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Safer Procedures for Removing Dragline Wire Rope Terminations

By G. K. Derby

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

yd^3	cubic yard	in	inch
ft	foot	lb	pound
ft•lbf	foot pound (force)	pct	percent
ft/s	foot per second	psi	pound per square inch
gr	grain	V	volt

SAFER PROCEDURES FOR REMOVING DRAGLINE WIRE ROPE TERMINATIONS

By G. K. Derby [1]

ABSTRACT

The Bureau of Mines investigated methods for removing dragline bucket wire rope terminations with the objective of finding efficient methods that are safer than the method most commonly used at U.S. surface mines, which is to use the explosive impact of a projectile fired from a cannon to remove the rope termination. Removal of a wire rope termination for repair or replacement requires separation of the wedge and socket that lock together to secure the rope end. The Bureau investigated currently used methods and improved upon and tested two safer alternate methods for removing wire rope terminations. A cannon test program was conducted, using 40- and 50-gr primer (detonating) cord, to establish the possible force produced with a 4-in-bore cannon and a 55-lb projectile. Wedge and socket units supplied from cooperating mines were separated under controlled conditions to establish data on separation force requirements. The two alternate methods investigated were use of the force generated by (1) a pendulum ram and by (2) a portable hydraulic pusher. Both methods are capable of providing sufficient force to effect wedge and socket separations on draglines with up to 78-yd^3 buckets under normal conditions.

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INTRODUCTION

The main impetus for the research described in this report was the potentially hazardous nature of the predominant method used in the United States for separating wedges and sockets that secure dragline wire rope ends. Possible hazards of the method commonly known as the cannon method were brought to the attention of a Bureau of Mines representative during a routine visit to a surface mine that uses draglines for overburden removal. A drag rope broke, and when inquiries were made concerning repair methods, the cannon method was explained. During the discussion, the maintenance personnel who removed the rope terminations stated that they considered the method efficient but hazardous. They felt apprehensive during the task and relieved when it was completed without an accident or injury. This concern was repeated by personnel at other mines and by industry representatives. Review of accident data collected by the Mine Safety and Health Administration (MSHA) failed to uncover any fatal or lost-time accidents directly attributable to use of the cannon method. However, investigation revealed that the method has been outlawed in Canada. Equipment manufacturers contacted by the Bureau were aware of problems being experienced during rope removal, but some were not fully aware of how the operation is performed. As a result of these findings, the Bureau initiated a detailed investigation of the cannon method (and other methods) to determine its possible drawbacks and/or merits and attempt to devise less hazardous and, if possible, more efficient methods. The results of this investigation are presented in this report.

The investigation was conducted as part of the Bureau's Minerals Health and Safety Technology Program. One objective of this program is to reduce industrial hazards in surface mining operations through the establishment of safer work habits and procedures. Tests and other research described in this report were conducted on-site at participating surface coal mines and at Bureau research facilities. Background research and inquiries uncovered no previous efforts by government or industry agencies to determine force requirements for wedge and socket separation or to establish standard procedures for wire rope removal.

ACKNOWLEDGMENTS

The author expresses his graditude for assistance given by the management and maintenance personnel of the Consolidated Coal Co., Pinkneyville, IL. They provided guidance by detailing their experience in dragline bucket rope removal and supplied detailed drawings and materials which were used to fabricate the explosive impact device used in the Bureau's testing program.

Appreciation is also extended to the management and maintenance personnel of the Morison-Knudson Co., Inc., Sarpy Creek Mine, Hardin, MT; Long Construction Co., Colstrip Mine, Colstrip, MT; and Washington Irrigation Co., Centralia Mine, Centralia, WA; for supplying joined wire rope wedge and socket units for separation testing, for allowing Bureau personnel to perform socket removal technique testing at their facilities, and for assisting in this testing. The research reported here would not have been possible without the cooperation and assistance volunteered by these firms.

EXISTING WIRE ROPE REMOVAL PRACTICES

A dragline wire rope termination point consists of a rope socket and socket wedge (fig. 1). Termination points are located at the ends of the drag, hoist, and dump ropes (fig. 2). Termination point separation is necessary when a wire rope must be changed because of wear or because of a rope break. As a

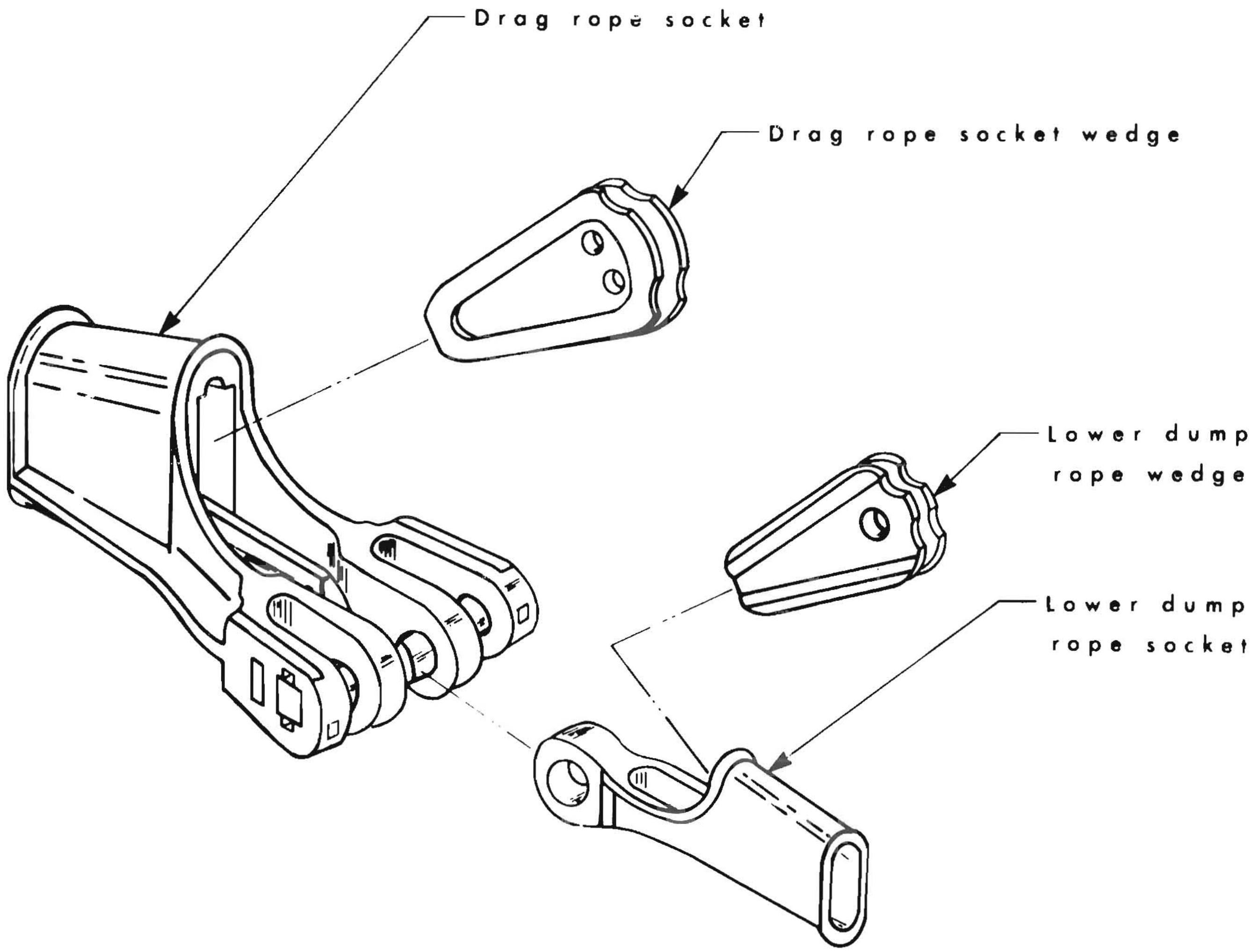

FIGURE 1. - Typical dragline wedges and sockets.

precautionary measure, rope changes are generally scheduled on a periodic basis. The rope end is locked in place between the wedge and socket by friction-press action. Finding a way to overcome the socket and wedge locking action in a safe, efficient manner was the main objective of this research project.

Wedge and socket separation to accomplish rope removal is usually accomplished by one of three methods: explosive impact, manual impact, or burnout. These three methods are described briefly below:

1. Explosive impact--Two means of using explosive force are employed: (1) installing an explosive agent and packing with a neutral material to provide backing for the charge and (2) what is commonly called the cannon method. The main body of the device used in the cannon method to hold and direct the charge and projectile is generally fabricated from whatever type of steel material is available (fig. 3) in sizes ranging from 14 to 18 in OD by 32 to 36 in long. The bore--generally 4 to 6 in--must be equal to or smaller than the width of the wedge to be removed if the cannon is to be effective. The projectile is made of steel with a diameter one-eighth inch smaller than the bore and is from 12 to 20 in long. Explosive force is generated by either 40- or 50-gr primer (detonating) cord. The length of the charge is determined by the trial-and-fail method: A starting length of charge is decided upon and tried. If separation is not

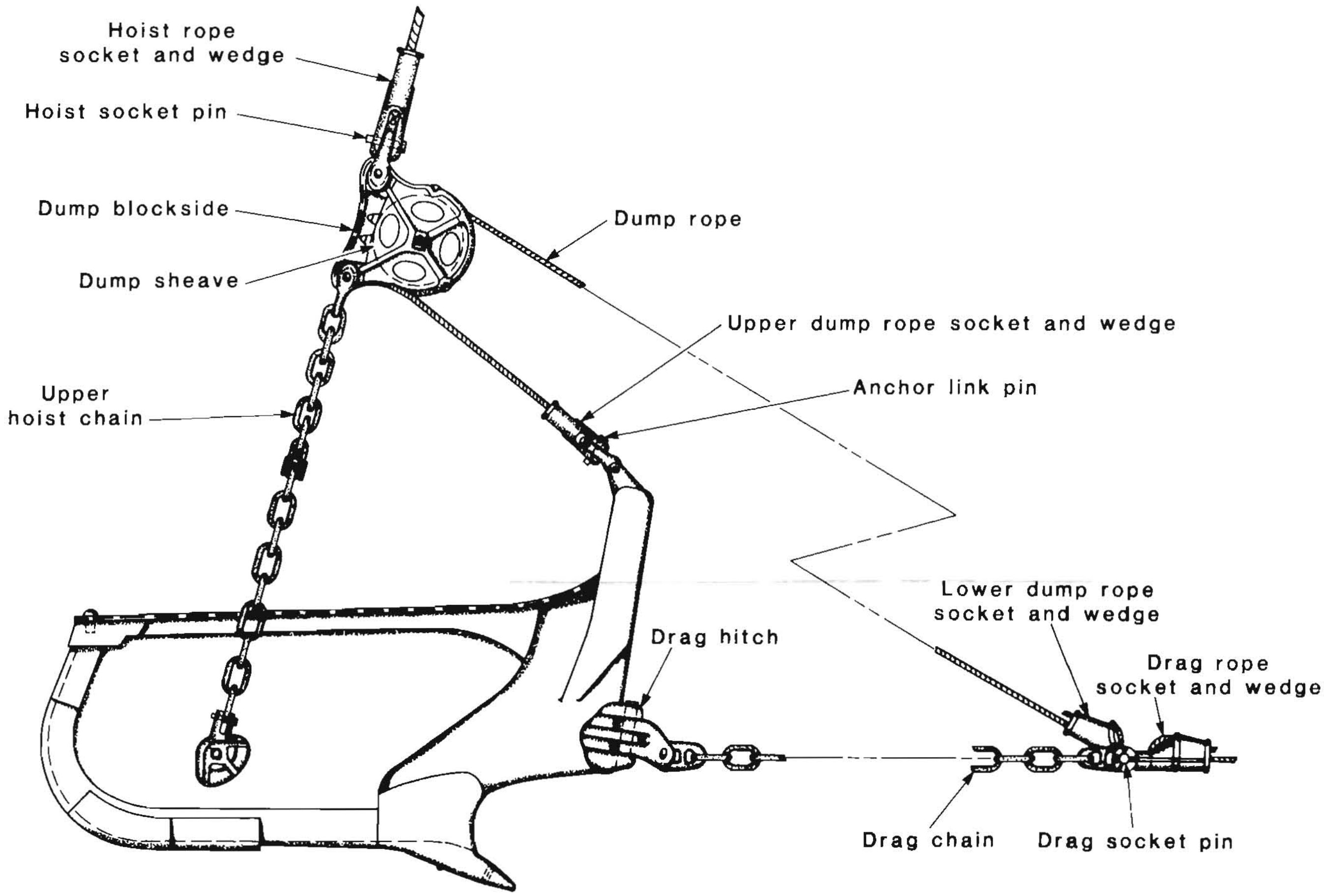

FIGURE 2. - Typical drag bucket rope termination points.

achieved, the length is increased in increments until separation is accomplished. Thereafter, the amount of charge that proved successful is used unless a failure to effect separation occurs. In this event, the length of the charge is again increased until separation is accomplished.

2. Manual impact--This method is now in general use in Canada and by some operators in the United States. Impact force is applied by use of a handheld sledge hammer or a pendulum ram suspended from a mobile crane. Because the degree of force required to effect separation increased in relation to the size of the dragline, use of handheld sledge hammers is restricted to draglines with capacities of less than 40 yd^3.

3. Burnout--This method is no longer in general use because it is labor intensive and time consuming. An extended oxyacetylene nozzle is used to flame-cut the wire rope wedged inside the socket to relieve the pressure fit.

The rope removal operation is accomplished as follows: (1) The wedge and socket assembly is positioned on the ground; (2) the rope is flame-cut (or it may be cut with an electric arc) where it enters the socket and on the arc of the wedge; and (3) the wedge is separated from the socket, using either explosive or manual impact.

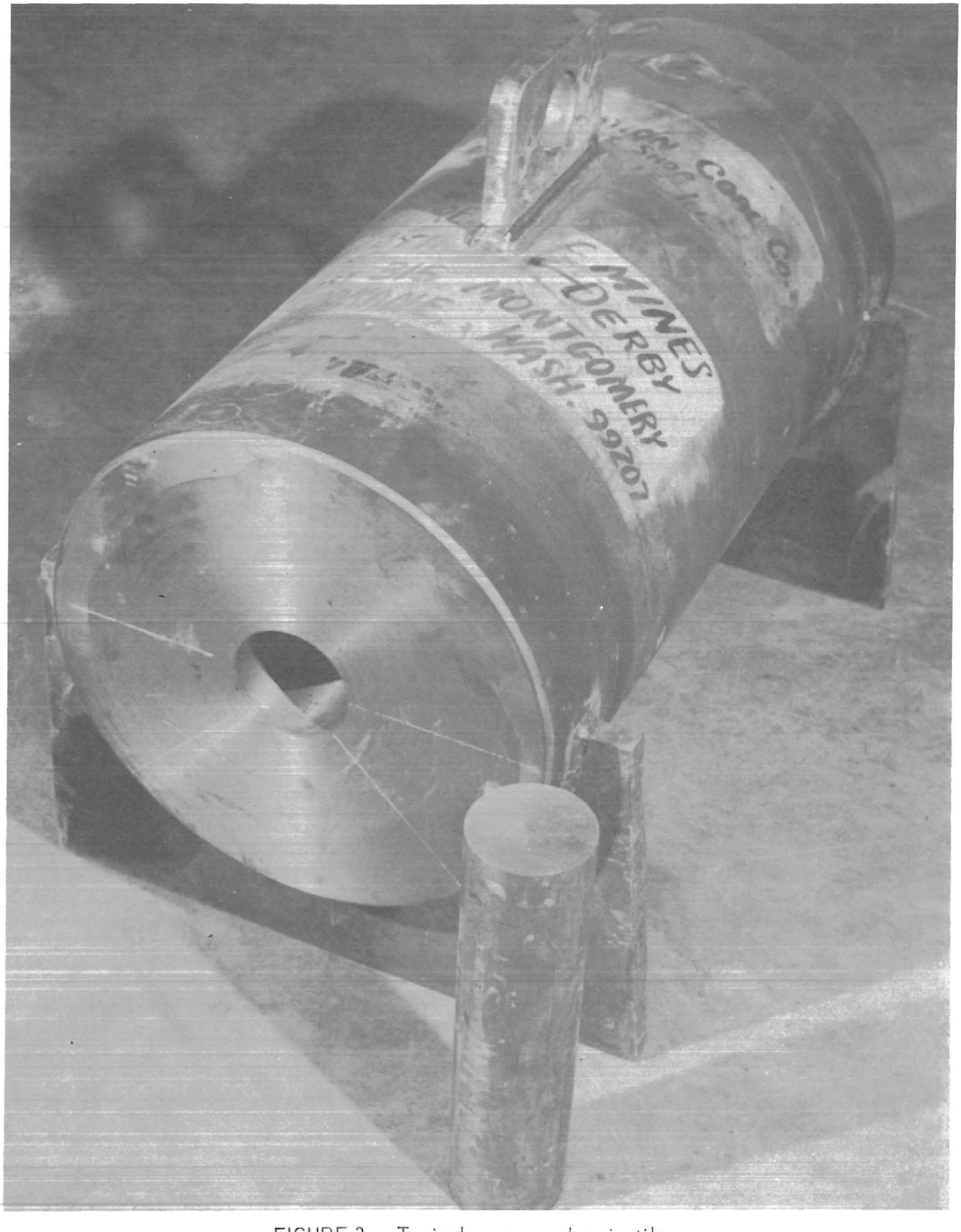

FIGURE 3. - Typical cannon and projectile.

RESEARCH PLANNING

Based on initial study, four distinct task areas were identified as necessary for accomplishment of this research project; they were--

1. Recruitment of mine operators to voluntarily cooperate in the research by supplying joined wedge and socket units and allowing Bureau personnel to use their facilities for testing purposes.

2. Determination of forces required to effect wedge-socket-rope separations.

3. Determination of forces generated by the cannon method.

4. Development of less hazardous methods and equipment.

Cooperating operators were recruited, which made possible research in the second, third, and fourth task areas. The results of the research in these task areas are detailed below.

DETERMINATION OF FORCE REQUIREMENTS FOR WEDGE AND SOCKET SEPARATION

A statistical base establishing force requirements for wedge and socket separation was essential for making knowledgable design decisions concerning the type of equipment and techniques most likely to be successful. Three cooperating mines sent joined wedge and socket assemblies from their operating draglines to the Bureau's Spokane Research Center, where the assemblies were separated under controlled conditions. The number of mines considered for inclusion in this phase was restricted by shipping time and funding factors. Turnaround time for the wedge and socket units was a critical concern of the cooperating mine operators. These units are a high-cost item not normally stocked by local suppliers, and in the event that an emergency wire rope change became necessary at one of the mines, the operators did not want to be without replacement units for an excessively long time. Shipping distance was therefore restricted to an area that would require no greater than a 1-week turnaround time under normal conditions. Three mine operators were located within the geographic area so defined who were willing to participate in the project.

A Tinius Olsen Universal Testing Machine[2] with a load capacity of 400,000 lb was used to apply and measure separation force. Holding fixtures to accommodate the wedge and socket units were designed and fabricated by the Bureau (fig. 4). A total of 17 units were separated, and the results are shown in table 1.

TABLE 1. - Wedge and socket separation force requirements, pounds of load

Wedge and socket unit[1]	56-yd^3 bucket[2]	60-yd^3 bucket[2]	78-yd^3 bucket
1............	59,300	45,250	196,250
2............	76,900	31,250	155,250
3............	132,200	146,500	NAp
4............	104,750	115,750	NAp
5............	98,500	[3]130,000	NAp
6............	93,000	[3]108,000	NAp
7............	NAp	43,750	NAp
8............	NAp	55,000	NAp
9............	NAp	[4]234,000	NAp

NAp Not applicable.
[1]Drag links except for units 7 and 8, which were hoist links.
[2]The 56- and 60-yd^3 buckets both used 3-1/4-in wire rope and wedge and sockets of the same size.
[3]New design: three-piece wedge.
[4]Unit was separated after failure to effect separation with the hydraulic pusher built as part of this project; see "Portable Hydraulic Pusher" section for details.

It was learned that many factors govern and vary the amount of force required to effect separation. Large force variances were recorded for units removed from the

[2]Reference to specific products does not imply endorsement by the Bureau of Mines

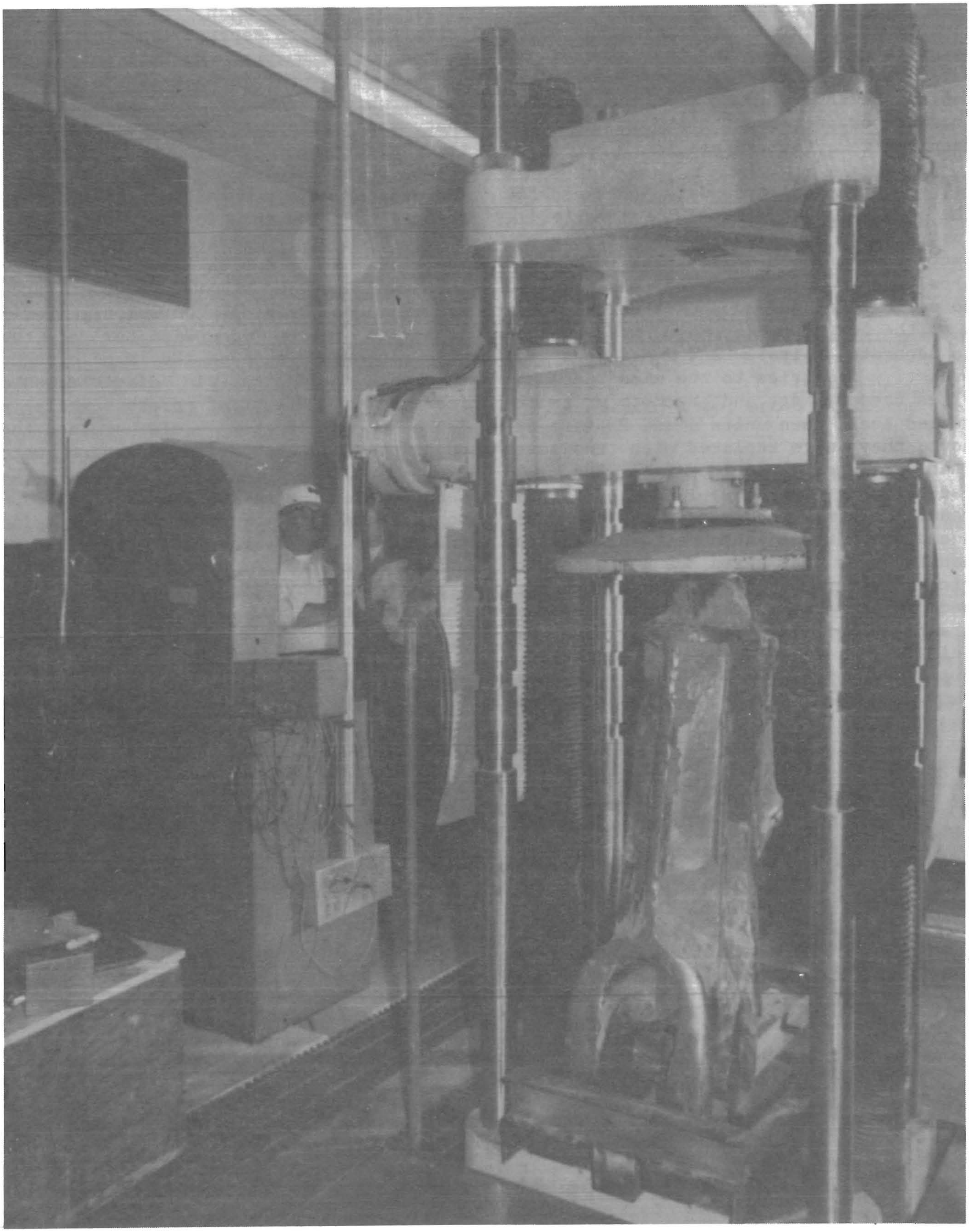

FIGURE 4. - Apparatus for controlled wedge and socket separation.

same dragline operating under similar conditions. It was discovered that even a slight variance in the dimensions, hardness, or material composition of the wedge, socket, or wire rope can greatly increase or decrease the amount of force required to effect separation.

The separation force data obtained for the 56-yd^3 bucket (table 1) clearly illustrate how a variable can greatly affect the force requirements. The data show that much more force was required to separate wedge and socket units 3 and 4 of the 56-yd^3 bucket than was required to separate units 1 and 2 of the same bucket. Inquiries to the mine that supplied these wedge and socket units revealed that when units 1 and 2 were removed they were replaced with two units that were newly acquired from the manufacturer and later supplied to the Bureau; the newly acquired units were units 3 and 4. It was then learned from the manufacturer that units 3 and 4 were fabricated after a design change had been made in the material composition and heat treatment of its product. These two units were assumed to be of a softer composition, which would allow the rope to seat more firmly, and this in turn would result in a higher reverse force requirement to effect separation. When asked, the manufacturer's design representative said consideration had not been given to the effect the design change would have on separation force requirements. A variance in the hardness or material composition of the wire rope would also increase the reverse force requirement for separation.

As with the 56-yd^3 bucket, the force required to separate units 3 and 4 of the 60-yd^3 bucket was much greater than the force required to separate units 1 and 2 of the 60-yd^3 bucket. Units 1 and 2 were old and well worn, in contrast to units 3 and 4, which were new. It was learned that when units 3 and 4 were installed, the wedge-angle clearances were too great, which allowed the cables to slip. The wedges were removed and their sides trimmed to allow them to enter the sockets more deeply. This greatly increased the bite on the cables and consequently increased the amount of reverse force required to effect separation. Variances in the outside diameter of the wire rope would produce the same effect; that is, an increase in diameter would increase the amount of press, while a decrease in diameter would produce the opposite result. Units 5 and 6 were from the same 60-yd^3 bucket, but the wedges were of a new design that was supposed to simplify removal by decreasing the amount of reverse force required to effect separation. However, the results indicated no appreciable progress toward this objective.

With the limited number of controlled separations performed, definite conclusions could not be made setting a firm range of separation force requirements. However, the initial results indicated that a device capable of developing and delivering 200,000 lb of thrust would have a high probability of success for a majority of rope removals performed on draglines equipped with buckets with capacities up to and including 78 yd^3. Therefore, a force production capability of 200,000 lb was set as an equipment development goal for the project.

THE CANNON METHOD

DETERMINATION OF FORCES GENERATED

Available information indicated that no previous effort had been made to determine how much primer (detonating) cord charge was required to effect wedge-socket-rope separations for different sizes of draglines other than the trial-and-fail method described earlier. Dragline operators observed using the cannon method for wedge and socket separation did not know and had made no attempt to determine the force generated by a given length or type of primer cord. A test program was therefore conducted to determine if a direct relationship could be established between the amount and strength of a primer cord and a stable level of force generation. It was assumed that if such a relationship could be established, minimum or maximum force requirements could be established for individual draglines by correlating data from this research project to the size of the cannon and the amount of primer cord charge used to effect separation for a given dragline.

The cannon fabricated for the test program had an 18-in OD, a 36-in length, a 4-1/8-in bore, and a finished weight of 2,800 lb. The steel projectile had a 4-in diam, was 14 in long, and weighed 55 lb. The design was typical of those used in the industry. Instrumentation to measure the internal force generated in the cannon and the speed of the projectile was a mix of specially designed and fabricated items and commercial products.

Test firing of the cannon was performed at a semiremote site west of Spokane, WA, from December 1979 to August 1980. Due to inclement weather, firing was performed in a temporary building from December through May, then moved to an outside area (figs. 5-6). Forty- and fifty-grain primer cord was used for the charges in amounts ranging from 10- to 50-ft lengths for the 40-gr charges and 10- to 40-ft lengths for the 50-gr charges. Electric detonators with 6-ft leads were used, with electric impulses supplied by a 6-V blasting machine. A total of 138 test firings was completed. Of these, 64 were 40-gr charges and the remainder were 50-gr charges.

The firing sequence was as follows:

1. Set velocity-measurement trip wires (fig. 7).

2. Measure, wrap, and install the load (fig. 8).

3. Load the projectile (fig. 9).

4. Place detonator in port; connect detonator leads (fig. 10).

5. Clear the area and detonate the charge (fig. 11).

FIGURE 5. - Inside cannon test firing.

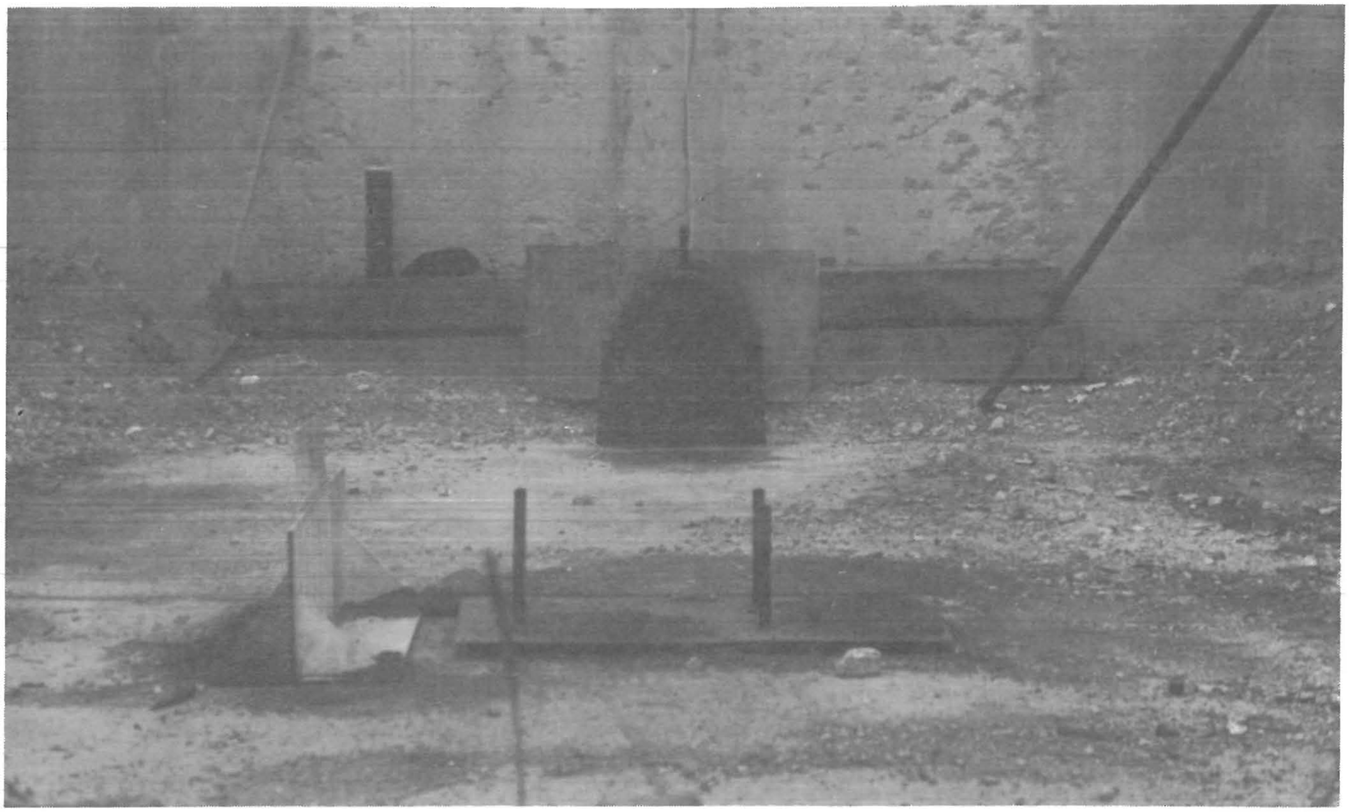

FIGURE 6. - Outside cannon test arrangement.

FIGURE 7. - Setting velocity-measurement trip wires.

FIGURE 8. - Installing primer cord charge.

FIGURE 9. - Loading the projectile.

FIGURE 10. - Connecting detonator leads after placement of detonator in port.

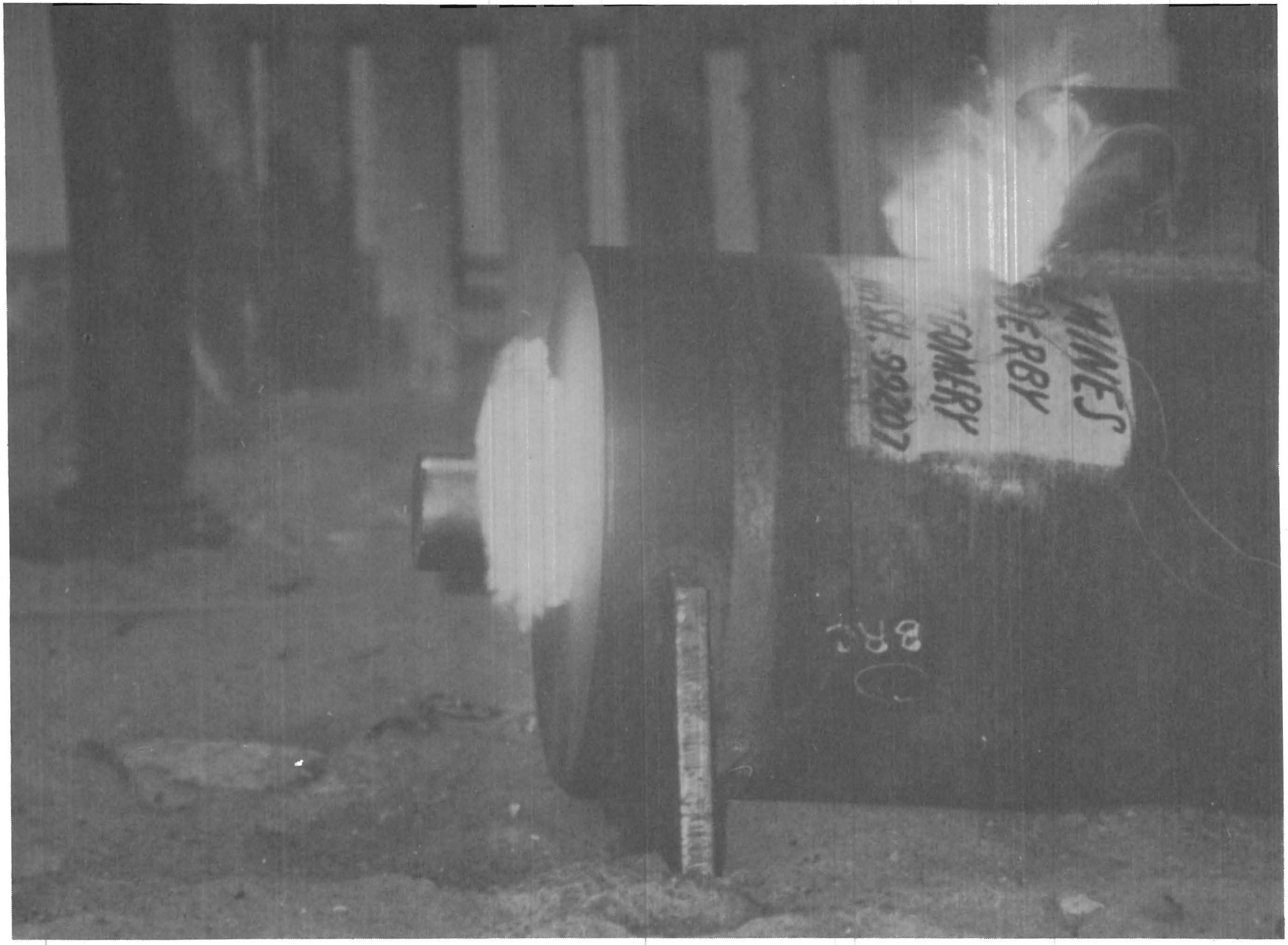

FIGURE 11. - Cannon at detonation.

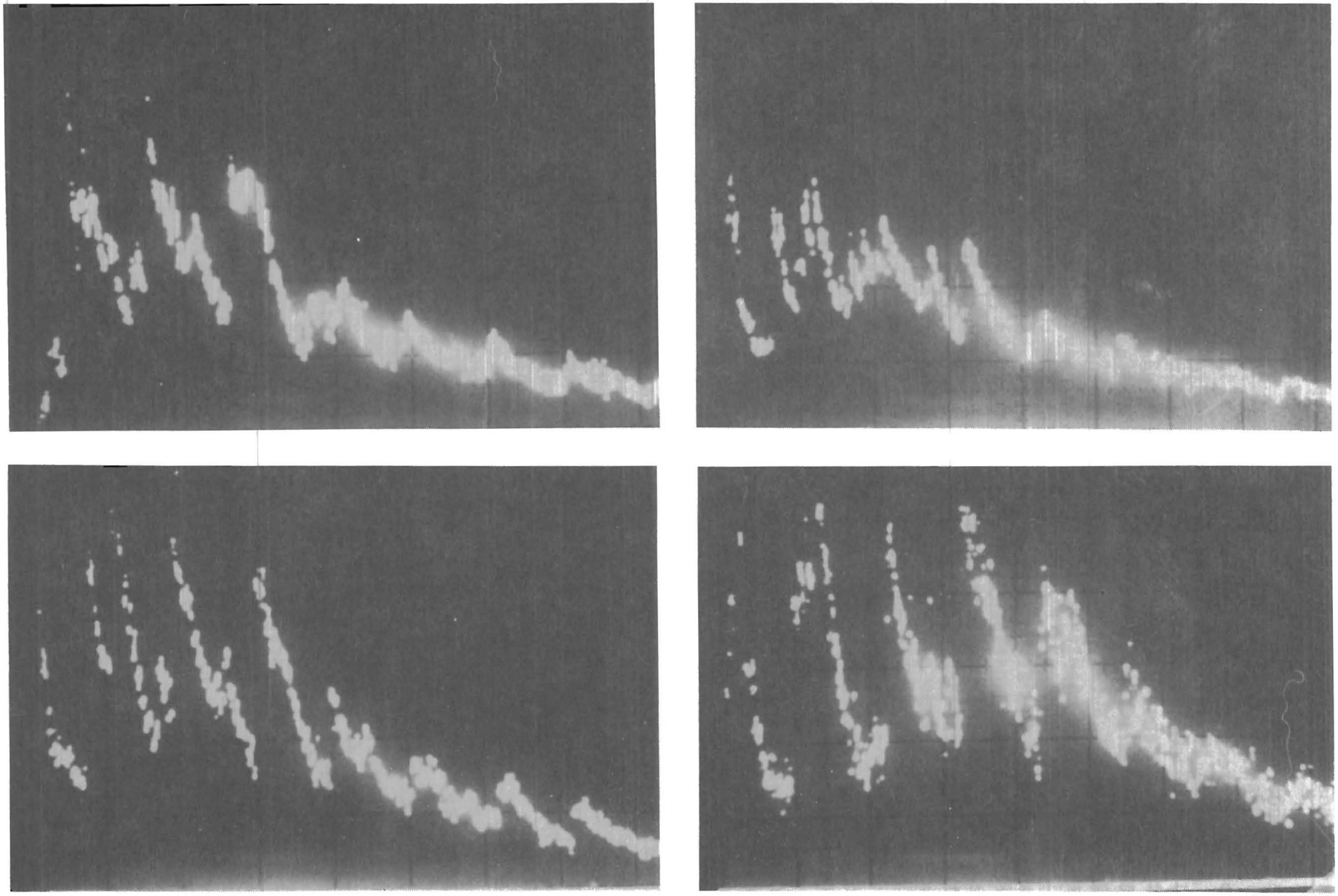

FIGURE 12. - Representative oscilloscope displays of internal cannon force generation.

Internal Cannon Bore Pressure

Internal cannon bore pressure was measured by a piezoelectric system that generated, amplified, and transmitted a voltage signal. The signal was representative of the pressure buildup during the time of the explosion. The piezoelectric system was made up of the following components: (1) a transducer-amplifier, (2) a power supply with a decoupling capacitor, and (3) two lengths of coaxial cable. The signal from the piezoelectric system was displayed on a storage oscilloscope and photographed by an oscilloscope camera. Figure 12 shows a representative series of results obtained using this measurement method.

The internal pressures recorded were averaged and charted (fig. 13) in an attempt to prove a correlation between the amount and type of charge used to internal pressure generated. A wide variance was noted using a given type and amount of charge that could not be explained by measuring-instrument malfunction. Experiments using four different methods of loading the charge produced as much as a 100-pct variance in the pressure produced using a given length of primer cord.

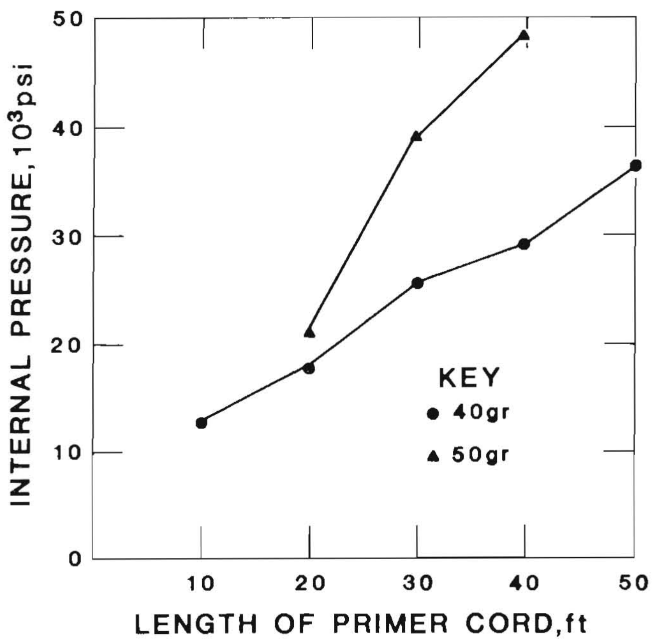

FIGURE 13. - Average internal cannon pressures.

Projectile Velocity

Projectile velocity was measured through the use of a breakwire stand with measured distances between wires, a timing and control logic unit, and a frequency counter. The moving projectile passed along the measured distance, breaking the wires and thereby providing start and stop signals for use by the timing and control logic unit. The frequency counter counted the high-frequency precision time base inside the timing and control unit and the resultant count was the projectile's velocity. Midway through the testing program, this method was augmented by the use of high speed camera photography to provide a record of the projectile's trajectory and a secondary method of determining its velocity.

Projectile velocities for each length and type of primer cord were averaged and charted (fig. 14). The force (F) generated for each length of charge was computed using the formula $F = 1/2\ MV^2$, in which M = projectile mass and V = velocity, ft/s. The results, based on a projectile weight of 55 lb, are shown in table 2.

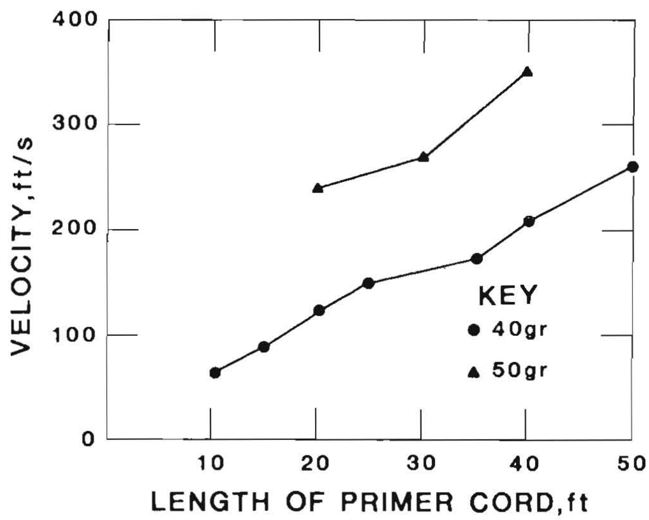

FIGURE 14. - Average projectile velocities.

TABLE 2. - Force produced by 55-lb projectile

Primer cord size, gr	Length of charge, ft	Force, ft•lbf
40...........	15	6,660
	20	15,674
	25	19,869
	35	27,248
	40	37,207
	50	58,136
50...........	20	49,536
	30	60,394
	40	109,606

Discussion of Cannon Tests Results

It was assumed at the start of testing that the results shown in table 2 could be used to determine the force required to separate individual wedge and socket units. The intent was to correlate the data shown in table 2 to the type and amount of charge actually used by a mine to separate the wedge and socket under consideration. However, based on the degree of variance experienced, it was determined that the results of such a correlation would not be accurate. Too many variables are involved which affect the degree of force produced, including the weight of the projectile; clearance, or the difference in the outside diameter of the projectile and the cannon bore; and the condition of the primer cord charge and how it is packed in the cannon in relation to the projectile. These were the main factors uncovered during testing that affected the level of force generation. In addition, indications were that climactic conditions were a factor. There were also indications that the outer wraps of the primer cord spool aged during even short periods of storage and that this reduced the cord's effectiveness. It is believed, however, that even though deductions cannot be made to determine exact wedge and socket separation force requirements based on the force-generation data collected, good approximations can be made, even if available information is limited to the amount and type of primer cord charge presently used by an individual mine.

POTENTIAL HAZARDS

The cannon testing phase was a valuable learning experience and a useful tool for evaluating the effectiveness and potential hazards involved in using the cannon. In terms of generating an immediate energy force, the cannon method is highly effective. However, the inherent hazard potential of using any explosive device is always high and, in the case of the cannon, is increased by certain procedures now in general practice. There is presently no known uniformity in the cannons or procedures used. Cannon and projectile fabrications vary from mine to mine. How the charge detonator and projectile are loaded varies, depending on personal preference. Power sources used for electric detonation are not uniform and, in many cases, do not conform to safety regulations. Misfires due to shorting or cutting of detonator wires occur but can be avoided if the detonator is positioned separately from the primer cord and projectile through a detonator port, which correctly designed and fabricated cannons have.

An occurrence experienced during the outside tests, when a 40-ft, 40-gr charge was fired, graphically illustrated a possible inherent potential hazard of the cannon method. As a rule, the concussion from one firing would move the cannon a short distance from the retaining wall--a retaining wall is shown in figure 7--and it would return on the next. On this particular shot, the previous shot (also a heavy charge) had apparently forced the cannon away from the retaining wall a sufficient distance to allow it to rear back on detonation. The projectile exited in an arc, to at least 40 ft above the standing horizontal plane of the cannon, and traveled 250 ft before penetrating a corrugated sheet metal building (figs. 15-16) on the immediate wall and striking the opposite concrete wall, where it came to rest. This indicates that a hazard potential exists whenever a cannon is not firmly anchored before firing. Cannon anchoring is currently a part of normal procedure at many mines. It is generally accomplished by resting a bulldozer blade on the cannon.

FIGURE 15. - Building hit by projectile: photo taken from firing position of cannon.

FIGURE 16. - Wall penetrated by projectile.

CANNON SAFETY RECOMMENDATIONS

It is possible that many of the suspected hazards of the cannon could be eliminated or reduced if standard safety procedures were established and adhered to by mine management and maintenance personnel. Basic items for standard procedures should include the following:

1. Uniformity of cannon and projectile design and use.

2. Mandatory separate loading of charge and detonator and insertion of the detonator through a separate port.

3. Electrical wire hookup after the charge and projectile have been loaded and the cannon is placed in final position for firing.

4. Mandatory use of approved detonating devices.

5. Firm anchoring of cannon before firing.

6. Possible use of armor netting over the cannon during detonation.

No operation involving the use of explosives can be made absolutely foolproof, eliminating all hazards. However, an accident caused by, or in conjunction with, use of the cannon that results in serious injury or fatality could bring about drastic remedies such as those instituted in Canada, where the cannon method is outlawed entirely. This would deprive the industry of an effective tool that may prove difficult to replace.

ALTERNATE ROPE REMOVAL METHODS

IMPROVEMENT OF PREVIOUSLY TRIED METHODS

A major objective was to identify and improve upon alternate methods for dragline wire rope removal. This was not for the purpose of mandatory replacement of the cannon method but rather to provide supplemental and/or alternate means that would give mine management and maintenance personnel a choice among proven tools for separating wedge and socket units.

Pendulum Ram

The first alternate technique explored for improvement was the pendulum ram method. Past and current users of pendulum rams were informally surveyed to determine what, if any, problems and success they had. Users were asked if they preferred this method over the cannon method, and why. They were also asked the weights of the rams they used, as a way of determining an optimum range of sizes for testing. The largest ram uncovered weighed 1,600 lb and is in use in a mine in Canada to remove rope wedges from 100-yd^3-bucket draglines.

Previously Encountered Problems

The main problems reported by ram users were that rams were unwieldy and difficult to hold level for proper impact and that the ram's impact caused excessive reverberation in the crane cables. Information gathered and photographs of existing rams were analyzed to determine what changes would improve this method.

Analysis of the maneuvering and balance problems of rams in current use indicated that the primary cause was in the design. Rams studied were locally fabricated from whatever material was available in the simplest manner possible (fig. 17). They were hung from a single point on the cable hook. This made it very difficult to balance the swing load and produce a solid impact on the wedge. Also, impact was transmitted directly to the crane cable, causing excessive reverberation. Generally, the device was swung by holding and putting pressure on the cable, which made balance more difficult and decreased the potential force generation. If handles were installed, they were generally placed along the sides of the body of the ram, requiring the user to work in a bent

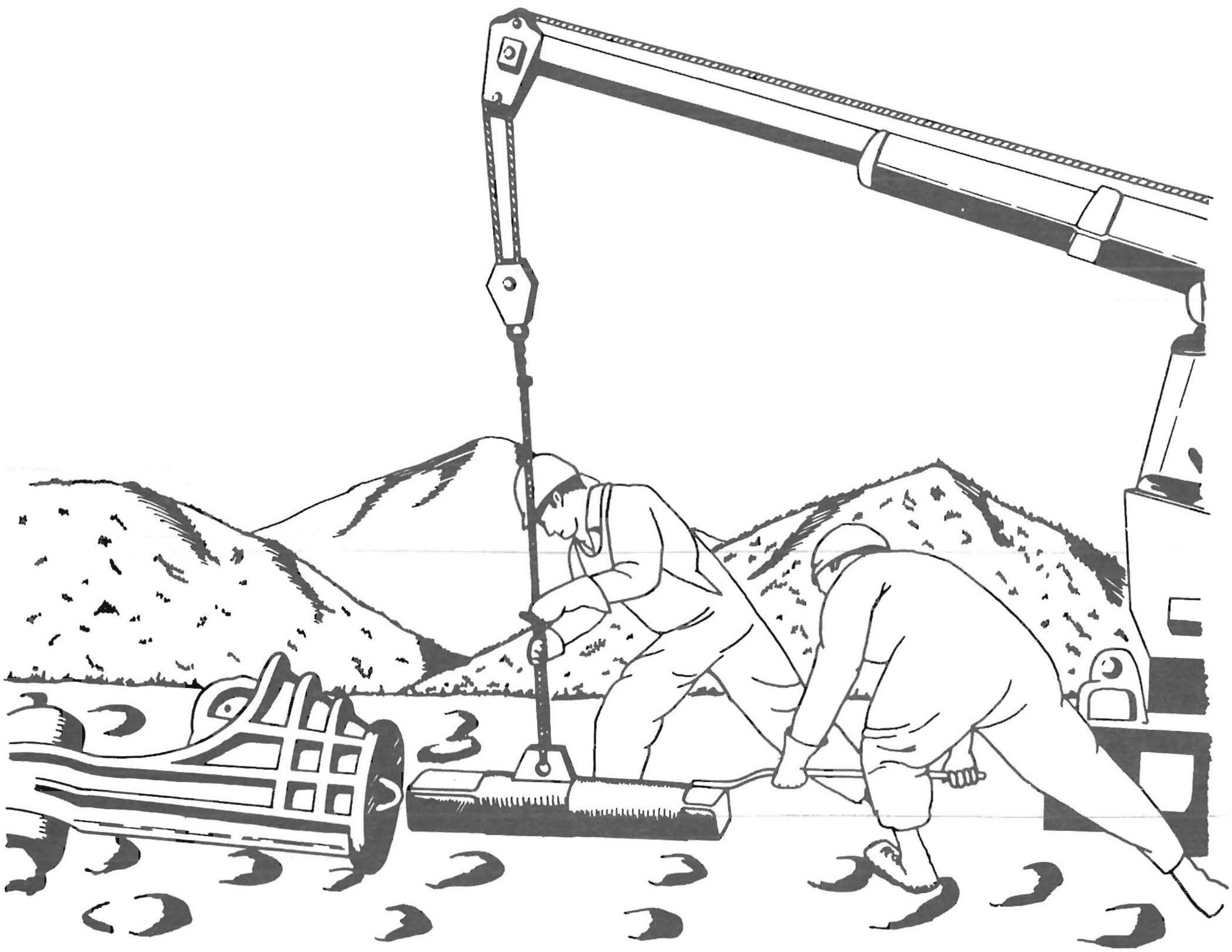

FIGURE 17. - Typical use of pendulum ram for wedge removal.

stance. In one case, a bar was found welded to the rear of the ram so that when two people performed the operation, one could exert pressure on the cable while the second held it level from the rear.

Test Design

The steel ram developed for this project (fig. 18) included design changes to alleviate or eliminate known problems. Balance problems were eliminated by incorporating a two-point hookup. To make the ram more maneuverable and less unwieldy, its length was kept constant with weight changes controlled by the diameter of the body. Handles were installed approximately waist-high for easier handling. A hoist sling was designed which incorporated a chain yoke connected to a single length of 14-ft chain; this chain was long enough to cinch the crane hook to the boom block to reduce reverberations.

It was decided that a ram could be designed with sufficient weight to exert the maximum required force, incorporating the Bureau's improvements, yet still be built within manual handling range. However, the author's opinion was that operators with smaller draglines would not consider using the method if they believed the unit tested was too large for their specific requirements nor commit resources to build and experiment with smaller rams. This consideration was the deciding factor in determining the weights of four rams built for testing

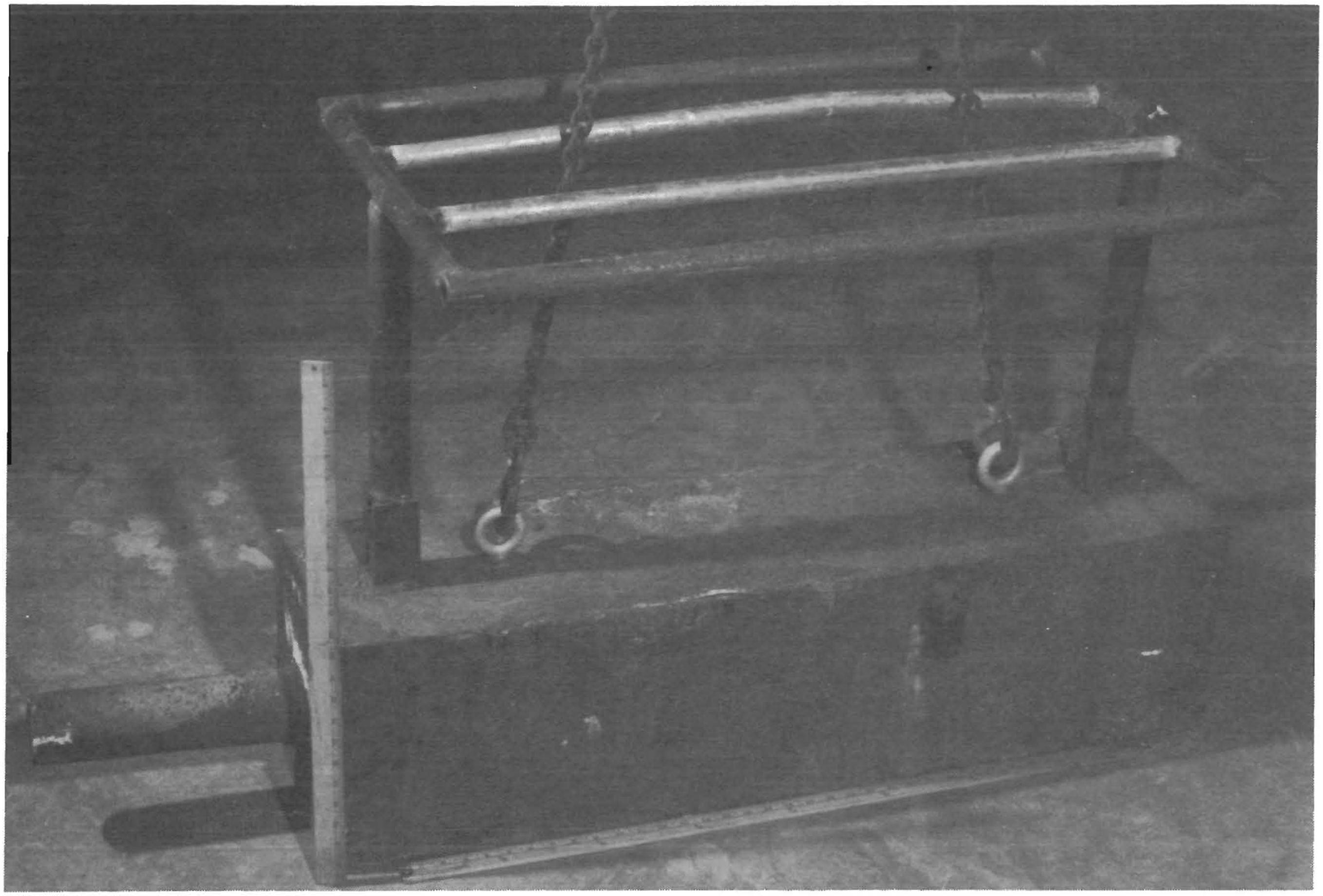

FIGURE 18. - Cast steel 1,400-lb pendulum ram.

purposes. The test rams weighed 400, 800, 1,000, and 1,400 lb. The three lighter ram bodies were made from standard-size round stock. The largest was cast in a square billet due to the unavailability and cost of round stock to meet the weight requirements and retain the standard length agreed upon.

Hydraulic System

Previous Mine Experience

In interviews, some mine operators reported that hydraulic presses had been used for wedge removal but had been abandoned because of the operation time and dragline downtime cost involved. This method had been replaced by the simpler, less time-consuming cannon method. Standard shop presses had been used. The procedure required that the joined wedge and socket units be moved from the dragline to maintenance shops where they were mounted on special holding jigs designed to be used in conjunction with a standard fixed-location hydraulic shop press. The method was similar to that used during this project to determine separation force requirements (fig. 4). The procedure greatly increased dragline downtime unless extra wedge and socket sets were available for immediate changeover while the operation was performed. In contrast, use of the cannon greatly reduced the downtime and the need for surplus wedge and socket sets, and the shop press method was therefore discontinued. Mine maintenance personnel indicated, however, that if portable hydraulic equipment could be made available that was as proficient, timewise, as the cannon, and could be transported to and used at the dragline, they would be open to its use.

It was determined that to win industry acceptance, a hydraulic system would have to be (1) portable to the extent that it could be transported to and used at the dragline; (2) fabricated mainly from commercial products, to keep fabrication simple; (3) capable of completing rope removal as efficiently as the cannon does; and (4) capable of producing up to 200,000 lb of thrust to the wedge (based on available results of laboratory separations testing).

Test Design

Complicating the development of a workable hydraulic system were the various sizes, configurations, and designs of rope sockets that are in use. The main problem was to design a system that would hold in position securely enough to offset the force required to effect separation. A common socket design feature was desired that would allow the development of universal holding points, but a survey of five socket manufacturers' products failed to uncover such a feature. Two manufacturers make models with a suitable feature--a rectangular hole on each side of the socket; however, these holes are included in only a small number of their sockets and therefore were not considered as possible holding points. However, three mines cooperating in the project had one type of socket in predominant use that contained a usable common feature. It was decided that points to provide sufficient support to offset the reaction force could be determined for the type of socket the investigators worked with, at the area of the yoke curvature and the lip on the opposite side (fig. 19). However, the offset of these two points further complicated design efforts. The offset and the angles involved would compound spreading problems of whatever type of holding leg was incorporated into the design (fig. 20). It was decided that the goal would be to design a hydraulic system that could accommodate sockets for use on draglines with up to 78-yd^3 buckets because these were the largest sockets made available for separations testing; above this size was an unknown factor. However, a system capable of producing the 200,000-lb goal

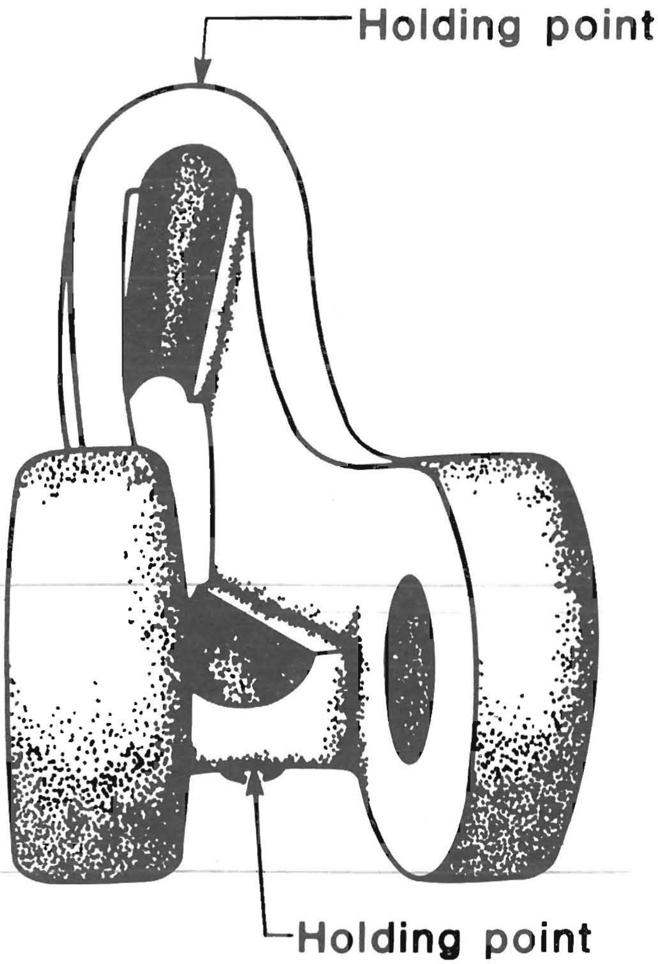

FIGURE 19. - Hydraulic pusher leg holding points on rope termination socket.

thrust might also be effective for use on larger draglines.

The final design (fig. 21) incorporated offset legs to provide reverse force and an adjustable crossbeam (slide-bar brace) to prevent leg separation. The connecting adapter plate was procured through the same supplier as the cylinder and modified to meet increased strength requirements. Force is supplied by a commercially available 200-ton hydraulic cylinder and a manual hand pump with oil reservoir. Although the system fabricated and tested is not adaptable to all manufacturers' sockets, the basic concept should be adaptable by leg and crossbeam design changes for use with most or all sockets now available.

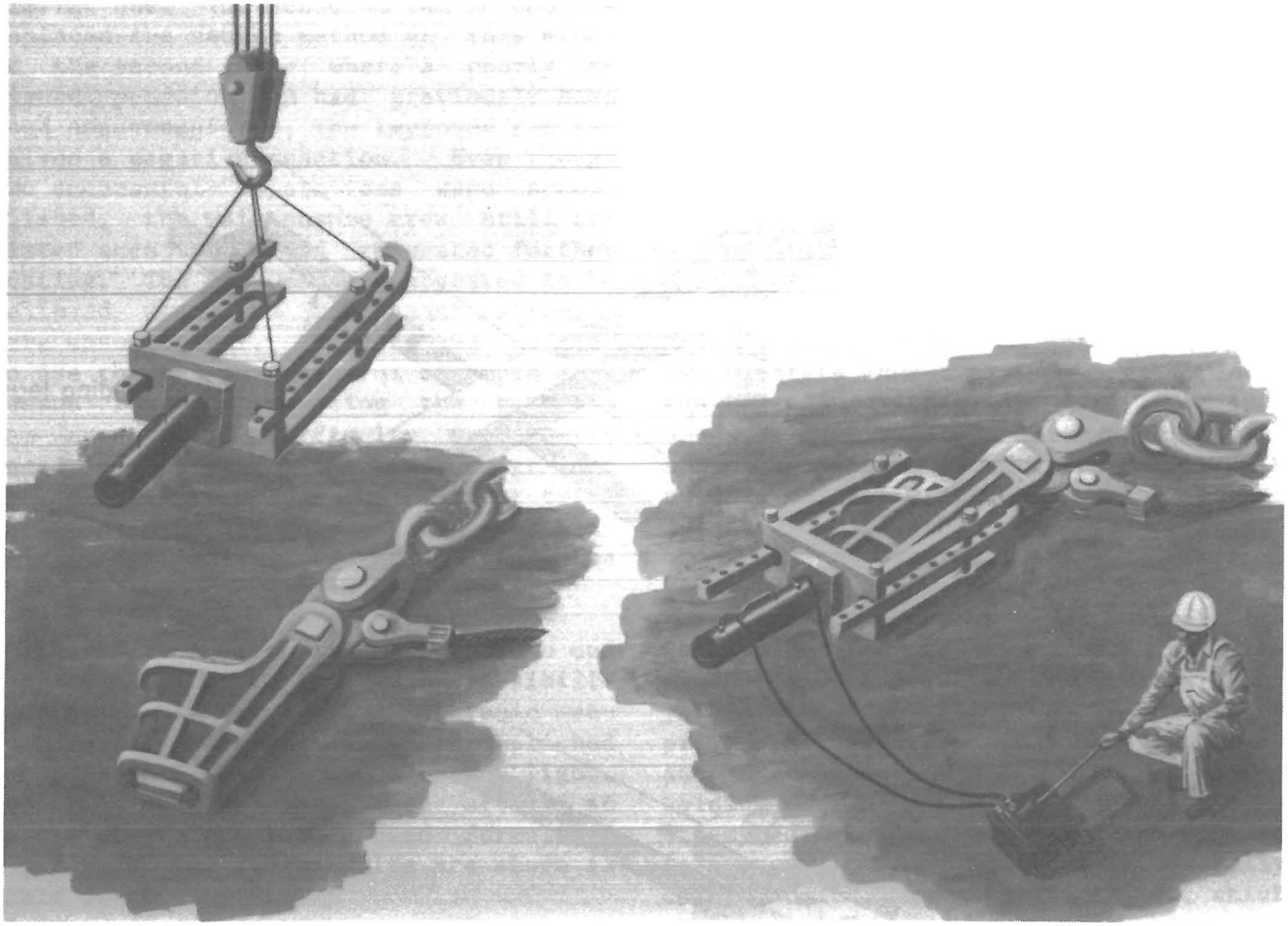

FIGURE 20. - Conceptual drawing of portable hydraulic pusher for wedge removal.

TESTING

Pendulum Ram

The improved pendulum rams were tested during actual dragline bucket rope maintenance changeovers on four separate occasions. In each instance, two drag wedge and socket separations were attempted. The result was four positive and four negative conclusions. The two successful attempts were on a 60-yd^3 dragline at Colstrip, MT, and a 56-yd^3 dragline at Centralia, WA. On both occasions, the 800-lb ram was used to effect separation. Of the two unsuccessful attempts, one was on the sockets from the 56-yd^3 bucket (on which a prior attempt had been successful) and the second was on a 78-yd^3 bucket. The 800- and 1,000-lb rams were used during both unsuccessful attempts.

All ram separation attempts were made during the early part of the project, before many of the conditions governing the degree of force required to effect separation were known. A subsequent investigation to determine why separation was not attained--especially on the 56-yd^3 bucket, for which one of the previous attempts had been successful--produced the following results:

1. New wedge and socket units had been installed on the 56-yd^3 dragline after the first test. The new units were manufactured after a metal composition design change which apparently made the rope mating surfaces softer than those of the older units. This allowed the wire rope to cut more deeply into both the wedge and socket, producing a tighter fit. Laboratory separation of the newer units proved that a much higher force was

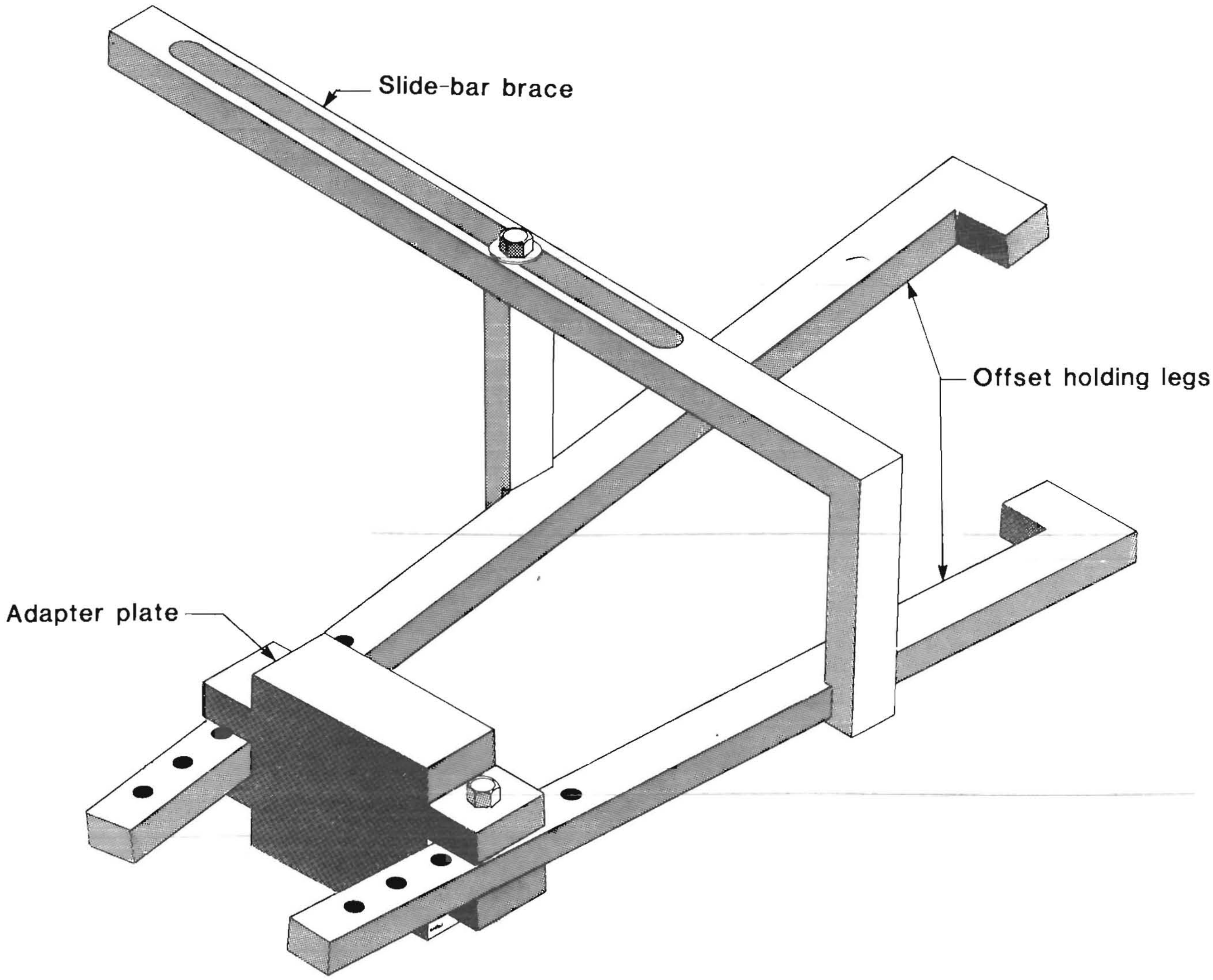

FIGURE 21. - Final hydraulic pusher design.

required to effect separation than was required for the older units.

2. The second negative result was apparently caused by the researcher's failure to recognize the need to firmly anchor the socket during ram impact. Visual observations made during this attempt, and later interpretation of photographs taken during the operation, indicated that a major portion of the impact force was absorbed by movement of the socket. Joined units from the bucket were later supplied for laboratory determinations of separation force requirements. Based on estimates of possible ram force production, it was determined that sufficient force had been applied to effect separation--if the unit had been anchored. It is believed that the lack of anchoring also contributed to the other separation test failure.

It is the author's belief, based on the reactions of maintenance personnel at two mines where testing was performed, that successful use of the improved pendulum ram may depend greatly on users' attitudes toward the pendulum ram method. At one mine, the maintenance crew wanted a replacement for the cannon method. An effort was made to prove the pendulum ram, and testing was successful. Maintenance personnel requested and received permission to use the Bureau's improved pendulum ram until they could fabricate a similar one. The pendulum ram method has replaced the cannon method at this mine. At the second mine, where a poorly designed pendulum ram had previously been used unsuccessfully, the improved ram received a negative reaction. Even though two successful separations were accomplished, the maintenance crew still resisted acceptance and requested further testing. The crew members appeared to be relieved when two subsequent attempts were unsuccessful. They seemed anxious to use the two unsuccessful attempts as a reason for not accepting the pendulum ram--even though difficulty was experienced in separating the two wedge and socket units with a cannon. Almost twice the normal primer cord charge was required to attain separation with the cannon.

Laboratory testing was performed to determine the force generation possibilities of the impact rams. Electronic measurement of ram velocity was accomplished using a photocell counter and light. Possible force generation was arrived at by use of the previously used formula, $F = 1/2\ MV^2$. The test results are shown in table 3.

TABLE 3. - Estimated separation forces produced by experimental pendulum rams

(Assumptions: Socket is firmly anchored, maximum wedge movement on impact is 1/100 ft, ram is hung 20 ft from boom, and ram is drawn back 10 ft from perpendicular. Velocity of rams (12.9 ft/s) was determined by free fall acceleration.)

Ram size, lb	ft•lbf
400	104,000
800	208,000
1,000	260,000
1,400	364,000

Portable Hydraulic Pusher

Static testing of the portable hydraulic pusher was accomplished on a locally fabricated holding device to provide reverse force. The leg and crossbeam design sustained cylinder pressures up to 154,000 lb thrust, at which point a metal failure in the holding device occurred. Due to time limitations, further testing was suspended. Up to this pressure, no spreading of the crossbar occurred. Slight bending of the holding legs occurred forward of the crossbar but was not sufficient to render the unit unsafe or unusable. No failure of the leg welds was detectable.

The hydraulic pusher was tested on two joined Marion wedge and socket units on two separate occasions. The first test was the separation of two drag links from a 60-yd^3 bucket. Both units were pressed apart at pressures under 60,000 lb with no difficulties experienced. The second trial was with the same two wedge and socket sets approximately 10 months later. Both units had again been used in the drag links on a 60-yd^3 bucket, but unlike the previous time, each unit included a welded-on steel block that joined the rope tail to the socket to prevent slippage. The block was removed and the area cleaned of any possible holding matter before separation was attempted. The first separation attempt (of the second trial) was successfully completed at 160,000 lb of thrust, which at that time was the highest force recorded for a unit of the same size. The second unit could not be separated on the first attempt due to failure of the long-leg weld at 164,000 lb. The joint was rewelded and both leg joints reinforced with a 1/4- by 3-in steel collar. Separation was again attempted but proved unsuccessful even at the 200,000-lb maximum pressure of the hydraulic cylinder.

Nonetheless, this last separation attempt was a realistic test of the hydraulic pusher in that with the design changes made, it had performed to its expected limits with no further failures. The wedge and socket unit was later separated under controlled conditions. A force of 234,000 load pounds was required to effect release, which was the highest force required during this project for any size unit. This was a clear example of how a change in the usual procedure of installing the cable termination can cause drastic changes in separation force requirements.

CONCLUSIONS AND RECOMMENDATIONS

WEDGE AND SOCKET SEPARATION FORCE REQUIREMENTS

No constancy or continuity of force requirements was found. The amount of force required to effect wedge release proved to be governed by so many variables that no constant relationship of wedge and socket unit size to amount of separation force required could be determined except that the force requirement will normally increase in relation to unit size. Other factors that govern force requirements include wedge and socket material composition and treatment, hardness of the wire rope mating surfaces of the socket and wedge, hardness of the rope, variances in the outside diameter of the rope, clearance between the wedge to socket (which governs the depth the wedge is pulled into the socket, which in turn determines the amount of press on the rope), and certain changes in normal installation procedures.

It is recommended that manufacturers of wedge and socket units give more consideration to how their current designs affect rope removal operations and what the effects of proposed design changes will be. If possible, they should conduct investigations to determine these effects.

THE CANNON METHOD

The explosive impact or cannon method, the most widely used method for wire rope removal in the United States, is efficient, but in the manner in which it is generally performed has inherent hazards. To date, no fatal or disabling accidents could be directly attributed to its use. However, results of this investigation do not justify recommendation of its use; but neither would they justify an enforced discontinuance of its use.

It is recommended that mine management where the cannon method is used investigate the methods and procedures of their respective operations. If conditions warrant action, firm directives on safe procedures should be instituted. (See the previous section, "Cannon Safety Recommendations.") As necessary, management should periodically review operations to ascertain that the guidelines are being adhered to by maintenance personnel. Procedural instructions should include a safety and procedural checklist to be logged and signed by the crew foreman, stating that directed procedures were followed during each operation.

ALTERNATE METHODS FOR WIRE ROPE REMOVAL

Pendulum Ram

Testing has proved a definite potential for successful use of the pendulum ram if it is properly used. One mine, influenced by its participation in this project, fabricated a ram unit that has been successfully used for wedge removal on its 60-yd^3 draglines. It appears that success of the pendulum ram can depend greatly on the mine maintenance crew's positive reaction or attitude toward its use. If the personnel believe that the ram method is a workable procedure, it will have a high probability of success. If their outlook is negative, effort on their part may be reduced and failure is likely. The basic obstacle to overcome is to initially convince the using personnel that the ram does work and will reduce hazards and save time.

Mine management should first determine the most suitable ram size and weight for a given mine's needs and then thoroughly indoctrinate personnel as to its use, stressing the need to, and the ram's capability to, accomplish rope removal in a less hazardous manner. The most convenient method for anchoring the socket during ram impact is to power-place a bulldozer blade on the socket (a procedure currently used at many mines for cannon anchoring).

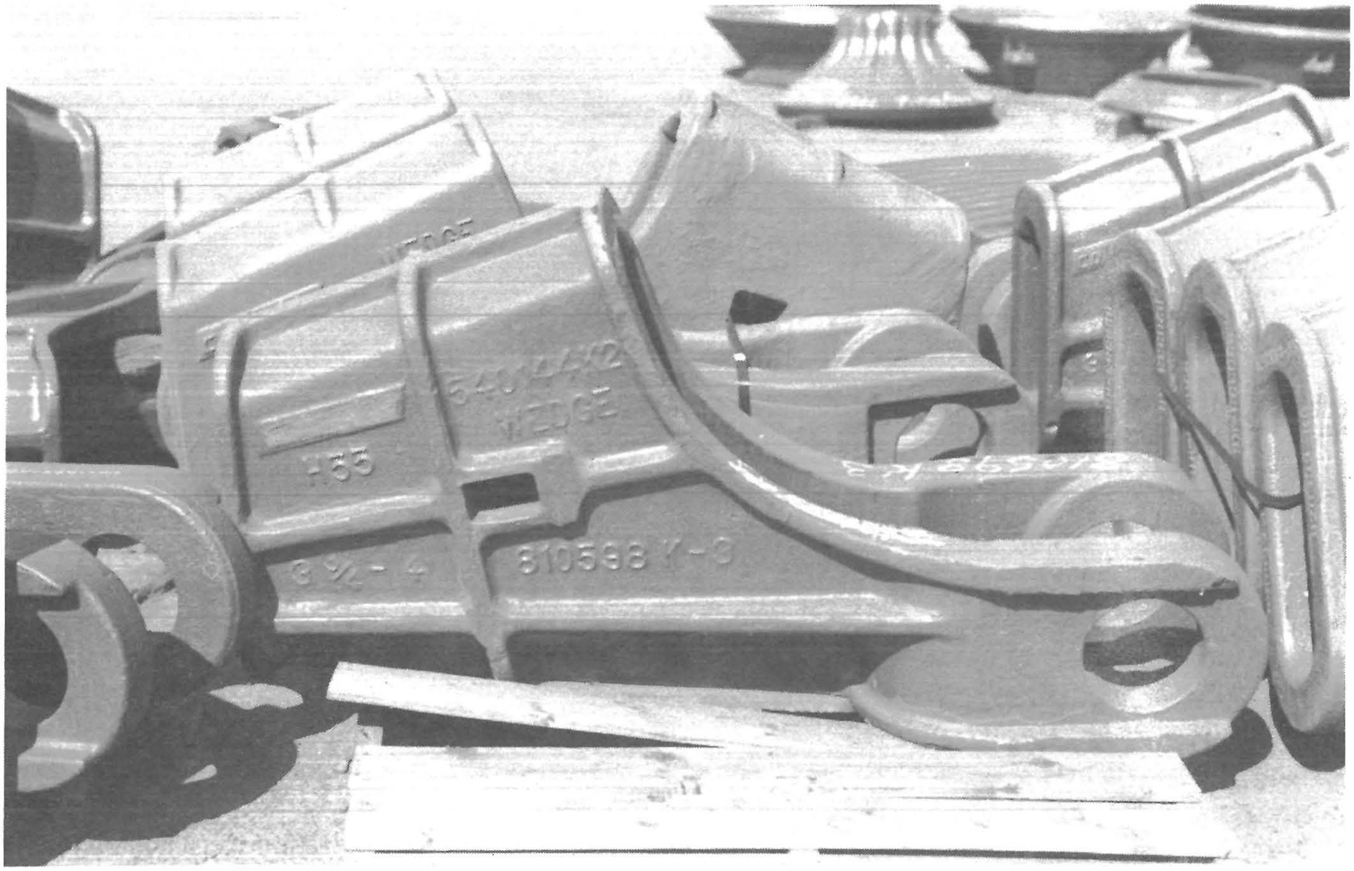

FIGURE 22. - Wire rope socket with rectangular hole suitable for providing a standard holding point for the hydraulic pusher legs.

Hydraulic Pusher

The leg and crossbar concept was proven able to sustain sufficient reverse force up to its design limits. As was suspected and subsequently confirmed, the hydraulic pusher system as designed will not fit all manufacturer's sockets currently produced for draglines in the 36- to 78-yd^3 range. Various models have certain design characteristics that eliminate one of the holding points used by the unit fabricated. With minor design changes, the system could probably be adapted to fit most sockets now produced. This conclusion is based on a survey of the sockets made by the five major manufacturers. Although possible holding points differ on the sockets investigated, the basic design of the pusher could be adapted by changes in the holding legs and cylinder connecting plate.

To enable development of a universal hydraulic pusher, it is recommended that all manufacturers include one standard design feature on all future sockets which would provide a holding point for the pusher legs. A design feature such as the rectangular hole currently included on some models (fig. 22) would provide such a solution. It would provide a holding point that would be universal and more stable than the holding point used for the test device.

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