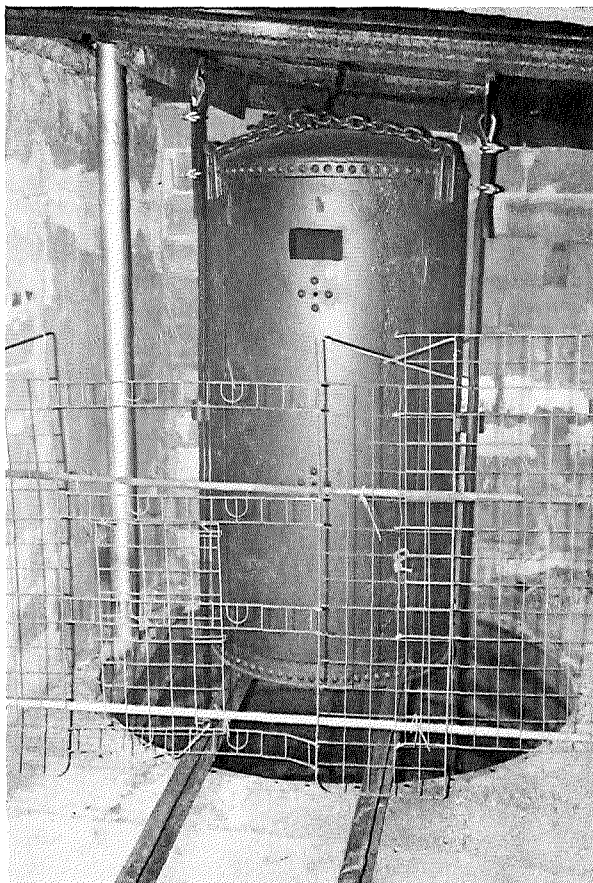
Clutch
Lever

Brake Pedal

Peabody Coal Company

No. 10 Mine

Figure 10



V-Day Coal Company

V-Day Mine

Figure 11

This survey provided detailed information on complete emergency hoist packages as well as equipment and components presently available which could be used as part of future emergency hoist designs. This information was gathered through interviews with representatives of the USBM and MESA, coal mine operators, equipment manufacturers and through field visits to inspect equipment. Advertisements, catalogues, and indexes of manufacturers were additional sources of information. A comprehensive investigation, including on-site inspections, was made of all the complete emergency hoist packages currently available. In addition, a general survey was undertaken to examine typical pieces of equipment which could be used in building an emergency hoist. The categories of equipment included:

1. Mobile, Materials Handling Cranes
2. Hydraulic Pedestal Cranes
3. Stiff-legged Derricks
4. Jib Cranes
5. Hoists (including power supply, winch and controls)
6. Winches
7. Controls, Interlocks and Limit Switches (including Lilly and Simplex Controllers)
8. Automatic Elevator Controls

The seven suppliers of packaged emergency hoists (see Appendix E) provided installed or operator-installed units costing \$20,000 - \$50,000. It was estimated from the component surveys that purchased parts for a minimum escape system could be obtained for as little as \$10,000 excluding fabrication and installation labor.

2.3.2 Survey Conclusions

The information collected in this survey provided the background necessary to develop standards and guidelines relative to the operation and maintenance of emergency hoists. Further, the survey results provide the mine operator with the information he will need to select equipment for future hoist installations. Components and

complete systems are presently available that permit a large degree of design flexibility for any potential installation. The reader is referred to the Interim Report (26) for a complete description of the components and systems available.

2.4 Foreign Requirements and Equipment Used for Emergency Evacuation of Mines

A study was made of foreign experience with the emergency evacuation of shaft mines. The principal objective was to investigate hoisting systems, currently available, that could be used for emergency hoists in U.S. mines. Foreign experience, regulations, and standards for emergency hoisting could also provide background for the guidelines developed for U.S. coal mines.

2.4.1 Summary of Emergency Evacuation Requirements

This study revealed that emergency escape systems are not well regulated and, in most countries, ladders are the only method of evacuation required. Ladders are required in Germany, Holland and Australia but no provision for emergency evacuation is required in Sweden or Poland. In South African and Zambian mines where flooding is considered a greater hazard than fire, water tight doors and ladders are provided. In Great Britain, however, emergency evacuation (egress) is well regulated, and mobile power supplies and a gravity-winding system are used to evacuate mines during a power failure or emergency.

"The owner of every mine shall ensure that there is at all times in force a scheme providing for the provision and maintenance of apparatus for affording to persons employed below ground in the mine, means of egress in an emergency for the purpose of such apparatus being constantly available for use in an emergency in the event of the mechanically operated winding apparatus failing to function." (8)

The Mines (Emergency Egress) Regulations (8) also require the systematic examination and testing of the apparatus, and for training and practice in its use.

2.4.2 Emergency Hoist Equipment Used in Great Britain

There are two distinct emergency hoist systems currently available in Great Britain: mobile emergency "winding engines" and gravity-winding systems. Twenty-three emergency "winding engines" are located throughout the country. They are diesel powered, electrically driven winches capable of operating to depths of 3,600 feet. A typical unit is illustrated in Figure 12. The winding shafts at each colliery are equipped with the following:

1. A hard access road
2. An emergency conveyance (cage)
3. A concrete pad to secure the mobile winding engine
4. A pulley and headframe permanently installed.

In operation, the mobile "winding engine" is brought to the shaft and secured to either the emergency conveyance or to the regular man lift in the shaft.

Gravity winding systems have been mandated since 1970 to eliminate the time required to transport and set up the mobile "winding engines". In this system, the regular hoisting cage and the counterweight compartment are provided with tanks or inflatable water bags. If a power failure occurs while men are underground, men enter the hoist cage, and the counterweight compartment is filled with water. The men are raised when enough water is added to offset their weight. The hoist speed is controlled by the regular hoisting brake. The gravity winding concept is discussed more fully in the Design section 4.3.2.

2.4.3 Potential Applications for U.S. Emergency Escape Hoists

Gravity winding is a safe and effective means of operating a counterweighted man-lift after a power failure has occurred provided that the hoist is still operational. There is no guarantee, however, that the regular hoisting conveyances will be operational after

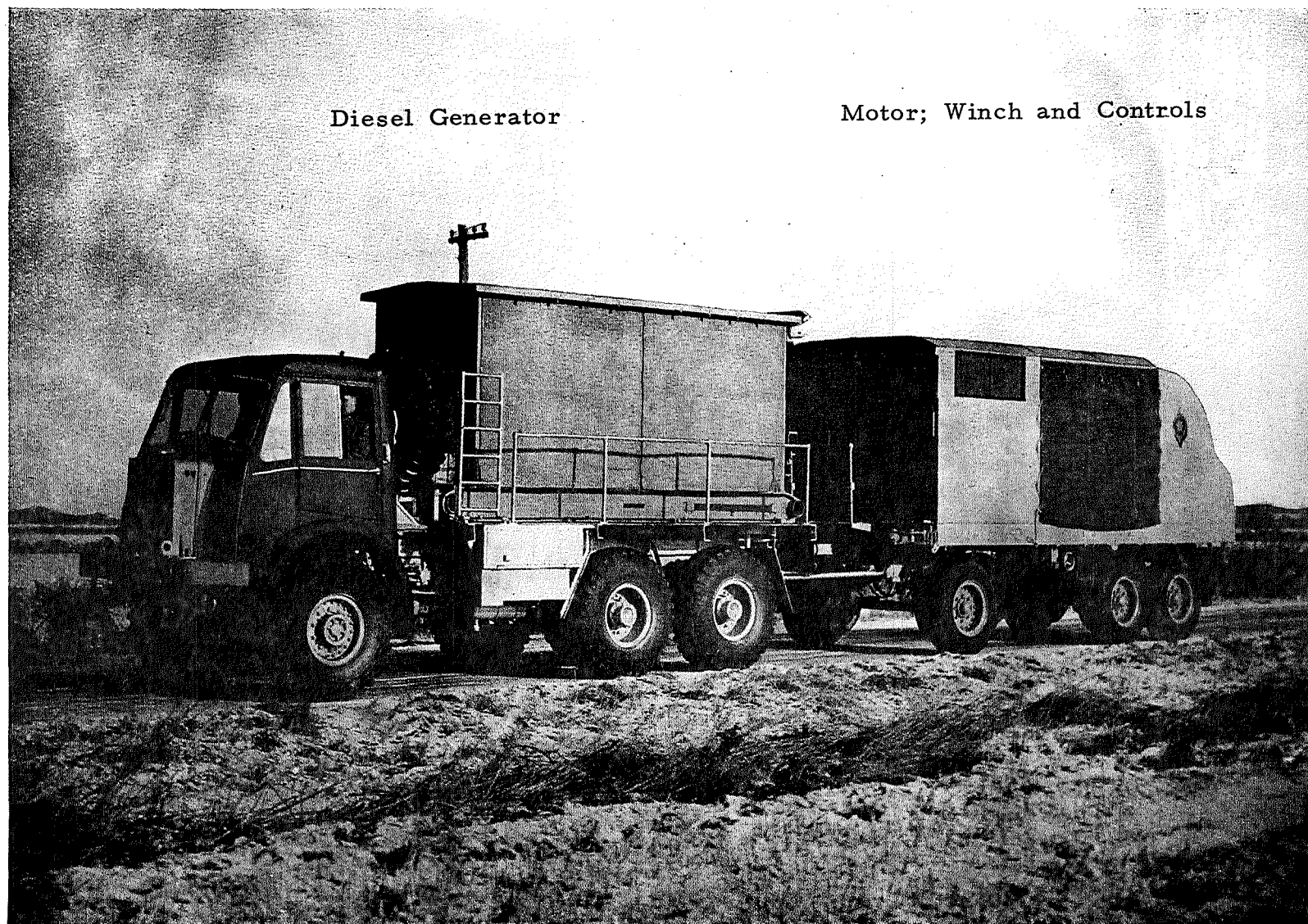


Figure 12. Mobile Emergency Winding Engine Used in the United Kingdom.

a mine emergency. The gravity winding system currently used in Great Britain can not provide "fail-safe" operation. The emergency mobile winding engines, coupled with the platform, headframe and cage provided at the colliery can ensure that men underground will be evacuated under all conceivable emergency conditions. The transportation and set-up time are the major disadvantages of the mobile winders. It is unlikely that an economic system of mobile units in the U.S. could be designed that enables miners to be rapidly evacuated.

2.5 Preliminary Guideline Objectives

As a result of the inspections of current installations and through discussions with the MESA District Managers and other Bureau and industry sources, a short set of minimum functional requirements for any emergency hoist installation was developed (see Table I). These requirements outline the type of hoist design and the operational requirements that are necessary to guarantee the safe operation of the emergency hoist. During the second portion of the research, each of these objectives was investigated and eventually expanded into one or several guidelines. Once the objectives were established, the main research effort lay in specifying the hoist requirements in sufficient detail to avoid ambiguities, provide straightforward inspection and maintenance requirements, and to prevent any substandard design from being accepted.

Table I . Preliminary Guideline Objectives

1. An emergency hoist must be available within a short period of time.
2. The hoist should not interfere with mine ventilation.
3. Adequate illumination must be specified.
4. Power to the hoist should be independent of mine power.
5. Drive train should be direct and not allow slippage.
6. The hoist must be protected and maintained ready for use under all conditions.
7. The cage must protect its occupants and have a minimum size required.
8. The wire rope should have a conservative safety factor, be non-spin type, and include safety chains.
9. The cage and headframe must be stored clear of the shaft to prevent damage during an explosion.
10. A manual or automatic hoist control is acceptable as long as a depth indicator, overspeed and over and underwind protection are installed.
11. Two brakes should be provided; one operating as a safety brake on the winch drum.
12. Two forms of communication from the passage level to the surface should be provided.
13. Regular maintenance and servicing must be required, but should rely on the manufacturer's specified maintenance procedures when possible.
14. Some form of "proof test" to demonstrate the safe operation of the hoist to a MESA official is essential.

3. Emergency Hoist Guidelines

3.1 Scope of Proposed Guidelines

The guidelines proposed for Emergency Escape Hoists, are applicable to all U.S. underground coal mines. Because there is a great diversity in shaft depths, concentration of working areas, shaft locations, distance from the working face, and available hoist equipment, the guidelines have concentrated on the functional requirements of the hoist. Specific requirements on size, loadings, dimensions, etc. have been kept to a minimum.

The guidelines have allowed for the fact that the Emergency Hoist will be operated under conditions of high stress both on miners to be rescued and the Hoist operator. The safety controls required on the Hoist have been combined so that, under no circumstances, can negligence by the Hoist operator produce a catastrophic failure of the Hoist. Cage loading and unloading is planned to provide safe access for miners who might be dazed, disoriented or injured.

To compensate for the need to reduce specific design specifications to a minimum, an "Operational Test" procedure has been included to better demonstrate and check the operation of Emergency Hoist installations by a MESA inspector at each hoist inspection.

3.2 Definition of Emergency Hoist Components

For clarity each of the major emergency hoist components will be defined prior to the presentation of the hoist guidelines. This procedure is intended to eliminate any ambiguities which may arise from the use of these terms in the guidelines.

3.2.1 Emergency Rescue Hoist

The Emergency Rescue Hoist is an auxiliary unit, designed and constructed explicitly to satisfy the federal requirements for

escapeways in shafts greater than 20 feet deep. It is not used regularly as a man or materials lift, or used in regular mine maintenance operations. Section 75.1704 of (1)

3.2.2 Emergency Escape Shaft

The escape shaft at which the Emergency Hoist is located may be any mine ventilating shaft (including return shafts), or a specially prepared shaft planned and located for emergency escape use. Acceptance of common mine operating shafts for emergency use will be based upon the emergency evacuation plan and approved by the District Manager (MESA).

3.2.3 Power Supply

The power supply is a prime mover which produces shaft power to drive the hoist. It includes any fuel or other power source needed to power the drive mechanism and the required operating and safety controls needed to ensure safe operation.

3.2.4 Winch Assembly

The winch converts the shaft output of the power supply to a line pull on the hoisting wire rope. The winch drum spools rope during the hoisting operation. Any gear reduction, clutch, transmission, or pumping systems which transmit power from the power supply to the winch drum are considered part of the winch.

3.2.5 Wire Rope

The wire rope transmits the lifting force from the winch drum to the cage. Any method for locating and guiding onto the winch drum, and the attachment to the cage, are considered part of the wire rope.

3.2.6 Cage

The cage is the container or compartment in which mine personnel are hoisted. In addition to ensuring the safety of its occupants, the cage design must include methods for safe loading and unloading of the mine personnel.

3.2.7 Headframe

The headframe guides the wire rope from the winch to the cage. It locates and supports the cage in the escape shaft, and can be moved or rotated to permit off-loading of men, and storage of the cage, away from the shaft.

3.2.8 Standard Hoisting Terms

Over and Underwind Control

Over and underwind ensure that the upper and lower limits of travel of the cage are not exceeded. Overwind control prevents the cage from striking the headframe or sheave. Underwind control prevents the cage from striking the shaft bottom and/or letting slack into the hoisting rope.

Overspeed Control

The overspeed control ensures that a safe operating speed of the cage is not exceeded. This is achieved by a monitor which senses the speed of the cage and a brake which stops the winch drum.

Depth Indicator

The depth indicator provides a visual display for the hoist operator of the position of the cage in the escape shaft and the location of the surface and working levels.

Safety Bridle

The safety bridle provides a second method of attaching the cage to the wire rope. The bridle consists of two or more chains (or wire rope) which are secured to the hoist rope and top of the cage by proper clamps. If the rope fails at its attachment to the cage, the safety bridle will support the cage and prevent it from falling.

3.3 Emergency Hoist Guidelines

I. General

1. All underground shaft coal mines, under MESA jurisdiction, with shafts greater than 20 ft. deep shall be equipped with at least one Emergency Hoist defined and described in these guidelines.
2. The Emergency Hoist Installation shall be fenced with an 8' chain link fence (or equivalent). Four signs, located uniformly on the fence perimeter, shall state at least the following in 2" letters (white letters/red background):

WARNING!

EMERGENCY ESCAPE HOIST INSTALLATION

Any tampering or damage to this installation
will endanger men's lives.

3. Hoists shall be operational (at the shaft bottom ready to evacuate mine personnel) within 30 minutes after mine personnel at the surface have been notified of an accident or disruption requiring evacuation. (Except as noted in III.1).
4. Hoists operating in fan housings shall not disrupt the mine ventilation.
5. Adequate illumination for night operation shall be provided at the hoist controls, and at the top and bottom of the shaft. The minimum illumination shall be as follows:
 - (a) The hoist controls shall be illuminated by a 150 w. flood light (No. 150 PAR/FL or equivalent): mounted behind and above the operator in his normal operating position, less than 10 ft. from, and in an unobstructed line to the hoist controls and communications.

- (b) The unloading position at the surface shall be illuminated by two 150 w. flood lights (No. 150 PAR/FL or equivalent): mounted at least 10 ft. above, and no more than 20 ft. away from the loading position. The lights must be at least 10 ft. apart, and in an unobstructed line to the cage at the unloading position. The lights shall not be directed toward the hoist operator.
 - (c) The shaft bottom shall have a 50 w. light, certified by MESA, mounted no more than 2 ft. above the hoist communications and hoist controls (if provided).
- 6. One trained operator per hoist shall be on duty on the surface, whenever men are underground. The training and responsibilities of the Emergency Hoist Operator are described in Section VIII.
 - 7. The maximum time required to lift a loaded cage from the passage level to the surface shall be 4 minutes. A jog speed of 25 ft/min maximum shall be provided for lowering the cage to the unloading position at the surface. The maximum acceleration rate for the cage, under normal operation of the hoist, shall be $\pm 6 \text{ ft/sec}^2$. During emergency stopping (overspeed, overwind and underwind), the cage deceleration rate shall not exceed 16 ft/sec^2 .
 - 8. Approval of the hoist installation by the MESA District Manager shall be required. Permission for a waiver or variance from these guidelines shall be given only by the Director of MESA.

II. Structural Guidelines

- 1. The Emergency Escape Hoist shall operate within a temperature range of 0°F to 104°F .
- 2. The Hoist shall be capable of operating from 0 to 10,000 ft. A.S.L.
- 3. No part of the system shall be located closer than 8 ft. from the shaft edge during storage.

4. The suspended cage shall clear a 4 ft. barrier surrounding the escape shaft.
5. The unloading position shall be at least 4 ft. from the shaft edge.
6. Loading Requirements:
 - (a) General
 - i - All primary structures shall be designed such that the maximum working stress is 20% of the material yield stress under all operating conditions.
 - ii - System shall be designed to withstand air pressure loads equivalent to 5 lb/ft² on projected vertical areas under operation; and 30 lb/ft² non-operating.
 - (b) Cage
 - i - The maximum cage live load shall be 120 lb/ft² of cage floor area.
 - ii - The maximum cage side loading shall be 50 lb/ft of cage horizontal side length.
7. The Hoist shall have a rated line pull at least 150% of the maximum load (based on the weight of a loaded cage at the bottom of the shaft).
8. Brakes shall have a rated capacity of at least 150% of the maximum load.

III. Power Supply, Drive Train, and Winch

1. The power supply shall be independent of the general mine and ventilation fan power. An auxiliary generator shall provide power to the Emergency Hoist within 1 hour after a utility power failure has disabled the hoist. This capability shall be demonstrated to the MESA Inspector on each inspection. All electric hoists shall be provided with two circuit breaker combination type starters (NEMA Part ICS-2-327A) with interlocks, or an Automatic transfer switch (NEMA Part ICS-2-447). All electrical connections for the auxiliary generator shall be clearly labeled.
2. For all internal combustion engines, the coolant or lubricating oil shall be maintained to at least 60°F. The heaters shall be permanently installed. "Dipstick" heaters are not permitted. Batteries shall be equipped with trickle chargers, and capable of three 30 sec. engine cranking tests (at 1 minute intervals) without stalling the starter motor.
3. The drive train shall be direct gear or roller chain and sprocket drive. All roller chains shall be totally enclosed with oil seals on the shafts. The oil level must reach at least to the midpoint of the lower row of the chain. All roller chain drives shall be designed in accordance with ANSI B29.1-1963. All gear reductions shall be designed in accordance with AGMA standards. No drives which permit freewheeling of the winch drum are allowed.

4. For all hoists, a fuel tank shall be provided. The quantity of fuel stored shall be adequate for complete evacuation of the operating shift without refueling. As a standard, the following number of lifting cycles shall be required:

$$\begin{array}{l} \text{No. of required} \\ \text{lifting cycles} \end{array} = \frac{2 \cdot (\text{No. of men underground})}{\text{Cage Floor Area (Sq. Ft.)}}$$

The mine operator shall determine the fuel consumption/lifting cycle from an average of five continuous cycles with a loaded cage, and submit the calculations and tank size estimate to the District Manager (MESA) for approval.

A portable fuel tank is permitted when an auxiliary generator is required, provided the same lifting cycle requirement is satisfied.

Fuel tanks shall be equipped with a measuring stick or gauge which indicates the fuel quantity stored (accuracy shall be $\pm$ 5 percent).

Gasoline or diesel oil tanks shall be equipped with a glass bowl (or equivalent) in which water or sediment will collect and be discharged. A drain petcock shall be provided.

All pressurized fuel tanks shall be designed in accordance with Section VIII of the ASME Boiler and Pressure Vessel Code, and be fitted with a fuel strainer.

Gasoline tanks shall not be located in direct sunlight and shall be drained and refilled with fresh fuel at least once a year (365 days).

5. The power supply and winch shall be fully enclosed to protect the hoisting equipment from any adverse weather conditions.

The enclosure shall be fire proof, and a window or opening provided to enable the hoist operator to view the cage, wire rope and headsheave support.

6. The winch drum flange shall extend at least 3 rope diameters beyond outermost lay of wire rope.
7. For hoists not equipped with automatic or manual level wind, the fleet angle shall be no less than 30 min. and no more than;

1° 30' for smooth faced drums

2° for grooved single layer drums

IV. Cage

1. The cage shall be fully enclosed and covered with a steel roof (1/8" thick minimum). A 3/8" dia. rod shall not pass through any opening in the closed cage.
2. The cage door shall be latched; and be operable from the inside and the outside.
3. The top and bottom edges of the cage shall be tapered or bevelled 45° for a minimum of 6 inches of vertical height.
4. Handholds for the occupants shall be provided 7' above the floor level and support a 500 lb. load.
5. The cage shall be designed with a minimum floor area of 10 sq. ft.; a 7 ft. high by 2.5 ft. wide access door; and support a payload of at least 120 lbs/ft² of floor area.

6. No latch or other cage fitting shall protrude more than 1/2" beyond the cage exterior walls.
7. The cage and headframe shall be stored away from the shaft, with the cage resting on the ground.

V. Wire Rope

1. A safety factor of 10, based on the cage fully loaded at the shaft bottom, shall be required.
2. "Non-Spin" or "non-rotating" 19 x 7 or equivalent rope shall be used. Rope size and attachments shall conform to ANSI Specification No. M11.1-1960. "Spin resistant" rope is not acceptable. A minimum of three wraps of wire rope shall be provided on the winch drum when the cage is at the passage level.
3. A safety bridle, with two bridle ropes or chains, shall secure the cage to the wire rope at least 3 feet above the wire rope socket or uppermost wire-rope clip.
4. Each leg of the safety bridle shall have a breaking strength equal to the hoist rope. During normal operation, both legs of the safety bridle shall be slack.
5. Any wire-rope clip securing the wire rope to the cage shall be spaced and torqued in accordance with the following specification:

Number, Spacing, and Torque of Clips for Wire Rope*

Wire Rope Diameter (in.)	Typical** Breaking Strength (tons)	Minimum Number of Clips	Center-to-Center Space Between Clips (in.)	Torque Required (ft. -lb.)	
				U-Bolt	Fist Grip (Twin Base)
3/8	6.15	3	2-1/2	20	35
7/16	8.33	3	2-3/4	35	65
1/2	10.8	3	3	35	65
9/16	13.6	4	3-1/2	65	125
5/8	16.8	4	3-3/4	65	125
3/4	24.0	4	4-1/2	120	220
7/8	32.5	4	5-1/4	220	220
1	42.2	5	6	220	220

*From: RI 7789: Establishing Standards for Effective Wire Rope Clip Installation.

**Data for Bethlehem 19 x 7 Purple Plus Wire Rope

6. Wire rope terminations shall have a minimum efficiency of 80% of the rated wire rope strength. Spelter filled, swaged, and babbited wedge sockets are permitted. U-Bolt and Twin Base type wire rope clamps are permitted provided the requirements of V.5 are satisfied. Splices in the wire rope shall not be permitted. Reterminations shall be made at least once per year (365 days).
7. Wire rope shall be lubricated at least once every 90 days. A light, penetrating lubricant with rust inhibitors shall be required (Texaco Crater "A" or equivalent). The lubrication shall be frequent enough to prevent signs of rust and corrosion on the rope and attachments.
8. The winch drum and sheave diameter shall be no less than 36 times the diameter of the wire rope.
9. The wire rope shall be replaced at intervals not to exceed 5 years.

VI. Emergency Escape Shaft

1. The shaft designated as the Emergency Escape shaft shall be free of all obstructions except those explicitly permitted in these guidelines.
2. The cage must be at least 2 ft. from the shaft wall, in any horizontal direction, at all times during normal hoisting. This measurement is made while the cage is stationary in the shaft. A smooth walled, steel cased shaft is exempted from this requirement.
3. The shaft shall be smooth walled, plumb, and concrete or steel cased. Any shaft not sealed from ground water shall be maintained free of any ice buildup.
4. A 4 ft. high (minimum) guard rail shall be placed within 1 ft. of the shaft opening at the surface. The rail shall be designed to support a loading of 200 lb. per foot of perimeter.
5. For operation in a ventilation shaft, the cage cross-sectional area shall occupy at most 25 percent of the cross-sectional area of the shaft.
6. The shaft bottom for emergency hoist facilities shall be no more than 1 ft. lower than the floor of the mine passage and kept free of water or debris. The entrance to the shaft from the mine passage shall be at least 5 ft. high and 6 ft. wide.
7. Electrical cables shall be secured to the shaft wall and be metal cased.

VII. Controls, Communications and Safety Equipment

1. A depth indicator, gear or roller chain driven off the winch drum, shall be provided and be clearly visible to the operator. The bottom and top locations shall be indicated to within $\pm$ 1 ft.
2. Overspeed, overwind, and underwind controls shall be provided and driven off the winch drum shaft.

Overspeed control shall apply the safety brake and disconnect the power supply when the hoist speed exceeds no more than 125 percent and no less than 115 percent of the maximum operating speed.

Overwind control shall keep the uppermost point of the safety bridle at least 3 ft. below the head sheave or other stationary structural part of the hoist. Underwind control shall prevent the cage from striking the shaft bottom.

3. A dual braking system shall be installed. At least one brake shall be installed on the winch drum. The winch drum brake shall be spring or gravity-set, power released, and operated by the overspeed, over and underwind controls.
4. Two communications systems shall be installed within reach of the hoist operator. One system shall be the normal operating mine communications system. The operating codes and directions for their use shall be posted at the hoist control and shaft bottom stations. Any sound signals shall be audible to the hoist operator during the hoisting operation.
5. The voltage on all electrical control circuits shall not exceed 120 volts.

VIII. Emergency Hoist Operator

1. The hoist operator shall be a qualified hoisting engineer.
2. The hoist operator shall be trained in and perform all the regular maintenance and operations of the Emergency Hoist. If more than one operator is assigned to a hoist, all operators shall be capable of performing the regular maintenance. One operator shall be designated "in charge of maintenance" and responsible for the periodic maintenance of the hoist.
3. Training shall be provided by the manufacturer of the emergency escape hoist or the current emergency hoist operator. For hoists assembled from purchased parts, the mine operator shall provide training.
4. The specific instruction shall include:
 - a. Operation and maintenance of I. C. engines and/or portable motor/generators
 - b. Care and maintenance of wire rope
 - c. Adjustment of limit switches and speed controllers
 - d. Adjustment of the hoist brakes and clutches
 - e. Operation and testing of communications systems
 - f. Operation of the headframe to swing cage away from shaft.

IX. Maintenance Procedures

1. The operator "in charge of maintenance" shall inspect the hoist installation daily to insure that all equipment is in proper working order.
2. All internal combustion engines shall be started daily and operated for 10 minutes.
3. The hoist shall be operated, for one complete lifting cycle, every seven days. Every 28 days the cage shall be dead weight loaded to its capacity when the lifting cycle is performed.
4. All fluid levels shall be inspected and maintained every time the hoist is operated.
5. The escape shaft shall be inspected for debris and ice build-up every time the hoist is operated.
6. All hoist components shall be lubricated and serviced in accordance with the manufacturer's recommended service schedule. A summary of these service schedules shall be maintained at the hoist installation and verified by the District Manager (MESA) prior to approval.
7. The fuel supply shall be measured and inspected for contamination daily. The fuel sediment collection bowl shall be inspected daily.
8. Records of all maintenance and hoist operations shall be kept at the hoist.

X. Inspection Procedures

1. A MESA inspector shall inspect the hoist prior to MESA approval of a new installation. The inspector shall be trained and experienced in the inspection of regular hoisting installations. The training shall include study and demonstration of wire rope handling, terminations and methods for determining wear and incipient failure.
2. Regular inspections of the hoist shall be performed at least four times a year. They will be unscheduled and without prior notification to the mine operator.
3. At each inspection, the MESA inspector shall verify that the installation complies with all specified emergency hoist guidelines. This check list shall be followed:
 - a. Fuel, lubrication, coolant, and battery fluid levels shall be checked. The fuel quantity shall be adequate (see III.4) to permit evacuation of all men underground at the time of the inspection.
 - b. The three 30 second battery tests shall be performed.
 - c. Check all sheaves, pillow blocks, and external bearings for proper lubrication, and cracks or other structural damage.
 - d. Check limit switches for proper operation and maintenance.
 - e. Check Controller or Depth Indicator drive for excessive slack and proper lubrication.
 - f. Check torque on all wire-rope clips.

- g. Inspect the cage for damage. Check that the cage door opens freely and closes securely. Ensure that a 3/8" diameter rod cannot pass through any opening in the closed cage.
- h. Check that the shaft is free from debris, ice build-up or other obstruction before the Operational Test is performed.

4. Inspection of Wire Rope

- a. The wire rope shall be clean of any dirt or excessive lubricant prior to the inspection.
- b. Inspect the wire rope as it leaves the winch drum while the hoist is operated at slow speed. Any location of broken wires, evidence of kinking, inadequate lubrication, or corrosion shall be marked and inspected with the hoist stopped.
- c. Kinking which interferes with the proper laying of the wire rope on the drum or any sheave requires rope replacement.
- d. Any location of broken wires shall be inspected closely to determine if local damage to the strand exists. Three broken wires within one lay length shall require replacement of the rope.
- e. The point of attachment to the cage and the length of rope wound over any sheave in the stored position shall be closely inspected for corrosion. Any rusting or other evidence of corrosion, buildup of metal oxides on wires or sockets, wires weakened or broken by corrosive attack indicates an area of inadequate lubrication and improper maintenance. The extent of the corrosion shall determine

whether the rope requires cleaning and relubrication, retermination, or replacement. The corrective action shall be at the discretion of the MESA inspector.

- f. At all strain points encountered during a lifting cycle, the wire rope shall be calipered. The rope shall be replaced when any section measures less than 90 percent of the rated diameter. The measurements shall be made with the cage dead-weight loaded. Measurements shall be taken at least at the following locations:

1. At the wire rope termination
2. Above the safety bridle attachment
3. At both sides of any sheave in the fully lowered and fully raised hoist positions.
4. At the winch drum in the lowered and raised positions.

The "rated" diameter of the wire rope shall be determined by measurement of the new wire rope by the inspector and recorded in the maintenance records at the hoist site.

- g. The inspector shall verify, based on the wire rope size, rated strength and cage floor area and weight, that the safety factor of 10 is satisfied.
5. An Operational Test shall be carried out (in accordance with Section XI).
 6. After the Operational Test is performed, the Inspector shall ride in the cage for one complete hoisting cycle.

7. All maintenance and operation records shall be inspected and verified to be in accordance with the following:

- a. Daily installation inspection by the operator "in charge of maintenance".
- b. Daily start-up of all I.C. engines.
- c. Weekly (7 day) lifting cycle.
- d. Monthly (28 day) loaded lifting cycle.
- e. Wire rope lubrication, retermination and replacement schedule.

XI. Operational Test Methods

An "Operational Test" is required for MESA approval of the hoist installation. The "Test" is the only effective means by which the compliance of the hoist with these guidelines can be determined. This performance will be verified by the MESA field inspector. In addition to the basic design requirements, the test will demonstrate the proper installation and adjustment of the safety controls and communications equipment. Specific objectives include:

A verification of the 30 minute operational requirement;

Proper depth indicator adjustment;

Adequate freewheeling control;

Under and overwind control, and

The ability to operate the hoist during a utility power failure.

The MESA field inspector should be accompanied by the regular hoist operator, and a mine safety official. During the Test, an

observer should be located at the communications station at the passage level to report on the downhole positioning of the cage.

Test Sequence

Hoist testing involves two complete down/up cycles of a cage loaded with a deadweight load equivalent to the rated payload of the system. Satisfactory completion of these tests must be witnessed by a MESA official.

Test 1: Verify that:

1. Thirty minutes or less is required from notification at the mine office or hoist operator's station to locating the hoisting cage at the shaft bottom.
2. The hoist is operated over one complete cycle under the normal manual and/or automatic controls at the proper lowering speed, noting that,
 - a. The depth indicator position of the shaft bottom and shaft collar are accurate, and
 - b. Both communication systems function properly.

Test 2: A power source separate from the general mine or utility power must be available at the hoist site during this test. If the hoist power is utility supplied, the following tests must be performed using the auxiliary power supply.

1. The cage, loaded as in Test 1, is located over the escape shaft, and lowered under the normal operating mode. During the lowering, the motor power or drive train is disconnected. Note that the cage comes to a quick halt in the shaft, and does not move thereafter.

2. The motor or drive is re-engaged and lowering is continued. If the equipment is manually operated, lowering is continued until operation is automatically halted by the underwind switch. Note that the cage must not strike the shaft bottom before coming to a stop, and the cage should be able to be loaded while in the limit position.
3. The cage is then raised, until operation is automatically halted by the overwind switch. Note that no part of the safety bridle or cage may be less than 3 ft. below the hoist housing, headframe or headsheave.

3.4 Discussion of the Proposed Guidelines

These guidelines have been developed to guarantee the operation of the emergency hoist after any mine emergency requiring evacuation has occurred. While considerable difference of opinion has existed on the most effective means of presenting the requirements for emergency hoists, the guidelines are as specific as necessary to prevent any sub-standard designs from being approved. Towards this end, most of the guidelines are straight forward, presenting the minimum acceptable design requirements. The numerical requirements have been based on accepted industry standards or procedures, previous mine experience or our own engineering evaluation of the design factors needed to insure a safe and reliable system.

Some of the proposed guidelines are the result of more general assumptions about the required performance and operating environment of the emergency hoist. In this section, these requirements are discussed more fully as a means of presenting some of the background reasoning for them. No new requirements are set forth, and the following discussion is intended only to clarify and justify the set of guidelines we have presented above.

I. General

1. All underground shaft coal mines, under MESA jurisdiction, with shafts greater than 20 ft. deep shall be equipped with at least one Emergency Hoist defined and described in these guidelines.

There is no way to guarantee the operation of regular mine hoists under all evacuation conditions. Even a slight explosion will damage elevator doors and permanent structures in a mine shaft. Power failures will also incapacitate these lifts unless large generator stations are provided at the mine. Under these conditions, the Emergency Escape Hoist will still be capable of evacuating miners.

3. Hoists shall be operational (at the shaft bottom ready to evacuate mine personnel) within 30 minutes after mine personnel at the surface have been notified of an accident or disruption requiring evacuation.

"Operational" implies that the hoist operator is at his station, the hoist power is on, and the cage has been lowered to the shaft bottom. This time limit permits the Hoist Operator to be working elsewhere on the surface. 30 minutes was selected as a reasonable time required for miners to reach the shaft bottom and for a "standby" system to become operational.

4. Hoists operating in fan housings shall not disrupt the mine ventilation.

Hoisting through fan housings is not recommended for several reasons. Debris from the housing or damage to fan house may make the shaft inoperative after an explosion; miners using a return air escapeway must be evacuated quickly if polluted air exists in the mine; and the difficulties of raising and lowering a cage through a fan housing without interrupting the air flow are great. For the few installations in which this is unavoidable, an airlock through which the cage passes must be provided to satisfy the requirements of these guidelines. An assistant to the hoist operator will be needed to control the airlock doors in the housing, and the travel controls of the hoist must be

provided to prevent the cage from striking a closed door during its operating cycle. Under unusual circumstances, the cage could be stored near and unloading take place in the fan housing (see Section 4.5.2).

6. One trained operator per hoist shall be on duty on the surface whenever men are underground.

"On duty" does not mean that an operator must be stationed at the hoist. The operator must be on the surface at a location which enables the hoist to be ready within 30 minutes (I.2). If a mine has more than one emergency hoist, each hoist must have an operator whenever men are underground.

7. The maximum time required to lift a loaded cage from the passage level to the surface shall be 4 minutes.

The selection of a time requirement for the lifting cycle rather than a maximum and minimum speed requirement is based on two factors:

- a. Maximum and minimum speeds would have to be specified at several different shaft depths to be effective; and
- b. Hoisting time is more easily measured than the actual lifting speed.

Specification of the time and maximum accelerations permitted is adequate to guarantee a minimum acceptable design.

II. Structural Guidelines

The structural guidelines were drawn up in accordance with the requirements we found necessary to specify our own hoist design. These guidelines are intended specifically for the designer and manufacturer of the hoist. They insure that the sizing of the hoist components is adequate to guarantee structural stability and adequate lifting power under all conditions.

III. Power Supply, Drive Train, and Winch

1. The power supply shall be independent of the general mine and ventilation fan power.

"Independent" means that any electric power used in the hoisting system will not be supplied by the same line that powers the regular passenger elevator, the ventilation fans, or the underground portion of the mine. The most common need for an escape hoist is when underground or fan power has been lost. In this case, the law (1) requires that the mine evacuation start within 15 minutes after the fans have stopped. Requiring that electric power for the emergency hoist be supplied directly from the utility lines insures its operation under these circumstances.

3. No drives which permit freewheeling of the winch drum are allowed.

"Freewheeling" is defined as the capability of the cage, when fully loaded, to descend due to its own weight. Interlocks must be included in the hoist system to prevent free wheeling under any conditions, including disengagement of any clutch that may be in the drive train. This requirement may be satisfied by:

- a. Install a gravity or spring-set (and power released) brake which sets automatically if the clutch is disengaged.
- b. Install a self-locking worm gear (usually a single stage reduction of 30:1 or greater).
- c. In addition to the brake, a reverse-locking clutch may be used.

Any anti-freewheeling device used must have a torque and speed rating consistent with the system in which it is being used.

IV. Cage

The design of the cage has been specified in sufficient detail to ensure that the occupants are protected from any falling objects in the shaft, striking the shaft walls, and from falling out. The beveling of the top and bottom edges will prevent any "hanging up" on ledges, irregular surfaces or ice buildup. Because the cage is likely to be filled to its maximum capacity during evacuation, the cage size is based on floor area and maximum weight rather than number of occupants. The access door is sized so that a standard stretcher (MSA or equivalent) can be placed in the cage.

V. Wire Rope

Because the cage is lowered without the use of guides, it is essential that "non-spin" rope be required. The safety factor of 10 is also required to insure that excessive rotation of the cage does not occur at any depth. The critical requirements on the wire rope are the method of attachment to the cage and maintenance procedures. The wire rope is the one element of the Emergency Hoist design which cannot be provided with a backup system if it fails. The guidelines are specific in the terminations allowed and wire rope maintenance procedures to be followed. It is up to the MESA inspector, however, to determine that the wire rope remains in a servicable condition throughout its life. His judgment, based on a thorough exposure to wire rope practices and mechanisms of failure, must be relied upon for approval of this critical element. Appendix E describes the proper method of measuring and terminating wire rope. Causes of wear are also discussed.

VII. Controls, Communications and Safety Equipment

1. "A depth indicator, gear or roller chain driven off the winch drum, shall be provided and be clearly visible to the operator. The bottom and top locations shall be indicated to within $\pm$ 1 ft."

Accurate indication of the cage position is essential for a manually operated hoist. The depth indicator provides a visible display of the cage position relative to the surface and shaft bottom. Gear or roller chain drive guarantees precise and repeatable indication. To ensure that the depth indicator remains repeatable, any telescoping or raise and lower booms will have to be pinned or secured against stops when the cage is being raised or lowered.

2. Overspeed, overwind and underwind controls shall be provided and driven off the winch drum shaft.

The control functions may be independent or combined into a single controller ("Simplex" type or equivalent). Examples of overspeed control methods are illustrated in Figure 13.

3. "A dual braking system shall be installed. At least one brake shall be installed on the winch drum. The drum brake shall be spring or gravity set, power released, and operated by the overspeed, over and underwind controls."

The traditional "deadman" switch, or automatic stop has been replaced by a spring or gravity-set brake. Because the brake is actuated by the overspeed and limit wind controls, there is no conceivable situation in which a "deadman" control would provide an added margin of safety. During any condition in which the operator is no longer capable of controlling the hoist, the cage will be brought safely to a stop.

4. Two communications systems shall be installed within reach of the hoist operator. One system shall be the normal operating mine communications system. The operating codes and directions for their use shall be posted at the hoist control and shaft bottom stations. Any sound signals shall be audible to the hoist operator during the hoisting operation.

The normal mine system is required because it is the best method of communication during a mine emergency. Conditions at the hoist location (at the surface and shaft bottom), the location and number of miners needing evacuation, the best escapeway to follow,

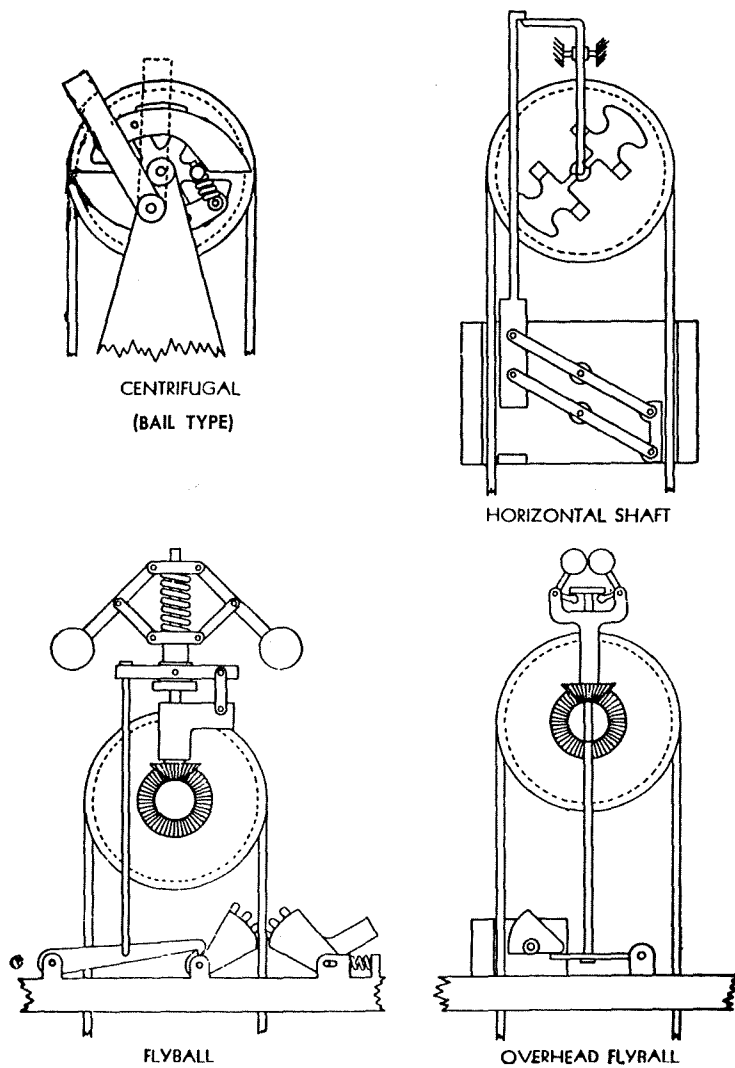


Figure 13: Typical Elevator Speed Controls (18).

the loading of the cage can all be communicated through the normal mine system. However, the possibility that the normal mine communications will be damaged, or that a power failure will occur during an emergency requires that a standby system, between the shaft bottom and the hoist operator be provided.

The auxiliary system can use any signalling device that is simple to operate and understand, provided that the power supply is independent from the general mine and ventilation power supply and the signals are visible or audible to the hoist operator.

Battery operated or sound powered phones, "walkie talkies", horns, bells, lights or buzzers are acceptable provided they are permanently installed and maintained. Underground installations must be certified permissible.

4. Foster-Miller Escape Hoist Design

4.1 Summary

This section contains a review and feasibility assessment of several escape system concepts and presents a detailed description of the selected design. Two types of systems are considered; self contained systems which are initially underground and can be driven out of the mine, and surface powered systems which can be deployed down a mine shaft in the event of an emergency.

Two self-contained systems are studied. Each system uses a regular below ground personnel carrier which carries an emergency independant power source. Two power packs are considered: pneumatic and electric. During emergency operation, the vehicle climbs a roller chain suspended down the escape shaft.

Three surface powered systems are studied namely gravity winding using two counter balanced cages alternately loaded with water, vacuum lift comprising a cage in a close fitting vertical tube which is raised by a vacuum pump operating on the surface and the traditional motorized winch and wire rope system.

The system selected for the Foster-Miller Escape Hoist design is a motorized winch and wire rope system designed to operate in all types of ventilation shafts greater than 8 feet in width. The system operates to depths of 800 feet and at this depth will evacuate 36 men an hour. The cage capacity is 6 men and the cage travel speed is 200 FPM. The system is driven by a gasoline engine which powers an hydraulic winch. The headsheave support is a simple jib crane arrangement which provides cage horizontal travel for cage unloading and storage. System cost, less installation and assembly, is estimated to be \$19,400.

4.2 Introduction

A complete Escape Hoist design, with specifications, has been developed as a means of implementing and demonstrating the proposed guidelines. The objective of the design effort is to present an Emergency Hoist that is ready for fabrication, and suitable for installation at over 90% of the mines surveyed in the "State of the Art" report.

The hoist design is intended for use by the mine operators, hoist manufacturers, and MESA inspectors. The mine operators are provided with a hoist design ready for detailing and fabrication, and a cost estimate to aid in allocating funds for this installation. Hoist manufacturers are provided with a competitive standard, which they may adopt, modify or improve upon. It is anticipated that hoist manufacturers may produce similar or custom designs that satisfy both the guidelines and the specific requirements of a particular shaft location. The MESA Inspector is presented with an illustration of the equipment necessary to satisfy the guidelines. The winch assembly, headframe, cage and safety controls are presented in detail and provide the inspector with a visual demonstration of the hoist equipment and layout needed for compliance with the guidelines.

4.3 Alternate Hoist Designs

The initial effort on the Hoist design investigated alternate methods of lifting miners in a vertical shaft. Special attention was given to hoisting techniques that do not incorporate a cage and wire rope. Unpowered methods, ladders, and hand crank winding are considered too slow and unreliable for deep shaft evacuation.

Two separate categories of rescue systems were examined: self-contained vehicles with an internal power supply and drive; and surface powered vehicles. Two operating parameters were held constant to provide a meaningful comparison of the alternatives; ascent speed and gross vehicle weight. A speed of 100 ft. /min. and a vehicle weight of 4,000 pounds were selected. One concept, the vacuum drive, was limited by tubing sizes and practical blower capacity to a smaller size. Appendix G presents estimates of the energy storage capacity and costs of these systems.

4.3.1 Self-Contained Rescue Vehicles

Vehicles independent of any mechanical drive or power transmission from the surface have two potential advantages in emergency hoisting situations: the need for drive machinery external to the vehicle is eliminated, and control of the vehicle is in the hands of miners who must use it. A smaller payload can be lifted, however, since drive machinery and energy storage must be part of the gross vehicle weight.

Internal combustion engines have attractive power/weight ratios and their form of energy storage, e.g. gasoline, is also light and compact. Such engines are not permissible, however, and would be especially hazardous in the uncontrolled environment which could result from a mine accident.

Other drive train systems considered were fuel cells, electric, mechanical springs, pneumatic or hydraulic power, and electric drive. Electric drive included both battery storage and umbilical cable systems.

4.3.1.1 Compressed Air Drive

Twenty five pounds of compressed air at a pressure of 3000 psi can provide enough energy to raise a 4000 pound vehicle approximately 200 feet. A prospective vehicle design is illustrated in Figure 14. It operates by climbing a roller chain located in the shaft and secured at the surface. High pressure air from the storage tank is throttled in a regulator valve and used to power an air motor. For increased efficiency a heat exchanger on the storage tank maintains the pressurized air at ambient temperature. The air motor drives a sprocket coupled to the roller chain.

During ascent, power is transmitted to the drive sprocket via a reverse locking clutch, so that the vehicle does not fall in the event of drive system failure. During descent, the drive system is passive and permitted to reverse drive. The motor serves

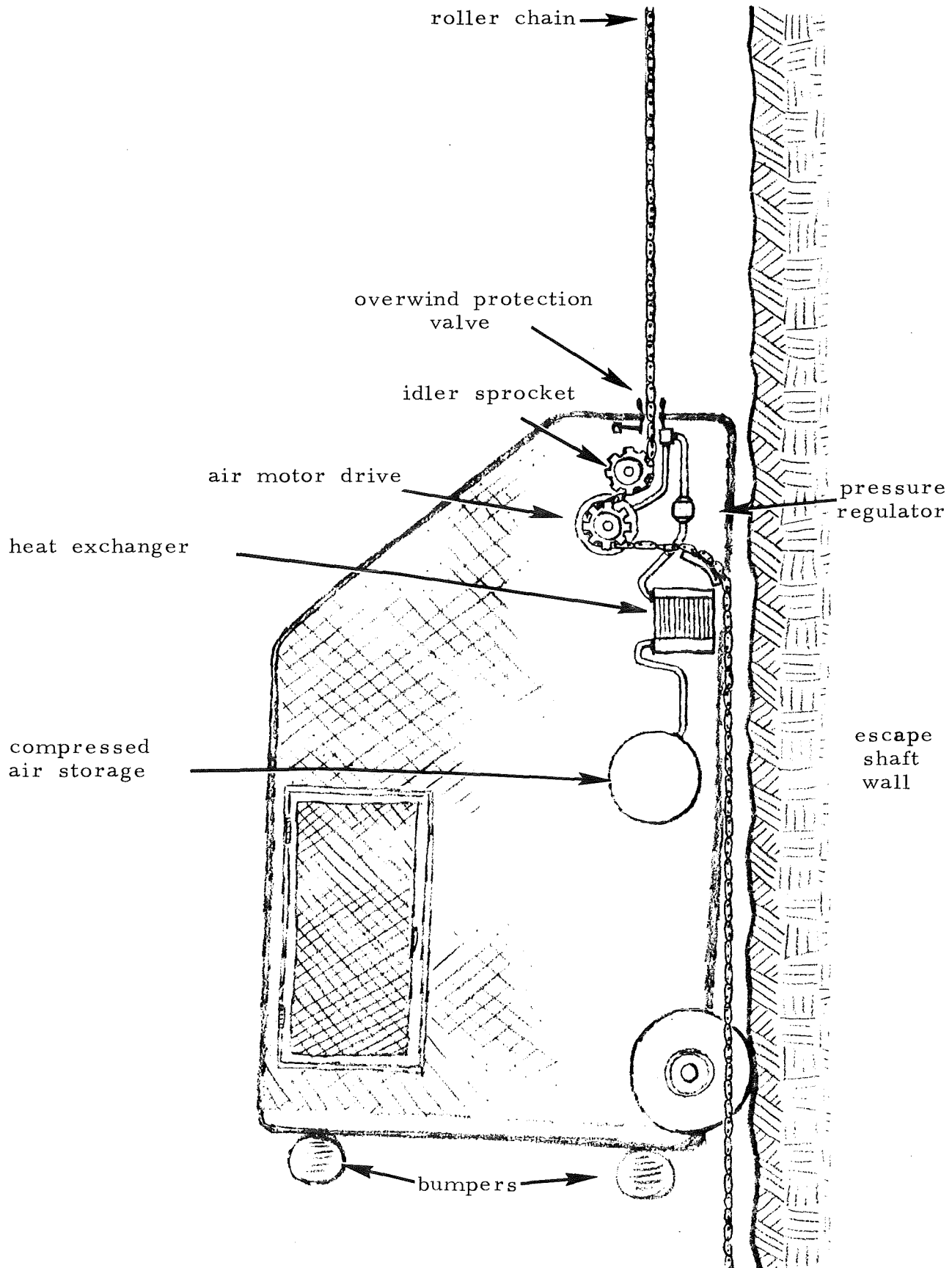


Figure 14. Compressed Air Drive Vehicle

as a viscous brake to limit speed. Overspeed protection is provided by a centrifugally activated, spring loaded brake. Overwind protection is provided by a valve in the motor supply line which turns off power on contact with a stop at the surface.

Surface equipment includes a small trolley-mounted boom which the roller chain hangs from. The boom moves to or from the escape shaft as required, and does not need to rotate. A compressor or spare air tanks are required at the surface to replenish the compressed air supply between trips.

Empty vehicle weight is projected at 1,400 pounds, for a vehicle operating at a depth of 200 feet. Capacity of this vehicle is 12 miners per trip. If the system were designed for deeper rescue operation, the vehicle weight would be greater (increased compressed air storage capacity) and would carry fewer men per trip. For example, to operate to 500 feet depth, the vehicle would weigh 1,600 pounds empty and carry 11 men.

Compressed air storage at 3,000 psi together with a well designed pressure vessel and piping is necessary to store sufficient energy in a small volume.

4.3.1.2 Electric Drive, Self-Contained

An electrically self-powered rescue vehicle is attractive for dual mode operation. The vehicle functions as a personnel carrier during normal mine operation, and in an emergency it operates as a chain climbing vehicle. This dual mode capability makes the system more cost effective than two separate miner transport systems.

The powered rescue cage rides on a heavy rail or wheeled undercarriage which is removable. During normal operation the vehicle power is supplied by overhead conductors through a

trolley boom. Power in the rescue mode is supplied either by an umbilical line from the surface or an on-board battery pack. The umbilical line power supply is illustrated schematically in Figure 15 in the personnel carrier mode.

There is no mechanical connection between the rescue cage and undercarriage other than a splined power shaft connection. For use as a rescue vehicle, the electrical connection between the trolley boom and the cage is disconnected, and the umbilical line in the rescue shaft connected. The bottom end of a hanging roller chain is threaded through the drive sprocket mechanism of the vehicle, and it then climbs the chain up the rescue shaft. Overwind protection is by limit switch on the vehicle, which breaks the power circuit on contact with the surface boom. The drive train includes a self-locking worm reducer, which provides inherent protection against the vehicle falling after a power failure. Because of the worm reducer, the vehicle must be powered in descent as well as ascent, and cannot fall or go into an overspeed condition. As a result, overspeed protection takes the form of electronically limiting the motor speed.

An electric power source, a winch for the umbilical cord and an unloading ramp are installed at the surface. Weight of the rescue portion of the vehicle (not counting the removable undercarriage and its associated machinery) is projected at 1,500 pounds. Capacity of the vehicle is 12 men per trip.

The depth to which this system can operate is limited by the length of the umbilical cable suspended from the surface. This is not a severe limitation and an operating depth of 1,000 feet is reasonable.

Electrical drive with lead-acid storage batteries is another way of implementing the dual-mode concept. The batteries are used only during rescue operation, and represent approximately 10% of the gross vehicle weight (see Appendix G). Considering electrical conversion and drive line efficiencies, a 4,000 pound vehicle

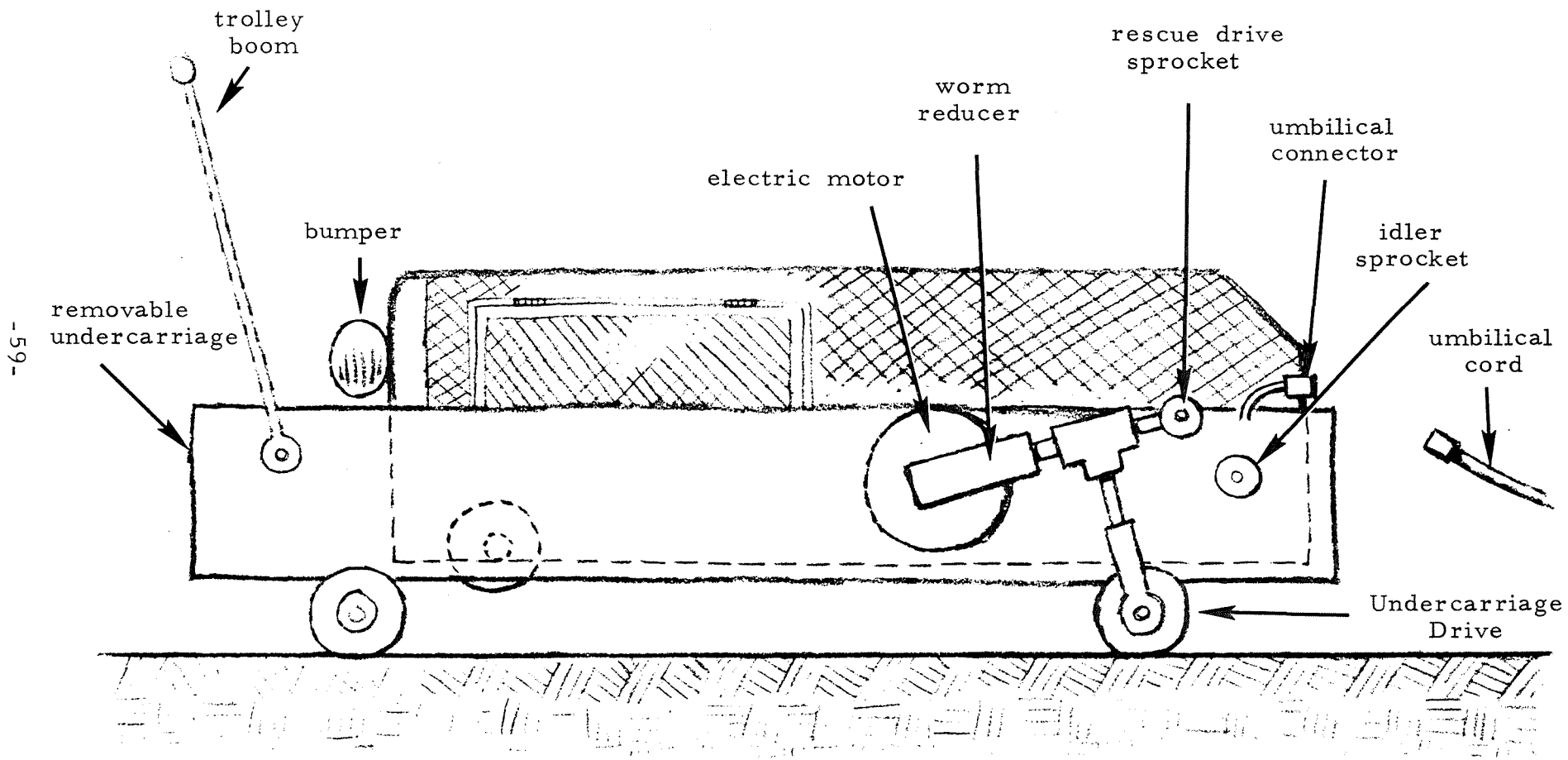


Figure 15. Electric/Umbilical Drive Vehicle: Trolley Configuration

can lift itself up a 500 foot shaft. The drive unit is straight forward: a D.C. motor with semiconductor switching control, e.g. pulse length or frequency control, for efficiency. The batteries, during personnel carrier operation, are kept charged by power from the overhead boom connection. The configuration is illustrated in Figure 16 in rescue vehicle mode.

The configuration of the drive system is essentially the same as the umbilical line drive. Instead of a worm reducer, a low friction reverse locking drive is used to provide protection against falling should a drive failure occur. The resulting improved efficiency allows a smaller motor to be used without degrading performance, i.e., 10 - 12 HP is sufficient.

The drive train includes a viscous brake for descent and a centrifugal actuated brake for overspeed protection. A limit switch provides overwind protection. Since several trips are required in a rescue operation, the surface installation includes extra battery packs and rechargers.

Vehicle weight is projected at 1,900 pounds. Carrying capacity of the vehicle is 10 people.

4.3.2 Surface Powered Rescue Vehicles

Since the power supply and drive systems are located at the surface, efficiency, size and weight are not critical to the design of surface powered rescue vehicles. Two methods of transmitting the power to the rescue capsule are considered feasible: Mechanical coupling, best exemplified by wire rope systems, and vacuum-controlled lifting of the capsule.

4.3.2.1 Gravity Winding System

Water ballast is used to provide the lifting force on the rescue cage. Rescue systems employing this method are currently used in Great Britain.

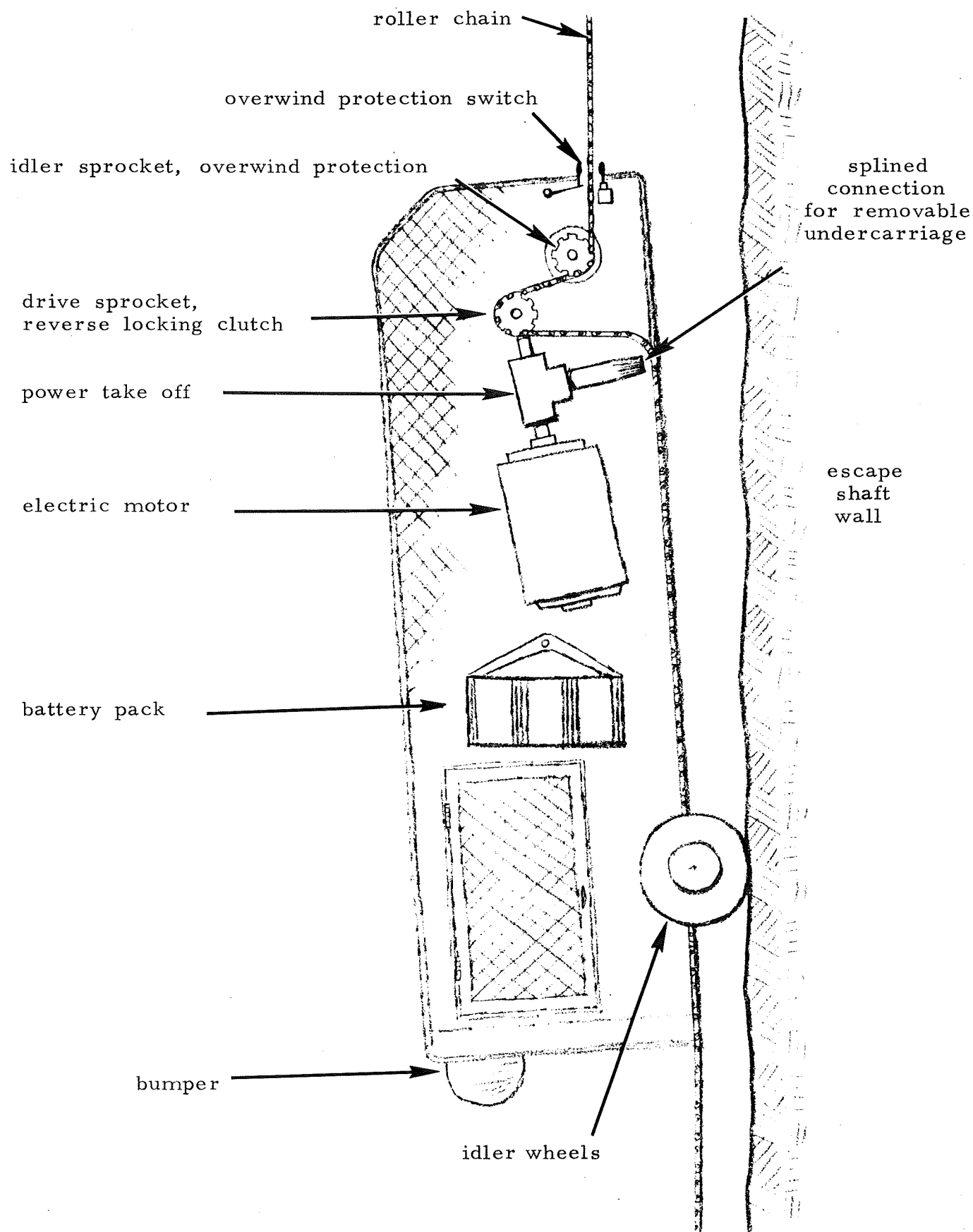


Figure 16. Electric/Battery Drive Vehicle:
Rescue Configuration.

Two cages are used, at opposite ends of the same rope. The rope is wound over a drum on a surface head-frame, with both cages hanging down the escape shaft. The rope length permits one cage to be at the surface, while the other is at the passage level. Figure 17 illustrates the major components of a gravity winding system.

In operation, the cage at the surface has tanks which are filled with water until heavier than the cage at the passage level. It tends to fall, in turn raising the other cage.

After the miners unload at the surface, the ballast water is emptied from the weighted cage at mine level and miners enter the cage and wait to be raised.

The system does not require a power supply but does require access to a supply of water for ballast. If piped in water is not available, water must be stored in a tank above the rescue shaft. The amount of water stored must be greater than the total weight of miners to be evacuated.

Speed is controlled by braking the drum at the surface, and under wind and overwind control is provided by one limit switch at the surface.

Though the gravity winder eliminates the need for a hoist power supply, two water tight safety cages and two leads of wire rope are required. To avoid lengthy set-up times, a permanent installation in the shaft is necessary.

4.3.2.2 Vacuum Lift

A vacuum operated hoist lifts a capsule in a vertical, large diameter pipe without mechanical attachment to the surface. Propulsive force is developed by using a blower to create a

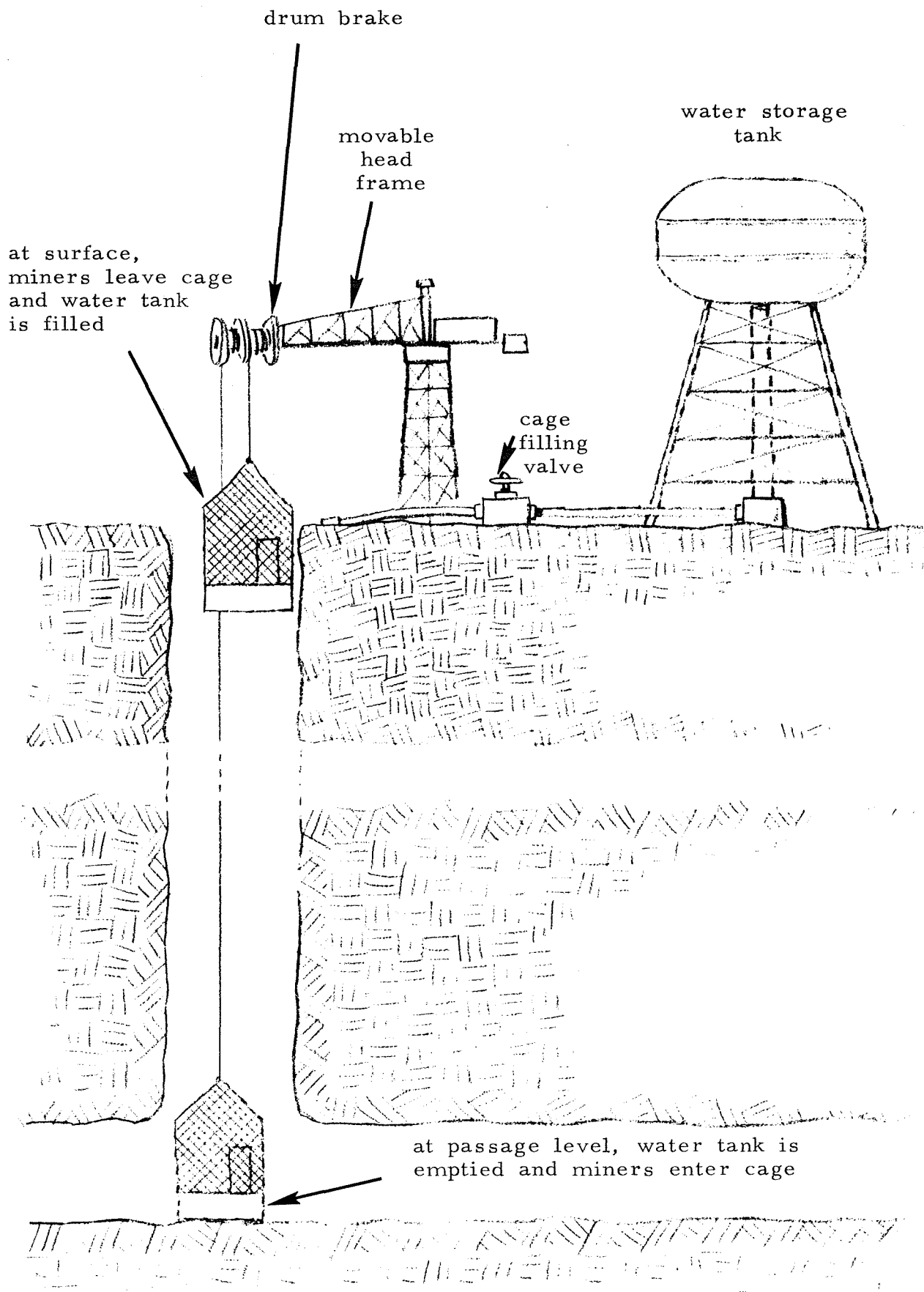


Figure 17. Gravity Winding System Description

partial vacuum above the vehicle. A 2 psi differential pressure is sufficient to accelerate the vehicle upward. For descent, a small bleed valve allows air to enter the pipeline above the vehicle. The valve setting regulates the descent speed (which can be limited by an orifice). Figure 18 illustrates this design.

The vehicle is sealed against the pipe I. D. to maintain the pressure differential. A high quality sliding seal is not required; considerable leakage can occur without affecting performance (50 cfm can be tolerated in this design). Depending on the detail design of the seals, leakage clearance up to 1/64" are acceptable. The rescue vehicle in the closed tube is relatively impervious to falling debris, and force levels throughout the system are low. Protection against system failure is provided by a differential pressure diaphragm which activates a set of locking brakes against the inside of the pipe. This mechanism can also provide overspeed protection.

The primary advantage of this system lies in its simplicity, with a minimum of parts requiring maintenance. The pressure regulated braking capability provides an extra measure of reliability over a rope hoist. The bulk of the surface equipment required for conventional hoists is eliminated by this design. The primary disadvantages lie in the vehicle size and design of the tube.

For deep shafts, the cost of pipeline and its installation becomes prohibitive. Since the pipeline is permanently installed, any explosion vented by the shaft may disable the hoist. The size of the system is limited by available pipe and large capacity blowers and a 36 inch diameter cage capable of lifting 3 miners is considered a practical limit.

4.3.2.3 Motor/Winch Systems

Virtually all modern hoisting systems consist of a power supply, wire rope winch, headframe and a cage or

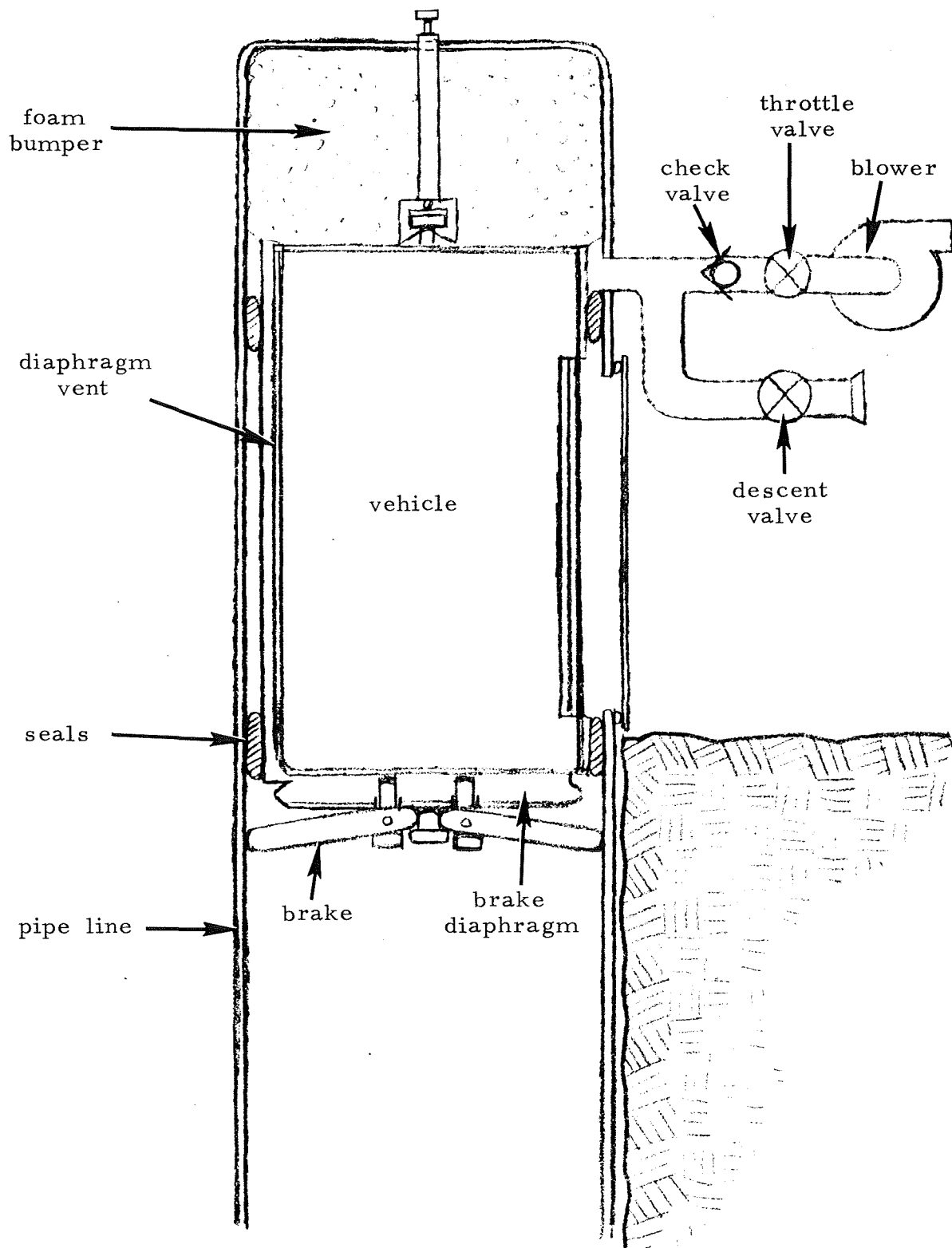


Figure 18. Vacuum Lift Design

bucket. In comparison to the alternate design concepts discussed above, a conventional hoist does not provide a significant cost or performance advantage. Both initial and maintenance costs for a conventional winch are higher than for most of the designs considered. For shallow shafts (less than 500 feet), there are several alternatives which can provide comparable evacuation rates to a conventional hoist.

In the final selection of the Foster-Miller Escape Hoist Design, however, several features of the wire rope hoist make it the most attractive design for the Emergency Hoisting application.

Power supplies, winches, wire ropes and structural components are readily available. No development costs are required and a conventional hoist could be fabricated and assembled in 6 months.

Every mine has hoisting engineers who are capable, with minimal additional training, of operating and maintaining a wire rope system.

Standards and specifications for man lifts and elevators (17, 18, 19, 21, 22) have been in existence for 50 years, and safe operation can be insured much more easily than with an experimental design.

Specific advantages for an emergency hoist system include:

- i. A wire rope hoist provides the greatest amount of design flexibility. One design, without modification, can be used at over 90% of all the present Emergency Hoist installations. There is no depth limitation for a wire rope system in American coal mines.
- ii. The cage can be easily removed from the shaft for storage and guarantees that, should the shaft vent an explosion, no damage to the hoist will occur.

- iii. Safety controls for wire rope hoists are simple to maintain, accurate, and readily available.
- iiii. A MESA inspector trained in inspection of regular coal mine hoists, can be readily trained to inspect a wire rope based Emergency Hoist.

These features were considered essential for a design suited to the widespread, and varied application of an Emergency Hoist.

4.4 Rationale for Selected Design

Before a design concept could be selected, a set of fixed conditions applicable to 90% of the installations surveyed under this contract had to be established. Reference is made to the State-of-the-Art interim report, dated December 1973, in selecting shaft depth, shaft type and cage capacity. Once these parameters were established, the overall system concept could be selected.

4.4.1 Fixed Conditions

a. Shaft Depth

Of 63 installations where shaft depth is specified, depths range from 40 feet to 1,238 feet. 92% of these installations have shaft depths less than 800 feet. 800 feet is the selected design depth of the FMA Emergency Escape Hoist System.

b. Shaft Type

85% of the escape hoists surveyed were installed in ventilation intake shafts, a very small percentage of which were blower systems. An intake shaft of an exhaust ventilation system is selected for this design. The design can be adapted for use in a fan housing. A minimum shaft width of 8 feet has been assumed in order to ensure adequate cage clearance.

c. Cage Capacity

Of the 63 installations where cage capacity is specified, 92% have a cage capacity of 6 men or less, a typical capacity is 4 men. The cage capacity selected for the Emergency Escape Hoist design is 6 men.

4.4.2 Overall System Concept

General

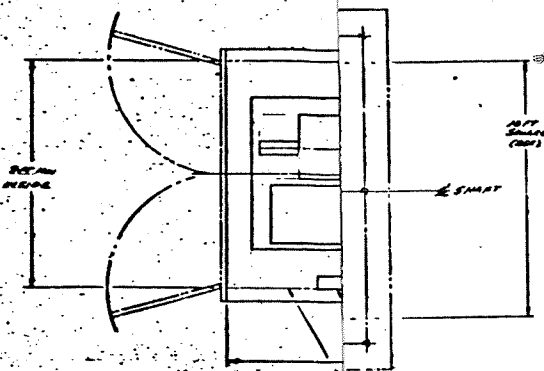
The design is based on the requirements of the proposed guidelines, cost-effectiveness, ease of operation and maintainability. Commercially available components and sub-systems have been selected wherever possible. The selected design arrangement is shown in Figure 19.

4.4.2.1 Cage

A circular cross-sectioned cage has been selected in order to hold the cage overall width to a minimum. This reduces the possibility of the cage striking the shaft wall. The cage is constructed from commercially available steel plate and channel and is of welded construction for ease of fabrication. The cage includes expanded metal siding and flooring to minimize weight. The cage has a door which slides on the inside of the cage. This reduces the possibility of door damage during operation which could render the system inoperable.

4.4.2.2 Headsheave Support Assembly

Several types of headsheave support were considered. Horizontal travel was selected since it is the most efficient means of moving the cage away from the shaft and secondly because it does not effect the system depth calibration. A rotating boom and winch house system was seriously considered but was rejected on the basis of cost, inefficiency in terms of the mass to be rotated and inflexibility in headsheave height and in installations involving a fan housing.



TERMS RODS/MENTS
1000, 1/2 VAC, 1000V

ALUMINUM JOINT CABLE
BOLD CAPACITY, NOT REACH

HOIST SHAFT ASSY - 2 CABLE
1/2" DIA. 30"
END, WELDED TO THE END
OF BOLT, ATTACH
TO THE END OF SHAF, 1000V

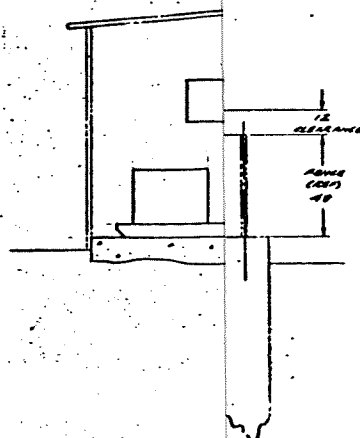
RE "TIP LIMIT"
TUBE & LIMIT
WITH ASSEMBLY.

SEE SPECIFIC
AND SHEET.

AS ASSY
VFE

SYSTEM SPECIFICATION

CAGE CAPACITY	6 MEN
CAGE LOAD CAPACITY	1500 LB.
CAGE SPEED - MAXIMUM	200 FPM
CAGE DEPTH - MAXIMUM	800 FT
CAGE HEIGHT ABOVE CEILING - MAXIMUM	5 FT
NUMBER OF OPERATES	1 MAX
CYCLE TIME - MAXIMUM	10 MIN
EVACUATION RATE - MAXIMUM	36 MEN/HR.



NOTE

1. MEET TO THE STANDARDS.
2. OVERHEAD SHAVE SUPPORT ASSEMBLY BY REMOVING OUT
DUT. 3. SCALE. APPLY 2 COATS OF ENE CHEMATE PRIMER
FOLLOWED BY 3 COATS OF AIR DRYING LUBRICANT TOP
DUT PAINT, AND YELLOW.
3. HOIST SYSTEM FOR ELECTRICAL SCHEMATIC (100V TO
1000V, 1000V, 1000V).
4. HOIST/MAN SHAVE. WIRING OF WHICH SIDE OF MAST, OR
WIRING. SHOWNED POSSIBLE CONDUIT BETWEEN MAST & JO
JUNCTION. CLAMPED CLEAR OF CABLESET & FREE TO MOVE
THROUGH. PULL JO TOWEL ETC.
5. SET TWO LIMIT SWITCH TO OPERATE WITH CAGE IN POSITION STOPPING.
6. SET TWO JOINT LIMIT SWITCH TO OPERATE WITH JO IN POSITION STOPPING.
7. SET JOINT LIMIT SWITCH TO OPERATE IN CAGE STOP POSITION.
8. RADIALLY CONTROLLER CANS TO PROVIDE A SMOOTH CAGE SPEED
TRANSITION OVER A TRAVEL DISTANCE OF 6 FT.
9. SET CONTROLLER OVERSPEED STOP TO OPERATE 12" IN ABOVE CAGE
POSITION STOPPING. SET UNDERSTAND STOP TO OPERATE 12" IN BELOW
LEAVING POSITION.
10. SET CONTROLLER OVERSPEED LIMIT TO OPERATE AT A WHICH
DOWN SPEED OF 36 FT/ MIN.
11. ADJUST EMERGENCY BRAKE SYSTEM TO STOP CAGE AT A RATE
OF 36 FT/ MIN. THIS IS EQUIVALENT TO STOPPING IN 12" IN LINE LEVEL
CABLESET AND A STANDBY COMMUNICATION SYSTEMS & 100V
CABLESET FOR LIGHT AT CAGE LEAVING POSITION.
12. PROVIDE SUITABLE HORIZONTAL FIRM SURFACE AND CAGE LEAVING.
MINIMUMS. CABLESET WITH SUITABLE HEAVY GEAR.
13. SUBSTITUTE WIRE ROPS WITH LIGHT LUBE OIL AT INTERVALS
NOT GREATER THAN 30 DAYS.
14. MAINTAIN, SERVICE & MAINTAIN SYSTEM PER PMA GUIDELINES &
INDIVIDUAL COMPONENT MANUFACTURERS RECOMMENDATIONS.

REV. 10/10/10		DATE	BY
PARTS LIST			
NIX FOSTER-MILLER ASSOCIATES			
11476			
11476			

The headsheave support selected is a jib-crane with a pivot line offset from the support column centre. This type of arrangement has several advantages. It is inexpensive, costing approximately \$1,600, and it moves a minimum mass, the cage and jib, away from the shaft in the horizontal plane. The offset pivot arrangement allows a three sheave system to be used. Two sheaves are mounted to the jib and one sheave is attached to the mast base. This arrangement ensures that the cage vertical position remains unchanged during rotation. Three sheaves and a reverse bend do not significantly effect wire rope life because of the infrequent use of the system.

Another significant advantage of this concept is that the height the cage can be lifted above surrounding obstructions can be readily varied by changing the mast height. Tube lengths up to 45 feet are commercially available.

4.4.2.3 Winch

The winch for the Emergency Escape Hoist is powered by a gasoline engine driving a variable displacement hydraulic pump. An hydraulic system has been selected because it is both efficient and cost-effective. The hydraulic system provides an infinite speed control over the system operating range. This provides the operator with sensitive control at the system travel limits. The minimum line pull of the winch is sized at 150% of the minimum static load and the nominal line speed is based on the 4 minute evacuation requirement which for the 800 foot shaft is nominally 200 FPM.

4.4.2.4 Controller

A Simplex-type controller is used to provide overwind, underwind and overspeed control. The unit is simple, cost-effective and well proven in industrial use. This unit additionally provides a depth indicator and a weight arm to power the emergency brake.

4.5 Design Description

The system is described in two parts: first a description of the equipment that is used in an open shaft; and second, a description of the overall system modifications required for operation in an enclosed fan housing.

4.5.1 Sub-system Description

The following is a detailed description of each of the system components.

4.5.1.1 Cage - Reference Figure 20.

The cage is designed to accommodate 6 men, is 4 feet in diameter, 8 feet high and weighs 715 pounds. The cage is fitted with an internally sliding door.

The cage is capped top and bottom with 10 GA (0.135 in.) CRS welded assemblies each 4 feet dia. by 9 inches deep with 6 inch high by 45° bevelled edges. The two end cap assemblies are structurally linked by four equally spaced vertical channel members. The top is reinforced by four horizontal channels each of which is welded to two of the vertical structural members. The bottom is similarly reinforced with two channels. Three of the four cage sides are covered with expanded metal grill which, when welded to the vertical channels and the top and bottom cap assemblies, provides additional torsional rigidity. The remaining side area is closed by a sliding door which is suspended from two roller assemblies at the top and restrained by two further roller assemblies at the bottom. Each pair of roller assemblies is limited by a track which allows the door to slide inside the cage through 90°. The door is locked closed by a latch mechanism which locks the door to the top and bottom track. To open the door two conscious positive movements must be made. The latch handle has to be pulled up and the door must then be slid open. The latch handle is accessible from both inside and outside of the cage.

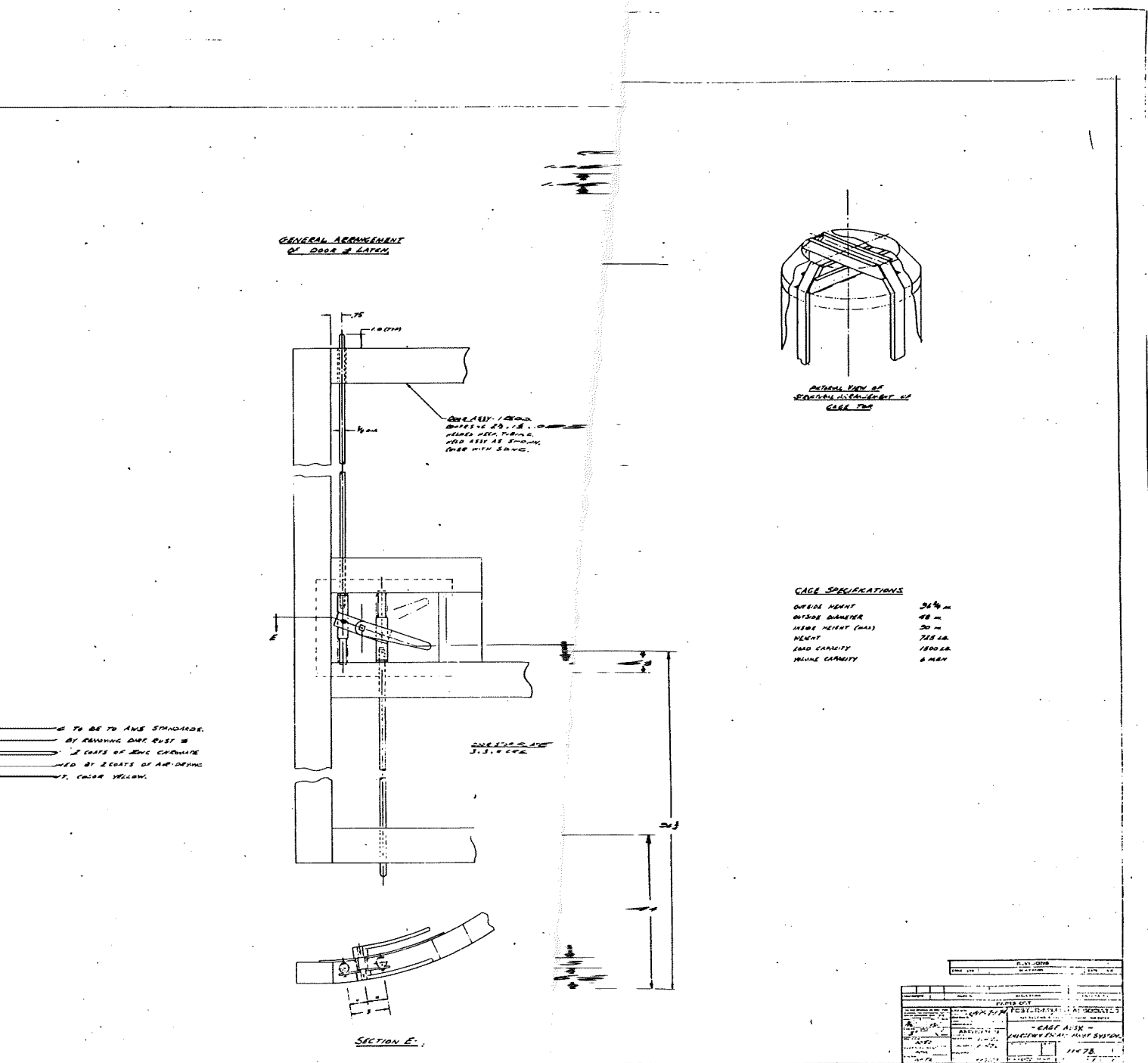


Figure 20. Cage Assembly: Emerge

The floor of the cage is expanded metal walkway which is welded to the cage edge and is also centrally supported by a single horizontal support channel.

The wire rope attachment is centrally located on the top of the cage. The attachment is a 7/8" dia. shouldered eyebolt which attaches through the roof to the cross-over point of the four top reinforcing channels. Lifting loads are therefore directly and equally transmitted through the four vertical members to the cage floor. The two bridle chain attachments comprise identical eyebolts again directly attached to the top reinforcing members. The bridles, of 1/2 in. diameter alloy chain are attached to the eyebolts by shackles. All attachment hardware for both the wire rope and the bridles is locked with cotter pins.

4.5.1.2 Wire Rope - Reference Figure 19.

The wire rope selected is 5/8" dia. 19 x 7 Non-Rotating, with a U.T. S. of 30,600 pounds. The rope operates with a safety factor of 11.0 under constant speed conditions and has a safety factor of 9.3 under the maximum acceleration loading of 6 fps².

The wire rope is attached to the cage by a spelter-filled closed socket to provide an attachment U. T. S. equal to the wire rope U. T. S.

The wire rope is run over two fixed sheaves and one sheave which is free to move both in the plane of rope bending and the plane normal to it. This freedom ensures that the rope is bent through a minimum arc and the sheave is always aligned. This holds rope wear to a minimum.

The rope total length is 900 feet. Three complete turns of rope exist on the drum with the system fully extended. The rope is terminated at the drum by attachment to the drum flange.

The wire rope is lubricated with light lubricating oil.

4.5.1.3 Headsheave Assembly - Reference
Figure 19.

The headsheave assembly comprises a commercial wall-mounted jib crane rated at 6000 pounds capacity with a maximum reach of 16 feet, attached to a free-standing tubular steel mast. Two sheave assemblies are bolted to the inner and outer ends of the jib boom. A third sheave assembly is mounted to the mast base and is located such that the point where the vertical rope enters the sheave is coincident with the jib rotational center line. This ensures that when the jib is rotated, the distance between the inner jib sheave and the base mounted sheave remains constant.

The jib is driven by a 1 HP, 6 rpm electric gearmotor through a 6 : 1 gear reduction, rotating the jib at approximately 1 rpm. The two extremes of horizontal travel are controlled by limit switches; one positioned to stop the jib over the shaft center and one at the storage position 165° away from the shaft center. The unload position is left to the discretion of the hoist operator at approximately 60° from shaft center.

The mast is set in an 8 x 8 x 5 foot concrete base and has an overall length of 35 feet, 30 feet of which is free standing. The mast is manufactured from commercial spiral welded 24 in. O/D tubing and has a 25 in. O/D capping plate at the top and a 27 in. square footing plate welded to its base. Jib and sheave attachment plates are welded to the mast.

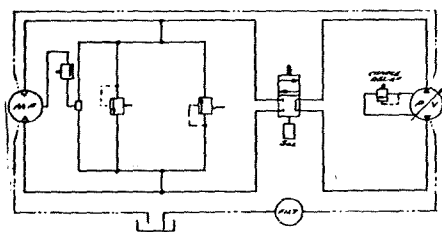
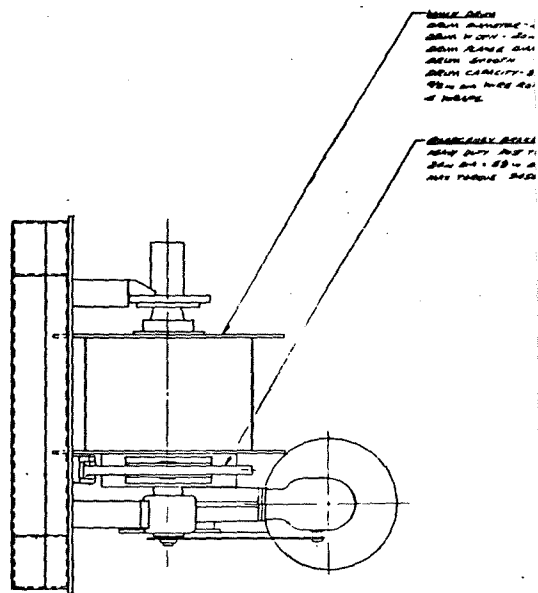
Attached to the outer end of the jib boom is the cage sensing arm and limit switch assembly. Two 150 watt lights are attached to the jib and positioned to illuminate the cage and not dazzle the hoist operator. Since the lights are mounted on the jib, the cage receives constant illumination throughout its lateral travel range.

4.5.1.4 Winch and Controller Assembly - Reference Figure 21.

The winch is hydraulically powered with a rated line pull of 4300 pounds on the first drum wrap. The winch drum is 24 in. diameter and 20 in. wide, and turns at 30 rpm. The power source is a 177 CID, 4 cylinder, gasoline powered engine which drives a variable displacement axial piston pump, delivering 15 GPM at 1800 rpm. The pump drives a fixed displacement hydraulic motor which delivers a maximum torque of 120 lb-ft., at a speed of 1100 rpm. The hydraulic motor output shaft is directly coupled to a spring applied, hydraulic pressure released, brake with a braking capacity of 400 pound-feet. The brake is directly coupled to a planetary gear reducer with a reduction ratio of 36.82:1 and a maximum torque capability of 15,000 pound-feet. The gear reducer is directly attached to the drum and provides the support bearing for one end of the drum.

The emergency brake drum is integral with the hoist drum and has a maximum torque capability of 9450 pound-feet. The emergency brake is connected to the controller weight arm by a direct linkage. The brake torque is varied by adjusting the linkage. Brake application rate is controlled by a bleed valve in the damping cylinder of the controller.

The controller is driven off the drum shaft by a chain and sprocket drive which provides an input speed of 130 rpm to the controller. The unit includes a fly-ball governor which is set to open the control switch at drum speeds in excess of 36 rpm. Opening of the control switch initiates both the shutoff of the hydraulic supply to the motor and emergency brake application. The controller includes a 24 inch diameter depth indicator dial with a pointer which rotates to indicate depth. Attached to the pointer assembly are two cams which define the overwind and underwind limits. The cams open the control switch when the limits are exceeded. The cam profile also controls the deceleration rates at travel limits. The profile and locations of these cams are established on site.



HYDRAULIC SYSTEM SCHEMATIC

REVISIONS		DATE	BY
1	REV		
PARTS LIST			
QTY	DESCRIPTION	UNIT	REMARKS
1	FORSTER-MILLER ASSOCIATES		
1	WINCH & CONTROL ASSEMBLY		
1	HYDRAULIC SYSTEM		
1	11476		

Figure 21. Winch and Control Ass

The winch is controlled by a single operating lever which is spring centered to off and allows for selection of any winch speed up to 200 FPM. The operating lever operates an arm on the body of the hydraulic pump which varies its displacement. With the lever in the off position the supply pressure to the hydraulic motor is reduced to a point where the spring operated hydraulically released brake is set. This feature ensures that the cage does not move when zero torque is applied by the hydraulic motor.

4.5.1.5 System Power Supply Controls and Communications - Reference
Figure 21.

General

The system controls and communication comprise the following.

a. Manual Transfer Switch

The primary system supply voltage is the standard utility supply at 115/230 VAC. The system also includes a 5 KW 115/230 VAC generator set which is used as a standby in case of a power-outage. A manual transfer switch is required to prevent feed back into the utility line. The switch selected is a 3 position, 2 pole, non-fusible 3 wire unit with a solid neutral and is UL approved to 250 volts with a 100 amp capacity. The unit is mounted on the winch house wall and has three positions, utility supply, off and auxiliary supply.

b. Auxiliary Generator

The auxiliary generator is a self-contained unit, gasoline fueled with a 12 V electric starter providing a 5 KW, 115/230 VAC output. The unit is driven by a 12 HP, 4 cycle engine governed at 3600 rpm. The controls comprise a start/stop switch and a choke.

c. Hydraulic System Power Source

The hydraulic system power source is a 4 cycle, 4 cylinder heavy duty gasoline fueled engine with 177 CID producing 47 HP at 1800 rpm. The unit has a 12 V electric starter and 17 amp generator. The control panel consists of a choke and variable-speed governor controls, ignition starter/stop switch, ammeter, oil pressure gauge, and hydraulic system pressure gauge.

d. Hoist Control Console

The hoist control console is mounted directly in front of the hoist operator and is divided into three sections; cage horizontal control, emergency stop and cage vertical control. The cage horizontal control comprises two momentary contact push buttons, one for cage forward, one for cage reverse. The center section contains the emergency stop button, a start button, and the emergency brake reset button which is used only when overtravel limits have been exceeded. The third section contains the cage vertical travel control lever which is forward for down, spring centered to off and back for up.

e. Mine Phone

The mine phone is part of the normal mine telephone network and connects the hoist operator with the below ground emergency hoist station and with the central mine switchboard. The unit is console mounted and within easy reach of the hoist operator when seated at the control console.

f. Standby Phone

A MSA Pager II type of standby phone is installed adjacent to the hoist operator's seated position. The unit is connected to a similar unit located below ground at the emergency hoist station by a two-line conductor. The conductor is run down the shaft or similar convenient route and is cased in steel conduit tubing.

4.5.1.6 System Safety Devices

The system includes the following safety features.

a. Controller

The controller senses overwind, underwind and overspeed conditions. The controller consists of a fly-ball governor which is mechanically linked to one electrical contact and a cam follower that is mechanically linked to a second electrical contact. Under normal operation the two contacts are closed. The cam follower runs in a profile that corresponds to the shaft depth and will open the contacts if the travel limits are exceeded. Similarly the governor will open the contacts should an overspeed condition occur. The controller contacts carry the electrical supply to the emergency brake weight latching solenoid and to the hydraulic system shut-off solenoid valve. When the contacts open, both these units are de-energized causing the emergency and hydraulic system brakes to operate.

The controller will also sense overlimit deceleration rates. The cam profiles are such that under normal operation when approaching the normal travel limits the cam follower contact will begin to open. However at the same time the governor senses the speed reduction and the governor contact follows the cam contact thus keeping the contacts closed.

b. Hydraulic System

Should an hydraulic system failure occur that results in loss of system pressure, the spring operated, pressure released brake is automatically applied.

c. Electrical System

Should electric power be lost at any point in the operational cycle then the emergency brake latching

solenoid and the hydraulic system solenoid operated, shut-off valve are de-energized causing both the emergency brake and the hydraulic system brake to be applied.

d. Emergency Stop Button

The emergency stop button will apply both braking systems in the manner of an electrical failure.

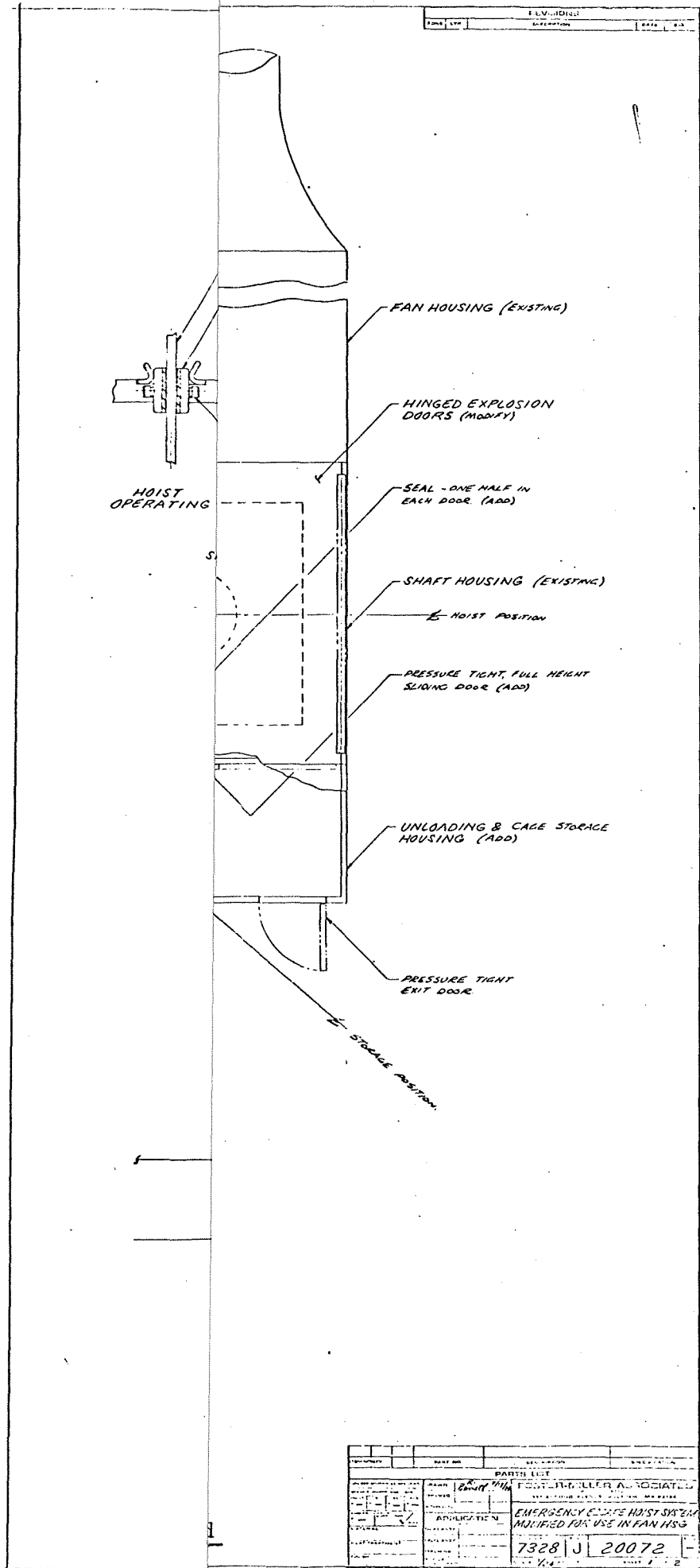
e. Travel Limit Switches

The system includes three limit switches used to control cage horizontal travel. The cage top limit switch ensures that the cage is above ground level before any horizontal travel can be made. The shaft limit switch ensures that when the cage is traveling towards the shaft, it will stop at the center of the shaft. The store limit switch defines the other extreme of travel.

4.5.2 System Installed in a Fan Housing

Figure 22 shows how, with minor modifications, the system can be modified to operate in a shaft ventilation fan housing.

The ventilation housing is modified by reshaping the two explosion doors and by adding a pressure tight enclosure to the side of the ventilation shaft. This is the cage storage and unloading room. The two explosion doors are modified such that their common interface includes a sealed track which is on the 15 feet radius defined by the swing of the headsheave jib. The edge of each door contains a channel track and a seal. With the doors in the closed position the seals provide an adequate pressure seal. The seal arrangement is continued from the edge of the door into the roof section of the cage unloading room providing a sealed arc of 40°. Running in the two track channels is the rope guide. This unit has two pairs of rollers which maintain the guide in the track and a central teflon lined bore through



which the wire rope runs. The top limit probe passes through the guide and the guide is shaped such that the seal opens and closes readily as it passes through the seal during the cage lateral travel. It is unlikely that a total pressure seal can be provided with this seal arrangement and for this reason an additional sealing plate is added. This plate is attached to one door only and will provide the normal quality seal of a standard explosion door arrangement. The plate is removed prior to emergency operation.

The unloading room is sized to contain the cage and six men during unloading. It is pressure tight and has two doors; one to the main ventilation housing and one to outside. Both doors are pressure tight units, the former being a sliding door of sufficient height to allow the cage and bridle to pass through and the second a normal sized door. Both the unloading room and the adjacent area of the main ventilation shaft contain windows which allow the hoist operator to judge the position of the cage in the housing.

The headsheave assembly modification is minimal. The mast height has been reduced by 3 feet, the jib lights are relocated in the ventilation shaft and the unloading bay and the top limit switch probe is modified to extend through the rope guide. The jib travel limit switch position is also modified to give a total travel of 40° from the shaft.

The system is operated as follows. The seal cover plate is removed. The hoist is started and with the exit door closed the internal sliding door is opened. This door is opened either by a second operator or automatically by the hoist operator. The cage is raised until the top limit position is reached. The cage is then swung through the open sliding door to the shaft center. The cage is then lowered, loaded and raised in the normal manner. The cage is then swung again through the open sliding door to the unloading position. The cage is lowered to the ground, the sliding door is closed and the men leave through the exit door, which is then closed and the cycle repeated.

With the system non-operating, the cage is stored in the unloading room with the sliding door closed. Should the shaft vent an explosion, the explosion doors will operate and the cage will be protected by the structure of the fan housing wall.

4.6 System Operation

The system operation can best be described by detailing the sequence of operation for a complete lowering and lifting cycle.

4.6.1 Normal Operation Reference Figure 23.

1. The electrical power supply is turned on. This energizes the Emergency Stop relay and closes the contacts.
2. The hydraulic winch is started and operating pressure is achieved.
3. The START button is momentarily pressed. This energizes the start relay which is self holding, closes the start relay contacts providing power to the hydraulic solenoid which opens, and provides power to the controller latching solenoid.
4. The Emergency Brake is released by lifting the weight which is then held by the latching solenoid.
5. The cage is raised from the ground by pulling the control handle back until the cage reaches the top limit position when the handle is centered. This position is judged by the operator from the relative positions of the cage rope clamp and the top limit probe. The two must be in contact. When contact is made the cage top limit switch is closed thus supplying power to the cage horizontal travel system.

REVISIONS			
LTR	DESCRIPTION	DATE	SNO

CONTACTOR NEMA SIZE 0, TYPE 1 RATED 24V, 18A CONTINUOUS 4 POLE 120V COIL

NEMA TYPE 4, WATERTIGHT 20A, 120V TARY CONTACT, WIRED N.C.

T WIRED N.O.

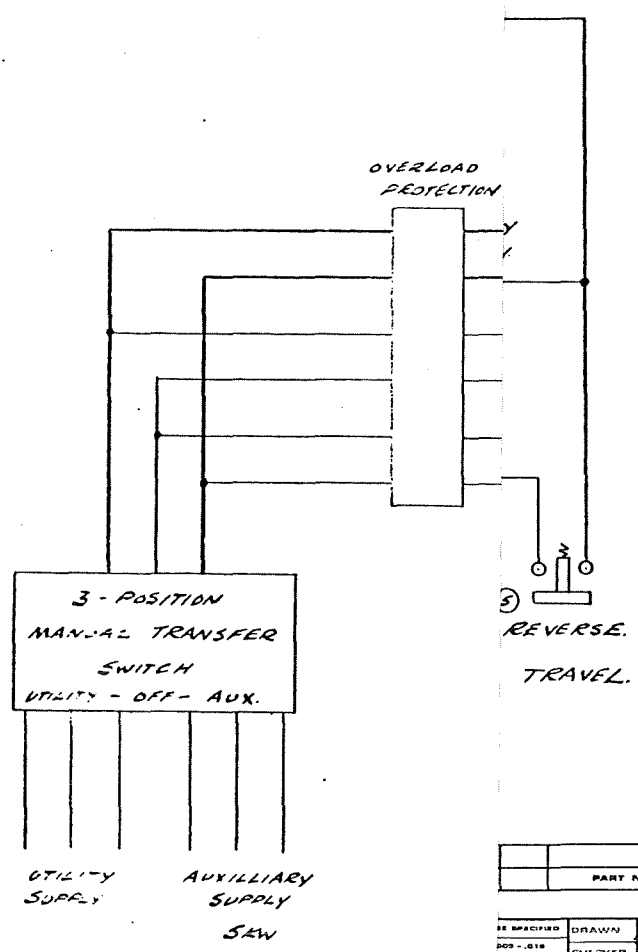
RELAY NEMA TYPE 1 SP. NO. CONTACT 1.

MOMENTARY CONTACT, N.O. NEMA TYPE 1 0US CONTACT RATING.

PF NC.

MOMENTARY CONTACT NO. NEMA TYPE 1 S CONTACT RATING WITH 15 SEC. HOLD.

FWD. MAG. T NC. CONTACTOR



115/220 VAC 1 PH 60HZ.

PART NO		DESCRIPTION		SPECIFICATION	
PARTS LIST					
RE BRACKET		DRAWN	FOSTER-MILLER ASSOCIATES		
DOS - 018		CHECKED	INCORPORATED		
11475		APPROVED	138 SECOND AVENUE WALTHAM MA 02156		
✓ MAX		APPLICATION		ELECTRICAL CONTROL SCHEMATIC	
NEXT ASSY		11476		EMERGENCY ESCAPE HOIST SYSTEM	
FINAL ASSY		11476		ORIGINAL PROJECT	SIZE
MACHINE				D	11475
ACTIVE PROJECT NO				SCALE 1/2" = 1"	WEIGHT
				SHEET	OF

6. The CAGE FORWARD button is pressed and the cage will rotate towards the shaft. When the cage is centered over the shaft the shaft limit switch opens shutting off power to the motor. The cage then stops. The operator then releases the CAGE FORWARD button.

7. The cage is lowered by pushing the control handle forward to the DOWN position.

8. The cage is stopped by the operator slowly centering the control lever when the depth indicator dial indicates that the cage is approaching the bottom. Cage height adjustment may be made at this time on instructions from the shaft bottom via the voice communication system.

9. On instruction from the shaft bottom, the cage is raised.

10. The cage is stopped by the operator when the top limit position is reached.

11. The cage top limit switch having closed in this position allows the operator to swing the cage away from the shaft by depressing the SHAFT REVERSE button.

12. When the cage is clear of the shaft and at the unload position the operator releases the SHAFT REVERSE button and the cage stops.

13. The cage is then lowered to the ground.

4.6.2 Emergency Stop

In order to restart the system following a controller initiated underwind or overwind emergency stop the following procedure must be followed.

1. Press START button. Release

2. Press RESET button. Release. The reset button will hold for 15 seconds. In this time the operator must release the emergency brake by lifting the weight and re-engaging it in the latch and then move the cage out of the overtravel position. This closes the Controller contacts and allows normal operation to be resumed.

4.7 System Cost

An estimate of the system cost is presented showing the cost of the subsystem parts. This cost estimate does not include the cost of the winch house, the concrete footing for the headsheave assembly mast or system on site assembly, erection and calibration.

<u>Subsystem</u>	<u>Cost</u>
Cage Assembly	\$ 3,200
Wire Rope - with socket	580
Jib Crane - unassembled	440
Jib Drive Motor - with mount	600
Jib Drive Gear Set	410
Mast Assembly	1,210
Fixed Sheave Assembly (2)	630
Sheave Block	470
Winch Assembly	8,100
Controller	1,800
Generator with manual transfer switch	1,050
Standby Communication System	370
Electrical Controls	<u>550</u>
	\$19,410

4.8 System Specifications

Cage

Volume Capacity	6 men
Load Capacity	1500 pounds
Dimensions	8 ft high x 4 ft diameter
Construction	Welded C3 x 4.1 steel channels and 10 GA (0.135) thick steel plate with expanded metal siding and flooring
Weight	715 pounds
Safety Bridle	1/2 inch diameter alloy chain UTS = 40,500 pounds
Bridle and Rope Attachment Fittings	Min. UTS = 32,500 pounds
<u>Wire Rope</u>	5/8 dia. 19 x 7 non-rotating UTS = 30,600 pounds

Headsheave Support

Jib Crane	Commercial wall mounted; 6000 pounds capacity with 16 feet reach
Mast	24 in. dia x 0.344 commercial spiral welded steel tubing. Overall height = 30 feet.
Sheaves	2 fixed sheaves, and one rope bearing swivel eye sheave. Tread dias. = 24 in. with 5/16 RAD x 30° grooves.
Jib Drive	1 HP 115/230 VAC 1 PH 60 HZ capacitor start/capacitor run gear motor. 5775 lb in at 6 rpm output. Final reduction gearing 6.4:1 spur gears Jib rotational speed 5.6°/sec.

Winch

Line Pull	4,300 lb maximum on first wrap
Line Speed	Variable line speed 0-200 FPM
Drum Capacity	850 ft. 5/8" dia. rope in 4 wraps
Drum Size	24 in. diameter, 20 in. wide, 35 in. diameter side flanges
Drum Speed	30 rpm maximum

Winch (Continued)

Power Source

177 CID, 4 cycle, 4 cylinder, air cooled, heavy duty, gasoline fueled engine developing 47 HP at 1800 rpm

Power Transmission

Axial piston variable displacement hydraulic pump with a maximum output of 15 GPM at 1800 rpm and 3000 psi. Pump drives a fixed displacement hydraulic motor delivering a maximum torque of 1400 lb in at 1100 rpm. Motor output to spring applied pressure released brake with 400 lb ft brake torque at pressures less than 200 psi. Brake output to 36.82 : 1 planetary gear box with 15,000 lb ft maximum torque capability and 43,000 lb radial load capability.

Emergency Brake

Post brake operating on 24 in. dia. drum delivering a maximum brake torque of 9,450 lb. ft.

Miscellaneous

Reservoir capacity 100 gal. indicator filter, oil temperature gauge, oil pressure gauge, solenoid operated shut-off valve, pressure relief valves charge relief valves, check valves oil level gauge reservoir breather filter.

Controller Weight Unit

Controller

Driven from winch drum shaft by 4.34 : 1 roller chain and sprocket drive at 130 rpm. Underwind and overwind set to operate at 1 ft above and below normal travel limits. Overspeed limit set to 36 rpm. 24 in. diameter depth indicator dial with pointer traveling through 300° over depth range

Weight Unit

50 lb weight on 20 in. arm providing 83 lb to 333 lb operating load through 60° travel range. Application rate controlled by adjustable hydraulic damping cylinder.

Electrical System

Utility Supply

115/230 VAC Single Phase 60 HZ
50 amp. supply

Auxiliary Power

5 KW 115/230 VAC Single Phase
60 HZ generator set driven by 12 HP
3,600 rpm gasoline fueled engine with
electric start.

Transfer Switch

Manually operated 3-position switch.
2 pole non-fusible, 3 wire with
solid neutral. 250 V, 100 amp.

Miscellaneous

AC magnetic contactor, NEMA size 0
Type 1 rated at 2 HP at 230 V. 18
amp continuous, 4 pole, 120 V coil.
Limit Switch NEMA Type 4
Watertight 20 A 120 V SPDT Momentary
Contact. Control relay NEMA Type 1
SP. NO 25 Amp contacts. Push
button, momentary contact. N. O.
NEMA Type 1. 10A continuous contact
rating. Push button, momentary
contact, NEMA Type 1 10 amp
continuous contact rating with 15 second
hold. Solenoid operated hydraulic shut-
off valve 120 V coil, normally closed.

Lights

Exterior floodlight 120 V, 150 W, NEMA
Type 4 (No. 150 PAR/FL or equivalent)
Internal light, NEMA Type 1, 120 V,
150 W. Shaft bottom light, MESA
approved 120 V, 50 W.

Communications

Main

Mine phone system - supplied by user.

Standby

MSA Pager II or equivalent. 12 V dry-
cell powered, solid state with loud-
speaker and handset.

Site Requirements (User Supplied)

Headsheave Support

10 ft x 10 ft x 1 ft concrete footing
with 8 ft x 8 ft x 5 ft concrete base
for setting mast.

Winch house

22 ft long x 9 ft wide x 10 ft high
(internal) winch house with concrete
footing and full length swing doors
front and rear. Fireproof weather-
proof. Located 30 ft from mast
center. 115/230 VAC 1 PH 60 HZ
50 A utility supply.

5. Conclusions

As a result of the surveys, interviews and research performed on this contract, the following conclusions are drawn:

1. Present Emergency Escape Installations are generally inadequate and some are either inoperative or unsafe. A few installations have demonstrated an effort to provide a safe and well designed hoisting system.
2. The MESA Districts have different local needs and impressions of what is necessary to ensure compliance. No guidelines up to the present have been effective and widely enforced.
3. There is equipment available at present which can be used to design and build safe and economic emergency hoists.
4. The guidelines that have been proposed under this contract are intended to permit mine operators to select an economic and safe hoisting system, and to provide the District Managers with the information needed to guarantee that only safe and operational systems are approved. Sufficient detail and procedures have been specified so that a mine inspector can verify the safe operation of the hoist in the field and cite violations if necessary.
5. The Escape Hoist Design that Foster-Miller Associates has developed, demonstrates an acceptable hoisting system, suitable for use at over 90% of the installations investigated, and in full compliance with the proposed guidelines.

BIBLIOGRAPHY

1. Code of Federal Regulations, Title 30, Mineral Resources, Chapter 1 - Bureau of Mines, Department of the Interior, U.S. Government Printing Office, Washington, D.C., 1973.
2. Fujimoto, Robert, T., Establishing Standards for Effective Wire Rope Clip Installation R.I. 7789, U.S. Bureau of Mines, Washington, D.C., 1973.
3. Humphrey, H.B., Historical Summary of Coal Mine Explosions in the United States, 1810-1950, Bulletin 586, Bureau of Mines, Washington, 1960.
4. Keenan, C.M., Historical Documentation of Major Coal-Mine Disasters in the United States Not Classified as Explosions of Gas or Dust: 1846-1962, Bulletin 616, Bureau of Mines, Washington, 1963.
5. Larsen, C.H. et al, Investigation of Requirements and Performance of Safety Catches on Wire Rope Suspended Man-Carrying Conveyances in United States Coal Mines. Battelle Columbus Laboratories, Long Beach, California, 1972.
6. Larsen, C.H. et al, Wire Rope Applications and Practices Associated with Underground Coal Mining in the United States. Battelle Columbus Laboratories, Long Beach, California, 1971.
7. Staff-Mining Research, Mine Communications, Proceedings: Bureau of Mines Technology Transfer Seminar, Bruceton, Pa. March 1973, I.C. No. 8635, U.S. Bureau of Mines, 1974.
8. The Mines (Emergency Egress) Regulation, Statutory Instrument No. 194, National Coal Board, England, 1973.
9. Walker, C.D., Jr. and R.W. Stahl, Recommended Procedures for Mine Hoist and Shaft Installation, Inspection, and Maintenance, I.C. No. 8031, U.S.B.M. Department of the Interior, 1961.

WIRE ROPE HANDBOOKS

10. Bethlehem Wire Rope, Bethlehem Steel Corp., Bethlehem, Pa.
11. Care and Abuse of Wire Rope, American Wire Rope Manufacturers Association, Silver Spring, Md., 1963.
12. Safe Use and Applications of Wire Rope and Wire Rope Fittings, U.S. Steel Corp., 1958.
13. Tiger Brand Wire Rope Engineering Handbook, U.S. Steel Corp., Pittsburgh, 1972.
14. Universal Engineering Handbook, Universal Wire Products, Inc., New Haven.

STANDARDS

15. AGMA Standard Practice for Single and Double-Reduction Double-Enveloping Worm and Helical-Worm Speed Reducers, AGMA 441.03, Washington, 1963.
16. AGMA Standard Practice for Single and Double-Reduction Cylindrical-Worm and Helical-Worm Speed Reducers AGMA 440.04, Washington, 1971.
17. AGMA Standard Practice for Spur, Helical, and Herrington Gear Shaft-Mounted Speed Reducers AGMA 480.05, Washington, 1974.
18. American National Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks, ANSI A17.1-1971, A.S.M.E., N.Y., 1971.
19. American National Standard Safety Requirement for Personnel Hoists, ANSI A10.4 - 1973, American National Standards Institute, New York, 1973.
20. American National Standard Practice for the Inspection of Elevators, Escalators, and Moving Walks, Inspector's Manual, ANSI A17.2 - 1973, A.S.M.E., N.Y., 1973.
21. S.A.E. Recommended Practices For: Life Test for Automotive Storage Batteries - SAE J240a, Storage Batteries - SAE J537h, Storage Batteries for Construction and Industrial Machinery - SAE J930a, Society of Automotive Engineers, New York, 1972.
22. Safety Standard for Manlifts, USAS A90.1 - 1969, A.S.M.E., New York, 1969.
23. USA Standard Safety Requirements for Material Hoists USAS A10.5 - 1969, ANSI, New York, 1969.
24. USA Standard Specifications for Use of Wire Ropes for Mines, USAS M11.1 - 1960, U.S.A. Standards Institute, Washington, 1960.

INTERIM REPORTS

25. Foster-Miller Associates, "State of the Art for Coal Mine Escape Hoist Standards" Interim Report submitted under U.S.B.M. Contract H0133020, December 1973, Unpublished.
26. Foster-Miller Associates, "Equipment Available for Use in Coal Mine Emergency Escape Hoists" Interim Report submitted under U.S.B.M. Contract H0133020, January 1974, Unpublished.

APPENDIX A

MANDATORY SAFETY STANDARDS FOR EMERGENCY ESCAPE HOISTS IN COAL MINES

Section 75.1704 -- Escapeways

. . . Escape facilities approved by the Secretary or his authorized representative, properly maintained and frequently tested, shall be present at or in each escape shaft or slope to allow all persons, including disabled persons, to escape quickly to the surface in the event of an emergency.

Section 75.1704-1 -- Escapeways and Escape Facilities

(a) . . .

(b) Each escape shaft which is more than 20 feet deep shall include elevators, hoists, cranes, or other such equipment, which shall be equipped with cages and buckets. When such facilities are not automatically operated, an attendant shall be on duty during any coal-producing or maintenance shift. An "attendant" as used in this subsection means a person located on the surface in a position where it is possible to hear or see a signal calling for the use of such facilities and who is readily available to operate such facilities or to readily obtain another person to operate such facilities.

(c) Stairways shall be installed in all escape shafts which are 20 feet or less in depth; however, in shafts 5 feet or less in depth, ladders may be substituted for stairways. Stairways and ladders shall be installed and maintained as follows:

(1) Stairways shall be of substantial constructions, set on an angle not greater than 45 degrees with the horizontal and equipped on the open side with suitable handrails. Where landing platforms are necessary, they shall be at least 2 feet wide and 4 feet long and properly railed.

(2) Ladders shall be anchored securely, set on an angle of not more than 60 degrees and be substantially constructed and maintained in good condition.

APPENDIX B
GUIDELINES ISSUED BY ACTING ASSISTANT DIRECTOR
FOR
COAL MINE HEALTH AND SAFETY, May 17, 1972
(Reissued March 19, 1973)

Section 75.1704, Escape Facilities in Shafts and Slopes

The information submitted by the operator should include the following information.

1. Name, identification number, and address of mine.
2. Name of company.
3. Dimensions of shafts or slopes including depth.
4. Manufacturers' specifications pertaining to hoist, cranes, cables, elevators, or other such equipment.
5. If facilities are manually or automatically operated.
6. Number of men employed underground.
7. A statement as to how the facilities shall be maintained and tested, including method of recording.
8. Procedure to be followed in the event of an emergency.

Guidelines to be Used in Approving Emergency Escape Facilities

Conveyances

1. Where escape facilities involve a fan housing, safe effective means shall be provided for the conveyance to enter and leave the shaft with minimum interruption of ventilation.
2. Shaft conveyances shall be fully enclosed -- metal mesh of suitable strength can be used.

3. Shall be provided with a door or other no less effective means to prevent one from falling out. When a door is used the latch shall be designed so that it can be operated from either the inside or the outside.
4. Shall travel in the center of shaft if possible. If a multi-compartment shaft, shall travel in center of compartment designated.
5. Shall be provided with bridle chains or ropes.
6. Shall be connected to the hoist rope in such a manner that will minimize tipping.
7. Shall accommodate at least three persons and shall be equipped with handholds or similar means for persons to maintain their balance.
8. Conveyances used on slopes shall be equipped with a drag or other device while ascending that will insure positive stopping action in the event of failure of the hoisting equipment.

Ropes and Attachments

1. The breaking strength of the hoist rope shall be eight times the static (dead weight) load.

Static load = weight of conveyance + weight of load + weight of rope from head sheave to the attachment when conveyance is at lowest point in shaft.
2. The sheave tread diameter shall be at least 24 times the diameter of the rope.
3. The hoist rope fleet angle shall not be great enough to permit the rope to contact the outside diameter of the groove in the sheave.
4. Ropes shall be attached to the conveyance by a spelter (zinc) filled socket or by rope clips (clamps) installed according to the instructions included in Section 77.1402-1 of the surface manual.

5. Only no-twist or nonrotating ropes shall be used, unless other effective means are provided to prevent the conveyance from swinging.
6. Hoisting ropes shall be securely attached to the hoist. (See Section 77.1907(d), surface manual.)

Hoists

1. Shall be provided with overwind safety devices.
2. Shall be provided with dual brakes capable of stopping and holding the conveyance when fully loaded.
3. Drum shall be mechanically connected to source of power (no "V" belts).

General

1. A safe means for getting off the conveyance shall be provided.
2. If electrically operated, it shall be connected to a circuit independent of the underground power circuit.
3. Communication shall be provided between the top and the bottom of the shaft or slope.
4. Permanent automatic installations shall have controls at the bottom and top of the shaft, and a control on the conveyance so that it can be stopped if trouble is encountered.
5. A mobile crane will be acceptable if it meets these requirements, is located where it can be in operation within 30 minutes after notification of an emergency, and a sufficient number of persons are trained in its operation. In addition, starting procedures and operating instructions shall be posted in an accessible location.
6. Supporting structure for the head sheave shall be of sufficient strength and adequately braced to withstand the hoisting forces, and shall be provided with a means to prevent side movement while hoist is in operation.

APPENDIX C

DISTRICT 2, COAL MINE HEALTH & SAFETY, GUIDELINES,

The following summation lists those guidelines in which we (District 2) have made deviations and those guidelines not mentioned in Mr. Stahl's memorandum. (Appendix B).

1. Conveyances

a. Item No. 7. We have relaxed the minimum number of persons a conveyance is to accommodate to "injured man on a stretcher accompanied by at least one man accompanying the injured."

b. Item No. 2 has been changed to "a totally covered roof or canopy and the remainder of the conveyance can be enclosed with wire mesh."

2. Ropes and Attachments

Item No. 2. We have relaxed this requirement when sheaves and drums were already installed.

3. Hoists

Item No. 2. We require one brake to be operated by a friction-type brake on the drum.

4. General

Item No. 3. We have required dual communication systems between top and bottom of the shaft.

5. The following items were not included in Mr. Stahl's guidelines:

a. We require overwind and automatic stop.

b. We require that a depth indicator be installed where it is prominently located for the operator to read.

- c. We require illumination at the top and bottom of the shaft.
- d. In shaft sinking, we require guides.
- e. We require the motor horsepower and other motor name plate data.
- f. We require rope dimensions and rope characteristic data.
- g. We require that an emergency hoist be used for no other task than as an emergency hoist facility.

APPENDIX D
GUIDELINES DRAWN UP BY
USBM HEALTH AND SAFETY OFFICIALS OF DISTRICT 7

Section 75.1704 -- Escape Facilities in Shafts and Slopes

Where a shaft or slope is equipped with hoisting facilities that are used regularly to transport persons into or out of the mine, and such facilities are examined regularly by Duly Authorized Representatives and comply with the applicable Rules and Regulations, they shall be considered as approved with no further action.

Failure of the operator to install any means of escape in designated escape shafts or slopes shall be a violation of this provision, and a Notice of Violation shall be issued.

When a Notice of Violation is issued, the operator shall be informed that he can submit a proposed plan of the facilities for tentative approval by the District Manager prior to installation of such facilities.

The information submitted by the operator should include the following information:

1. Name, identification number, and address of mine.
2. Name of company.
3. Dimensions of shafts or slopes including depth.
4. Manufacturers specifications pertaining to hoist, dranes, cables, elevators, or other such equipment.
5. If facilities are manually or automatically operated.
6. Type of facilities which persons will be transported on (such as cage, capsule, platform, or other devices).
7. Facilities for safe loading and unloading of men from such facilities.
8. Number of men employed underground. Number of shifts per day and days per week.

9. A statement as to how the facilities shall be maintained and tested.
10. When escape facilities involve fan housings, all relevant information pertaining to the fan.
11. The expected date of completion of the installation.
12. Signal system and communication system.
13. Procedure to be followed in the event of an emergency.

When the plans are received, they shall be reviewed and the operator informed of tentative approval or disapproval.

Where means of escape are installed in emergency escape shafts or slopes, but have not been approved in writing by the District Manager, the inspector observing the facilities shall inform the operator of the requirements to have the facilities approved and a memorandum shall be forwarded to the District Manager informing him of such facilities. A Representative shall be assigned to examine the escape facilities.

If the Representative determines the escape facilities conform to the guidelines a memorandum shall be forwarded to the District Manager recommending the escape facilities be approved. After review, the District Manager shall notify the operator of the approval. The approval shall contain a complete description of the escape facilities and procedures to be followed in the event of an emergency. The operator shall also be informed that any change in the escape facilities without prior written approval from the District Manager will be a violation of this provision and a Notice of Violation shall be issued.

If the Representative determines the escape facilities do not conform to the guidelines, a memorandum shall be forwarded to the District Manager recommending the approval not be granted. After review, the District Manager shall inform the operator by letter that the facilities are not approved and the reasons for such decision. The letter shall also establish a time to make the necessary changes. If the operator does not make the necessary changes in the time allotted, a Notice of Violation shall be issued.

The following are guidelines to be used for the approval of emergency facilities in shafts or slopes:

1. Slopes used as emergency escapeways more than 19 degrees but less than 30 degrees shall be equipped with stairways or adequate walkway with cleats; over 30 degrees but less than 45 degrees stairways shall be installed; over 45 degrees approved hoisting facilities shall be installed.
2. Where escape facilities involve a fan housing, the facilities shall be installed and the housing designed so that while in use the mine ventilation will not be appreciably disrupted.
3. In escape shafts more than 20 feet deep, escape facilities shall conform to the following provisions: Elevators, hoists or cranes, or other such equipment equipped with cages, capsules, or other devices shall be used.
4. Unless automatic hoists or elevators are used, a qualified engineer located on the surface shall be within 20 minutes traveling time of the hoisting facility at all times when any person is underground, and the hoisting facility must be operative within 30 minutes after notification of the emergency.
5. Cages, capsules, platforms, or other devices used to transport persons shall be fully enclosed to protect the persons being transported.
6. Hoists shall have rated capacities consistent with the loads to be handled and the recommended safety factors of the ropes used in such hoists and shall be equipped with an accurate and reliable indicator showing the position of the cage, capsule, platform, or other device, which shall be installed in clear view of the hoist operator.
7. Hoists shall be equipped with brakes capable of stopping and holding the cage, capsule, platform, or other devices when fully loaded.
8. A second person familiar with and qualified to stop the hoist shall be in attendance, except where the hoist is fully equipped with overspeed, overwind, and automatic stop devices.

9. Hoisting ropes shall be equipped with a spelter-filled socket or a thimble with an adequate number of clamps properly spaced and installed along the rope.
10. Cages, capsules, platforms, slope cars, or other devices when used for hoisting or lowering men shall be provided with two bridle chains or cables connected securely to the rope at least 3 feet above the socket or thimble and which are securely fastened to the cage, capsule, platform, slope car, or other device.
11. Where slope cars are used, the car shall be equipped with a drag or other device while ascending that will insure positive stopping action in the event of failure of the hoisting equipment.
12. Where hooks are used to attach cages, capsules, or platforms, or other devices to the socket or thimble of a hoisting rope, they shall be self-closing.
13. Hoisting ropes shall contain at least three full turns on the hoist drum when the rope is extended to its maximum working length. At least one full turn of the hoist rope shall be placed around the drum shaft or around the spoke of a free drum and both shall be fastened securely by means of clamps.
14. Where the depth of the shaft exceeds 100 feet, shaft guides and guide attachments, or other no less effective means, shall be installed to prevent the cage, platform, or capsule from swinging. Less than 100 feet, anti-spin devices may be used.
15. All guides and guide attachments, or other no less effective means, installed shall be maintained to the bottom of the shaft.
16. Where men are required to embark or disembark from a cage, platform, or capsule suspended over or within a shaft, a loading platform shall be installed to insure safe footing.
17. The speed of cages, capsules, or platforms transporting persons shall not exceed 500 feet per minute.

18. Two independent means of signaling shall be provided between the hoistman, and bottom and all landings in a slope or shaft. At least one of these means shall be audible to the hoistman. Signal codes used in any communication system shall be posted conspicuously at each slope and shaft landing and the hoisting station.
19. Signaling systems used for communication between slopes and shafts and the hoistman shall be tested weekly.
20. Hoists shall be inspected weekly by responsible persons, and each such inspection shall include examination of the headgear (headframe, sheave wheels, etc.), ropes, connections, links and chains, and other facilities.
21. A complete hoisting operation shall be conducted at not less than 30-day intervals. Where mine ventilation will be disrupted by such tests, the test shall be conducted when no persons are underground.
22. The results of all inspection and tests conducted shall be recorded in a book approved by the Secretary, and shall be signed by the person making the inspection.
23. Where internal combustion engines are used, they shall be maintained in operative condition at all times and started at least weekly, and positioned or vented to prevent fumes from entering the mine.
24. During cold weather where internal combustion engines are used, they shall be kept housed and maintained at temperatures which will insure quick starting.
25. Where electric motors are used, they shall be provided with a separate power circuit independent of any underground mine circuit.
26. The hoist and the immediate surface area shall be adequately illuminated.
27. Where skips used to regularly transport coal are designated as escape facilities, they shall be provided with a visible locking device and safe riding platforms. The hoisting facilities of such skips shall conform to the approval guidelines and be operated manually.

- 28(a) In escape shafts less than 20 feet deep, stairways may be used providing:
- A. They are of substantial construction, installed on an angle of not more than 45 degrees with the horizontal and equipped with handrails on the open side.
 - B. Where landing platforms are necessary, they shall not be less than 2 feet wide, 4 feet long and railed properly.
- 28(b) In escape shafts 5 feet or less, substantially constructed unpainted ladders may be used providing:
- A. They are set on an angle of not more than 60 degrees with the horizontal and anchored securely.
- 28(c) The escape facilities shall be examined at least weekly and a record shall be recorded in a book approved by the Secretary and shall be signed by the person making the inspection.

APPENDIX E:

TABLE E-1: SUMMARY OF BASIC FEATURES OF COMMERCIALLY AVAILABLE ESCAPE HOIST SYSTEMS (26)

Manufacturer	Cost, Dollars	Capacity	Maximum Service Depth	Running Speed	Braking	Power Supply & Drive Train	Full Automatic Controls	Height of Head Sheave Rest Clearance from Shaft	Safety Features	Boom Type
Dover Conveyor	18,000	4 man 800 lbs	500 ft, standard up to 1000 ft available	100 FPM w/4 men or 800 lbs load	Spring set motor brake spring set drum brake	Propane engine generator. Electric motor, direct drive to hoist	No	20 ft 20 ft	Linear footage counter with limit switches for over, under- wind. Additional boom-mounted overwind switch. Cable overlap switch. Over- speed switch.	Fixed boom angle, rotating on pivot and track
Coeur D'Alenes	22,000 F. O. B. Spokane, Wash.	8 man	1000 ft	two speed 150 FPM 300 FPM	Spring set motor brake Gravity set drum brake	Electric motor, direct drive	Yes option available for \$3000	15 ft Rotate 90° to either side	Over speed, over travel Worm drive will not free wheel with motor off	Fix head frame, rotates on pivot and track
Connellsville	45,000 - 60,000 includes install.	5 man 1000 lbs safe to 2000 lbs	To order	400 FPM or 200 FPM	Gravity set drum brake	Electric motor, hydraulic drive	Yes	As required can clear fan housing ~ 2 ft	Lilly Model D controller checks over speed, over travel. Limit switches for cable slack, over travel in head frame	Fixed frame on moveable car
Scott Midland	19,000 - 21,000 not including capsule	7,000 lbs less capsule weight	500 ft	Range between 125-215 FPM	Spring set Friction brakes	Gasoline engine, hydraulic drive	No	15' max. boom length 360° rotation	Motor governor over wind switch mounted on boom	One piece with hydraulic lift rotation
Phillips Mine and Mill Supply	~50,000 guess incl. install.	6 man 4,000 lbs. less capsule weight	any depth 5/8" rope	300 FPM	Spring set drum brake	Electric motor, hydraulic drive	Yes	20' more can be arranged 5' -6', more can be arranged	Over travel, over speed	Swans Neck, moves forward to shaft
Equipment Corporation of America	20,000 - 25,000 F. O. B. Pitts.	3000 lbs. or 5000 lbs. less cage weight	400 ft or 1000 ft with 3/4" rope	300 F. P. M.	Manually set drum brake, spring set motor brake	Gasoline engine, fluid torque converter	No	Approx. 30 ft 20 ft or more	Simplex Controller for under wind, over wind, over speed. Brake is spring set, electrically released.	Rotating stiff leg derrick
W. W. Williams Co.	Approx. 25,000	4 man	900 ft with 9/16" wire rope	400 FPM	Dual braking Spring set brake on winch shaft	Electric motor, hydraulic drive	No	55 ft max. boom length 360° rotation	Linear footage counter, with limit switches for over and under wind	Telescopic boom, hydraulic extension, lift rotation

APPENDIX F

WIRE ROPE MEASUREMENT, TERMINATION, AND MECHANISMS OF WEAR

The proper method for measuring wire rope diameter is illustrated in the following:

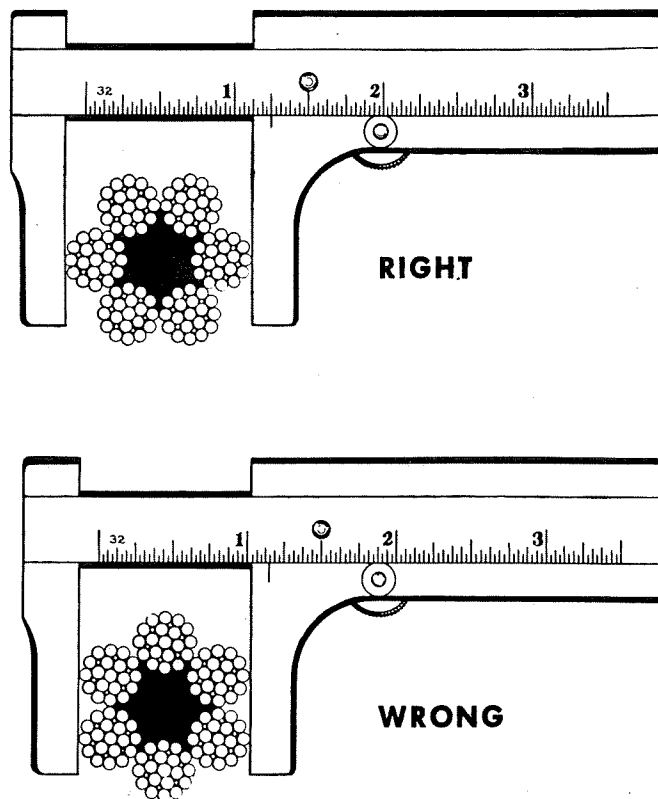
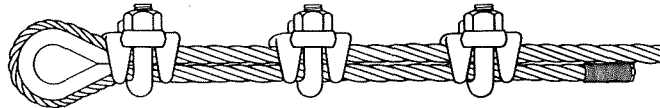


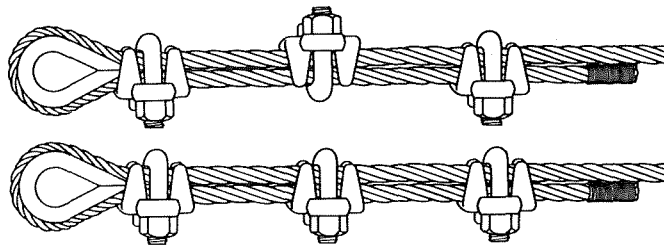
Figure F-1: Wire Rope Measurement (10)

Three acceptable methods of terminating a wire rope are illustrated in the following sections.

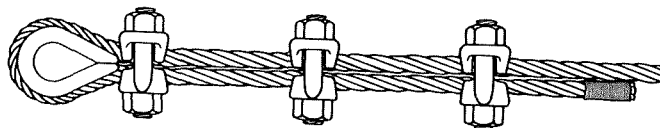
F.1 Wire Rope Clips (9)



The Right Way to Clip Wire Rope



The Wrong Way to Clip Wire Rope



Twin-base clips—drop-forged steel, galvanized.

Figure F-2: Wire Rope Clip Attachment

F.2 Spelter Filled Socket (13)

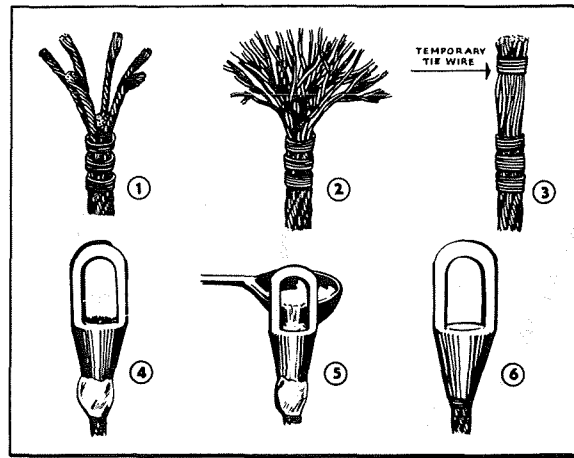


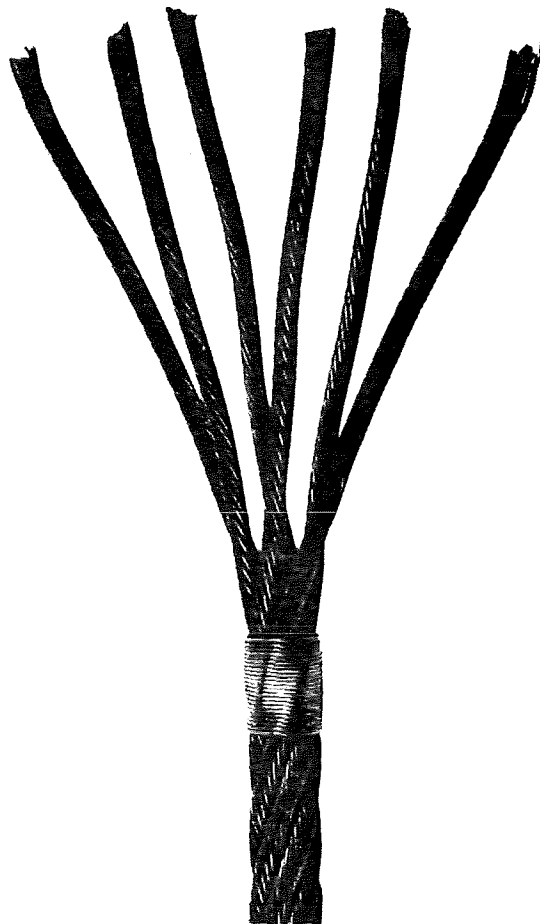
Figure F-3: Spelter-Filled Socket Attachment

- (1) Measure from end of rope length equal to basket of socket. Apply seizings at this point. Open strands and cut out hemp center. On wire center ropes let center remain.
- (2) Separate and straighten wires. Cleanse all wires with gasoline and wipe dry.
- (3) Dip wires to a depth so as not to immerse the end of the hemp core in acid solution. (50% Commercial Muriatic Acid and 50% water) and keep in acid until wires are thoroughly clean. Wipe dry. Seize end temporarily so that socket can be slipped over all the wires.
- (4) Slip socket over wires and remove temporary seizing. Spread out wires evenly and flush with top of basket. Seal bottom of socket with clay or asbestos. Line up socket with axis of rope. If cold, warm socket.
- (5) Pour with pure molten zinc. Do not use lead, babbitt or other alloy.
- (6) When cool remove fire clay and all seizings except one nearest the socket. Sockets properly attached will develop 100% efficiency.

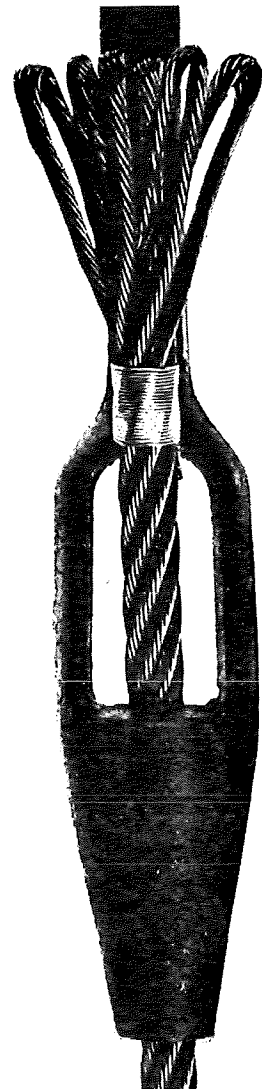
F.3 Babbitt-Filled Socket



a. Rope End Showing
Three Seizings



b. Strands Separated
and Straightened



c. Strand Ends
Turned In

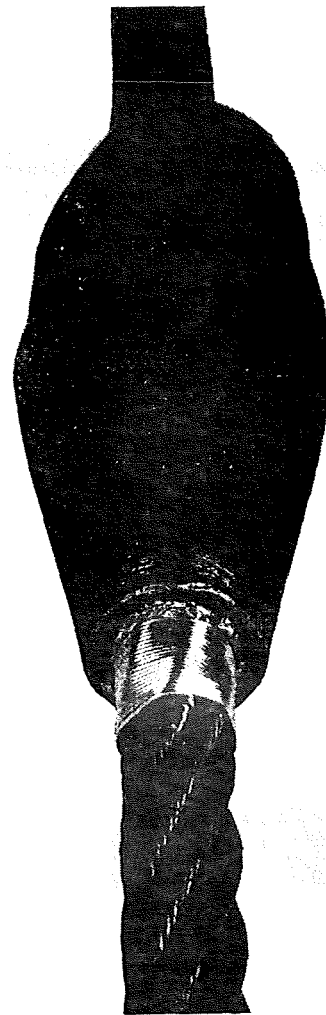
Figure F-4: Babbitt-Filled Socket Attachment



d. Turned Ends Pulled
Into Basket Ready
for Pouring



e. Top View of Basket
After Pouring

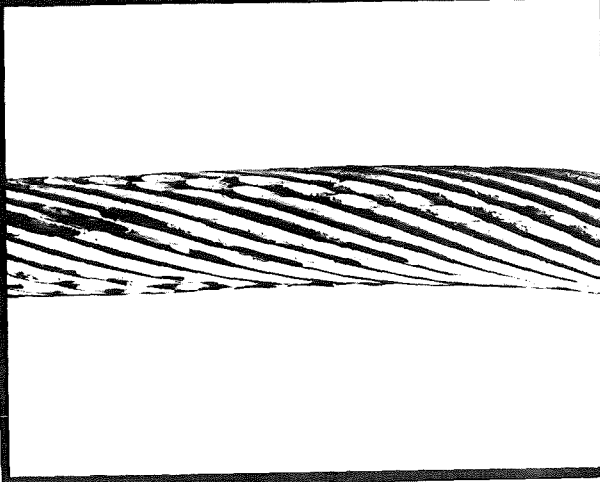


f. Close-Up of
Bottom of Basket
Showing Babbitt

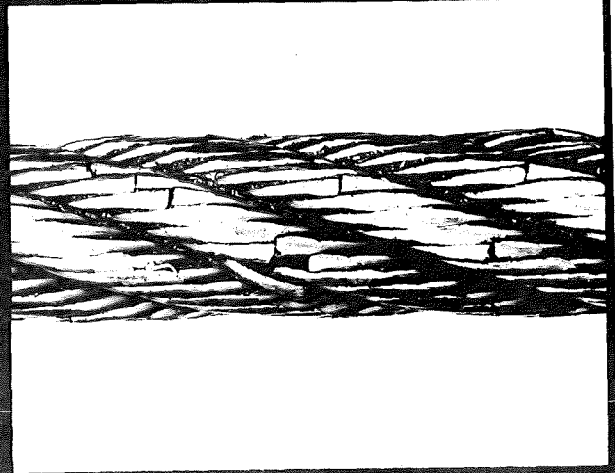
Figure F-4: Babbitt-Filled Socket Attachment (Continued)

The following are illustrations of wire rope damage and failure (10, 12):

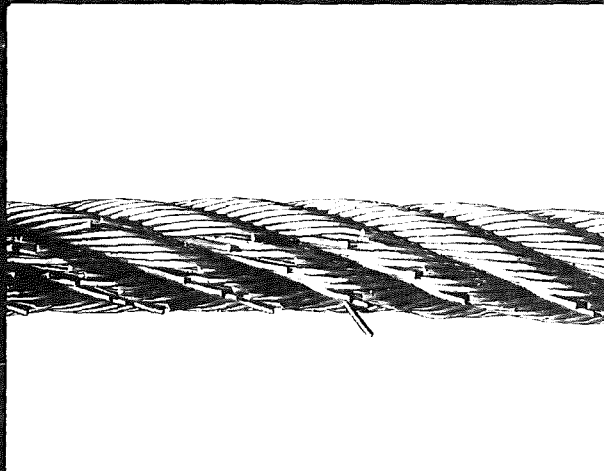
A single strand removed from a wire rope subjected to "strand nicking". This condition is the result of adjacent strands rubbing against one another and is usually caused by continued operation of a rope under high tensile load. The ultimate result will be individual wire breaks in the valleys of the strands.



A typical failure of a rotary drill line with a poor cut-off practice. A predetermined, regularly scheduled, cut-off practice will go far toward eliminating this type of break.



A wire rope which has been subjected to repeated bending over sheaves under normal loads. This results in "fatigue" breaks in individual wires, these breaks being square and usually in the crown of the strands.



An example of "fatigue" failure of a wire rope which has been subjected to heavy loads over small sheaves. The usual crown breaks are accompanied by breaks in the valleys of the strands, these breaks being caused by "strand nicking" resulting from the heavy loads.

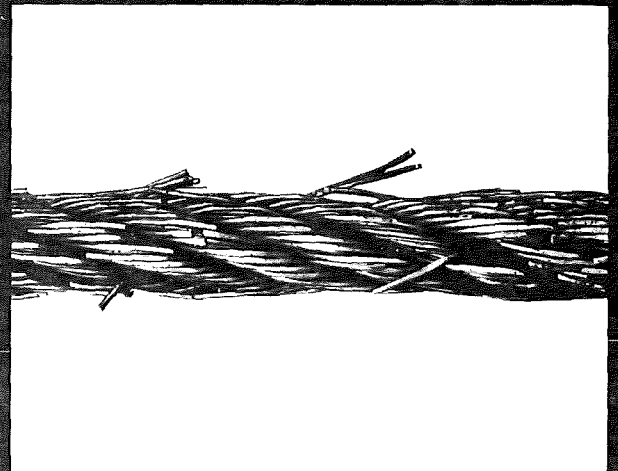
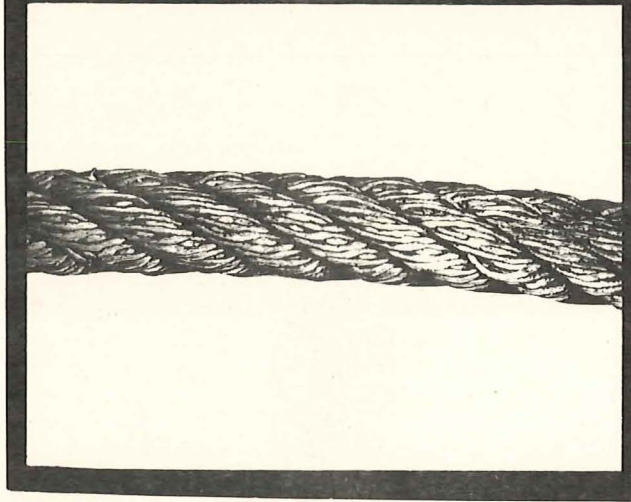
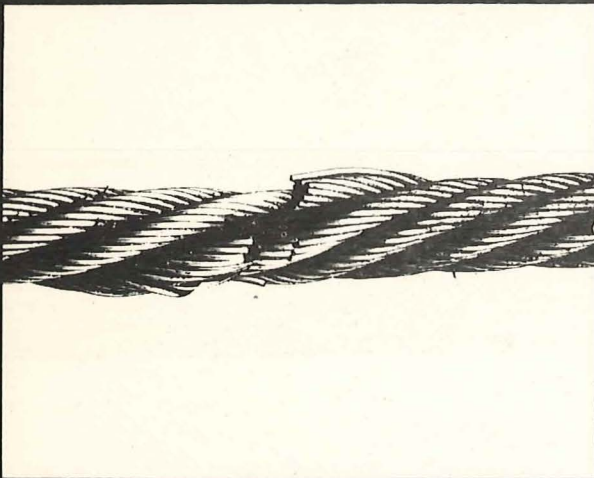


Figure F-5: Examples of Wire Rope Wear and Failure

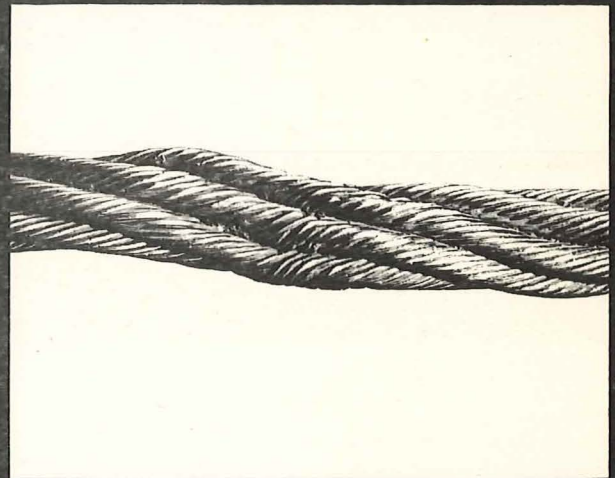
A close-up of a rope subjected to drum crushing. Note the distortion of the individual wires and displacement from their normal position.



A fatigue break in a cable tool drill line caused by a tight kink developed in the rope during operation.



A wire rope which has been kinked. A kink is caused by pulling down a loop in a slack line during improper handling, installation, or operation. Note the distortion of the strands and individual wires. Early rope failure will undoubtedly occur at this point.



A Worn Regular Lay Rope Showing Results of Abrasive Wear



A Worn Lang Lay Rope Showing Results of Abrasive Wear and Pounding Action

Figure F-5: Examples of Wire Rope Wear and Failure (continued)

APPENDIX G

ALTERNATE HOIST DESIGNS:

ENERGY STORAGE CAPACITY AND COST ESTIMATES

I. Compressed Air Driven Hoist

(a) Energy Storage Estimate

The energy stored in the compressed air is converted into shaft power in the air-driven motor. The regulator reduces the tank pressure (3,000 psi) to 100 psi. The air is then adiabatically expanded to ambient pressure in the motor. A heat exchanger maintains the air in the pressure vessel near ambient temperature. The maximum work that can be obtained in this device is:

$$\Delta H = MC_p (T_1 - T_2)$$

where:

M = mass of air used

$$C_p = 0.24 \text{ Btu/16}^\circ\text{R}$$

$$T_1 = 520^\circ\text{R}$$

Assuming an isentropic expansion of the air through the motor:

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}}$$

where:

$$P_1 = 100 \text{ psi}$$

$$P_2 = 14.7 \text{ psi}$$

$$k = 1.4$$

$$T_2 = 300^\circ\text{R}$$

$$\Delta H = 53 \text{ Btu/lb.} = 4.11 \times 10^4 \text{ ft. lb/ lb of air}$$

Assuming a 75% efficiency of the air drive each pound of compressed air will lift a 4000 lb vehicle 7.7 ft. To lift a vehicle 200 ft., approximately 26 lb. of compressed air at 3000 psi must be stored.

Volume of air at 3000 psi:

$$v = \frac{RT}{P}$$

where:

$$R = 53.3 \text{ ft. lb/16}^\circ\text{R}$$

$$T = 520^\circ\text{R}$$

$$P = 3000 \text{ psi}$$

$$v = 0.064 \text{ ft}^3/\text{lb.}$$

$$V = 26 \cdot v = 1.66 \text{ ft}^3$$

The pressure vessel and heat exchanger weight is estimated at 100 lb.

This system is feasible for shallow shafts and single trip operation.

(b) Cost Estimate

The following cost estimates are, for components only, for a system operating at a depth of 100 ft. Development, engineering and installation costs are not included.

motor	\$ 600
compressor	1,000
roller chain (100 ft. of Rex No. 120)	900
air motor (12 HP)	300
centrifugal activated brake (overspeed protection)	500
surface boom	1,000
valving, heat transfer equipment, tubing	400
pressure vessel (1-1/2 ft ³)	400
sprockets, reducer, general power transmission	300
reverse locking clutch	300
vehicle frame and body	2,000
surface trolley	1,000
overwind protection valving	<u>200</u>
Total component costs	\$ 8,900

If this system were to be used in shafts deeper than 100 feet, the cost would increase and load capacity would decrease (due to additional weight of compressed air storage). Typical projections, for different operating depths, are:

<u>Shaft Depth</u>	<u>Component Cost</u>	<u>Capacity</u>
100'	\$ 8,900	12 people
300'	11,500	11 people
500'	14,100	10 people

II. Lead Acid Battery Storage

(a) Energy Storage Requirement

A heavy duty, commercially available battery (55 lb.), rated at 90 amp. hr (at a twenty hour rate) can deliver 250 A. at 10 volts for at least five minutes.

Assume a 4000 lb. vehicle operating in a 500 ft. shaft at 100 ft./minute. The total energy required to lift the vehicle is 2.0×10^6 ft. lb.

Assuming a 50% conversion efficiency in the electric drive, the electrical energy needed is:

$$4.0 \times 10^6 \text{ ft. lb.} = 1.5 \text{ KWH}$$

The energy provided by one battery is:

$$H = VA t$$

where:

$$V = 10 \text{ V}$$

$$A = 250 \text{ A}$$

$$t = 5 \text{ min.}$$

$$H = 0.210 \text{ KWH}$$

A 8 battery pack, weighing 440 lb, will be adequate for lifting the vehicle 500 ft.

(b) Cost Estimate

The following cost estimates are for components only. Since this is a dual mode system, some of the components are wholly or in part determined by the portal bus function.

generator	\$2,000
DC-explosion proof motor (10-12 HP)	1,000
viscous brake	300
battery chargers (2)	500
detachable undercarriage*	8,000
roller chain	900
surface boom	1,000
surface trolley	1,000
explosion proof controls*	600
transmission and drive train*	300
overspeed protection	300
overwind protection	100
reverse locking drive	400
vehicle frame and body*	2,000
battery packs (3)	<u>1,200</u>
Total component cost	\$19,600

* Denotes component with cost due (at least in part) to portal bus function.

Typical projections for different operating depths are:

<u>Shaft Depth</u>	<u>Component Cost</u>
100'	\$19,600
300'	21,400
500'	23,200

III. Dual Mode System with Umbilical Line

No energy storage is required.

The following cost estimates are for components only, for a self-contained electrically driven system with umbilical power line from the surface. Assumed operating depth is 100 ft.

generator	\$3,000
DC-explosion proof motor (20 HP)	1,500
detachable* undercarriage and associated machinery	8,000
roller chain (100 ft. of Rex No. 120)	900
surface boom	1,000
surface trolley	1,000
explosion proof harnessing and controls*	1,000
drive train, power take off*	3,000
overspeed protection electronics	200
overwind protection equipment	100
worm reducer	300
rescue vehicle frame and body*	<u>2,000</u>
Total Component Cost	\$19,300

*Denotes component with cost due (at least in part) to portal bus function.

If this system were used in shafts deeper than 100 feet, it would be more expensive due to additional roller chain and electrical power transmission gear required. Capacity of the vehicle would be unchanged, however, as no additional on-board equipment would be needed. For example, to operate in a 300 foot shaft the system component cost would be about \$21,300 and vehicle capacity would be 12 people.

IV. Vacuum Lift

Assume a vehicle of 3' O.D., being lifted in a close fitting tube (small clearance and a sliding seal on the vehicle). The vehicle has a lightweight shell and carries three miners at a time. Gross vehicle weight is 1,000 lbs. The vacuum (above the vehicle) required to lift the vehicle is:

$$\text{Area} = \frac{\pi D^2}{4} = 1020 \text{ in.}^2$$

$$\text{Weight} = 1,000 \text{ lb.}$$

$$\Delta P = \frac{\text{Weight}}{\text{Area}} = 1.0 \text{ psi.}$$

To find the air flow rate required, assume vehicle speed is 100 ft./min:

$$\begin{aligned} \text{Volume/minute} &= (\text{tube area})(\text{speed in ft/min}) \\ &= (7.07)(100) = 707 \text{ CFM} \end{aligned}$$

This flow rate, at this vacuum, is well within the capability of many small, commercially available blowers requiring about 8 hp.

The following cost estimates are for components only, for a vacuum lift system to operate to 100 ft. depth.

Generator	\$ 800
pipeline support structure	300
blower	1,800
pipeline (100' long x 36" diam x 3/16" wall)	1,300
vehicle frame and body	1,000
overspeed brake mechanism	500
pressure-failure brake mechanism	400
surface latches and controls	<u>600</u>
Total	\$ 6,700

If used in shafts deeper than 100 feet, system cost would increase due to the need for more pipeline. Capacity would be unchanged. For example, to operate in a 300 ft. shaft, the system component cost would be about \$9,700 and capacity would be 3 people.

APPENDIX H

FMA EMERGENCY HOIST DESIGN CALCULATIONS

I. Cage Design

A. Cage Dimensions

The cage is designed to carry 6 men and to be circular in cross-section. Allowing 2 ft² floor area/man.

Cage internal diameter = 3.91 ft

A cage outside diameter of 4 ft. is used. The cage accommodates an 80 in. long stretcher mounted vertically and has 6 in. high bevels top and bottom. Cage overall external height is:

Stretcher height + 2 bevels + 2 skin thickness + floor

thickness + clearance = $80 + 2 \times 6 + 2 \times \frac{1}{8} + \frac{1}{2} + 4$

Cage height = 96 3/4 in.

B. Cage Weight Estimate - Reference Figure No. 20

Component	Weight - lb	Quantity	Total Weight - lb
Disc	39.1	2	78.2
Bevel Ring	43.7	2	87.4
Ring	17.6	2	35.2
Top Channel	13.3	2	26.6
Support Channel	15.4	2	30.8
Side Channel	34.3	4	137.2
Hip Strap Hoop	8.8	1	8.8
Upper Floor Channel	15.4	1	15.4
Lower Floor Channel	13.3	1	13.3
Siding	97.2	1	97.2
Floor	49.5	1	49.5
Door Frame	47.8	1	47.8
Door Siding	23.8	1	23.8
Mount Ring	9.2	2	18.4
Track Ring	5.5	2	11.0
Guide Ring	1.4	2	2.8
Latch	4.0	1	4.0
Roller Assy	0.75	4	3.0
Eyebolt Assy	7.0	3	21.0
Miscellaneous			<u>3.6</u>
			715.0

Weight of Complete Cage = 715 lbs.

C. Cage Loading and Stress Calculations

Maximum cage loading will comprise the following:

Cage Weight	=	715 lb
Maximum floor loading at 120 lb/ft ²	=	<u>1,500 lb</u>
∴ Maximum cage static load	=	2,215 lb
Dynamic load at 6 fps ²	=	<u>415 lb</u>
∴ Maximum cage loading	=	2,630 lb

(i) Stress in Top Support Channels and Support Channels

Ignoring top disc support, assume 4 channels each 42 in. long with pinned ends and centrally loaded with a point load. The channels are to ASTM A7 and have a minimum yield strength of 33,000 lb/in.². The Section Modulus S for these C3 x 4.1 channels is 1.10 in.³

The maximum stress in the channels occurs at the center = $\frac{WL}{4S}$

where $W = \frac{2630}{4}$

$$L = 42 \text{ in.}$$

$$S = 1.10 \text{ in.}^3$$

$$\text{maximum stress} = 6,250 \text{ lb/in.}^2$$

$$\therefore \text{Yield Safety Factor } S.F_y = 5.3.$$

(ii) Stress in Side Channels

There are 4 side channels of C.3 x 4.1 channel. The channel cross-sectional area = 1.21 in.². Ignoring siding support and assuming the maximum cage loading is equally applied to all 4 channels:

$$\text{Maximum stress} = \frac{W}{A}$$

where $W = \frac{2630}{4} \text{ lb.}$

$$A = 1.21 \text{ in.}^2$$

$$\text{Maximum stress} = 544 \text{ lb/in.}^2$$

$$\therefore S.F_y = 60.0$$

(iii) Stress in Floor Support Channels and Flooring

$$\begin{aligned}\text{Maximum load applied to floor} &= \text{floor loading} + \text{floor dynamic} \\ \text{loading at } 6 \text{ fps}^2 &= 1500 + 280 \\ &= 1780 \text{ lb.}\end{aligned}$$

Assume loading is equally shared between floor and floor supports.

$$\therefore \text{Load on floor beams} = 890 \text{ lb.}$$

Assume a worst case condition of a point load of 890 lb. applied at beam centers.

$$\text{Maximum stress occurring at beam centers} = \frac{WL}{4S}$$

$$\text{where } W = \frac{890}{2} \text{ lb}$$

$$L = 42 \text{ in.}$$

$$S = 1.10 \text{ in.}^2$$

$$\therefore \text{Maximum stress in floor beams} = 4240 \text{ lb./in.}^2$$

$$SF_y = 7.8$$

Load on flooring is 890 lbs uniformly distributed. Flooring is nominally 48 in. diameter and is supported circumferentially by its attachment to the cage side ring and diametrically by the top floor support channel. A rectangular section of the flooring used measuring 25 in. x 48 in. when supported along the two 48 in. edges meets the Federal Specification for walking comfort, in terms of deflection, up to centrally applied line loads of 400 lb. The cage flooring will therefore adequately support the 890 lb distributed load.

II. Wire Rope

The wire rope selected for the system is 5/8 dia. 19 x 7 non-rotating with a manufacturers breaking strength of 30,600 lbs.

A. Wire Rope Design Load

The wire rope design load is considered as the load on the wire rope at the headsheave with the wire rope fully extended and the cage fully loaded.

Cage Weight	715 lb.
Rope Weight at 0.71 lb/ft.	568 lb.
Maximum Payload at 120 lb/ft ² Floor Area	<u>1,500 lb.</u>
∴ Wire Rope Design Load =	2,783 lb.

To ensure best non-rotating performance of the wire rope a safety factor of 10 is required.

$$\text{Wire Rope Design Load S.F.} = \frac{30,600}{2,783} = 11.0$$

B. Maximum Wire Rope Load

Maximum wire rope load occurs under the above condition with the system accelerating at 6 fps².

Dynamic load at 6 fps ²	= 517 lb
∴ Maximum wire rope load	= 3,300 lb
∴ Minimum operational S.F. = $\frac{30,600}{3,300}$	= 9.3

C. Wire Rope Bending

The drum and sheave diameters are designed such that both are in excess of the minimum required diameter of 36d, where d is the nominal wire rope diameter. Drum and sheave tread diameters of 24 in. are used for this design.

The drum, rope and sheave arrangement selected is shown in Figure No. 19 and comprises one overwound drum and three sheaves. Considering a bend in a wire rope to be a change from its previous state i.e. from straight to bent or from bent to straight, then with the drum and three sheave system the wire rope is bent 14 times during each complete lowering and hoisting cycle. The bending per cycle for the three sheave system is more severe than that which would occur with the conventional system of one drum and one headsheave. For this system the bends/cycle are 6. The three sheave system also includes a reverse bend. In discussions with wire-rope manufacturers it is generally agreed that reverse bending can reduce rope life by up to a factor of 2. So comparing the two types of systems the 3 sheave system is approximately 5 times more severe in terms of rope bending, and therefore rope life, than the single sheave system.

Considering the single sheave system conservatively operating at 6 cycles an hour, 8 hours a day with the wire-rope being replaced every 6 months. The cycles/life for this system would be 8,500.

Now consider the three sheave Emergency Escape Hoist system. Normal operation comprises one cycle per weekly inspection and 3 cycles during each three-monthly inspection. The yearly cycle rate is therefore 64. The equivalent cycle rate when the severity factor of 5 is included is 320 cycles a year. Thus the equivalent rope life of the three sheave system when compared with the conservatively lifed single sheave system is 27 years. In terms of bending therefore the selected configuration for the three sheave Emergency Escape Hoist system will not be a major influence on rope life.

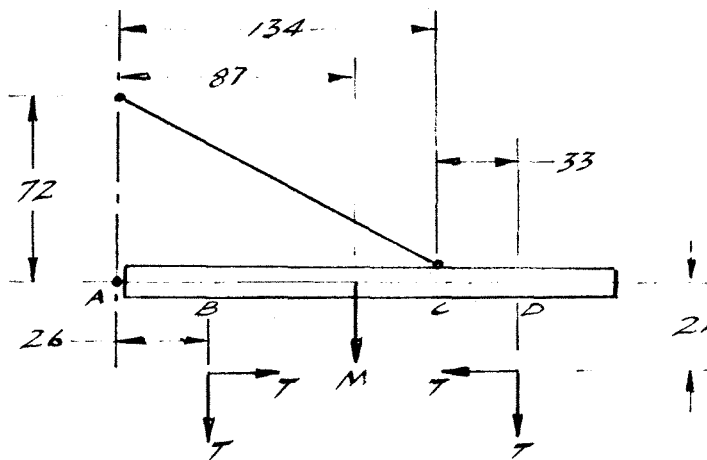
III. Headsheave Support

The headsheave support arrangement is detailed in Figure No. 19. The support comprises a commercial wall mounted jib crane mounted to a tubular, free standing mast. The mast is set in a concrete base.

A. Jib Design

The jib crane selected is designed to AISE Standards and when conventionally loaded, with a travelling electric hoist, has a rated capacity of 6,000 lb operating up to a maximum arm of 16 ft. The selected design is a non-conventional arrangement. The two sheaves mounted to the jib boom subject the jib boom to additional bending and comprehensive loads. A complete analysis of the jib boom stresses will therefore be made.

The jib beam is loaded as follows:



where T = maximum line pull = 3,300 lb

M = weight of jib assembly comprising gear motor and gear = 120 lb

Beam 510 lb

Tie Rod 70 lb

Sheave Assembly (2) 250 lb

950 lb

(i) Compressive Load

The maximum pure compressive load occurs in BC and is the sum of the horizontal reaction load at A and the compressive load due to the horizontal line pull T .

$$\text{Reaction load at A} = \frac{T (26 + 167) + M \times 87}{72}$$

$$= 10,000 \text{ lb}$$

Compressive load due to line pull T = 3,300 lb.

∴ Total compressive load in BC = 13,300 lb.

(ii) Bending Load

The maximum bending moment in the jib beam occurs at

$$C = T (33 + 21)$$

$$= 178,000 \text{ lb.-in.}$$

(iii) Maximum Stress

The maximum stress in the jib beam is a compressive stress at C due to compressive and bending loads. The jib beam is an I 12 x 31.4 section with the following properties:

$$\text{Cross sectional area } A_B = 9.35 \text{ in.}^2$$

$$\text{Section Modulus } S_B = 36.4 \text{ in.}^3$$

$$\text{Minimum Yield Strength} = 33,000 \text{ lb/in.}^2$$

$$\text{The maximum stress in the beam due to compressive load} = \frac{13,300}{A_B} = 1425 \text{ lb/in.}^2$$

The maximum stress in the beam due to bending load = $\frac{178,000}{S_B} = 4,880 \text{ lb/in.}^2$

$\therefore$ Total maximum beam stress = $6,305 \text{ lb/in.}^2$

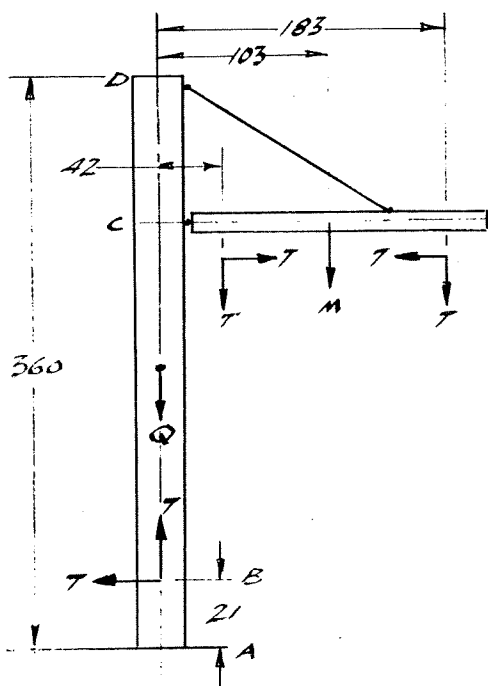
S.F.y = 5.2

B. Mast Design

The mast selected is made from 24 in. O/D x 0.344 in. wall commercial spiral welded steel tubing. The tube has an overall length of 35 ft. with 30 ft. of the mast being free standing.

(i) Mast Loading

The mast is loaded as follows:



where:

T = maximum line pull = 3,300 lb.

M = weight of jib assembly 950 lb.

Q = mast assembly weight
comprising:

Mast = $30 \times 85.5 \text{ lb/ft} = 2,560 \text{ lb.}$

Drive Gear = 120 lb.

Bottom sheave assy. = 120 lb.

2,800 lb

The maximum load in the mast will occur at point B and comprises an axial load due to mast weight, jib weight, line pull T, and a bending load due to T, M and wind loading.

Axial Load

$$\begin{aligned}\text{Axial load at B} &= Q - \frac{85.5 \times 21}{12} + M + 2T \\ &= 10,200 \text{ lb.}\end{aligned}$$

Bending Load

The system is required to operate under 5 lb/ft^2 wind loading conditions. A worst case condition of the wind direction being in the plane of bending is considered.

$$\text{Bending moment about B} = T (183 + 42) + M \times 103 + \frac{WL^2}{2}$$

$$\text{where } W = \frac{5 \times 2}{12} = 0.83 \text{ lb-in.}$$

$$L = 339 \text{ in.}$$

$$\therefore \text{Bending moment about B} = 887,000 \text{ lb-in.}$$

(ii) Mast Stresses

a. Operating Stresses

The mast tubing conforms to ASTM spec A-53 Grade B and has the following properties:

$$\text{Section Modulus } S_M = 151 \text{ in.}^3$$

$$\text{Cross-Sectional Area } A_M = 25.2 \text{ in.}^2$$

$$\text{Minimum Yield Strength} = 35,000 \text{ lb/in.}^2$$

$$\text{The maximum axial stress in the mast} = \frac{10,200}{A_M} = 405 \text{ lb/in.}^2$$

The maximum bending stress in the mast = $\frac{887,000}{S_M} = 5870 \text{ lb/in.}^2$.

∴ Total maximum mast stress = 6275 lb/in.^2

$$S F_Y = 5.6$$

b. Non-Operating Stresses

Non-operating stresses occur with the system due to the headsheave assembly weight and to windloading. When the system is non-operating the cage is resting on the ground and the line pull $T = 0$.

The maximum stress occurring at the mast base A due to headsheave assembly weight = $\frac{103 M}{S_M} + \frac{Q + M}{A_M}$
 $= 765 \text{ lb/in.}^2$

The dynamic airload acting on the headsheave assembly is 30 lb/ft^2 on projected vertical surfaces. Consider windload acting normal to plane of bending considered above.

$$\begin{aligned} \text{Moment due to mast loading} &= \frac{30 \times 2}{12} \times \frac{360^2}{2} \\ &= 324,000 \text{ lb.-in.} \end{aligned}$$

$$\begin{aligned} \text{Moment due to jib and sheaves} &= (16 + 8) \times 30 \times 273 \\ &= 196,000 \text{ lb.-in.} \end{aligned}$$

∴ Total moment due to air loading = $520,000 \text{ lb.-in.}$

$$\therefore \text{Bending Stress} = \frac{520,000}{S_M} = 3,450 \text{ lb/in.}^2$$

$$\therefore \text{Principle stress} = \sqrt{765^2 + 3,450^2}$$

$$= 3,980 \text{ lb/in.}^2$$

$$S F_Y = 11.3$$

IV. Jib Drive Design

A. Gearmotor

The maximum operating load for the jib drive occurs under windloads of 5 lb/ft^2 on projected vertical areas.

Windloading generates the following moments about the jib pivot:

$$\text{Jib boom} = 16 \times 1 \times 5 \times 96 = 7,730 \text{ lb-in.}$$

$$\text{Sheaves} = 4 \times 5 \times (171 + 27) = 3,960 \text{ lb-in.}$$

$$\text{Motor} = 2 \times 5 \times 36 = 360 \text{ lb-in.}$$

$$\text{Cage} = 8 \times 4 \times 0.5 \times 5 \times 196 = 15,700 \text{ lb-in.}$$

Note: A 50% permeability has been assumed for the cage.

Assume maximum bearing friction torque = 2,000 lb-in.

$$\therefore \text{Total torque required at jib pivot} = 29,750 \text{ lb-in.}$$

A 6.4:1 gear reduction is used between the jib pivot and the gearmotor drive.

$$\therefore \text{Maximum gearmotor torque required} = 4,650 \text{ lb-in.}$$

The gearmotor selected is a right angled 1 HP unit with the following rated output:

6 rpm

0.55 H. P.

5,775 lb-in. torque

6230 lb maximum shaft overhung load.

$$\text{The maximum H. P. required} = \frac{4,650 \times 6}{12 \times 5,250}$$

$$= 0.44 \text{ H. P.}$$

$$\therefore \text{Effective Service Factor} = \frac{0.55}{0.44} = 1.25$$

B. Final Reduction Gearing

The final reduction gearing is a 6.4:1 spur gear pair. The larger gear is mounted to the mast centered about the jib pivot and the smaller gear is mounted to the gearmotor output shaft. The gearing is 3 pitch, 3 in. face 14 1/2° P.A.

Input gear: 15 teeth, 5.00 Pitch diameter

Output gear: 96 teeth, 32.00 Pitch diameter

To determine the maximum working load capability of the gear pair:

Using the Lewis formula for spur gearing

$$W = \frac{F \cdot s \cdot y \cdot c}{P_d}$$

where: W = maximum working load capability

F = Face width = 3 in.

$$c = \frac{600}{600 + v} \text{ for ACMA standard gearing}$$

v = pitch line velocity (fpm)

y = form factor = 0.283 for spur gears

s = maximum allowable stress = 20,000 lb/in.²

P_d = Pitch diameter

$$v = \frac{6 \times \pi \times 5}{12} = 7.86 \text{ fpm.}$$

$$c = \frac{600}{607.9} = 0.988$$

$$\therefore W_{\max} = 3,360 \text{ lb.}$$

Actual maximum working load at tooth = $\frac{\text{gearmotor output torque}}{\text{pitch radius}}$

$$= 2,300 \text{ lb.}$$

$$\therefore \text{Effective Service Factor} = \frac{\text{Maximum Load Capability}}{\text{Maximum Working Load}}$$

$$= 1.45$$

To determine additional safety factor on overhung load

$$\text{Additional Safety Factor} = \frac{\text{Maximum Overhung Load Capability}}{\text{Maximum Overhung Load}}$$

Maximum overhung load = working load at tooth

$$\therefore S F = 2.7$$

To determine jib rotational speed

$$\text{Speed} = \frac{6}{6.4} \times \frac{360}{60} = 5.6^\circ/\text{second}.$$

∴ Approximate time to travel from shaft center to unload position = 10 seconds.

V. Winch Design

A. Winch Drum

i. Drum Size

The required drum width is a function of the maximum allowable fleet angle which for a smooth drum is $1^\circ 30'$. The distance from the drum center to the first sheave is 32 ft. minimum.

$$\therefore \text{Drum width } W = 2 \times 32 \times 12 \tan 1^\circ 30'$$

$$W = 20 \text{ inches}$$

$$\text{Drum diameter } D = 24 \text{ inches}$$

$$L = \text{Factor} \times W \times h (D + h)$$

where L = rope length = 800 feet

Factor = 0.670 for 5/8 in. dia. rope

$$W = \text{Drum width} = 20 \text{ in.}$$

$$L = \text{Depth of rope (in.)}$$

$$D = \text{Drum diameter} = 24 \text{ in.}$$

Substituting in the above equation

$$h = 2.3 \text{ inches.}$$

A 3 inch clearance is allowed between the outer layer of the wire rope and the edge of the drum flange.

$$\begin{aligned} \text{Drum flange diameter} &= D + 2 (h + 3) \\ &= 34.6 \text{ inches} \end{aligned}$$

A 35 inch drum flange diameter is used.

ii. Drum and Line Speed

A drum rotational speed of 30 rpm will produce the following wire rope line speeds:

Minimum Line Speed.

Minimum rope diameter measured to rope ϕ = 24.62 in.

$$\begin{aligned} \therefore \text{Minimum line speed} &= \frac{30 \times 24.62}{12} \times \pi \\ &= 193 \text{ FPM.} \end{aligned}$$

Maximum Line Speed.

Maximum rope diameter measured to rope ϕ =

$$24 + 2 \times 2.3 + 0.62 = 27.98 \text{ in.}$$

$$\therefore \text{Maximum line speed} = 219 \text{ FPM}$$

$$\therefore \text{Average line speed} = 206 \text{ FPM.}$$

iii. Drum Torque

The drum line pull required is 1.5 times the maximum static line pull.

Maximum static line pull of 2,783 lb occurs with wire rope fully extended.

∴ Wire rope diameter = 24.62 inches.

$$\begin{aligned}\text{Maximum drum torque required} &= \frac{2,783 \times 1.5 \times 24.62}{2 \times 12} \\ &= 4,300 \text{ lb. ft.}\end{aligned}$$

B. Winch Drive

Using a commercial planetary gearbox at the drum hub having a ratio of 36.82:1

$$\text{Torque input required to gearbox} = \frac{4,300 \times 12}{36.82} = 1400 \text{ lb. in.}$$

$$\text{Speed} = 30 \times 36.82 = 1,105 \text{ rpm.}$$

A commercial fixed displacement motor is selected which delivers 1,450 lb in. torque at 1,100 rpm at 3,000 psi and 15 GPM. This unit is matched by a variable displacement pump which delivers 15 GPM at 1,800 rpm input speed. The pump is driven by a gasoline fueled engine developing 47 HP at 1,800 rpm.

C. Winch Braking

Normal braking of the winch is achieved by the hydraulic system. At low system flow rates the system develops insufficient torque to hold the drum so a spring set, hydraulically released brake is included.

The brake operates at supply pressures less than 200 psi and provides 400 lb.ft. of braking. The unit is located between the hydraulic motor and the gearbox where the maximum torque required to drive the system is 1,400 lb. in.

Brake Safety Factor = 3.4

The Emergency Brake when operated by the 50 lb weight supplies a 9,450 lb. ft braking torque on the drum. When compared with the maximum drum torque required of 4,300 lb. ft. the brake safety factor is 2.2.

D. Winch Power Source

$$\text{The power required at the hydraulic motor} = \frac{1,450 \times 1,100}{12 \times 5,250}$$

$$= 25.3 \text{ HP}$$

The hydraulic system efficiency at a pump input speed of 1,800 rpm is 55%

$$\therefore \text{HP required at gasoline engine} = 46 \text{ HP}$$

The maximum output of the gasoline engine at 1,800 rpm is 47 HP. This engine selection therefore ensures that the winch is capable of exerting a line pull equivalent to 150% of the maximum static load and no more. The system can therefore not be overloaded to any greater extent than the 150% loading.

VI. Electrical Power

The generator is sized to meet the system electrical power requirement:

Lighting

Three 150 W lights are used and one 50 W = 500 W

The motor starting power for a 1 HP capacitor start unit is 2,500 W and the running power is 1,200 W. A factor of 1.25 will be added since the unit has a high inertial load = 3,100 W max.

The controls include 5 coils which can be energized together. With a maximum of 1 amp/coil. = 600 W max.

Total power required = 4,200 W

A 5 KW unit will provide an additional 20% margin.