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16. Abstract (Limit: 200 words) Since crushing of rock to a smaller size is an integral part of almost any mining and quarrying operation, a study was carried out to identify and develop improved techniques for alleviating a major cause of accidents and work stoppages arising when an oversize rock or boulder lodges in the throat of the crusher. The configurations and operations of various crusher types is described, sources of boulders in the mining operation, and a detailed review is made of mining, quarrying, and construction regulations for all states, Canada, and the Federal Government for applicable provisions. Representative mines were visited and other operations contacted for their boulder handling techniques where it was found that blasting techniques used included mudcapping, bombs, and blockholing, often done very crudely and inefficiently with poor practices, and various mechanical systems were used such as hooks on overhead cranes, impact hammers, and grapplers. Safety analyses of all methods pointed out the hazards associated with blasting in the open and the dangers of entering a crusher. Boulder blasting can be done in a safer fashion if a planned step-by-step procedure is followed, and inherently safer blasting products such as exploding bridge wire blasting caps and improved blockholing techniques. In general, though, the installation of a suitable mechanical system such as an impact breaker will prove safer and cost effective even in a smaller mine or quarry.		13. Type of Report & Period Covered Final February - August 1981	
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FOREWORD

This report was prepared by Engineers International, Inc., under U. S. Bureau of Mines Contract No. JO100007. This contract was initiated under the Metal/Nonmetal Mine Health and Safety Program. It was administered under the technical direction of the Twin Cities Research Center with Mr. Larry R. Fletcher acting as Technical Project Officer. Ms. Janice D. Johnson was the Contract Administrator for the Bureau of Mines. This report is a summary of work recently completed as a part of this contract during the period of November 1979 through August 1981. This report was submitted by the authors in November 1981.

The work on the project was significantly aided by the contributions of Mr. Larry R. Fletcher of TCRC/USBM, Mr. J. S. Brower, Consultant, and the numerous mining, crusher, and explosives manufacturing companies whose personnel were both patient and cooperative. In addition, the mining and explosives regulatory agencies and state mining associations and the Health and Safety Analysis Center in Denver significantly aided the project work. The efforts of Mr. Ronald J. Kozid of the National Safety Council in assisting in searches of the extensive and valuable NSC files are greatly appreciated. Mr. Bennie G. Wheelis, Jr., EI staff Mining Engineer, also participated on the field and office work of this project.

This project was under the technical supervision of Mr. Francis S. Kendorski, with Mr. Michael F. Dunn as Project Engineer, and Swapan Bhattacharya, who are the authors of this report, under the overall direction of Dr. Madan M. Singh, President.

TABLE OF CONTENTS

	REPORT DOCUMENTATION PAGE	1
	FOREWORD	2
	TABLE OF CONTENTS	3
	LIST OF FIGURES	4
	LIST OF TABLES	6
1.0	INTRODUCTION	7
2.0	CRUSHERS	9
	2.1 Delivery Systems	9
	2.2 Crusher Types	9
3.0	BOULDERS	19
	3.1 Sources	19
	3.2 Delivery	19
4.0	APPLICABLE REGULATIONS	22
	4.1 Regulatory Agencies	22
	4.2 Methods of Regulation	25
	4.3 Specific Indirect Regulations	29
	4.4 Applicable Regulations	35
5.0	BOULDER HANDLING METHODS	36
	5.1 Use of Explosives	36
	5.2 Newer Explosive Techniques	43
	5.3 Mechanical Methods	47
6.0	SAFETY ANALYSIS	59
	6.1 Crusher Accident Analysis	59
	6.2 Boulder Handling Accident Analysis	68
	6.3 Specific Accidents	72
	6.4 Boulder Handling Analysis	79
	6.5 Damage Potential to Crusher from Blasting	79
7.0	COST ANALYSIS	87
	7.1 Initiating Devices	87
	7.2 Explosives	87
	7.3 Operational Costs	89
8.0	FUTURE APPLICABLE TECHNOLOGY	95
	8.1 Explosives Methods	95
	8.2 Non-explosive Methods	99
9.0	RECOMMENDATIONS FOR SAFER PRACTICES	109
	9.1 Improved Accessibility	109
	9.2 Formal Adopted Procedure	109
	9.3 Improved Blasting Methods	112
	9.4 Other Considerations	114
	9.5 Recommendations for Further Research	115
10.0	REFERENCES AND BIBLIOGRAPHY	118

LIST OF FIGURES

Figure 1	- Hopper and Vibrating Grizzly Feed to a Crusher	10
Figure 2	- Stationary Grizzly Feed to Crusher. Note Missing Grizzly Bar Allowing Passage of Oversized Material	10
Figure 3	- Bridging of Rocks in a Pan Feeder	11
Figure 4	- View into Throat of a Gyratory Crusher	13
Figure 5	- Schematic of a Typical Gyratory Crusher	14
Figure 6	- Schematic of a Typical Jaw Crusher	15
Figure 7	- Schematic of Typical Single Roll Crusher	16
Figure 8	- Schematic of Typical Hammermill	18
Figure 9	- Boulder Hungup on Spider of Gyratory Crusher Feed	21
Figure 10	- Blockholing a Boulder	39
Figure 11	- Mudcap Cross-Section	41
Figure 12	- Exploding Bridgewire Cap	46
Figure 13	- Schematic of a Rock Splitter	48
Figure 14	- Hydraulic Rock Hammer	50
Figure 15	- Available Rock Hammer Points	52
Figure 16	- Use of a Mobile Rock Hammer in a Quarry	53
Figure 17	- Grapplers. Above, a one Four Prong Type in Action Below a Three Prong Type	54
Figure 18	- Slings and Hooks for Boulder Removal from Crushers	56
Figure 19	- Hydraulic Boom-Mounted Hook for Boulder Repositioning	58
Figure 20	- Double Bar Diagram Showing the Number of Crusher Accidents and Man-Days Lost Between 1975-1979	60
Figure 21	- Pie Diagram Showing Distribution of Accidents by Accident Circumstance	62
Figure 22	- Frequency Ranking for Injured Body Parts	63
Figure 23	- Frequency Chart for Accident Type	64
Figure 24	- Histogram Showing Accident Severity	66
Figure 25	- Pie Diagram Showing Accident Causes	67
Figure 26	- Sources of Boulder Handling Accidents	69
Figure 27	- Military Explosives and Ordnance Applicable to Boulder Breaking	96
Figure 28	- Contained Projectile Charge	98
Figure 29	- Electron Beam Rock Breaker	100
Figure 30	- Spark Rock Cratering Mechanism	101
Figure 31	- Flame Jet Burner	102
Figure 32	- REAM Cannon Installation in a Crusher Area.	104
Figure 33	- Electrical Disintegration Method Installed in a Crusher Area	106
Figure 34	- Examples of an Exponential Type Pulsating Jet Nozzle	107

Figure 35 - Steep Access to Crusher Mouth 110
Figure 36 - Cluttered Access to Crusher Mouth 110
Figure 37 - Crusher Dump Warning Light 111
Figure 38 - Home-Made Grizzly Cleaner 116
Figure 39 - Air Gap Blockholing Technique 117

LIST OF TABLES

Table 1	- Regulation Coverage by State	23
Table 2	- Relevent Regulations for Boulder Blasting in Crushers and Grizzlies	26
Table 3	- Boulder Blasting Regulation Coverage	30
Table 4	- Explosives Breaking Methods	37
Table 5	- Explosives Properties	45
Table 6	- Part of Body Injured Versus Source of Accident for Boulder Handling in Crushers.	70
Table 7	- Accident Affects	71
Table 8	- Boulder Handling Analysis	80
Table 9	- Hazard Notation	83
Table 10	- Initiating Devices	88

1.0 INTRODUCTION

In mining and quarrying, the mineral commodity as present in the ground may be composed of rock blocks that must be reduced in size, to suit market requirements. The rock in place will be blasted, loosened, and then hauled away to the first processing step - size reduction. As delivered from the blasting area the rocks will range in size from dust to blocks several feet on a side. The crusher employed for the initial size reduction will have a maximum size rock capacity, and when any oversized rock is delivered, it lodges in the crusher and the materials flow in the mine or quarry is halted.

Whenever rock passes through openings, there exists a possibility for blockage by oversize pieces. This is particularly true when dealing with rock undergoing blasting primary breakage or collapse and drawing in a caving mine. Crusher and grizzly openings are the first size restriction for the materials handling process and therefore may plug by bridging or by oversized material. When this happens, several courses of action can be taken, depending on the hangup accessibility.

Manual techniques like sledge hammers or pry bars may be used to break or loosen boulders, but take excessive manpower and time. Hydraulic and pneumatic impact breakers are available but they are expensive. Blasting is often viewed as the most economical and quickest method for boulder breaking, and also requires very little effort from personnel. However, the person doing the blasting may not be experienced with explosive use. Since a blast in a crusher can be carried out at any random time, the blast area may be difficult to keep clear of personnel and equipment. Equipment near the crusher or grizzly could be damaged from blasting. Although blasting is the quickest method it is also potentially the most dangerous and destructive method. With improved practices and technology in this area, it is hoped that accidents resulting from boulder blasting can be reduced.

The Bureau of Mines recognizes the hazards involved and initiated this project to examine present practices, regulations, and safety records so as to recommend safer procedures and present improved technology for boulder blasting in crushers. In addition, all available literature dealing with boulder handling practices was examined.

Field visits were conducted to meet with operators firsthand about problems in handling boulders and the development of their chosen procedures. These visits were nationwide and covered many different types of rock, mining methods, and boulder handling equipment.

2.0 CRUSHERS

Crushers are generally very large machines that subject rocks to compressive forces that cause rock failure and thereby size reduction. The various components of a crusher system will be described below as well as the problems of boulder handling in each.

2.1 Delivery Systems

There probably are as many kinds and types of material delivery systems as there are applications for them. The delivery systems generally are pan type feeders or vibrating grizzlies that transport the rock from the hopper to the crusher mouth. Pan feeders are basically steel segmented conveyor belts, while grizzlies, whether vibrating or stationary, are a set of parallel bars set apart from each other a distance which permits passage of only the maximum size rock that can be easily handled in the next stage of rock processing. Grizzlies are usually built heavier than necessary in order to withstand secondary blasting either above or below the grizzly level. Vibrating grizzlies utilize the motion to feed a crusher with properly sized rocks while allowing undersized material to bypass the crusher, decreasing required crusher capacity. Figure 1 shows a hopper and vibrating grizzly arrangement. Grizzlies can also be installed stationary as equally spaced parallel bars sloping from the dump to the crusher mouth as shown in Figure 2. Storage hoppers are not needed since oversize rock falls down the incline immediately after dumping. Oversized rock can bridge or hang-up in these feed systems as in Figure 3. The advantage in such a system is in dealing with a disruption in rock flow and hang-up before the crusher mouth with easier access to the problem area.

2.2 Crusher Types

Rock can be broken by compression, impact, and attrition in the various types of crushers developed for mining. Crushers are selected on the basis of the material being crushed, such as physical structure, geological classification, hardness, and the chemical constituents.

Blockage occurs when a rock, because of size or shape, bridges across the crusher feed opening so that the crusher forces cannot be applied. This blockage can also prevent

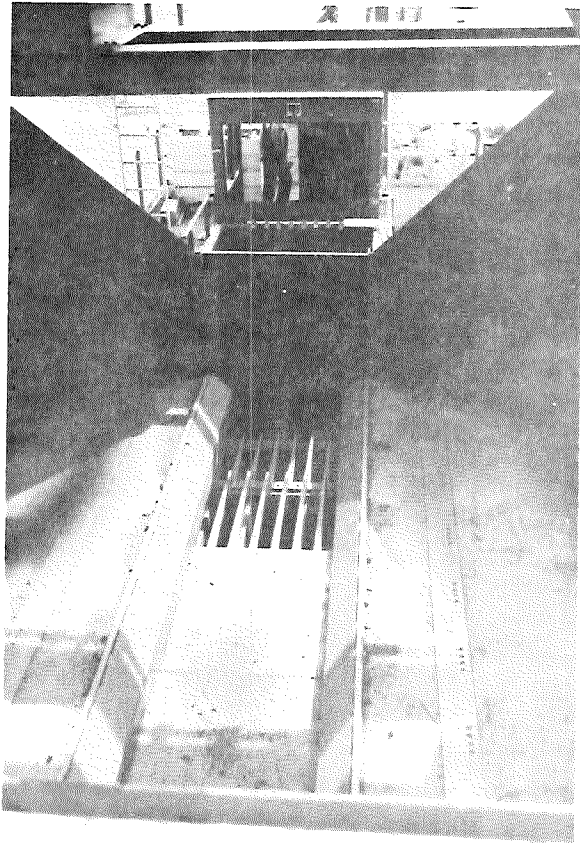


Figure 1 - Hopper and Vibrating Grizzly Feed to a Crusher

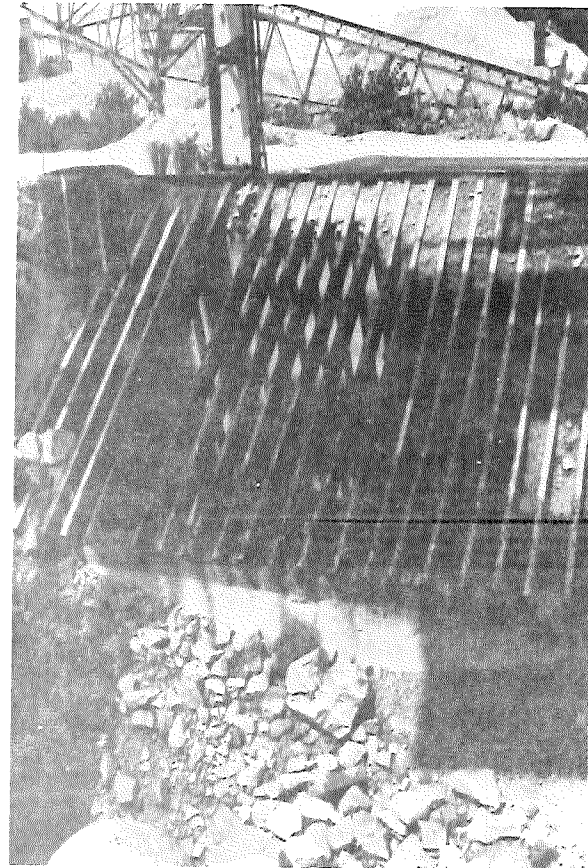


Figure 2 - Stationary Grizzly Feed to Crusher. Note Missing Grizzly Bar Allowing Passage of Oversized Material

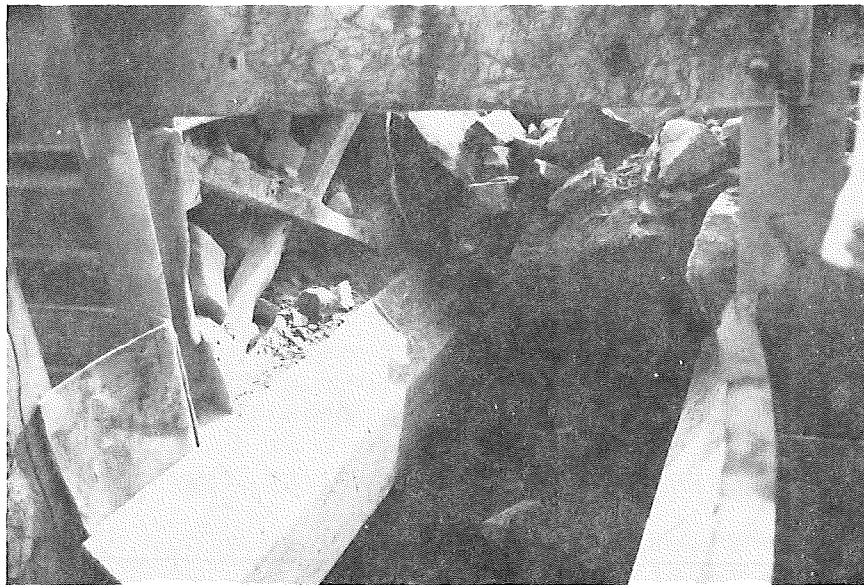


Figure 3 - Bridging of Rocks in a Pan Feeder

empty. This is a beneficial condition for blasting in that the existing air space acts as a cushion and therefore reduces excessive shock transfer to the crusher. This can offer some solace to the operator, but several crusher manufacturers contacted recommend blasting only as a last resort.

2.2.1 Gyratory Crushers

Gyratory crushers, shown in Figures 4 and 5, have a conical head with an eccentric movement inside an outer concave bowl. They are designed for high capacities. A straight vertical discharge prevents the packing of sticky materials (Pit and Quarry, 1977). Boulder blockage will occur if rock bridges the crusher perimeter and the spider supports that span the intake diameter. Obviously, any blasting can affect these supports and throw the cone out of alignment. The majority of the operating mechanisms are underneath and to the bottom side of the cone. Hence this area is susceptible to shock forces from boulder blasting which could cause cracking of the outer shell or loosening of the drive shaft.

2.2.2 Jaw Crushers

Jaw crushers, shown in Figure 6, are the oldest type of crusher in use. They are economical when dealing with a coarse or blocky feed although capacities are low. The swing jaw, powered by an eccentric, moves downward and toward the stationary jaw to crush, then moves up and back to allow crushed material to exit. Slabby rocks tend to slide down the crushing chamber untouched until their width equals the discharge dimension. Jaws can be concave to encourage rock falling lower in the crushing chamber, preventing packing (Pit and Quarry, 1977).

A boulder could bridge the opening, or be at an odd position relative to the moving jaw, so that crushing action does not take place.

The eccentric wheel mechanism location prevents easy access to a boulder. It also is most vulnerable to blasting effects. The swing jaw and main frame, as well as toggle bolts and bearings, are also susceptible to blasting damage.

2.2.3 Roll Crushers

Single roll crushers, shown in Figure 7, use shearing action to break soft rock. The main part is a knobbed roll where the knobs extend 3 to 4 inches beyond the roll surface. Rock is caught between the roll and the stationary breaking

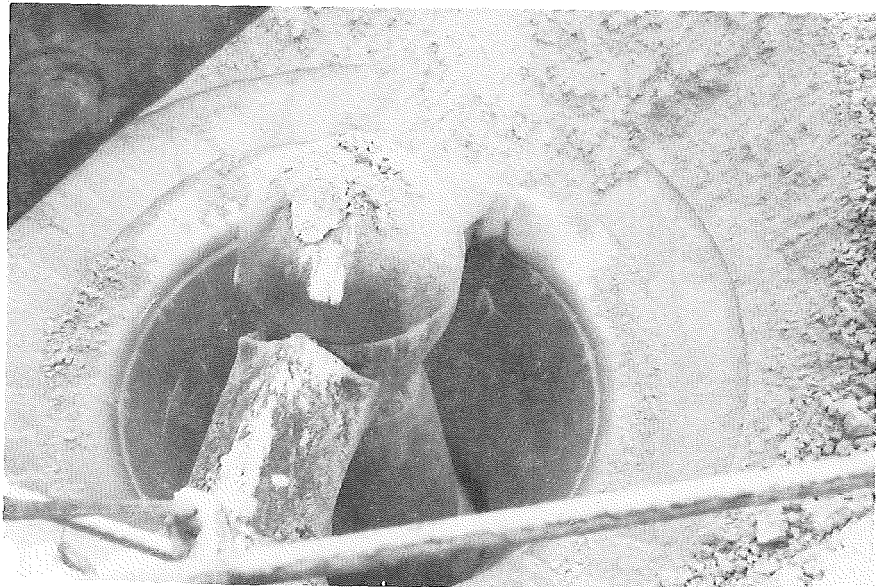


Figure 4 - View Into Throat of a Gyratory Crusher

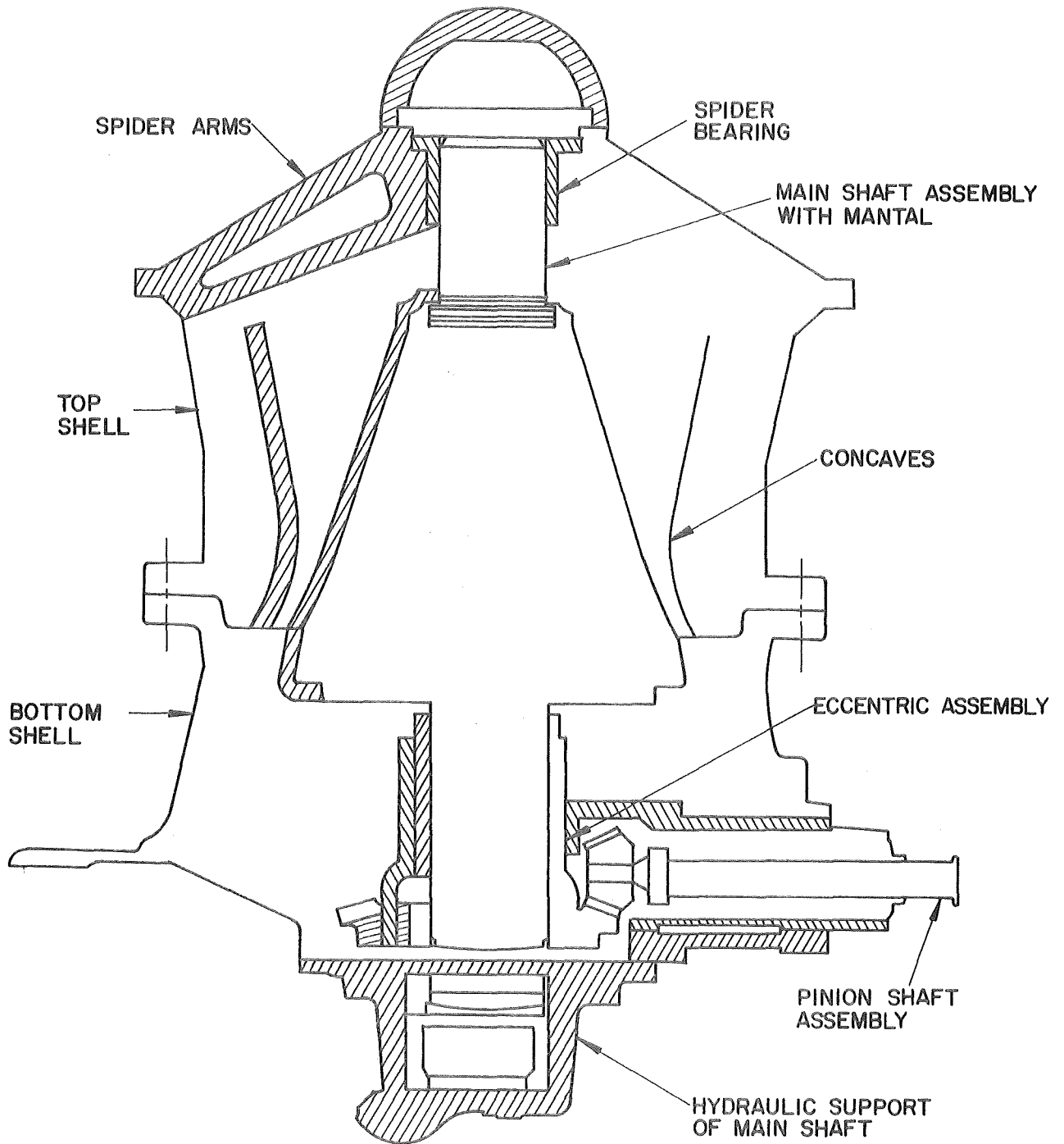


Figure 5 - Schematic of a Typical Gyratory Crusher

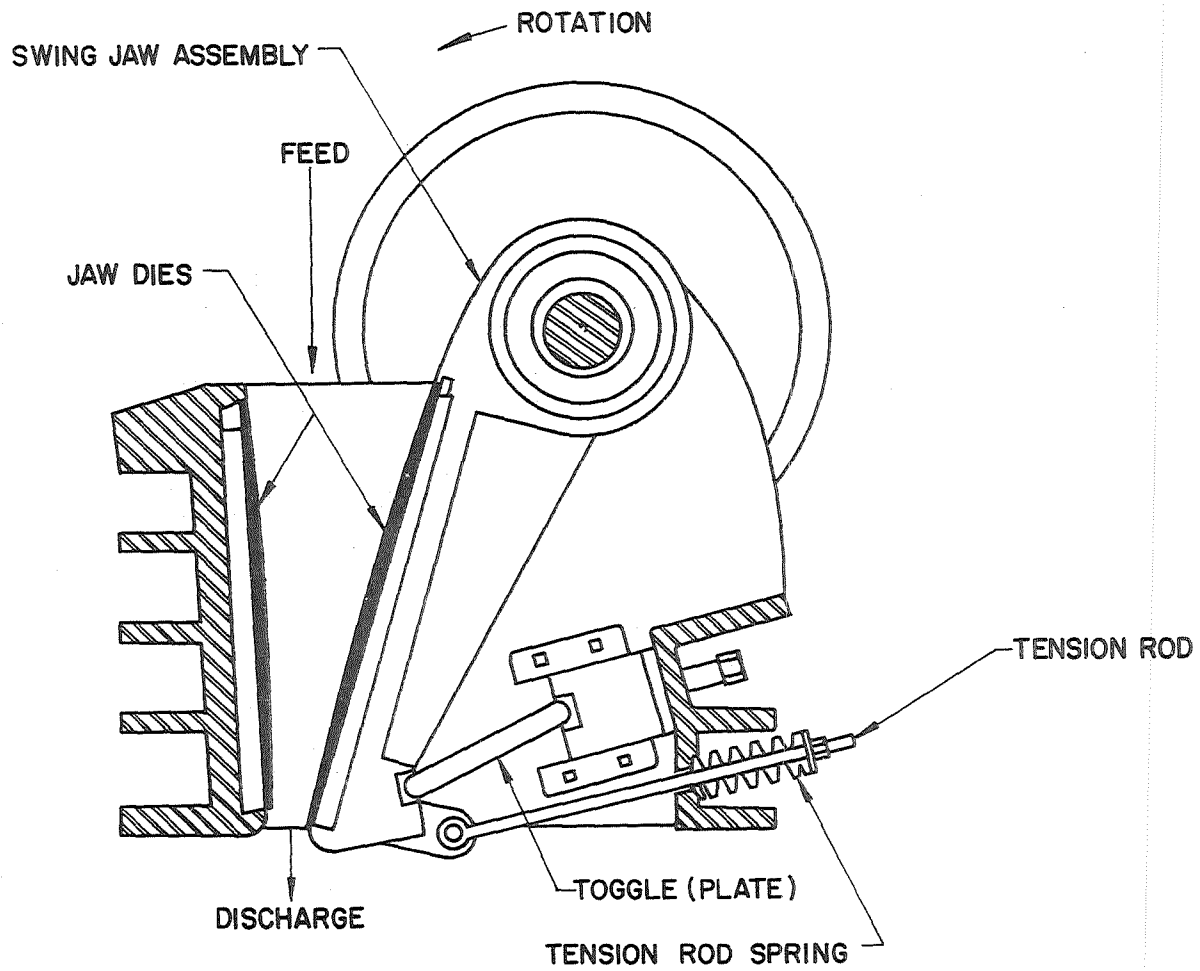


Figure 6 - Schematic of a Typical Jaw Crusher.

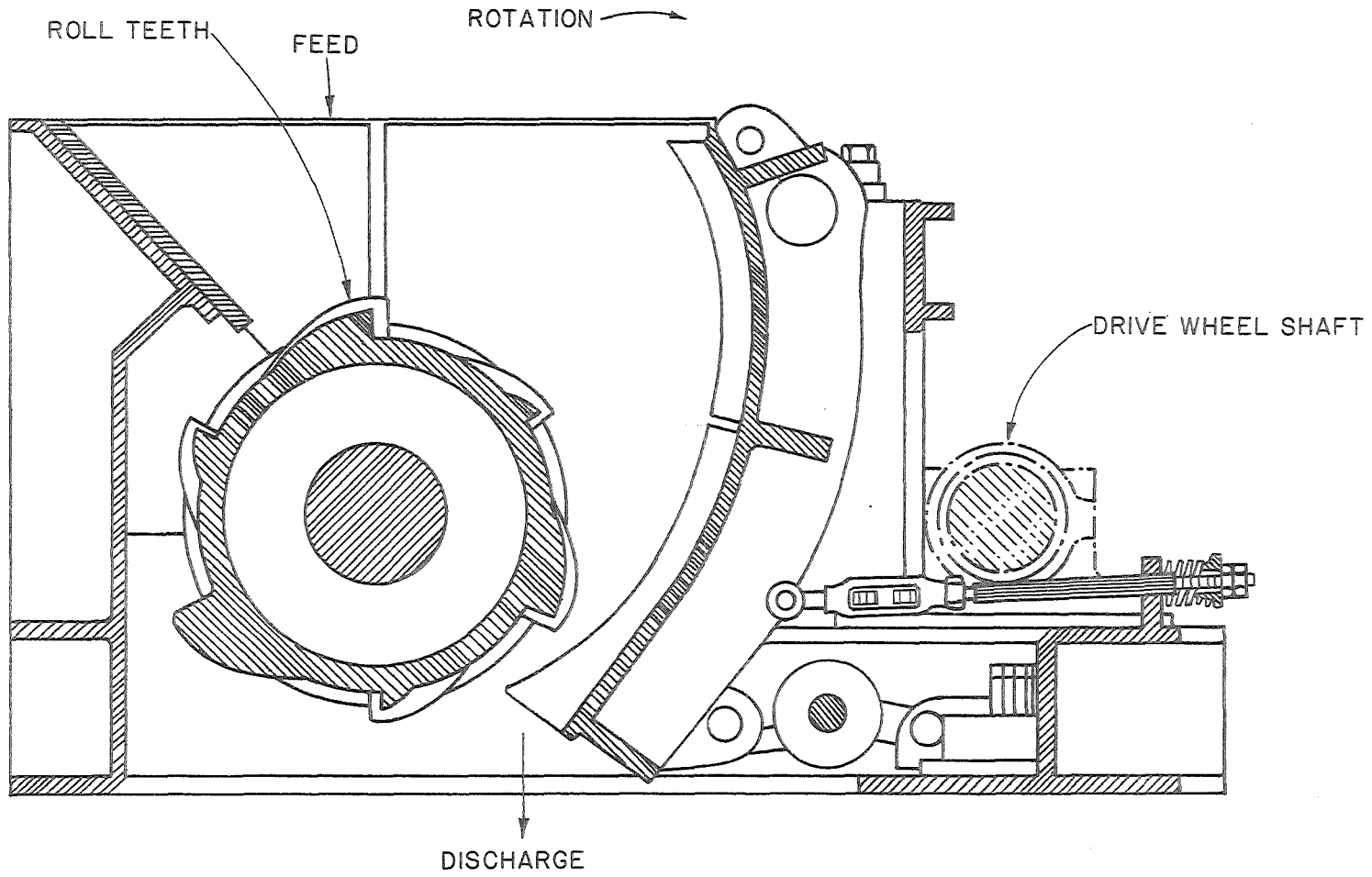


Figure 7 - Schematic of Typical Single Roll Crusher.

plate where it is continually hit and pushed by the roll knobs. The breaking plate, hinged at the top with the lower edge set on springs, can back off if an uncrushable material enters (Pit and Quarry, 1977). Large boulders can easily bridge themselves over the roll and avoid contact. The crusher knobs must be kept sharp so that a boulder does not bounce off the knobs and avoid crushing. Roll crusher drive wheels and roll shafts are extremely vulnerable to blasting damage.

2.2.4 Hammermills

A typical single roll hammermill or impactor is shown in Figure 8. In the hammermill the feed drops free and is hit by the crushing surface traveling at high speed. The rock shatters on impact and pieces are thrown toward a breaker plate for further size reduction. Blockage can occur whenever a boulder does not fall far enough into the feed opening to be exposed to the crusher hammers; consequently, no work can be performed on the rock. In many cases, the crusher design offers a means of access to alter the boulder position or enable other remedies to be tried (Pit and Quarry, 1977). Boulder blasting in this type of crusher can cause damage to the impactor shaft or bearings.

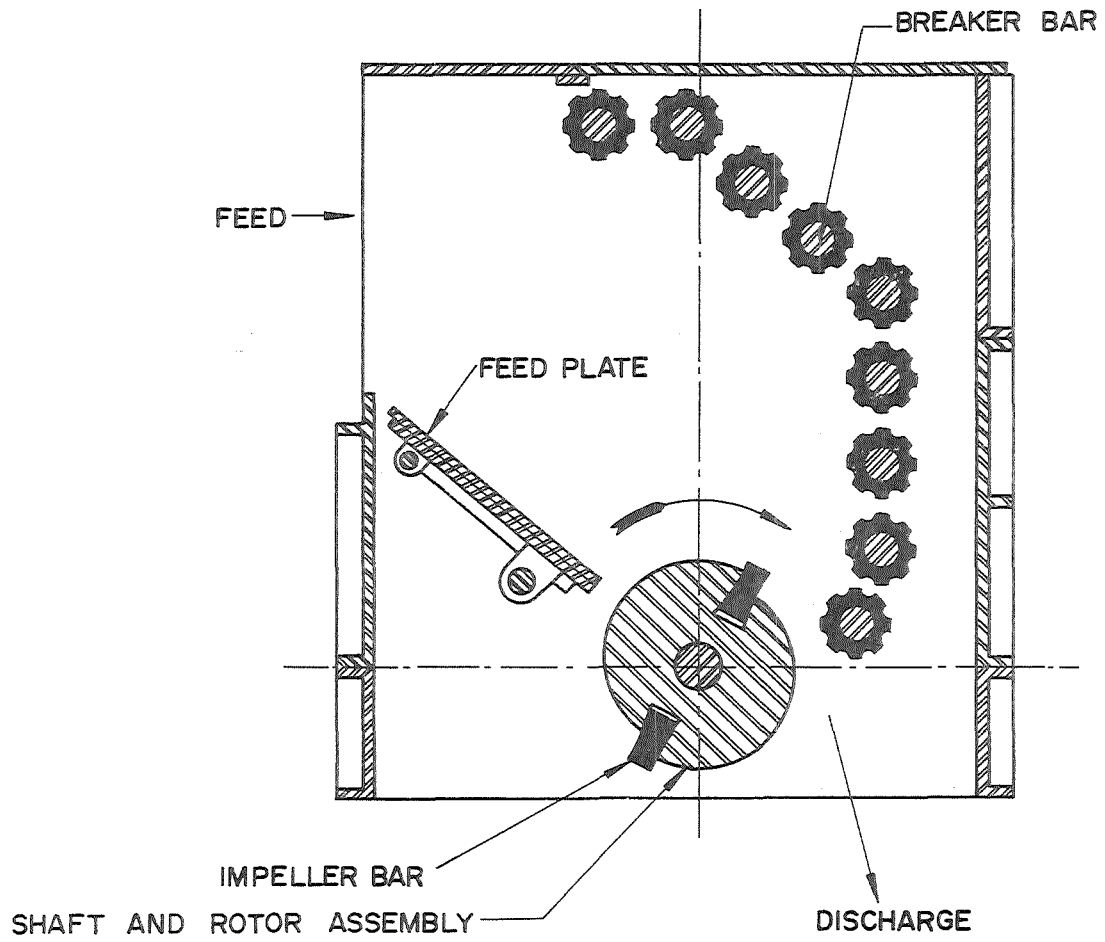


Figure 8 - Schematic of Typical Hammermill

3.0 BOULDERS

A boulder, in common mining usage, is any rock larger than the desired size. What is desirable in a riprap operation may be a problem in another operation.

3.1 Sources

Boulders originate in a mining operation during the primary blasting of the commodity mined. This blasting must adhere to accepted design and execution to result in good rock fragmentation. Long stemming or poor hole spacing, for example, contribute to the creation of boulders. Geology also enters in that hard lenses may occur and be difficult to break or easily dislodged from the bench. Joints, bedding planes, and clay seams in the rock are also factors that determine blasting fragmentation, and some mineral deposits may tend toward slabbiness or blockiness. As previously discussed, primary crushers are selected chiefly on the basis of the incoming material characteristics.

3.2 Delivery

Most boulders are set aside from the loading area and are blasted later. Sometimes a boulder may be truck loaded inadvertently if hidden in the muckpile. Loading operator experience and close supervision can prevent this from happening too often. It is important, for safety reasons, that boulder blasting be done in the pit. Loading equipment should have a proper bucket size matched with the crusher feed in order to help eliminate the transportation of over-size rock to the crusher.

Material handling equipment in a mining operation must be carefully matched for peak efficiency. For example, large capacity loading equipment would not be practical if the crusher mouth could not receive the larger loaded rocks. Oftentimes this mismatch occurs at smaller mining operations where equipment may be secondhand and purchased at a lower price rather than to meet specific requirements. The occurrence of boulders is further compounded in that small operators usually give inadequate attention to blast design, and cannot afford to hire a knowledgeable blasting foreman. The operator may not know how often boulders get hung up in the crusher, or how much time is lost to remedy that condition; it is just an accepted part of the operation.

Blockage of the crusher feed can be caused either by bridging of material or by a boulder too big for the feed opening. If material is wet and sticky, several smaller rocks can bridge over the feed opening and avoid crushing.

This usually happens when the delivery system is stopped and rock can settle and key together forming a bridge. Once the feed system activates, the material under the bridge is drawn out. The problem is more prevalent in cold weather where ice can freeze rock together.

Another form of crusher feed blockage results from a large boulder that cannot enter the feed, as shown in Figure 9. Occasionally the boulder can be repositioned in the feed system so that a smaller dimension of the boulder can be nipped by the crusher mechanism. If the feed system does not have this flexibility, then the boulder must be moved by auxiliary means which will be discussed at length in later sections.



Figure 9 - Boulder Hungup on Spider of Gyratory Crusher Feed

4.0 APPLICABLE REGULATIONS

This section contains a review and a critical evaluation of all federal, state, and Canadian regulations pertaining to boulder blasting or breaking in or on crushers and grizzlies. Mining, construction, and explosives use and safety regulations are covered, since rock crushing is done both for mineral industries and construction activities. Whatever technique is used or proposed for dislodging boulders in crushers, it must be in accordance with applicable regulations.

4.1 Regulatory Agencies

4.1.1 Understanding of Authority

In the United States, mining and industrial regulations can be both state controlled and enforced, and federally controlled and enforced. All states are required to follow the federal MSHA, OSHA, and OSM regulations. However, a state can have its own mining or industrial regulations which may be more restrictive or more inclusive than equivalent federal regulations, or the federal regulations take priority. If a mine operator or industrial operator opens a mine or business, state regulations and the federal MSHA, OSHA, and OSM regulations must be obeyed. (Where a conflict exists, the most restrictive one will take precedence.)

Since boulder blasting in crushers and grizzlies can take place in metal/nonmetal mining and coal mining, both surface and underground, and in rock excavation for construction, regulations that must be considered concern mining, construction, and explosives use. Direct inquiries were made to each state and Canadian provincial agency, and the nature of applicable regulations discerned. The provinces of Canada have been included because the information was readily obtainable and of potential interest.

4.1.2 Agencies Concerned

Table 1 is a breakdown of the manner in which mining is currently regulated by state and federal agencies, and the Canadian provinces.

The fifty states in the United States and the ten provinces in Canada are listed in Table 1. Corresponding to each listing are eleven columns, each representing a possible way that mining, construction, or blasting, may be regulated in a particular state or province.

The first nine columns are groupings of mining regulations. The first column "All Mining," means that a state has one set of regulations that covers all types of mining such as metal, nonmetal, coal, surface, and underground.

TABLE 1 - Regulation Coverage By State

States	1 All Mining	2 All Coal	3 Surface Coal	4 Underground Coal	5 Metal/ Non Metal	6 Anthracite Separately	7 Pits and Quarries Separately	8 Explosives & Blasting Separately	9 MSHA Only	10 General Industry	11 OSHA Only
Alabama	o	e	o	o	e	o	e	o	o	e	o
Alaska	e	o	o	o	o	o	o	e	o	e	o
Arizona	o	o	o	o	o	o	o	o	o	e	o
Arkansas	e	o	o	o	o	o	e	o	o	e	o
California	e	o	o	o	o	o	o	o	o	e	o
Colorado	o	e	e	o	e	o	o	o	o	o	e
Connecticut	o	o	o	o	o	o	o	o	o	o	e
Delaware	o	o	o	o	o	o	o	e	e	e	o
Florida	o	o	o	o	o	o	o	o	e	e	o
Georgia	o	o	o	o	o	o	o	o	o	o	e
Hawaii	o	o	o	o	o	o	o	e	e	e	e
Idaho	o	o	o	o	o	o	o	o	e	e	e
Illinois	o	e	e	o	o	o	o	o	o	o	e
Indiana	o	o	o	o	o	o	o	o	o	o	e
Iowa	o	o	o	o	o	o	o	o	e	e	o
Kansas	o	o	o	o	o	o	o	o	e	e	o
Kentucky	o	e	o	o	o	o	o	e	o	e	o
Louisiana	o	o	o	o	o	o	o	o	o	o	e
Maine	o	o	o	o	o	o	o	o	e	e	o
Maryland	o	o	o	o	o	o	o	o	e	e	o
Massachusetts	o	o	o	o	o	o	o	o	e	e	o
Michigan	o	o	o	o	o	o	o	o	e	e	o
Minnesota	o	o	o	o	o	o	o	o	e	e	o
Mississippi	o	o	o	o	o	o	o	o	o	o	e
Missouri	e	o	o	o	o	o	o	o	o	e	o
Montana	o	o	o	o	e	o	o	o	o	o	e
Nebraska	o	o	o	o	o	o	o	o	e	e	o
Nevada	o	o	o	o	e	o	o	o	e	e	o
New Hampshire	o	o	o	o	o	o	o	o	o	o	e
New Jersey	o	o	o	o	o	o	e	e	o	e	e
New Mexico	e	o	o	o	o	o	o	o	o	o	e
New York	e	o	o	o	o	o	e	e	o	e	e
North Carolina	o	o	o	o	o	o	o	o	o	o	e
North Dakota	o	o	e	o	o	o	o	o	e	e	o
Ohio	e	o	o	o	o	o	o	o	o	o	e
Oklahoma	o	o	o	o	o	o	o	o	o	o	e
Oregon	o	o	o	o	o	o	o	o	o	o	e
Pennsylvania	o	o	e	e	e	e	o	o	e	e	o
Rhode Island	o	o	o	o	o	o	o	o	o	o	e
South Carolina	o	o	o	o	o	o	o	o	o	o	e
South Dakota	o	o	o	o	o	o	o	o	o	o	e
Tennessee	o	o	o	o	o	o	o	o	o	o	e
Texas	o	o	o	o	o	o	o	o	o	o	e
Utah	o	e	o	o	o	o	o	o	o	o	e
Vermont	o	o	o	o	o	o	o	o	o	o	e
Virginia	o	o	o	o	e	o	o	e	e	e	o
Washington	o	o	o	o	o	o	o	o	o	o	e
West Virginia	o	o	o	o	o	o	o	o	o	o	e
Wisconsin	o	o	o	o	o	o	o	o	o	o	e
Wyoming	o	e	o	o	e	o	o	o	o	e	o
Canadian Provinces											
Alberta	o	e	o	o	o	o	o	o	o	e	o
British Columbia	o	o	o	o	o	o	o	o	o	e	o
Manitoba	o	o	o	o	o	o	o	o	o	e	o
New Brunswick	o	o	o	o	o	o	o	o	o	e	o
Newfoundland	o	o	o	o	o	o	o	o	o	e	o
Nova Scotia	o	o	o	o	o	o	o	o	o	e	o
Ontario	o	o	o	o	o	o	o	o	o	e	o
Prince Edward Is.	o	o	o	o	o	o	o	o	o	e	o
Quebec	o	o	o	o	o	o	o	o	o	e	o
Saskatchewan	o	o	o	o	o	o	o	o	o	e	o

e Regulations Applicable

o Regulations Not Applicable

Columns 2 through 7 are subset groupings of all mining regulations. Column 2 lists regulations that would cover all coal mining, and Columns 3 and 4 list regulations specifically for surface coal mining and underground coal mining, respectively. Column 5 covers the regulations for metal and nonmetal mining, while Columns 6 and 7 represent regulations concerning anthracite coal mining and pit and quarry mining, respectively. Column 8 represents separate explosives and blasting regulations that may or may not be specific to mining.

Column 9 is "MSHA Only" which means the states have no mining regulations of their own. This means that MSHA regulates and enforces MSHA mining laws as the sole mining authority in the state.

The last two columns, "General Industry" and "OSHA Only," indicate that either a state regulates its own general industry along with OSHA, or OSHA regulates and enforces industrial regulations as the sole authority. OSHA is included in the study because oftentimes on construction jobs, rock is crushed for ballast, roadstone, et cetera, and blockage can occur.

Under the listings in the Canadian provinces, the categories of "MSHA Only" and "OSHA Only" do not apply because MSHA and OSHA are United States government regulatory agencies and have no power in Canada. There are no regulatory equivalents of MSHA and OSHA in Canada.

The closed circles in Table 1 indicate that a certain set of regulations in the state apply.

The results of the investigation of the United States regulations are that 13 states have "All Mining" regulations; 7, "All Coal;" 5, "Surface Coal;" 3, "Underground Coal;" 11, "Metal/Nonmetal;" 1, "Anthracite Separately;" 5, "Pit and Quarry Separately;" 9, "Explosives and Blasting Separately;" 21, "MSHA Only;" 26, "General Industry;" and 24, "OSHA Only."

Throughout the United States, 21 states have no state mining laws at all. Their mining regulations and enforcement of mining regulations are only through MSHA. Of these 21 states, 15 have OSHA regulating and enforcing the industrial section of their state as well. This breakdown is shown in Table 1. The states in which MSHA does all regulating and enforcing are: Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Iowa, Kansas, Louisiana, Maine, Maryland, Massachusetts, Michigan, Mississippi, Nebraska, New Hampshire, North Carolina, Rhode Island, South Dakota, Texas, and Vermont. Although state mining laws may not exist, it is possible that a county may have its own regulations.

The following states have MSHA federal regulations and in addition have their own general industry regulations: Delaware, Iowa, Maryland, Massachusetts, Michigan, and North Carolina.

The 10 provinces of Canada have very little federal interference in the regulations of interest to this study. The provinces legislate and enforce their own regulations. All the provinces but Alberta, Nova Scotia, and Prince Edward Island have only one set of mining laws which cover all mining. Alberta has only "All Coal" mining laws. Nova Scotia has separated its mining laws into two sets, "All Coal" and "Metal/Nonmetal" regulations. Prince Edward Island has no mining laws at all because it has no mining industry.

All the provinces have their own general industry regulations.

4.2 Methods of Regulation

Table 2 lists relevant regulations for boulder blasting in crushers and grizzlies derived from Table 1. Each listing evaluates seven different possible, applicable procedures or items that can be regulated. These procedures and items are: blasting, boulder blasting, boulder breaking, boulder blasting in crushers, boulder removal from crushers, and grizzlies.

The closed circle indicates that a particular set of regulations cover that particular procedure or item whether directly or indirectly. For instance, boulder blasting or secondary blasting may not be specifically regulated, but there may be provisions dealing with mud-capping, unwrapping explosive cartridges, prohibiting detonation of explosives not contained within boreholes, and the like.

In our review we found that 76 out of 84 sets of federal and state regulations regulated blasting as a whole but 54 regulated boulder blasting and only 13 have any regulations on boulder breaking. Six of the 8 listings that do not regulate blasting are general industry regulations. There are no regulations in the United States dealing specifically with boulder blasting in crushers, boulder breaking in crushers, or grizzlies. Only California mining regulations, New Jersey pit and quarry regulations, and North Dakota general industry regulations have any provisions dealing with crushers. MSHA and OSHA have informed us that crushers are considered machinery and regulated accordingly for guarding rotating parts, and so on.

TABLE 2 - Relevant Regulations for Boulder Blasting in Crushers and Grizzlies

	Regulate Blasting	Regulate Boulder Blasting	Regulate Boulder Breaking	Regulate Boulder Blasting in Crushers	Regulate Boulder Removal from Crushers	Regulate Crushers	Grizzlies
MSHA Coal	•	•	○	○	○	○	○
MSHA Metal/Nonmetal	•	•	•	○	○	○	○
OSHA	•	•	○	○	○	○	○
OSM	•	○	○	○	○	○	○
Alabama Coal Mining	•	•	○	○	○	○	○
Alabama Metal/Nonmetal	•	•	○	○	○	○	○
Alabama Pit and Quarries	•	•	○	○	○	○	○
Alabama General Industry	○	○	○	○	○	○	○
Alaska Mining	•	○	○	○	○	○	○
Alaska Explosives	•	○	○	○	○	○	○
Alaska General Industry	○	○	○	○	○	○	○
Arizona Mining	•	○	•	○	○	○	○
Arizona General Industry	•	•	○	○	○	○	○
Arkansas Mining	○	○	○	○	○	○	○
Arkansas Pit & Quarries	•	•	○	○	○	○	○
Arkansas General Industry	•	•	○	○	○	○	○
California Mining	•	•	•	○	○	•	○
California General Industry	•	•	○	○	○	•	○
Colorado Metal/Nonmetal	•	•	•	○	○	•	○
Colorado Coal	•	•	○	○	○	○	○
Colorado Surface Coal Mining	•	•	○	○	○	○	○
Delaware General Industry	•	•	○	○	○	○	○
Illinois Coal	•	•	○	○	○	○	○
Illinois Surface Coal	•	○	○	○	○	○	○
Illinois Metal/Nonmetal	•	○	○	○	○	○	○
Illinois Explosives & Blasting	•	○	○	○	○	○	○
Indiana U.G. Coal Mining	•	•	○	○	○	○	○
Indiana General Industry	•	•	○	○	○	○	○
Iowa General Industry	•	•	○	○	○	○	○
Kentucky Coal	•	•	○	○	○	○	○
Kentucky Explosives & Blasting	•	•	○	○	○	○	○
Kentucky General Industry	•	•	○	○	○	○	○
Maryland General Industry	•	•	○	○	○	○	○
Massachusetts General Industry	•	○	○	○	○	○	○
Michigan General Industry	○	○	○	○	○	○	○
Minnesota Mining	○	○	○	○	○	○	○

• Regulations Applicable

○ Regulations Not Applicable

TABLE 2 - Relevent Regulations for Boulder Blasting in Crushers and Grizzlies

	Regulate Blasting	Regulate Boulder Blasting	Regulate Boulder Breaking	Regulate Boulder Blasting in Crushers	Regulate Boulder Removal from Crushers	Regulate Crushers	Grizzlies
Minnesota Explosive and Blasting	●	○	○	○	○	○	○
Minnesota General Industry	●	●	○	○	○	○	○
Missouri Mining	●	●	○	○	○	○	○
Missouri General Industry	●	●	○	○	○	○	○
Montana Metal/Nonmetal	●	○	●	○	○	○	○
Montana General Industry	●	●	○	○	○	○	○
Nevada Metal/Nonmetal	●	●	●	○	○	○	○
Nevada General Industry	●	●	○	○	○	○	○
New Jersey Pit Quarry	●	●	○	○	○	○	○
New Jersey Explosive & Blasting	●	●	○	○	○	○	○
New Mexico Mining	●	○	●	○	○	○	○
New Mexico General Industry	●	●	○	○	○	○	○
New York Mining	●	●	●	○	○	○	○
New York Pit & Quarry	●	●	●	○	○	○	○
North Carolina General Industry	●	●	○	○	○	○	○
North Dakota Surface Coal	●	●	○	○	○	○	○
North Dakota General Industry	○	○	○	○	○	○	○
Ohio Mining	●	○	○	○	○	○	○
Oklahoma Mining	●	●	○	○	○	○	○
Oklahoma General Industry	●	●	○	○	○	○	○
Oregon Metal/Nonmetal	●	○	○	○	○	○	○
Oregon General Industry	○	○	○	○	○	○	○
Pennsylvania Surface Coal	●	●	○	○	○	○	○
Pennsylvania Underground Coal	●	●	○	○	○	○	○
Pennsylvania Metal/Nonmetal	●	○	○	○	○	○	○
Pennsylvania Anthracite	●	●	○	○	○	○	○
Pennsylvania Explosives & Blasting	●	●	○	○	○	○	○
South Cadina Mining	●	○	○	○	○	○	○
Tennessee Mining	●	●	○	○	○	○	○
Tennessee General Industry	●	●	○	○	○	○	○
Utah Coal	●	●	○	○	○	○	○
Utah Metal/Nonmetal	●	●	●	○	○	○	○
Utah General Industry	●	●	○	○	○	○	○
Virginia Coal	●	●	○	○	○	○	○
Virginia Metal/Nonmetal	●	●	●	○	○	○	○
Virginia Pit & Quarry	●	●	○	○	○	○	○
Virginia Explosives	●	○	○	○	○	○	○
Virginia General Industry	●	●	○	○	○	○	○
Washington Metal/Nonmetal	●	○	●	○	○	○	○
Washington Explosive & Blasting	●	○	○	○	○	○	○
West Virginia Surface Coal	●	○	○	○	○	○	○
West Virginia Underground Coal	●	○	○	○	○	○	○
Wisconsin Mine Regulations	●	●	●	○	○	○	○

● Regulations Applicable

○ Regulations Not Applicable

TABLE 2 - Relevant Regulations For Boulder Blasting in Crushers and Grizzlies

	Regulate Blasting	Regulate Boulder Blasting	Regulate Boulder Breaking	Regulate Boulder Blasting in Crushers	Regulate Boulder Removal from Crushers	Regulate Crushers	Grizzlies
Wisconsin Explosive & Blasting	●	○	○	○	○	○	○
Wisconsin Industrial Regulations	○	○	○	○	○	○	○
Wyoming Coal	●	●	○	○	○	○	○
Wyoming Metal/Nonmetal	●	○	○	○	○	○	○
Wyoming General Industry	●	●	○	○	○	○	○
<u>Canadian Provinces</u>							
Alberta Coal Mining	●	●	○	○	○	○	○
Alberta General Industry	●	○	○	○	○	○	●
British Columbia Coal Mining	●	○	○	○	○	○	○
British Columbia Mine Regulations	●	○	○	○	○	○	○
British Columbia General Industry	●	●	○	○	○	○	○
Manitoba Mine Regulations	●	●	○	○	○	○	○
Manitoba General Industry	●	●	○	○	○	○	○
New Brunswick Mine Regulations	●	●	○	○	○	○	○
New Brunswick General Industry	●	○	○	○	○	○	○
Newfoundland Mine Regulations	●	●	○	○	○	○	○
Newfoundland General Industry	●	○	○	○	○	○	○
Nova Scotia Coal Regulations	●	○	○	○	○	○	○
Nova Scotia Metal/Nonmetal Mining	●	●	○	○	○	○	○
Nova Scotia General Industry	●	○	○	○	○	○	○
Ontario Mining Regulations	●	○	○	○	○	○	○
Ontario Industry Regulations	○	○	○	○	○	○	○
Prince Edward Island Industrial	○	○	○	○	○	○	○
Quebec Mining Regulations	●	○	○	○	○	○	○
Quebec General Industry	●	○	○	○	○	○	○
Saskatchewan Mining Regulations	●	○	○	○	○	○	○
Saskatchewan Industrial Regulations	○	○	○	○	○	○	○

● Regulations Applicable

○ Regulations Not Applicable

In the Canadian provinces all but 3 of the 20 sets of regulations control blasting, but only 7 regulate boulder breaking and only Alberta's general industry regulations govern grizzlies. The other four categories (boulder breaking, boulder blasting in crushers, boulder breaking in crushers, and crushers) are either not regulated or have no specific regulation on that topic.

In these tables, some categories are totally blank but are included for emphasis since we made a specific search for such provisions.

4.3 Specific Indirect Regulations

Table 3 shows more specifically the coverage of secondary blasting regulations. Since regulations for the handling and use of explosives cover both primary and secondary blasting, the table shows only operations that would be more associated with secondary blasting in the crusher. Consequently the table only represents a partial listing of the coverage of all blasting regulations.

Information obtained for Table 3 was gathered from the same sources as the other tables. Of course, in any industry, the governmental regulations of MSHA and OSHA must be applied. Therefore, only the states that have additional regulations pertaining to boulder blasting are included.

These descriptions appear in an order similar to the sequence of loading explosives during secondary blasting.

4.3.1 Pound Limit for Explosives

Many states that allow mudcapping usually limit the amount to 10 lbs. A typical regulation would be as follows:

"When explosives are not confined in a drill hole, not more than 10 pounds of explosives shall be detonated at any one time in a secondary shot."
(New Jersey A.C., 12:193)

It is doubtful that any amount near 10 lbs. would ever be used to dislodge a boulder in the crusher.

TABLE 3 - Boulder Blasting Regulation Coverage

State	1b. Limit For Explosives	Cannot Remove Expl. from Wrapper	Mudcapping Not Permitted Unless Nec.	Examine Boulders for stray expl.	Audible Blast Warning Needed	Elec. Mat. 1 Specified (Wire, Battery)	Restrict Use of Elec. Equip.	Require Blasting Shelters (or Mention their Use)	Require Guards	Prevent Flyrock	Wire Must Fire Shot	Stray Current Caution
AL Coal Mining Quarries	0	0	0	0	0	0	0	0	0	0	0	0
AK Mining	0	0	0	0	0	0	0	0	0	0	0	0
AZ Mining	0	0	0	0	0	0	0	0	0	0	0	0
AR Mining	0	0	0	0	0	0	0	0	0	0	0	0
CA Mining	0	0	0	0	0	0	0	0	0	0	0	0
CO Mining	0	0	0	0	0	0	0	0	0	0	0	0
IL Coal Surface Metal	0	0	0	0	0	0	0	0	0	0	0	0
IN Coal	0	0	0	0	0	0	0	0	0	0	0	0
KY Blasting	10	0	0	0	0	0	0	0	0	0	0	0
Coal & Clay	10	0	0	0	0	0	0	0	0	0	0	0
MA Ind.	0	0	0	0	0	0	0	0	0	0	0	0
MO Mining Labor Laws	0	0	0	0	0	0	0	0	0	0	0	0
MT Met./Nonmet	0	0	0	0	0	0	0	0	0	0	0	0
NJ Expl.	10	0	0	0	0	0	0	0	0	0	0	0
OK Mining	0	0	0	0	0	0	0	0	0	0	0	0
OR Min. & Quarries	10	0	0	0	0	0	0	0	0	0	0	0
PA Coal	0	0	0	0	0	0	0	0	0	0	0	0
TN Mining	0	0	0	0	0	0	0	0	0	0	0	0
UT Coal Blasting	0	0	0	0	0	0	0	0	0	0	0	0
VA Blasting Mining	0	0	0	0	0	0	0	0	0	0	0	0
WA Quarries Expl.	0	0	0	0	0	0	0	0	0	0	0	0
WV Mining	0	0	0	0	0	0	0	0	0	0	0	0
WI Blasting	0	0	0	0	0	0	0	0	0	0	0	0
WY Coal	0	0	0	0	0	0	0	0	0	0	0	0

0 Regulations Applicable 0 Regulations Not Applicable

4.3.2 Prohibit Stripping of Explosives

One technique to improve the efficiency of a mud-capped charge is to unwrap the explosive and conform it to the boulder's surface. This technique is often regulated against (usually in underground coal mines) in the following manner:

"No explosive, other than a detonator of detonating fuse, shall be used at or in any mine except in the form of a stick or cartridge." (Nova Scotia Revised Statutes, Chapter 183, 1976)

4.3.3 Mudcapping not Permitted

Many states prohibit firing explosives placed on a boulder unless drilling the boulder poses a great safety hazard. An example of this regulation is:

"Boulders which must be broken by blasting, shall be block-holed and adobe or mud-capped shots are hereby prohibited except that such shots may be permitted where no means of drilling such boulders is available
...."

(Alabama Open-Pit and Quarry Safety Rule, 1963)

"Mudcapping in blasting operations shall be permitted only where it would endanger the safety of the workman to drill the rock or material to be blasted...."

(Kentucky, Div. of Explosives and Blasting, 1978)

Mudcapping would be a likely method when blasting at the crusher in that it is a fast method, which means less lost production.

4.3.4 Examine Boulder for Stray Powder

It is possible for explosives not detonated in the primary blast to be lodged in a hole in the boulder. Drilling a hole for blockholing could be hazardous if the drill steel hit the explosives. Regulations regarding this condition are few, but explosives in a boulder have detonated upon crushing. An example of a very specific regulation is as follows:

"Oversize rock material set aside by the shovel runner for blasting shall be examined to determine whether or not any unexploded powder remains in such rock or boulder. It shall be the responsibility of the foreman, or such person he may designate, to determine whether or not rocks or boulders set aside for blasting are safe to drill."

(Alabama Open Pit and Quarry Safety Rules, 1963)

4.3.5 Blast Warning

Regulations generally require an audible signal to be given prior to initiating a blast.

"Before a blast is fired, a loud warning signal shall be given by the blaster in charge, who has made certain that all surplus explosives are in a safe place and all employees, vehicles, and equipment are at a safe distance, or under sufficient cover."

(Kentucky, Div. of Explosives and Blasting, 1978)

A warning signal may be a one minute series of long blasts five minutes prior to the blast signal. The blast signal could be a series of short blasts one minute prior to the blast, and an all clear signal could be a prolonged blast.

4.3.6 Electrical Specifications

Occasionally, regulations mention minimum specifications for electric blasting. This may include the minimum gage of wire needed, or call for only approved blasting machines. This is important to boulder blasting in that it can discourage the use of make-shift equipment. A regulation example follows:

"Lead wires from portable blasting devices or approved type battery blasters shall not be smaller than No. 14 insulated wire, and connecting wire shall not be smaller than No. 20 wire, both American wire gage."

(Colorado Mining Laws, Bulletin 20, 1971)

4.3.7 Electrical Equipment Restricted

The operation of electrical equipment most often is restricted in a blasting area. This will apply to blasting at the crusher if electric blasting caps are used. A typical regulation reads:

"No electrical equipment using direct current shall be in operation within 200 feet of holes loaded for electric blasting or while such holes are being loaded."

(Alabama Mine Safety Rules, 1962)

4.3.8 Use of Blasting Houses

Some regulatory authorities mention the use of blasting shelters in congested areas so that personnel can seek safety before a blast. The blaster can easily make a head count in these shelters so as to know everyone's whereabouts. The construction of these shelters is not specified in this typical regulation:

"Shelters shall be provided in all blasting areas where workmen cannot otherwise reach a safe area during blasting."

(Oregon Safety Code, 1962)

4.3.9 Guarding Requirements

The guarding of access ways to a blast area is commonly required under regulations. Crusher areas can be well traveled and personnel can be taken by surprise from a blast at irregular time periods. A typical regulation is:

"Areas in which charged holes are awaiting firing shall be guarded and posted, or flagged against unauthorized entry."

(Washington Safety Standards, Mines, Quarries, Pits....., 1972)

4.3.10 Flyrock Precautions

Some general regulations regarding flyrock exist, but their direct application to boulder blasting at the crusher is questionable. Other regulations require the use of protective devices. Several examples follow:

"When blasing in a location where fly-rock or material may damage other property, all loaded holes shall be covered with an adequate blasting mat that has been securely anchored."
(California Administrative Code, 1978)

"In blasting operation, flying rocks shall not be allowed to fall greater than one-half the distance between the blast and a dwelling house, public building, school, church, commercial or institutional building. Protective material should be used to insure this limit."
(Alabama Mine Safety Rules, 1962)

4.3.11 Wiring the Blast

When several persons are planning a blast it could be easy to misread the blast wiring status and it may be fired by the wrong person before the area is clear. This situation is particularly applicable at crushers where many persons travel. The blast could involve the crusher operator, the mucker, a truck driver, or any number of others. A pertinent regulation reads:

"Only the man who makes the leading wire connections in electrical firing shall fire the shot....and the leading wire shall remain shortened and not be connected to the blasting machine or other source of current until the charge is to be fired."
(Arizona Mining Code, 1976)

4.3.12 Stray Currents

Most regulations cover a watch for stray electric currents and some regulatory authorities are more specific than others. Stray current is particularly important near the crusher when electric blasting is practiced. Stray current can come from power lines, static electricity, or radio signals. A representative regulation reads as follows:

"Lead wires and blasting lines shall not be strung across power conductors, pipelines, railroad tracks, or within 20 feet of bare power lines. They shall be protected from sources of static or other electrical contact."
(Arizona Mining Code, 1976)

4.4 Applicable Regulations

From the foregoing it may be seen that there are no specific regulations dealing directly with boulder blasting in crushers and grizzlies. However, there are numerous regulations that an operator or inspector could apply in the situation and thereby regulate the act.

Other applicable regulations encountered during the regulation review include:

- Blasters must load explosives in a continuous operation.
- Only authorized people should do the blasting and remain in the area (from Arizona Mining Code, 1976).
- Blockholes shall contain at least 85% stemming material.
- Mudcaps should be free from stones which could become missiles during the blast (New Jersey A. C. 12:193).
- Miners must wear goggles when breaking boulders (new Mexico Mine Safety Code, 1975).
- Two persons must be present to light safety fuses.
- In case the drill steel breaks, drillers should position themselves before drilling so they won't lose their balance (MSHA Chapter 1, 1978).
- Equipment should not be operated within 50 feet of loaded holes (OSHA, 29 CFR Part 1926, 1979).
- Posting of signs does not constitute adequate warning (Manitoba Mines Act, Regulation 254/73).

In summary, there are numerous regulations, that vary from state to state, that could be applied to the situation of attempting to dislodge a boulder in a crusher or grizzly, but no specific regulations describing boulder removal.

5.0 BOULDER HANDLING METHODS

Boulders can be broken up using either explosives or mechanical methods which can be implemented in many ways. Handling boulders hung up in crushers is inherently inefficient for the overall operation, and the techniques in handling them each have their own advantages and disadvantages.

Table 4 shows a comparison of explosive boulder breaking techniques. When these methods are used it is important to make certain that the crusher feed is empty of rock that could transfer shock energy from the explosive detonation and damage the crusher. The table summarizes economic evaluations of some blasting methods on the basis of drilling need, and type and amount of explosives needed to break a cubic yard of rock. For each method, either dynamite or binary (two component explosives) can be used. The methods will be explained in detail, but it must be emphasized that cost figures shown in Table 4 cannot adequately include the cost for any increased accident potential that could result.

This section covers techniques found in use in mines and quarries or likely to be in use. A later section describes new technology that are not presently well enough developed for use for boulder breaking.

5.1 Use of Explosives

5.1.1 Blockholing

Blockholing is the placing of an explosive into a shallow drill hole in a boulder. Tamping the explosive makes better use of the explosive's energy, provided there is sufficient stemming material in the hole. Upon detonation, the explosive energy produces radial cracks about the drill-hole caused by shock waves. The radial cracks are then expanded by gases from the explosive's chemical reaction. Increased efficiency over other methods can be achieved by the lesser amount of explosive needed to perform the work. The object is to use just enough explosive to crack the boulder with as little violence as possible.

The blockholing technique has many disadvantages. Drilling the required holes is time consuming and hazardous. The boulder, probably containing cracks from the primary blast, will be hazardous to drill because it could split without warning. Also, the drill hole can be easily overloaded adding to the danger. Even with care, damaging fly-rock can be created, therefore, proper precautions must be taken as for any blasting operation.

TABLE 4 - Explosives Breaking Method

	<u>Mudcapping</u>	<u>Blockholing</u>	<u>Snakeholing</u>	<u>Bombs</u>
	No	Yes	No	No
Drilling				
Explosives types used	60% to 80% Dynamite Binary expl.	40% Dynamite Binary expl.	60% to 80% Dynamite Binary expl.	40% Dynamite Binary expl.
lbs to break 1 yd ³ of rock	2	0.5 to 1	0.5 to 1	2 to 3
Cost per ton to break rock	\$0.78 to 0.81	\$0.85 (Drilling Incl.)	\$0.74 to 0.80	\$2.20

Generally medium to low strength explosives such as 40% straight dynamite would be used for blockholing. Binary explosives for extra safety are also available in cartridge form but at a much higher cost. These explosives can be initiated with a number six blasting cap. Only a small amount of explosive is needed with this technique, and just enough explosive to cover the cap, if well confined. The objective is to dislodge the boulder, not to pulverize it.

Before any drilling is done, the boulder should be examined for stray powder and for the best hole location. A hole is then drilled to one-half the depth of the boulder or a little more. The explosive and cap are then placed at the bottom and the hole is stemmed to the top. The hole diameter should be large enough to allow ease of loading the explosive. An illustration of this method appears in Figure 10. The electric blasting cap should be placed into the explosive in the direction the shock energy is desired to travel. That is, for mudcapping, the leg wire end of the cap should be pointing up.

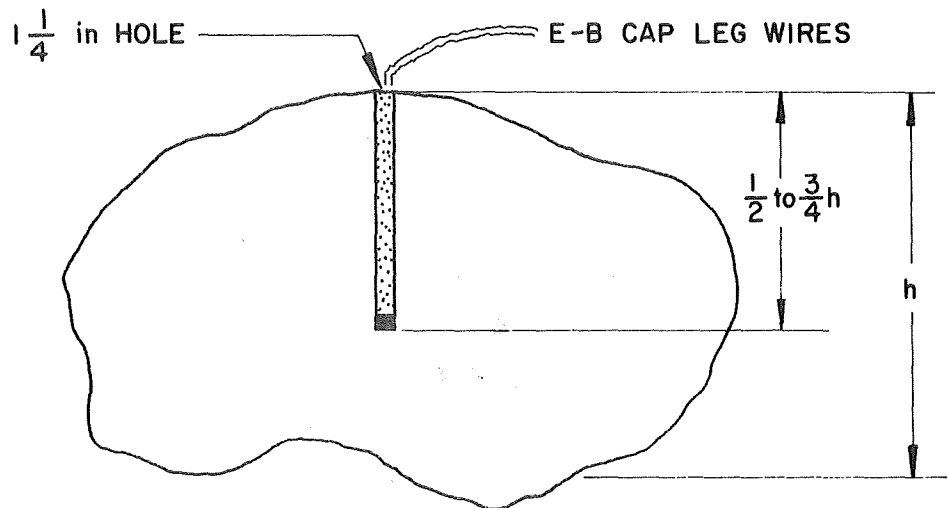
Mines visited that use blockholing first remove the boulder from the crusher and blast between shifts in order to reduce the danger of unauthorized personnel entering the area. The chief blaster is usually in charge of the operation. He judges where the hole should be placed, and loads the explosives. Electric blasting is practiced with 40% dynamite loaded in a 1-1/4 in. hole.

5.1.2 Snakeholing or Bombing

The method of snakeholing is not directly applicable to boulder blasting in crushers and grizzlies, but the method is analogous to placing a "bomb charge" under and tightly against a boulder. The main inefficiency would be in the lack of confinement for the explosive used in this manner because an access hole for placing the explosive is not used.

The "bombing" operation consists of wrapping explosive cartridges to a pole and placing it under the boulder. More explosives may be needed in that there is no confinement provided as in mudcapping. Explosive initiation can occur by any conventional means, though safety fuse is less desirable since the charge or boulder may shift after lighting and create a very dangerous situation.

Snakeholing may need to be used if access to the boulder from above is too dangerous or impossible. In this instance, safe access may be the major advantage to this system. The major disadvantages appear in the inefficient use of the explosive energy and in the greater possibility of damaging shock waves transmitted to the crusher. The air shock is



LEGEND

■ 40 % DYNAMITE (1 lb)

▤ STEMMING (PREFERABLY CLAY OR - 1/4 in CHIPS)

Figure 10 - Blockholing a Boulder.

also very damaging to the surroundings. Also, an extra item is the pole usually needed for safely placing the explosive. Obtaining the pole creates a storage problem and extra downtime during the operation.

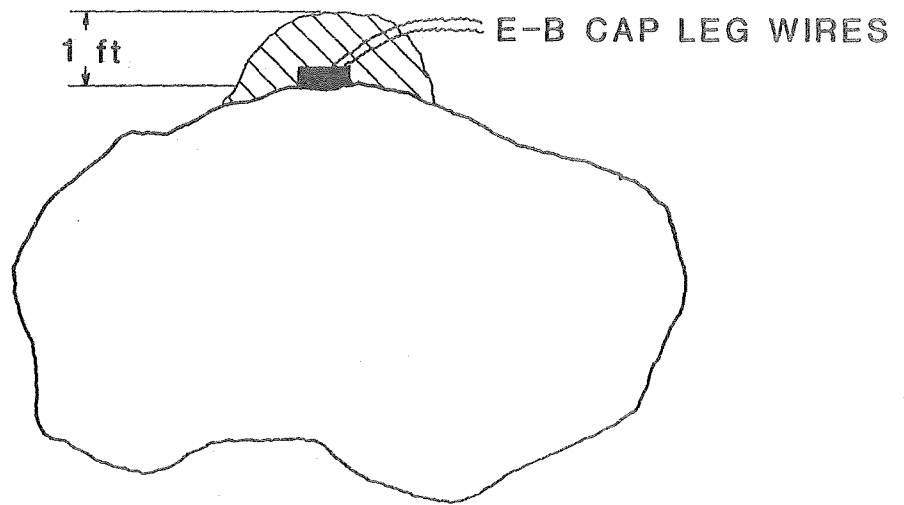
As with other methods, medium to low strength explosives would be used such as 40% strength dynamite. The system is very flexible and many explosive and initiating systems can be used as mentioned previously. For snakeholing, about 1 lb of explosive per cubic foot of rock opposite the charge is needed. When boulder blasting in crushers, less explosive should be used in that the boulder only needs to be cracked or jarred.

Materials needed to blast a boulder in this way are explosives, a wooden pole long enough for convenience of explosive placement, some material to tie the explosive to the pole, such as tape, rope or detonating cord, and an initiator. The explosive is fastened to the pole and the blasting cap inserted. Often the location of the explosive against the boulder is limited by safety of access or by space available. Leadwire can be stretched from the cap in the case of electric blasting, or a cap can be taped to the end of detonating cord used to fasten the explosives to the wooden pole.

5.1.3 Mudcapping

Mudcapping is a widely used, although not necessarily the safest, boulder blasting method. The method consists of placing an explosive on the boulder surface and then covering it with mud to provide greater confinement. The impulse action of the explosive causes breakage. The mudcap maintains the explosive detonation pressure which increases the impulse action and the explosive efficiency.

Advantages of mudcapping are evident with the reduction of downtime which is a beneficial economic factor. No drilling is necessary, but this is not offset economically due to the extra explosives needed. The elimination of drilling also provides greater safety by eliminating the driller's exposure to falling or hazards of falling rock in the crusher hopper. Mudcapping has deleterious effects also. The method is noisy, creates flyrock and airblast, all of which are objectionable in a quarry, especially if located near a metropolitan area. Care must be taken to assure that any mud used does not contain stones or other potential projectiles. The mudcapping techniques are shown in Figure 11.



LEGEND

- 40% DYNAMITE
- ▨ MUD/DAMP CLAY

Figure 11 - Mudcap Cross-Section.

Many explosives can be used for mudcapping, but due to the inherent inefficiency of the system, a 40% straight gelatin gives a good balance between cost and high detonation pressure. Binary explosives are widely used for mudcapping for their added efficiency and safety. Explosive initiation can be accomplished in a number of ways using safety fuse, electric blasting caps, or detonating cord.

The amount of explosive needed greatly depends on the rock size. A range of 0.5 to 2 lb per cubic yard is a good estimate for use. Regulations in many states prevent initiating more than 10 lb at a time, but this amount should never be approached when blasting in the crusher. Multiple charges should not be necessary either.

In mudcapping the boulder should first be examined for a depression that can best accommodate the charge. To increase the density of the interface between the charge and the rock, the explosive can be removed from the wrapper if permitted by law, and molded in a conical pile on the rock surface. Mud could also be placed on the rock, and the explosive embedded. The cap is then embedded in the explosive which is then covered by the wrapper if the explosive is unwrapped. Ideally then, 12 inches of mud, clear of debris, is placed on the explosive so as to provide confinement.

A dolomite quarry was visited where mudcapping was practiced. The small double impact crusher in use there becomes plugged several times during the day, and Tovex 1-1/4 x 8 inch sticks are used to clear the rock. One half stick and an electric delay cap are utilized with one foot of mud. The crusher has a side access door which facilitates placement of explosives. The access door is wedged in place so there is little danger of it flying off during blasting. Although an experienced chief blaster is employed at the operation, the plant foreman performs the crusher blasting. Blast warnings were given by signs and verbal communication. Even though a 12 v pickup truck battery was used to detonate the electric cap (which is improper and illegal), no history of misfires existed. The mudcap method was used at this operation because the crusher's limited access would not be conducive to other explosive methods or mechanical breaking methods.

A large crusher is planned for the future, and this is expected to reduce boulder blockage. The primary quarry blasts are well designed and utilize closely controlled drilling and loading procedures.

5.1.4 Blasting Mats

Blasting mats are devices for containing flyrock from a blast by catching the flyrock before it has a chance to escape. The mat is a tightly woven covering of heavy manila rope, wire rope, chain, used conveyor belt, or an old dump truck bed perforated with holes to vent the gas pressure produced by the blast.

The conveyor belt type blasting mat is inexpensive, and covers very well. It is made from three pieces of conveyor belt with the two outer pieces having a short piece of chain bolted to them. The center piece is laid out first with the two outer pieces hooked together and overlapping the first center piece. The two outer pieces are removed with a winch and a hook connected to the short chains.

In order to prevent the mat from getting blown into the air during use, one side should be anchored or fastened down. Then if the vent spaces are not large enough to relieve gas pressure, the mat can lift accordingly without being thrown from its location.

5.2 Newer Explosive Techniques

Several products have come on the market in recent years that improve the safety of secondary blasting operations. The most significant of these are binary explosives, exploding bridgewire electric blasting caps, and nonelectric systems.

5.2.1 Binary Explosives

Binary explosives are two nonexplosive materials that become cap sensitive, high energy explosives when mixed. One part can be fertilizer grade ammonium nitrate, and the other nitromethane. Oftentimes they are available in plastic tubes or flexible foil pouches that can easily conform to the boulder surface. These explosives can replace stick explosives for mudcapping although they are more expensive.

Since binary explosives are not classified as explosives until mixed, their storage and handling is greatly simplified and less costly. They are also less sensitive to shock than dynamite and do not cause powder headaches for the user. As mentioned, the extra cost of the product is a primary disadvantage. Care must be taken when inserting the cap in the charge to assure detonation. It is best to insert a blasting cap only about 0.5 in.

Several binary explosives are available as shown in Table 5. Their properties and costs are compared with conventional explosives.

5.2.2 Exploding Bridgewire Caps

One disadvantage of electric blasting caps is their susceptibility to stray currents. An exploding bridgewire (EBW) cap has been developed that can only initiate when supplied with a specific high voltage. This current heats a gold bridgewire to vaporization, a process that creates shock waves and thermal energy which is enough to detonate the base charge in the cap. Low voltage will not detonate the base charge because its lower density makes it less sensitive to impact.

Figure 12 shows an EBW cap in cross-section. The main difference from a conventional cap is in the material surrounding the bridgewire. This different construction permits the cap to fire only under certain circumstances. The firing system needed for these EBW caps consists of a control unit and a firing module. This specialized system is more expensive than blasting machines for conventional caps.

The control unit provides low voltage of about 40 volts of electrical energy to the firing module. For added safety, a hold-to-arm and a hold-to-fire button are supplied so that the shot firer can abort the firing by releasing either button. Batteries can fire 100 shots before requiring recharging by a 115 volt AC power source.

The firing module converts the input voltage from the control unit to 3,000 volts. The module must be placed relatively close to the cap (about 100 ft maximum) so as to assure minimum voltage loss and vaporization of the bridgewire.

One large metal mining company in Canada exclusively uses EBW caps for secondary blasting. The cap, because of its low sensitivity and specific detonation requirements, is allowed to be transported and stored as a blasting agent or nonexplosive, thus reducing storage problems. When needed, an explosive charge such as a two component binary explosive (which also is nonexplosive) is placed and the EBW inserted and fired by the special device required. Thus, all three components, the EBW cap and the two binary components, may be readily and safely stored and used with considerable safety.

However, the present cost of a single EBW cap is \$5 and there is only one manufacturer. Firing units are also expensive, but no magazines or other such precautions are necessary, thus the storage advantage may offset the cost.

TABLE 5 - Explosives Properties

<u>Properties</u>	<u>Atlas Kinepouch</u>	<u>Nipak Gold Label</u>	<u>40% Dynamite</u>	<u>60% Dynamite</u>
Density (gm/cc)	1.20	1.22	1.28	1.22
Det. Vel. (fps)	20,100	20,100	10,700	13,000
Unit Cost (lb)	1.50	1.63	0.84	0.87
lbs. to break 1 yd ³ of Rock	1	1	0.5-1	2
Cost per ton to break rock	0.69	0.75	0.80 -0.85	0.87

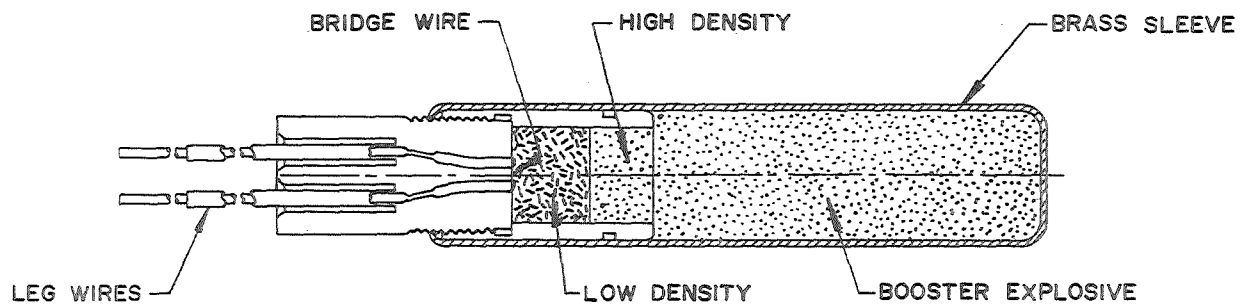


Figure 12 - Exploding Bridgewire Cap.

5.2.3 Nonelectric Systems

There are two types of nonelectric initiating systems which cannot be affected by stray electric current and are compatible with commercial explosives. One system utilizes a small diameter flexible tube that is lined with a small amount of explosive that propagates when initiated and fires the main explosive charge.

Another type of system uses a fuel/oxidizer gaseous mixture that is introduced through a network of tubing and then ignited by a special blasting machine.

Although special equipment is needed, both systems were developed for primary blasting and therefore the systems are adaptable to a variety of requirements. The systems are quite portable and only require special caps, blasting machine, and tubing which can be pre-cut to required length.

5.3 Mechanical Methods

5.3.1 Rock Splitting

Rock splitting utilizes a tensional force to crack the rock. This is achieved by inserting a split steel shank in a drillhole and driving a steel wedge between the center of the split shank thereby producing the tensile forces.

The advantages of the rock splitting technique over blockholing are the absence of explosives and the reduction of downtime provided there is quick and easy access to the rock splitting equipment.

The rock splitting technique does have some disadvantages. Drilling the required hole is time consuming and hazardous. Before any drilling is done, the boulder should be examined for stray powder and for the best hole location. The boulder, probably containing cracks from the primary blast, will be hazardous to drill in that it could split without warning. When actually splitting the rock with the splitter, a safe place on the boulder must be available to work from so as to avoid injury. Alternatively the procedure may be done by remote control whereby the operator is removed from the breaking area.

One type of rock splitting machine is illustrated in Figure 13. This hand held device utilizes hydraulic pressure to expand a plug placed in a drillhole creating tensile failure in the rock. The upper cylinder contains a piston which exerts force upon a wedge-shaped plug in the lower cylinder. The plug is pushed between two tapered bars or "feathers" causing them to expand outward and exert pressure against the drillhole wall. Operating pressure is 7,000 psi and splitting force can be from 176 to 410 tons depending on the size of machine used. This machine is generally used where blasting is not permitted.

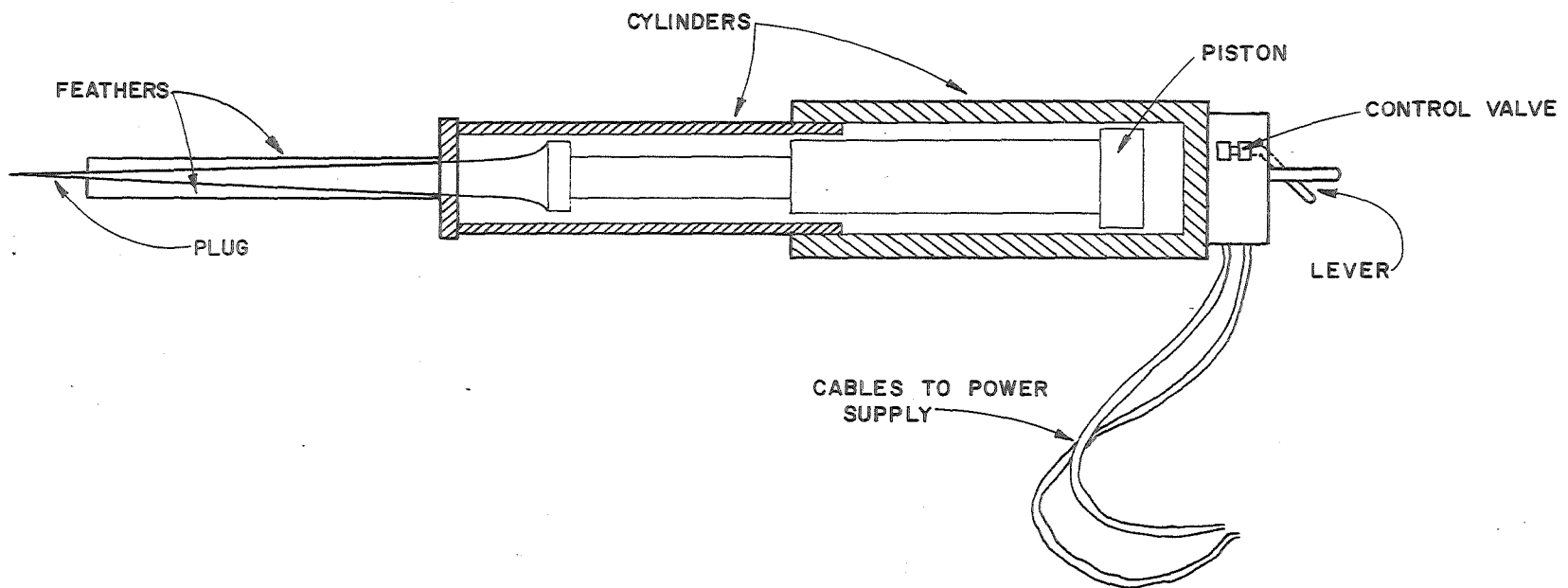


Figure 13 - Schematic of a Rock Splitter.

Because no explosives are used, blasters' licenses are not needed, magazine storage is not necessary, and excessive flyrock is not created except for small fragments which may fly tens-of-feet upon rock splitting.

In addition to the disadvantages mentioned for drilling boulders, the method requires a critical hole depth, which if too shallow, will break off the "plug" during expansion of the "feathers". Consequently the employee is in a dangerous position when drilling the access hole, and is again endangered when changing equipment to use the splitter which prolongs the employee's exposure to the possible hazards.

Use of the Rock Splitter requires the drilling of a 1-3/16 to 1-3/4 in diameter hole, of at least 12 to 26 in deep depending on the model used. The procedure then requires the placement of the splitter in the hole and oriented towards the desired direction for splitting. The control lever is then activated and splitting should occur within 10 to 60 seconds.

5.3.2 Rock Hammering

The rock hammering method of boulder breaking is a process of hammering the boulder by either a hydraulic or pneumatic hammer until the boulder breaks. The hammer is usually mounted on a boom. The motor, hydraulic pump, and oil reservoir are usually located near the boom. Figure 14 shows a typical hammer installation.

The advantages of this method are continuous operation (minimal downtime for boulders), no need for explosives, safer environment for the operator, and the hammer can be used to clean grizzlies.

The major disadvantage of the rock hammering method is the initial capital cost of the hammer.

The breakers have developed into a third generation model which requires less maintenance than earlier models. A variety of breaker points are available in order to achieve optimum performance for different rock characteristics.

Rock breaker designs are of two basic types. One type utilizes high impact blows at low frequency while the other type produces a much lower impact blow delivered at a much higher frequency. Frequencies can range from 25 to 450 blows per minute with blow energies developing between 1,000 and 20,000 ft-lbs per blow.

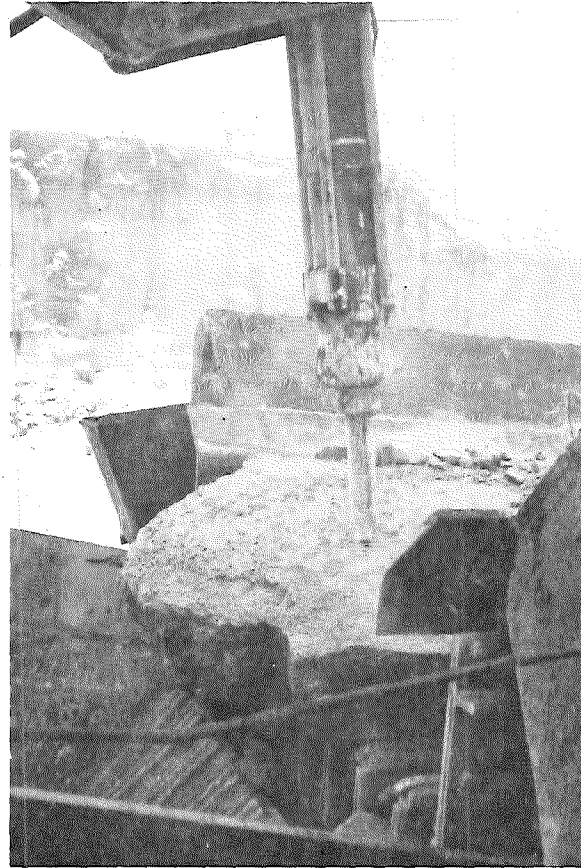
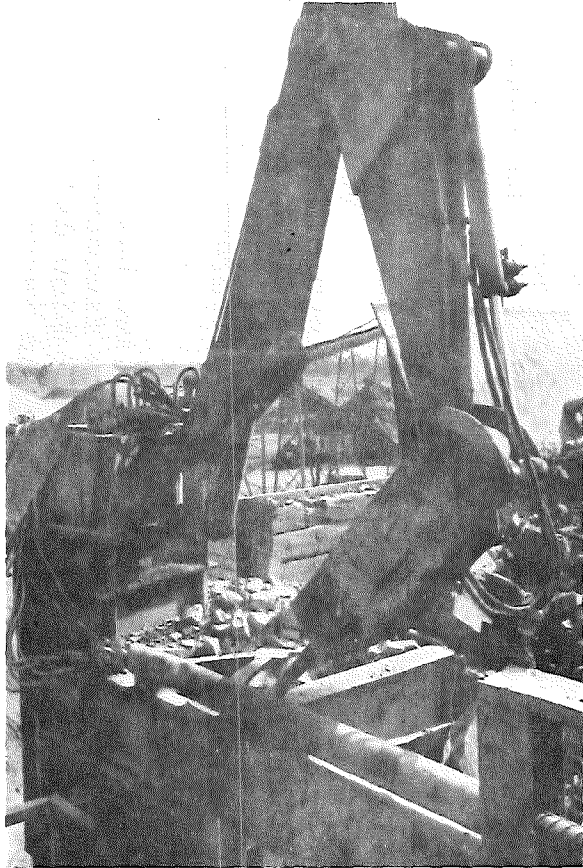


Figure 14 - Hydraulic Rock Hammer

A variety of breaker points are available as shown in Figure 15. They can easily be replaced by simply driving out the locking pin. Various shape points are necessary because different rock characteristics require a specialized point. In other words, one point design will not give optimum efficiency for all types of rock, rock hardness being the primary consideration.

A number of operations visited were using hydraulic or pneumatic rock breakers. With rock having compressive strength of 20,000 psi, breaking a boulder can take about 5 minutes. Oftentimes the breaker is used to clean a grizzly as a preventative measure to boulder blockage. Breakers can be mounted on mobile units so secondary breakage could be accomplished at the quarry pit before the boulder is loaded and sent to the crusher, as shown in Figure 16.

Owners of rock breakers generally overhaul the units every seven years depending on use. The newer heavy duty models may require less maintenance, particularly for the boom, where new design efforts have been concentrated.

5.3.3 Grapplers

A grapppler is a claw shaped device used for picking up boulders. The grasping mechanism of a grapppler is generally activated by a pneumatic or hydraulic cylinder, as shown in Figure 17. The cylinder is connected to each half of the claw and when activated forces the claw shut. Grapplers are used to remove or reposition boulders; they can only break rock by lifting and dropping.

There are two types of lifting mechanisms that can be used with the grapppler claw. One requires that the claw be mounted on the end of a large hydraulic boom. This gives the grapppler good mobility and good response to controls. The problem with this mechanism is that an extremely strong and large boom is needed. The other lifting mechanism is an overhead crane system which uses cables and pulleys. This mechanism is strong, but is slow and difficult to maneuver into the desired position.

A grapppler is most commonly used with a gyratory crusher because of the greater difficulty of access to a jaw, impact, or roll crusher (refer to figures 5 through 8). A grapppler is a capital intensive piece of equipment but is a safe method of boulder removal from a crusher, although breakage must be done by other means. Those seen in field visits have required frequent overhauls and a high degree of maintenance. Another complaint with pulley and cable arrangement is

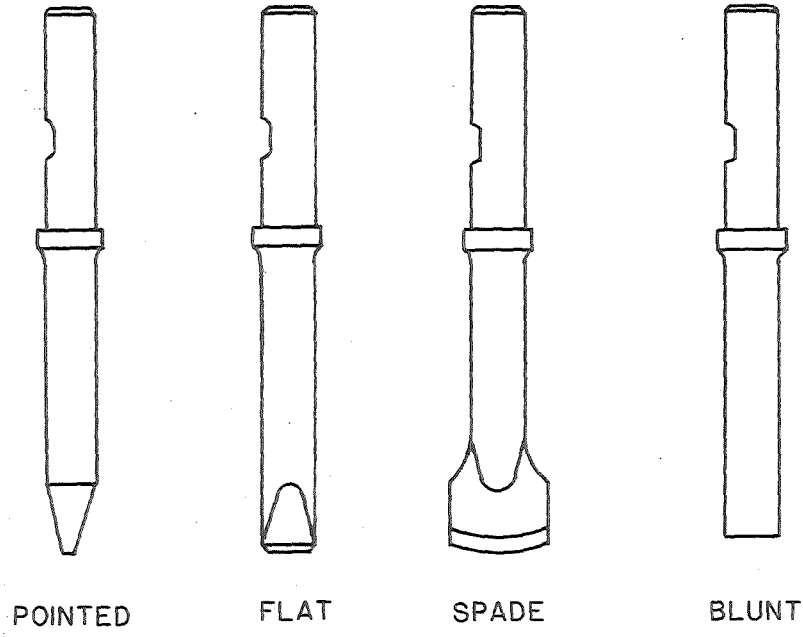


Figure 15 - Available Rock Hammer Points



Figure 16 - Use of a Mobile Rock Hammer in a Quarry.

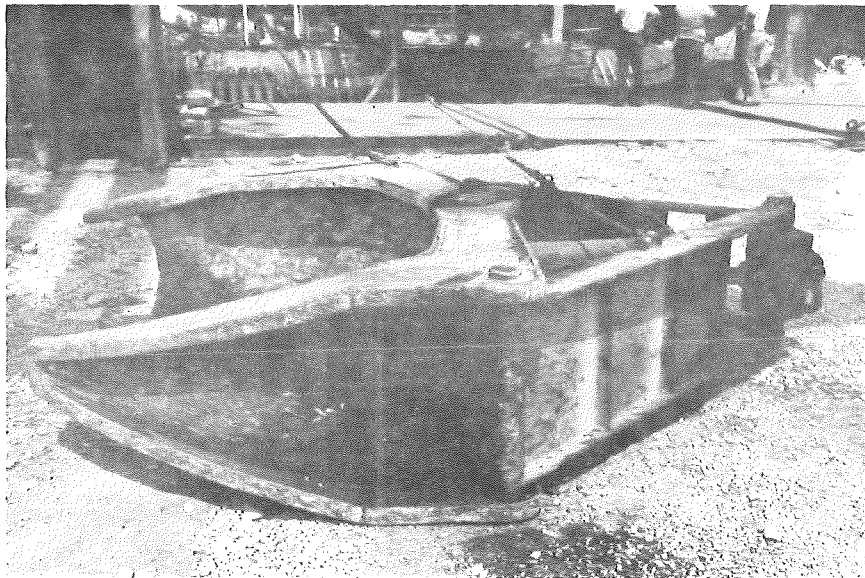
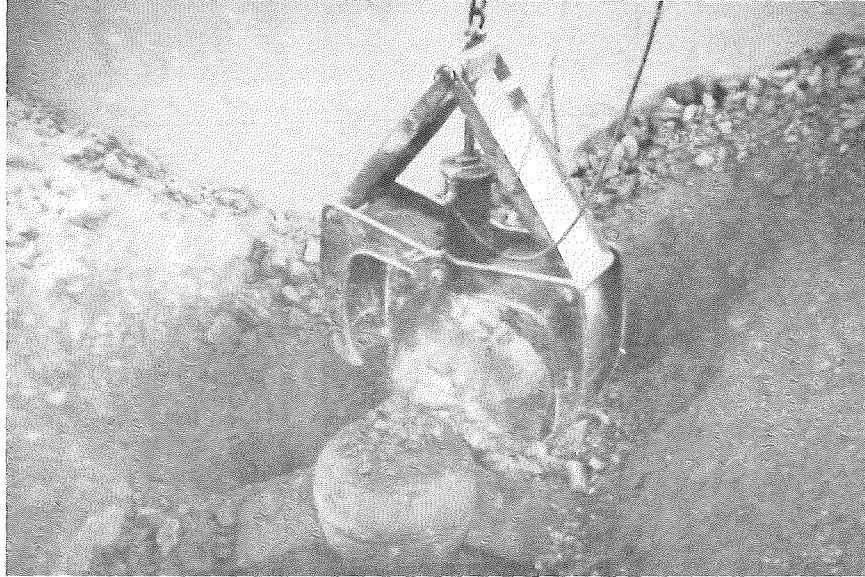


Figure 17 - Grapplers. Above, a One Four-Prong Type in Action; Below, a Three-Prong Type

that if a boulder is lifted and dropped on the gyratory cap for further breakage, the grappler sometimes twists around on the cables and requires some time to regain stability.

5.3.4 Slings and Hooks

A sling is a device for removing or repositioning a boulder or object in a crusher. A sling is made of a length of chain or cable with loop ends as shown in Figure 18c. To remove or reposition a boulder a sling is laced around the boulder and the looped ends are connected to a boom, winch, or overhead crane and hoisted out of the crusher or moved to where the crusher can nip it. The advantages to this method are the protection to the crusher parts because explosives are not used. The disadvantages are that the crusher has to be stopped, a person has to get in the crusher, and the length of time to move or remove the boulder can be excessive. Also, if an angled grizzly feeds the crusher, it must be cleaned of all loose debris before someone can enter the crusher mouth. Operators have spent as much as half a work shift doing this task.

A hook is a device which is primarily used for repositioning the boulder. Some of the more efficient hooks are shown in Figures 18a and 18b.

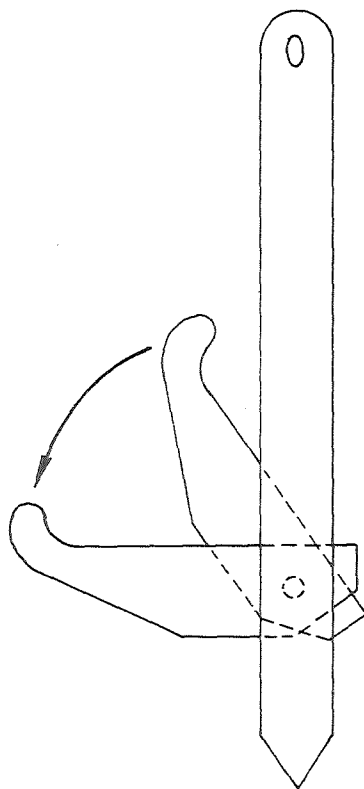
The hooks work by snagging the underside of the boulder and lifting it, causing the boulder to move or roll to a more advantageous crushing position. The lifting action of a hook is accomplished with the use of a boom or an overhead crane. The hook is safer than the sling because workers do not have to get into the crusher.

Figure 18 illustrates several hook and sling arrangements that have proven successful at some operations visited. The "Hidden Hook" is dropped in a space near the lodged boulder in the crusher mouth. When dropped, the hook arm is upright, but will lower to form a hook shape to move the boulder when it is raised and catches a boulder side. The "L" hook is of a fixed shape and requires some tricky maneuvering to be effective.

The "Sliding Hook" enables one looped end of a cable to be held from a hoist, while the other end is placed around the boulder. The sliding hook is drawn close above the boulder and hooked to the free end of the cable. This eliminates the need for hooking the free cable end to the hoist hook and greatly reduces the possibility of hand injuries when slack is taken in by mechanical means.

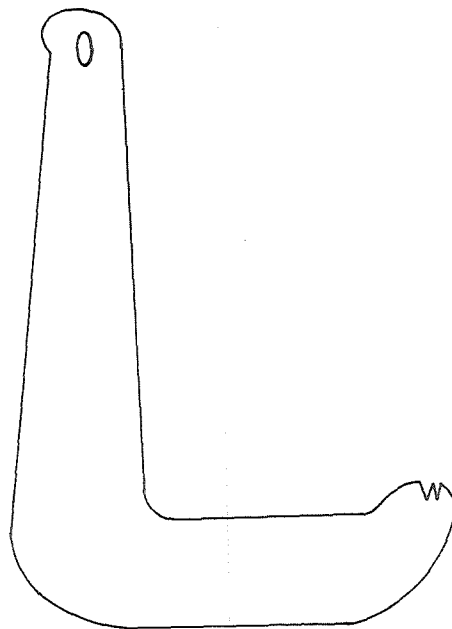
HOOKS AND ARRANGEMENTS

lin = 2ft



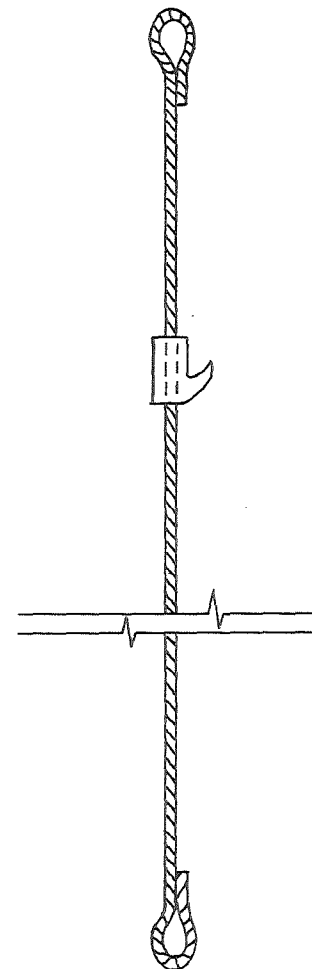
"HIDDEN" HOOK

a.



"L" HOOK

b.



SLIDING HOOK

c.

Figure 18 - Slings and Hooks for Boulder Removal from Crushers.

One operation visited utilized a hook mounted on a hydraulic boom, and proved quite effective. The device was homemade and required little maintenance, as shown in Figure 19. Basically, the moving apparatus is very similar to that of a backhoe boom.

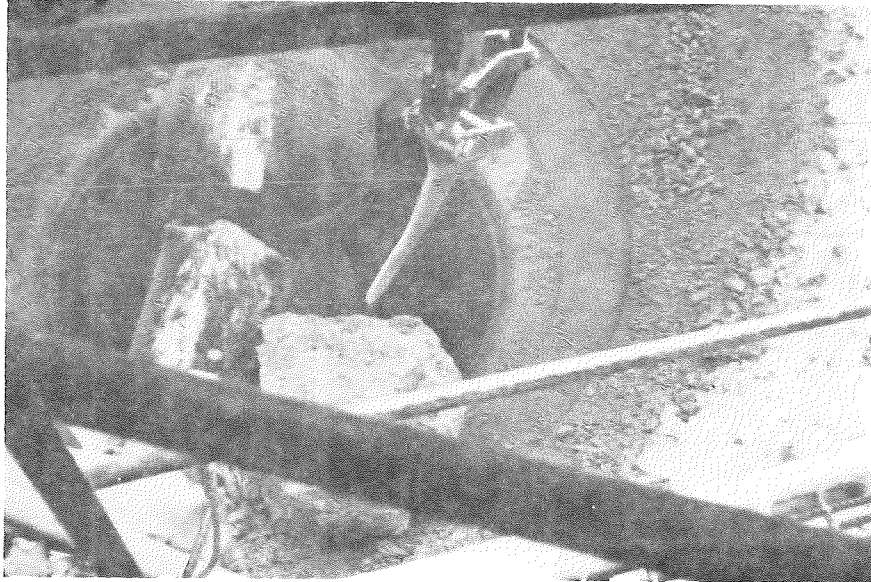


Figure 19 - Hydraulic Boom-Mounted Hook
for Boulder Repositioning

6.0 SAFETY ANALYSIS

In order to properly investigate improved boulder handling techniques, the existing accident records from crushers and boulder handling in crushers were examined in detail.

6.1 Crusher Accident Analysis

Crusher accidents constituted about 1.5% of all "lost time" injuries in U. S. metal and non-metal mines in 1979. This, in itself, may not be a very startling statistic, but bearing in mind that most crusher applications to date are fully automated, and requiring the services of only few trained personnel, the figure appears quite significant. To further emphasize the seriousness of the problem, the frequency and severity of all crusher accidents between 1975 and 1979 are illustrated in the form of a simple bar chart in Figure 20. From the great number of man-days lost and knowledge of the fact that lost time constitutes only a fraction of the total costs of an accident to a mining company, the need for safety analyses and safety improvements of crusher operations becomes quite self-evident.

Accident prevention depends upon recognizing accident-causing factors and hazardous work practices. These may be identified through the collection of accident data following investigations of accidents. For that purpose, Mine Safety and Health Administration HSAC data pertaining to over 450 crusher accidents and injuries were reviewed for the years 1978 and 1979. These reports, although rather brief and sketchy, combined with engineering judgement, revealed some interesting facts and led to a clear understanding of safety aspects in crusher operations.

The first step of the analysis consisted of classifying individual accidents in a form established by the American Standards Association. Six basic classes were chosen.

1. The accident circumstances
2. The injured body part
3. The nature of injury
4. The accident type
5. Probable cause, includes unsafe act and unsafe condition
6. Source of injury

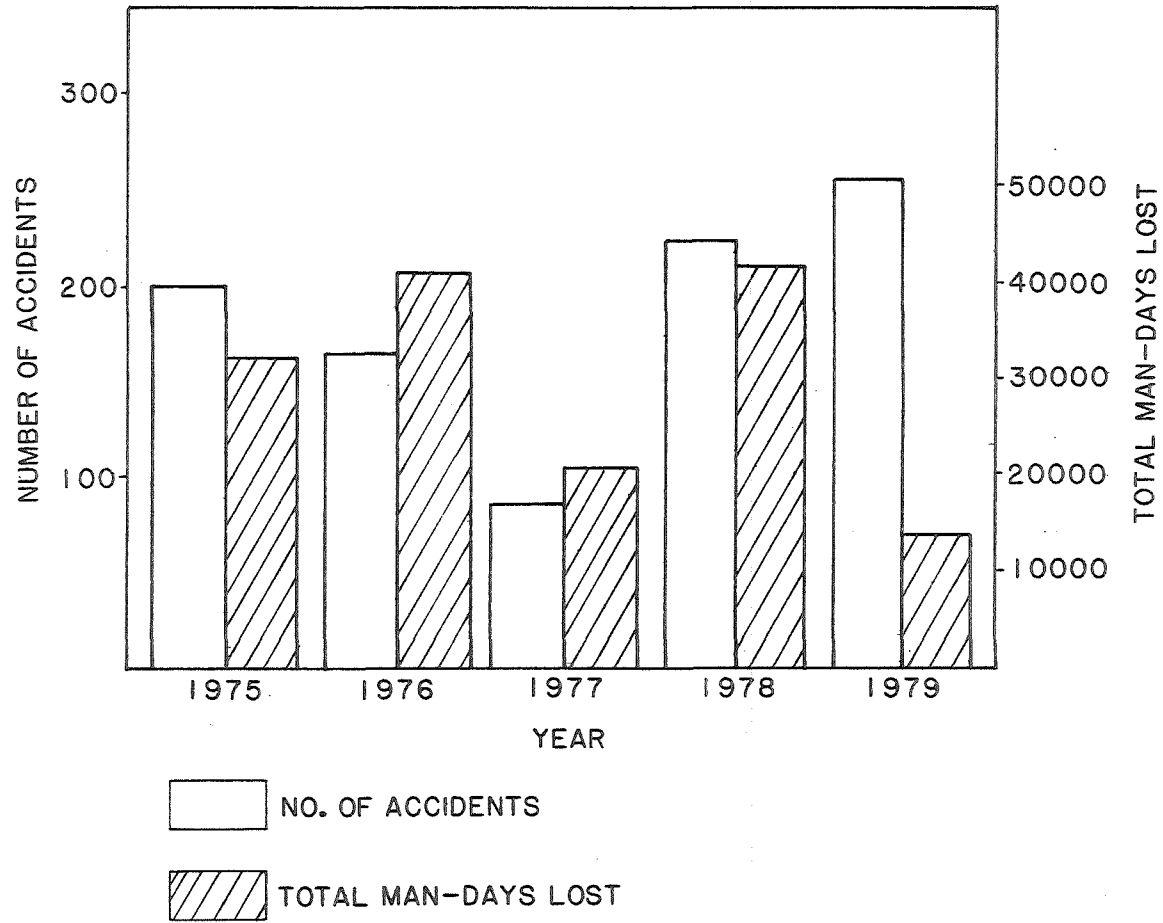


Figure 20 - Double Bar Diagram Showing the Number of Crusher Accidents and Man-Days Lost Between 1975-1979

Based on these classifications, the frequency of occurrence was computed and several informative charts drawn up.

"Accident circumstances" refers to the activity the injured person was involved with during the time of the accident. Due to the lack of clarity in the accident data regarding the exact nature of work the injured was carrying out, five categories were chosen. Figure 21 shows the percentages of accidents that fall into the various categories. Although maintenance activities occupy only a small portion of a work-day, accident hazard during such activity appears to be the highest. Also of interest is the high percentage of accidents occurring during boulder handling, indicating perhaps that existing methods need to be improved

The purpose of establishing the individual body parts that are most susceptible to injuries was to identify needs for additional personal protective equipment that may be provided to persons working around crushers. Figure 22 points out the percentages of accidents that involved different parts of the body. Fingers were injured in 22% of the accidents, followed by back injuries at 8%, and eyes, arms and hands at 7% each. Clearly, use of hand gloves could greatly minimize minor finger and hand injuries while improved design of safety glasses could virtually eliminate entry of dust or rock chips into eyes. Although no adequate back protection is practical, safety training on correct and incorrect postures during lifting, carrying, and prying or pushing could help reduce slipped disks and other minor back injuries.

A histogram plot of the nature of injuries in Figure 22 appears to further validate the above recommendations. Minor injuries like cut, laceration, bruise, sprain and dust in eyes constitute a major part of all accidents, and could be greatly reduced by adhering to the safety principles described above.

Figure 23 shows a frequency chart for accident type, which is defined as the manner of contact of the injured person with an object of substance, or the exposure or movement of the injured person which resulted in the injury. The grouping of the accident types are essentially the same as the American Standard. The figure shows that about 65% of all accidents fall within the types 1 to 3. Type 1 crusher injuries are usually caused by broken rock or movable machine parts striking the injured; type 2 injuries result from the victim's body part being caught under or between boulders or between belt and pulley; while type 3; usually occurs while climbing ladders or ramps.

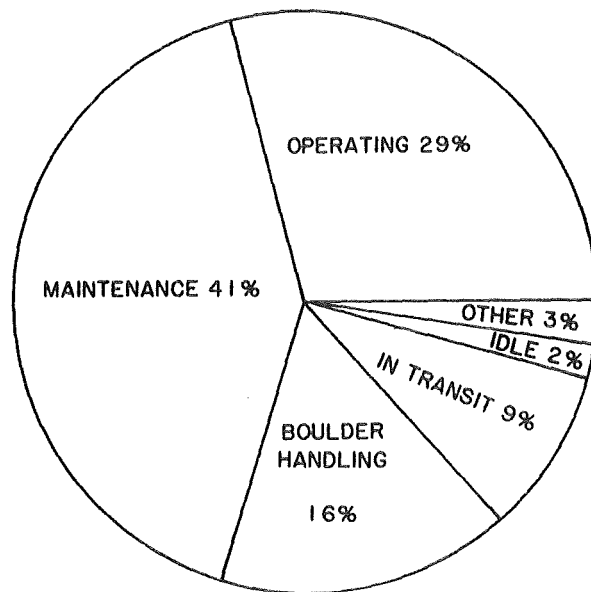
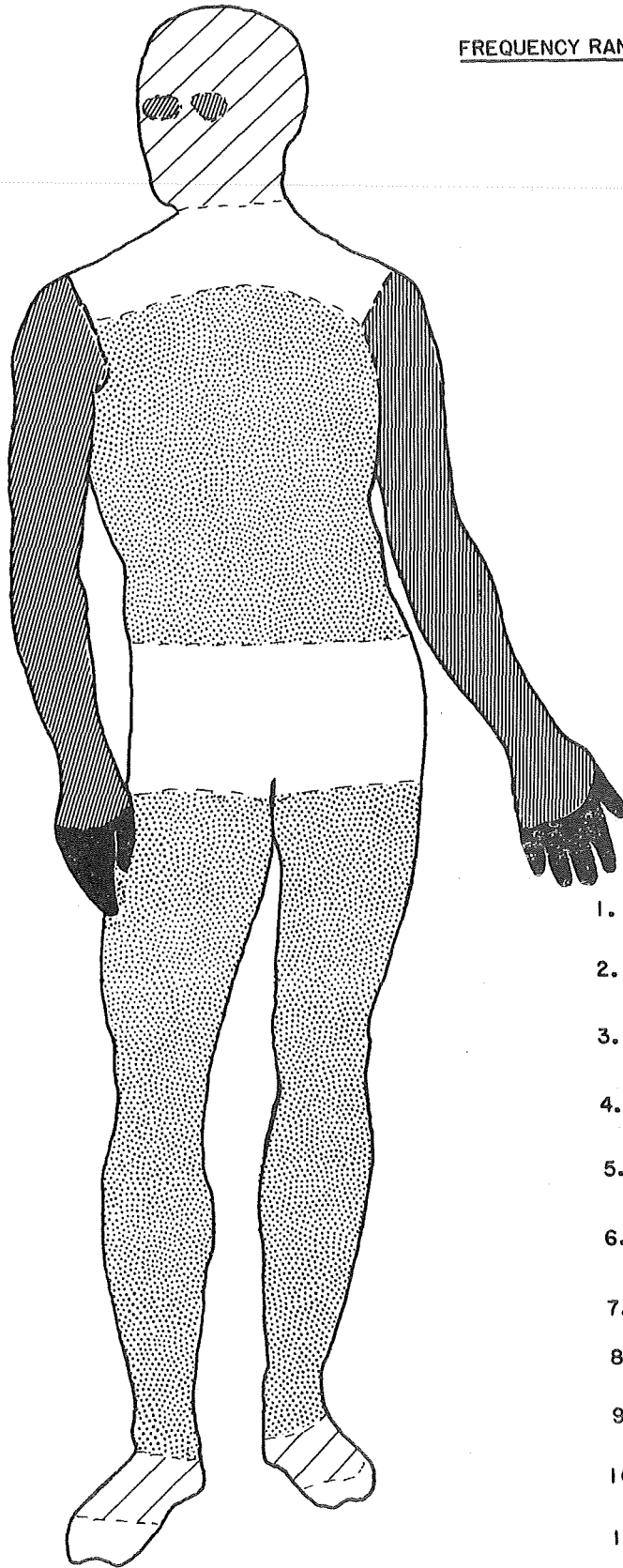
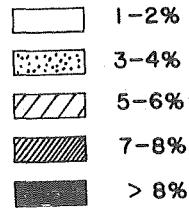


Figure 21 - Pie Diagram Showing Distribution of Accidents by Accident Circumstance

FREQUENCY RANKING FOR INJURED BODY PART



LEGEND



FREQUENCY CHART FOR NATURE OF INJURY

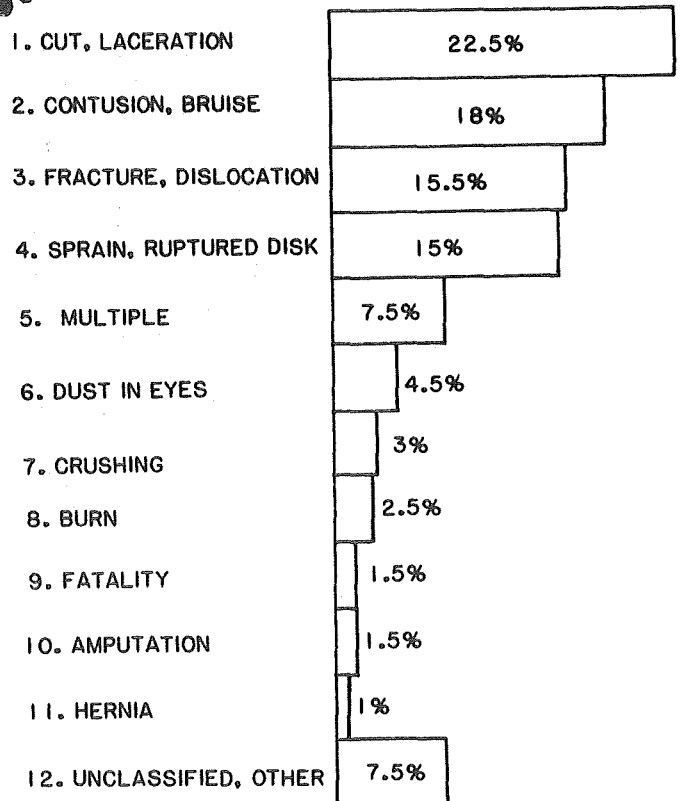


Figure 22 - Frequency Ranking for Injured Body Part

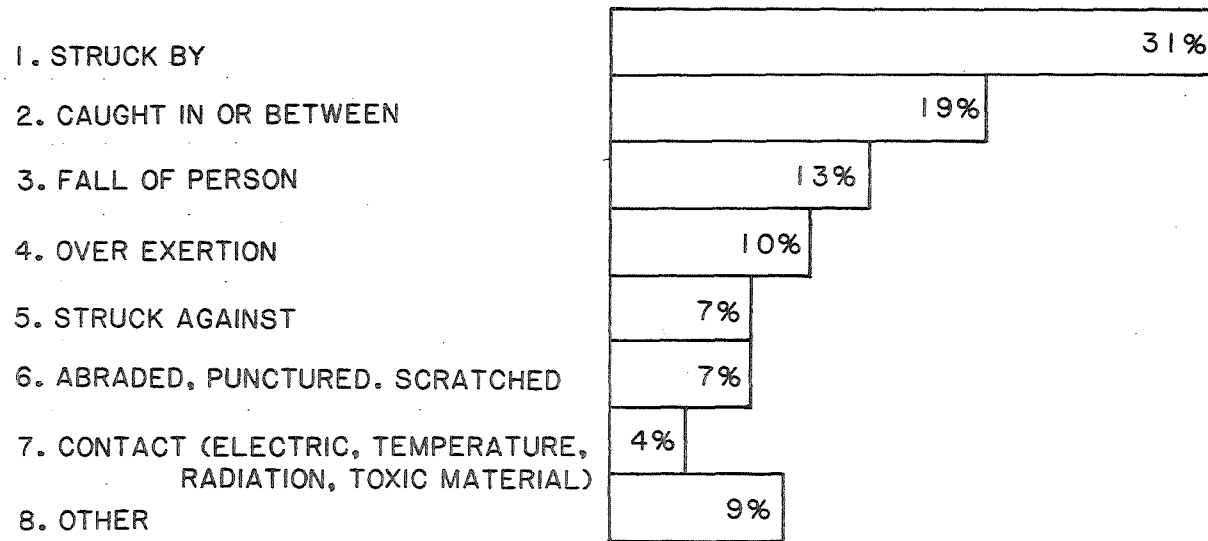


Figure 23 - Frequency Chart for Accident Type

Together with a description of the accidents, HSAC data also contained information on the actual days lost from individual accidents. Based on these data an accident severity histogram was developed, as illustrated in Figure 24. It can be seen that more than 50% of the accidents at crushers do not result in lost time, possibly because the injured is able to perform other duties and thus avoid a lost time accident. It should be emphasized, however, that even though an accident may be recorded as a "no-lost-time" injury, it is quite realistic to assume that the company did incur some costs due to it. Consequently, considerable savings could result with the elimination of such accidents by adopting appropriate safety measures.

In order to isolate specific areas of crusher operations and design requiring safety improvement, a pie diagram showing the different accident causes was prepared, as shown in Figure 25. Due to the nature of the HSAC accident narratives, no definite cause could be attributed to almost 43% of the accidents studied. Although it is well-recognized that most accidents are caused by an interaction of several factors, for the purpose of this analysis, it was desirable to choose, as objectively as possible, the most probable accident causing factor. In Figure 25, "unsafe act" refers to the types of the victim's behavior which led to the accident. "Unsafe conditions" are those factors which were present due to defect in condition, errors in design, faulty planning, or omission of essential safety requirements for maintaining a relatively hazard-free physical environment.

"Source of injury" refers to the object, substance, exposure, or bodily motion which directly produced the injury. Analysis of HSAC data revealed that broken rock accounted for about 30% of all accident sources. Most commonly, injuries resulted from forceful contact of broken rock with men working in or around crushers, usually in the form of flyrock or pieces of broken rock travelling at high speeds. Flyrock may be produced during crusher operation or during boulder handling, and in particular, due to boulder blasting.

Based on this analysis, the following guidelines are presented for improved overall crusher safety. The reader is cautioned, however, that the above analysis is based entirely on reported accidents, while in practice, many accidents have been known to remain off records.

1. Installation of adequate guarding facilities near the crusher and feeder to arrest the movement of flyrock.
2. Prevent entry of personnel within the protected area while the crusher or feeder is in operation.

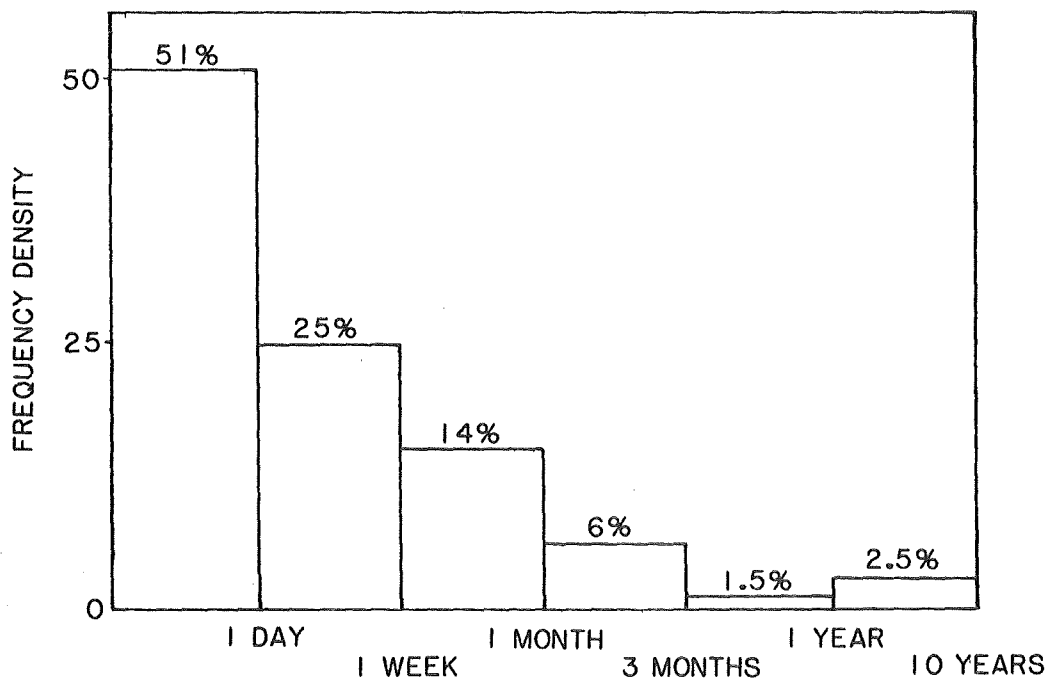


Figure 24 - Histogram Showing Accident Severity

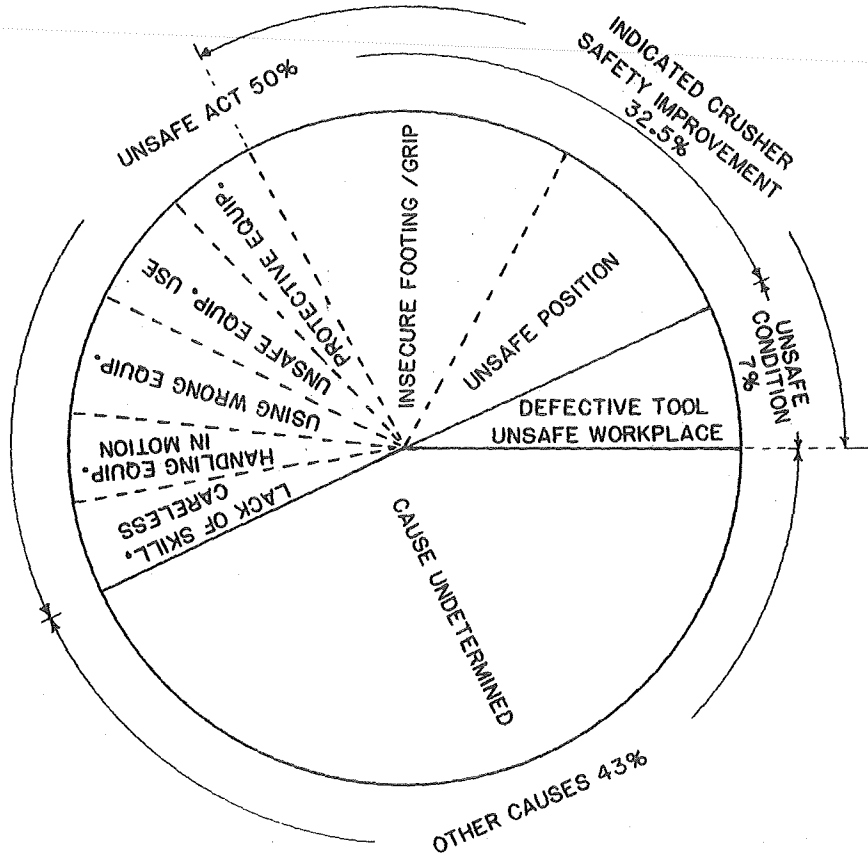


Figure 25 - Pie Diagram Showing Accident Causes

3. Improved design of ladders and provision of hand-rails.
4. Improved design of safety glasses or provision of special 'goggles' to prevent entry of dust into eyes.
5. Emphasis on the use of protective hand gloves.
6. Safety training on improved techniques of lifting and carrying.

6.2 Boulder Handling Accident Analysis

Mine Safety and Health Administration HSAC data pertaining to accidents in crushers resulting from attempts to remove oversized materials were reviewed for the years 1975 through 1979. Figure 26 shows the nature of the accidents by source or activity. These may be explained as how a person was injured while attempting to dislodge a boulder or preparing to do so. Prying means a person was prying the boulder with a bar of some kind and was injured; drilling means that a person was on or near the boulder drilling or jackhammering into it; sledging means a person was using a sledgehammer on a boulder; cables and hooks means that while arranging a cable or hook system the cable, hook or boulder injured the person; fall of person means that a person fell while engaged in activities other than actually dislodging the boulder such as climbing in or out of the crusher; and fall of rock means that a rock fell from the crusher feed onto a person. As the figure shows, from a total of 85 accidents, prying is a major source of injury at 39%.

But perhaps more importantly, just getting into a crusher accounts for a total of 38% of accidents. Blasting accidents are fewer in number, but their effects are much more serious.

Table 6 details the part of the body injured keyed to the source of the accident. It is clear that back injuries or injuries to exposed extremities are most common.

An attempt was made to rank injuries by taking into account both frequency and severity. Severity rate was estimated from the American Standard Scale of Time Charges by taking a standard proportion of the time charge for disability of the body part, and then multiplied by 0.01. Because of lack of correlation between data of days lost, a proportion was assumed as 1/100 of the days charged for a total disabling injury. In Table 7 injuries were ranked first according to frequency in Column A, as determined by

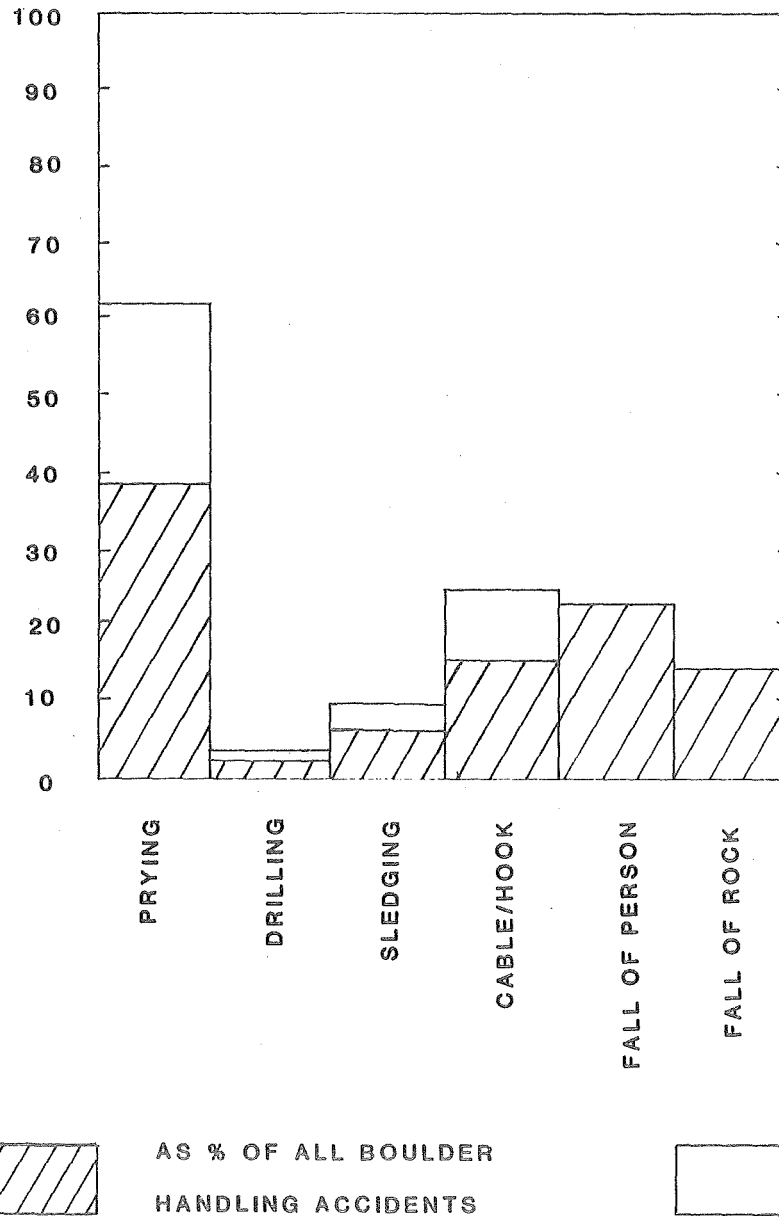


Figure 26 - Sources of Boulder Handling Accidents.

TABLE 6 - Part of Body Injured Versus Source of Accident
for Boulder Handling in Crushers

	<u>Total</u>	<u>Prying</u>	<u>Drilling</u>	<u>Sledging</u>	<u>Hooks and Cables</u>	<u>Fall of Person</u>	<u>Fall of Rock</u>
<u>Back</u>	13	4	1	2	3	3	0
<u>Hand</u>	7	1	0	2	1	1	2
<u>Leg</u>	7	2	0	1	0	2	2
<u>Knee</u>	5	1	0	1	1	2	0
<u>Arm</u>	5	1	0	1	1	2	0
<u>Finger</u>	15	5	1	1	5	0	3
<u>Foot</u>	6	2	0	2	0	2	0
<u>Ankle</u>	8	0	0	0	0	7	1
<u>Shoulder</u>	2	2	0	0	0	0	0
<u>Wrist</u>	2	2	0	0	0	0	0
<u>Eyes</u>	2	1	0	0	0	0	1
<u>Head</u>	8	6	0	0	0	0	2
<u>Face</u>	6	3	0	1	2	0	0
<u>Hernia</u>	1	0	1	0	0	0	0

Table 7 - Accident Affect

INJURY	FREQUENCY RANKING (A)	LOST DAYS PER INJURY	TOTAL LOST DAYS RANKING (B)	WEIGHTED AVERAGE (A + 2B) 3	WEIGHTED RANKING	ACCIDENT AFFECT RANKING
Fingers	1	3.02	9	6.33	6	Back
Back	2	60.00	1	1.33	1	Hand
Foot	3	5.08	10	7.66	8	Legs
Hand	4	30.00	2	2.66	2	Arm
Head	5	5.00 *	11	8.66	10	Knee
Legs	5	37.50	3	3.66	3	Fingers
Knee	6	30.00	5	5.33	5	Ankle
Ankle	6	24.00	7	6.66	7	Shoulder
Face	6	5.00 *	12	10.00	11	Foot
Arm	7	36.00	4	5.00	4	Wrist
Shoulder	8	45.00	6	6.66	7	Head
Wrist	9	30.00	8	8.33	9	Face

* Estimated

accident data, and then by the product of days charged per injury and the frequency to obtain the total days lost in Column B.

With respect to finger injuries many possible days can be charged depending upon the finger involved. Under these circumstances the lost days were averaged before multiplying by 0.01. The position of any injury in the first ranking was added to twice the position of the second ranking and averaged. Injuries were again ranked according to this number which is considered to have more of a weighted average meaning. For simplicity, only the first 12 injuries are shown in Table 7. The accident affect ranking in the last column represents a blend of the part of the body that is most affected by boulder handling methods and expected days lost.

6.3 Specific Accidents

Only four detailed descriptions of specific accidents were obtained through MSHA that concerned boulder handling in crushers. It is not possible to determine whether or not these accidents are included in the previous summary discussions since there are no direct indices. Fortunately all four accidents are of a different nature so much can be learned. One accident is apparently the only direct boulder blasting accident reported in recent years. All descriptions are taken directly from the detailed MSHA reports.

6.3.1 Blasting Accident

On Sunday, November 14, 1976, a scheduled work day, victim began work at 7:00 a.m., his regular starting time. Victim, classified as skip conductor, was assigned the duties of feeding and operating the jaw crusher.

During the process of feeding and operating the jaw crusher, it was occasionally necessary to blast hang-ups and oversized boulders with dynamite placed in the feed chute or jaw crusher mouth. The agent was stick dynamite (1" by 8"), usually detonated by instantaneous electric blasting caps, and initiated from 110 volt power lines. However, three days prior to the accident, due to the insufficient length of the available cap legwires, the powder man had brought two hundred (200) period 12 and period 13 delay electric blasting caps to the surface for use at the jaw crusher in this work.

On the day of the accident, victim stated that he had three incidents that morning in which he experienced misfires using the delays, prior to the accident, but managed to find instantaneous electric blasting caps in each situation to detonate the charge.

When victim observed the last hang-up which led to the accident, he could not find any instant caps in the day box to detonate a charge. He recalled the unsuccessful attempts earlier when the misfire incidents occurred with delay caps, so he notified his foreman to furnish instantaneous electric blasting caps. The foreman tried to get the powder man, who was on the 30th level in the underground mine, to bring the proper caps, however he was unsuccessful. At this point the foreman instructed victim to go into the mine and obtain the caps himself. However, victim found the shaft conveyance was occupied by the men mucking in the sump and the only way it could be released was in the case of an emergency.

Victim explained the situation to the foreman and stated that if he was to accomplish any work, it would be necessary to acquire instant E. B. caps. However, when he returned to the crusher and realized that he was alone with the hang-up and would be unable to operate the hook used to hoist and turn large rocks, he decided to detonate a charge by using two period 12 delay caps inserted in each end of the stick dynamite, which he placed between the two boulders causing the hang-up.

To initiate the detonation, victim proceeded to the enclosed power control building where the blasting switch and warning siren were located, turned the siren on, and activated the blasting switch. He later said that he instantly heard a pop, but was not certain it was a detonation; however, he was also uncertain there

was a hangfire. He waited approximately five (5) minutes and started to approach the crusher but decided to return to the blasting station and activate the siren again in case someone else should wander into the blast area. After the siren sounded a second time, victim said he waited approximately 10 minutes more before approaching the blast site. At that time he observed the dynamite burning and started to back away after he was within 5 feet of the burning charge. Before he could escape, the burning charge detonated.

Following the explosion, victim descended the stairs of the jaw crusher and met drill foreman, and the diesel repairman, who arrived in the repairman's truck. The drill foreman went to the aid of victim, who was partially in a state of shock, and visually examined him for injuries and applied compresses to his hands. The diesel repairman placed him in the repairman's truck and rushed him to the hospital located approximately two miles from the scene.

The victim was treated for perforated wounds, lacerations, bleeding ear drums bilaterally, and the removal of wire on the right hand, 4th finger. He was kept overnight for observation and, on the following day, was released and returned to the work schedule.

At the time of the accident, victim was wearing safety glasses which undoubtedly prevented severe eye injuries.

Observations relative to the blasting procedures here include: In a bunched, parallel circuit employing only delay E. B. caps, a minimum of 1.5 amperes per series is required. Also to prevent arcing with power line shooting, it is important that the maximum current delivered to any series in the circuit be less than 10 amperes or that each series circuit be interrupted in approximately 25 milliseconds.

The direct cause of the accident was using period 12 delay electric blasting caps

connected in bunched parallel circuit, initiated from 110V A.C. power line without limiting the current flow to a maximum of 25 milliseconds, or using a suitable power source for the type blasting circuit used.

The lack of knowledge and understanding of the hazards involved by the persons and responsible supervisors who use and handle explosives were contributing factors.

6.3.2 Prying Accident

The equipment involved in the accident was a Jaw Crusher. The pry-bar was a 6-foot-long, 1-1/2-inch-diameter drill steel. The area in which the accident occurred was in the jaw area at the crusher over the throat of the crusher.

The victim and his helper reported for work at 7 a.m., November 9, 1979, and performed their duties at the quarry in a normal manner until approximately 12 noon. While attempting to clear the crusher of an over size boulder with a drill-steel (pry-bar), the victim was struck on the right side of the head with the whipping bar and his helper was struck on the shoulder. The blow stunned the victim. His helper (loader operator) rendered first-aid and shut down the crusher while he summoned assistance. The rescue squad responded within minutes and transported the more seriously injured victim to the hospital, a distance of 20 miles.

Reportedly, his injuries were diagnosed as a depressed skull fracture, which required further surgery on November 10, 1979; his condition at the present time was listed as satisfactory and his recovery was expected to proceed normally. The helper escaped with a bruised shoulder and did not require hospitalization.

The primary cause of the accident was the unsafe practice of clearing the crusher of over-size material with a pry-bar while the crusher was operating, i.e. working on equipment in motion.

A contributing cause was the unsafe position of the victim while attempting to free the crusher.

6.3.3 Fall of Person

On the day of the accident, the victim, a primary crusher operator, reported for work at 7 a.m., his regular starting time. Work progressed routinely until about 3 p.m. when a large rock became lodged in the jaws of the crusher. Victim shut the feeder off but left the crusher running. He climbed down the stairway from the crusher control booth to the deck below. From there he observed the rock that was causing the problem.

The following description of ensuing events was obtained in an interview with a truck driver, who at this time arrived from the quarry with a load of rock.

The truck driver backed his truck into dumping position, but could not dump because the dump signal, a green light, was not on. He noticed that the feeder was not in operation. He got out of his truck and went to the deck where victim was standing. Together they looked at the large rock that was hung in the jaw. While they observed the rock moved a little but hung up again. Victim stated that he would have to call the loader operator to come and lift the big rock out of the crusher.

Then, with no further comment, victim climbed over the railing and onto the feeder. He picked rocks he could lift easily (6 to 10 inches) from the material on the feeder and threw them into the space between the large rock

and the swinging jaw of the crusher, trying to wedge the large rock loose. He did this for maybe a minute. Then, he either lost his balance or slipped on loose material on the feeder and fell into the crusher.

The truck driver ran up the stairway to the control booth and shut the crusher off, but left the crusher discharge conveyor running.

At this time, a truck driven by the victim's father arrived at the dump. The truck driver told him the victim had fallen into the crusher. Victim's father immediately went to the control booth and stopped the discharge conveyor.

The victim had by now passed through the crusher and had traveled a distance of about 50 feet from the crusher on the discharge conveyor. It was evident that he had not survived.

The County Coroner was called and the victim was pronounced dead at the scene. The coroner stated that death was instantaneous. The immediate cause of death was crushing cranial injuries.

The direct cause of the accident was the victim working at the mouth of the crusher while the crusher was in motion in disregard of the established safe work procedure for removing large chunks from the crusher.

6.3.4 Fall of Rock

The equipment involved in the accident was the hopper that was approximately 15 feet wide at the top, narrowing down to approximately 5 feet at the bottom. The hopper extended approximately 20 feet below the tunnel floor. At the bottom was a pan feeder that fed a crusher. The crusher was powered by a 500 horsepower, 4160-volt motor. Near the top of the hopper was the operator's shack where the electrical power boxes and

switches were located. The electric power switches were used to deenergize and lockout equipment when needed.

The victim reported for work at 3 p.m. on October 30, 1979, his normal starting time. Work proceeded normally until approximately 6 p.m. At that time, a large piece of material bridged itself in the narrow section of the hopper, approximately 3 to 4 feet above the pan feeder. Victim and helper went down into the hopper to place a bomb (dynamite sticks and mud) on the large piece of material. While standing on the bridged material, the large piece fell through the pan feeder below allowing material to slide down the hopper and on victim. The injured rolled with the loose material until it stopped. The injured was buried except for his head and one arm. The mine foreman, and helper who had been assisting victim, immediately went inside the hopper to help the injured. The injured was freed in about 5 minutes and walked out under his own power. The injured was brought out of the tunnel where the paramedics administered first aid and rushed him to the hospital. Total time to transport the injured from underground to the ambulance waiting on the surface was approximately 15 minutes.

The direct cause of the accident was the injured placing himself in a hazardous position without using all safety precautions that were available to him, and by supervision condoning these unsafe work procedures.

Contributing to the accident was the failure to use safety belts and lines and having a second person tend the lines while a person was working in the hopper. If the man had been wearing a safety line with a person in attendance on that line, the accident could have been averted. Also contributing to the accident was the failure to break the larger pieces of material at the working face, eliminating the need for employees to bomb the large pieces of material that bridge in the hopper several times a shift.

6.4 Boulder Handling Analysis

To better understand the accident potential of the many boulder breaking and handling techniques, several methods were divided into individual tasks. These tasks begin with the crusher operator noticing the condition, and ends with the restarting of the crusher. The accompanying Table 8 lists boulder breaking techniques and the related tasks in chronological order.

Following each task is a series of letters, each of which represents a particular hazard that is present while performing that task. An explanation of the hazards is presented in Table 9. The potential hazards presented are major hazards and do not include dust entering an eye or similar occurrences unless they are directly related to a boulder breaking technique such as using a pry-bar. All potential hazards cited are capable of generating lost time accidents. Special explanations may be needed for some of the hazard descriptions. For example, "caught in or between" is the result of a slip, "struck by" means being hit only, whereas "struck against" means being first hit, and then pushed against another object causing further injury.

An analysis for impact breaking techniques are not included in that the operator never need leave the control room, making potential injury very remote.

It can be seen from these safety analyses that gaining access, working on a boulder or in the crusher, and explosive hazards, are the chief causes of concern.

6.5 Damage Potential to Crusher From Blasting

Aside from injuries to persons, boulder handling in crushers can be damaging to the crusher if explosives are used. The sections below describe very briefly the nature of the explosive shock forces and the damage potential to the crusher.

The damage potential of mudcapping compared to blockholing is very high. If we assume that 2 pounds of 40% gelatin explosive are used in mudcapping, there is 2,044,800 ft-lb of work available to break a one cubic yard boulder. In blockholing 1/4 pound of explosives are used, which has 255,600 ft-lb of work available, assuming that the blockholing procedure is 100% efficient and that the 1/4 pound of explosive products is the exact amount of energy needed to break the boulder. With these assumptions a comparison of the two boulder blasting methods illustrates that 1,989,200 ft-lb excess energy is used to break up the boulder creating air blast, and damaging shock energy into the crusher.

Table 8 - Boulder Handling Analysis

*Accident Records Exist For This Task

<u>Step</u>	<u>Description</u>	<u>Accident Possibilities (see Key on p. 83)</u>
1.	Notice condition	
2.	Shut down feeder	
3.	Shut down crusher	
4.	Activate stop/dump signal for train or trucks	
5.	Notify belt cleanup man	d, e
6.	Lock out crusher	
7.	Travel to crusher bed	d, e, f *
8.	Gain access & examine condition	a, b, c, d, e *

I. Mudcapping

1.	Walk to get explosives to (magazine should be close)	d, e, f, g, h
2.	Take explosives to the crusher area	a, d, e, f
3.	Gain access to the crusher feed	a, b, c, d, e, f *
4.	Place explosive on boulder	a, b, d, e, g, h *
5.	Helper gets mud with shovel	d, e, f
6.	Get electric blasting caps/ cap & fuse	a, b, d, e
7.	Place caps in explosives	a, b, c, d, e
8.	Carry mud to crusher feed	d, e, f
9.	Place mud on explosives	a, b, c, d, e
10.	Connect lead wire to blast cables/cut safety fuse	a, b, c, d, e
11.	Reel out blasting wire	a, b, c, d, e, f

<u>Step</u>	<u>Description</u>	<u>Accident Possibilities</u> (see Key on p. 83)
12.	Connect wire to power source	f
13.	Give warning signal	
14.	Fire the blast/light fuse	b *
15.	Give "all clear" signal	
16.	Examine crusher feed (from control room)	
17.	Start up equipment	
II Blockholing		
1.	Connect drill to air & water liner	d, e
2.	Bring drill to crusher	a, d, e, f
3.	Climb on boulder with drill	a, b, c, d, e
4.	Drill hole	a, b, c, d, e *
5.	Climb off boulder & replace drill	a, b, c, d, e
6.	Obtain explosives & cap/safety fuse	d, e, f, g, h
7.	Regain access to crusher feed	a, b, c, d, e, f *
8.	Place blocking cap into explosives	
9.	Place explosives in the hole	a, b, c, d, e, g, h
10.	Place stemming in hole (obtained in hopper)	a, b, c, d, e
11.	Connect lead wires to blasting cable	a, b, c, d, e
12.	Reel out blasting wire	a, b, c, d, e, f
13.	Connect wire to power source	f
14.	Give warning signal	
15.	Fire the blast/light fuse	b *
16.	Give "all clear" signal	
17.	Examine crusher feed (from control room)	
18.	Start up equipment	

III Snakeholing

<u>Step</u>	<u>Description</u>	<u>Accident Possibilities</u> (see Key on p. 83)
1.	Obtain explosives & blasting cap	d, e, f, g, h
2.	Obtain wooden "bomb" pole	d, e,
3.	Fasten explosives to pole	a, b, c, d, e
4.	Place cap into explosives	a, b, c, d, e
5.	Place explosives under boulder	a, b, c, d, e
6.	Connect lead wire to blast cable	a, b, c, d, e
7.	Reel out blasting cable	a, b, c, d, e, f
8.	Connect wire to power source	f
9.	Give warning signal	
10.	Fire the blast/light safety	b
11.	Give "all clear" signal	
12.	Examine crusher feed (from control room)	
13.	Start up equipment	

IV Hooks & Cable, or Wedge & Cable

1.	Maneuver overhead crane to crusher feed	
2.	Travel to boulder with cable sling	a, d, e, f
3.	Wrap cable around boulder	a, b, c, *
4.	Hook cable to hoist	a, b, c
5.	Drive wedge under boulder	a,,b, c, d, e *
6.	Reposition boulder with hoist	a, b, c, d, e *
7.	Replace hoist & start up	

Table 9 - Hazard Notation

Notation

- | | |
|---|---|
| a | caught in or between the crusher and boulder (slip) |
| b | struck by a boulder or broken fragments of a boulder |
| c | struck against the crusher or rock when the boulder moves |
| d | fall of person to the same level |
| e | fall of person to different level |
| f | contact with electrical current |
| g | injury due to force created by an explosive |
| h | initiation from chemicals found in explosive material |

The potential damage available from blasting in the crusher can also be seen in the detonation pressure of 40% gelatin dynamite. A 1 1/8 inch x 8 inch stick produces 75 kilobars of pressure which is equivalent to 1,087,500 psi. The force of pressure impulse is equal to millions of pounds of force a fraction of which can propagate through the boulder into the crusher. Of course, due to inefficiencies this fraction is very small compared to the total energy available.

The boulder will absorb some of the energy; however, the remaining energy goes into the air and into the crusher. The energy and pressure the crusher receives can damage the crushing surfaces and the bearings in the moving parts.

Accordingly, several crusher manufacturers were contacted and their views on blasting in their crushers were obtained. In general, we tried to elicit frank and practical opinions from these persons and a typical conversation would go:

QUESTION: "We'd like to know how to shoot a boulder that gets stuck in one of your crushers."

ANSWER: "Don't do it."

QUESTION: "It's the only way we have to get a boulder out and we're going to do it anyway, and we'd like your advice."

ANSWER: "Don't do it, and if you do, don't tell me you did, because you'll damage the crusher."

QUESTION: "How can you damage a crusher, they're extremely stout machines?"

ANSWER: "They're not designed for the high dynamic forces in the places and directions the explosive energy goes so damage can result."

The following summarizes these interviews:

Crusher Manufacturer No. 1:

Blasting boulders is a bad practice, in jaw crushers it will damage the bearings, the toggle bearing, the frame, and welds in the frame; in impactor crushers it will damage the bearings, the shaft, and the frame welds.

Crusher Manufacturer No. 2:

Do no boulder blasting in a crusher as it can damage everything.

Crusher Manufacturer No. 3:

Do no boulder blasting in a crusher, since in an impactor it can bend the shaft.

Crusher Manufacturer No. 4:

Boulder blasting can be done if it's done right, it is quick and inexpensive, however, the damage is not predictable.

Crusher Manufacturer No. 5:

Do no boulder blasting in a crusher, in a gyratory crusher it will crack the shell, loosen the concave, and loosen the shaft; in a jaw crusher it can damage the swing jaw and frame.

Crusher Manufacturer No. 6:

Do no boulder blasting in a crusher, in a jaw crusher it can damage the swing jaw, main frame, small toggle bolts, and bearings; in a gyratory crusher it can damage the spider.

Crusher Manufacturer No. 7:

Do no boulder blasting or use great caution in a crusher, in a jaw crusher it can damage the overhead eccentric and knock out the side walls.

Crusher Manufacturer No. 8:

Do no boulder blasting in a crusher, in a roll crusher it can do \$10,000 to \$15,000 damage to the hydraulics and bearings, bend the roll shaft at one-third the crusher cost, and damage the housing at two-thirds of the crusher cost.

Crusher Manufacturer No. 9:

Do no boulder blasting in a crusher, in a jaw crusher it can damage the frame and swing jaw; in a gyratory crusher it can damage the spider.

Thus nearly every crusher manufacturer strongly recommends that no blasting be done in crushers, though most will admit it is being done, though much less than in the past because of the installation of mechanical breakers or grapplers on most new installations. In fact, an inquiry to a major mine and quarry design firm revealed that every crusher installation it has been responsible for ten years or more has had mechanical boulder handling means as a standard part of the package.

7.0 COST ANALYSIS

Several cost analyses were completed to compare boulder breaking methods against each other, and explosive methods against mechanical breakage so as to understand the economics involved. Costs include labor, materials, and maintenance, all amortized whenever applicable. Although boulder breaking techniques and support equipment costs are examined, many hidden costs exist that are not reflected in the analysis. For example, added costs for an operation handling large boulders appear in extra loading time, and extra wear and tear on equipment. All explosives related costs cannot be reflected and the possible crusher repair costs for blasting damage are difficult to predict. Overtime labor costs spent to make up lost production is not included and likewise the cost of accidents attributed to blasting, or tasks related to blasting or breaking boulders, is not included due to the lack of a firm data base and the extremely high cost of severe accidents.

7.1 Initiating Devices

Table 10 shows several systems for initiating explosives for boulder blasting, the component parts of the system, and the estimated cost of using the system for one blast. For electric blasting caps, the blasting machine considered is of the twist type having a 10 cap capacity, and its cost is amortized over 1 year while being used to blast two boulders per week. The cost of electric blasting caps can be misleading in that blasting wire (the major cost item) should not be used again for other blasts. A semi-permanent arrangement can be made using heavy wire and a reel for easy storage. Consequently, the total cost figure presented here is about the highest expected for using electric initiation.

7.2 Explosives

A number of different explosives can be used to break boulders. The higher strength explosives cost more initially, but less explosive may be needed to accomplish the same results as straight dynamite. This, plus the extra safety may outweigh the extra cost.

TABLE 10 - Initiating Devices

<u>Initiating Device</u>	<u>Material Needed</u>	<u>Total Unit Cost/Blast</u>
Cap and Fuse	No. 6 Blasting cap	\$0.250
	36 inch Safety Fuse	0.117
	Fuse Lighter	<u>0.150</u>
		\$0.517
Electric Blasting	No. 6 Cap	\$0.760
	Blast Wire (100 ft)	2.000
	Blasting Machine	<u>1.923</u>
		\$4.683
Exploding Bridge Wire Cap	Cap	\$4.91
	Control Unit	
	Firing Module	7.692
	Cable	<u> </u>
		\$12.602
Nonel Primadet Caps	Cap	
	Lead Tube	1.115
	Ignition System	<u> </u>
		\$1.115

7.3 Operational Costs

To better examine the cost differential between explosive and mechanical methods of boulder breaking, a hypothetical limestone quarry operation was developed having the following criteria:

Production	450 tons per hour
Personnel	2 front-end loader operators
	3 truck drivers
	1 crusher operator
	1 belt clean-up man
Boulder breaking . .	2 per week

The following sections itemize costs for several blasting techniques. Included are ownership cost for magazines, fees, and maintenance; capital costs for equipment; and labor costs based on estimated downtime for boulder handling. All associated costs for a particular handling technique are then summarized, and with depreciation and other factors, are presented in total costs per year for comparison. The factor with the most influence on method costs is the value of lost production which due to downtime can cost tens of thousands of dollars per year.

7.3.1 Magazine Owning and Operating Costs

7.3.1.1 Magazine Owning and Operating Cost For Dynamite Explosives and E-B Caps

1. License and Fees:

Storage of dynamite up to 500 lbs . . . \$15.00/yr

Storage of E-B Caps up to 100,000 . . . \$10.00/yr

2. Magazine Cost:

Dynamite storage
<200 lbs @ \$500 for . \$500.00/yr

Cap storage <5000 @ \$300 for \$300.00/yr

Labor cost for maintenance \$ 63.44/yr

Total magazine cost for first year - \$890.44

each year after - \$ 88.44

It is assumed that separate magazines for the storage of explosives used for blasting in the crusher would be built and maintained at a safe distance from the crusher. These magazines only need to be of minimum capacity and may be classified as "B" magazines. The main storage magazines would most likely be located a good distance away due to their large capacity. Surface magazines specifications are more stringent than for underground due to their vulnerability, and therefore are more expensive.

With regard to maintenance, the magazine areas must be kept clear of vegetation which could dry out and catch fire. It is assumed that policing the area with one person twice a year would be sufficient.

7.3.1.2 Magazine Owning and Operating for Two Component Explosives Plus EBW Caps

Two component explosives are not hazardous to store in that an explosive is not formed until the components are mixed, consequently, a special magazine is not necessary. Exploding bridgewire caps are not sensitive to stray currents and other means of initiation as are conventional caps. With the use of these items for blasting, magazine costs are not an economic factor.

7.3.2 Material and Equipment for Blasting

7.3.2.1 Mudcapping with Gelatin Dynamite and E-B Caps

Capital Costs:

1	Twist type blasting machine @ \$200. . .	\$200
1	Cable reel and cable @ \$300	\$300
1	Blasting galvanometer @ \$85.00	85
	Expendable Item Costs: TOTAL	\$585
2	E-B caps per week @ \$25.00/100. . . .	26.00/yr
4	lbs Dynamite per week @ \$63.80/cwt . . .	132.70/yr
	Total cost per year . . .	\$158.70

7.3.2.2 Mudcapping with Two Component Explosives and EBW Caps

Capital Costs:

1	Control unit, Firing Module, and Cable	\$800.00
---	--	----------

Expendable Item Costs:

2	E-B caps per week @ \$4.91 ea.	510.64
2	Pouches per week @ 72.00/48 unit	\$156.00/yr
	Total cost per year	\$1,466.64

7.3.2.3 Blockholing with Straight Dynamite and E-B Caps

Capital Costs:

1	Handheld rock drill @ \$1500	1,500.00
1	Twist type blasting machine @ \$200	200.00
1	Cable reel and cable @ \$300	300.00
1	Blasting Galvanometer @ \$85.00	85.00
	Expendable Items Cost: TOTAL	2,085.00
2	E-B caps per week @ \$25.00/100	26.00/yr
	1/2 lb dynamite per week @ 63.80/cwt	16.59/yr
	Total cost per year.	\$ 42.59

Four pounds of straight gelating explosive is assumed to be used in the mudcapping technique.

7.3.3 Boulder Blasting Cycle Time

This estimate can vary greatly depending on boulder accessibility in the crusher.

7.3.3.1 Mudcapping

1. Stop crushing and truck dumping, check boulder size. 5 minutes
2. Get explosives and return 10 minutes
3. Place and wire explosive. 5 minutes
4. Give required warning 3 minutes
5. Blast, check conditions and begin dumping 2 minutes

Total minimum downtime per blast . . 35 minutes

35 minutes by twice per week by 52 weeks equals 60.7 hours downtime.

7.3.3.2 Blockholing

1. Stop crushing and truck dumping, check boulder size. 5 minutes
2. Get drill, drill and remove drill . 10 minutes
3. Get explosives and return 10 minutes
4. Placing and wire explosives 15 minutes
5. Give required warning 3 minutes
6. Blast, check condition and begin dumping 2 minutes

Total minimum downtime per blast 45 minutes

45 minutes per day by twice per week by 52 weeks equals
28 hrs. downtime.

7.3.4 Labor Cost for Downtime

7.3.4.1 Mudcapping Procedure

- | | | |
|---|---|--------------|
| 1 | Crusher operator @ \$8.605/hr for 60.7 hrs. . | \$ 522.32/yr |
| 1 | Laborer @ 7.930/hr for 60.7 hrs. . | 481.35/yr |
| 3 | Truck drivers @ 8.605/hr/ea for
60.7 hrs/ea | 1,566.96/yr |
| 2 | Loader operators @ 9.185/hr/ea for 60.7
hrs/ea | 1,115.06/yr |

Total labor cost per year. . . \$3,685.69

7.3.4.2 Blockholing Procedure

- | | | |
|---|---|-------------|
| 1 | Crusher operator @ \$8.605/hr for 78 hrs. . . | 671.19/yr |
| 1 | Laborer @ 7.930/hr for 78 hrs. . . | 618.54/yr |
| 3 | Truck drivers @ 8.605/hr/ea for 78 . . . | 2,013.57/yr |
| 2 | Loader operators @ 9.185/hr/ea for 78
hrs. | 1,432.86/yr |

Total labor cost per year. \$4,736.16

7.3.5 Lost Tonnage Cost

This is the yearly cost of stone not produced during downtime from boulder breaking. Working overtime to make up the tonnage would reduce this figure, but an exact estimate is beyond the scope of this economic model.

7.3.5.1 Mudcapping Procedure

35 minutes downtime @ 450 tons per hour = 262 lost tons.

262 tons @ \$2.70/ton = \$707 per blast = \$73,528/yr

7.3.5.2 Blockholing Procedure

45 minutes downtime @ 450 tons per hour = 337 lost tons

337 tons @ \$2.70/ton = \$910 per blast = \$ 94,640/yr

7.3.6 Cost of Hydraulic Breaker

Capital cost	\$75,000
Erection cost	7,500
Freight cost	1,000
Total cost per year for 20 years	\$4,175

Depreciation

Depreciation	\$ 4,175/yr
Maintenance and repair	418/yr
Investment (12% x 0.6 \$83,500)	6,012/yr
Total owner and operating cost	\$ 10,605/yr

7.3.7 Cost Summary

7.3.7.1 Mudcapping with Gelatin Dynamite and E-B Caps

Magazine costs after first year	\$ 88.44/yr
Material and equipment for blasting	158.70/yr
Labor cost for downtime to blast	685.69/yr
Lost tonnage cost from downtime	73,528.00/yr
Total cost per year for blasting:	\$77,460.83
Total Capital Cost	\$ 585.00

7.3.7.2 Mudcapping with Two Component Explosives and EBW Caps

Magazine cost	Minimal
Material and equipment for blasting	\$ 666.64/yr

Labor cost for downtime to blast \$ 3,685.69/yr
 Lost tonnage cost from downtime 73,528.00/yr
 Total cost per year for blasting \$77,880.33
 Total Capitol Cost \$ 800.00

7.3.7.3 Blockholing with Straight Dvnamite and E-B Caps

Magazine costs after first year \$ 88.44/yr
 Material and equipment for blasting 42.59/yr
 Labor cost for downtime to blast 4,946.40/yr
 Total cost per year for blasting: \$99,507.19
 Lost tonnage cost from downtime \$94,640.00

7.3.7.4 Blockholing with Two Component Explosive and EBW Caps

Blockholing with two component explosives and exploding bridgewire caps as previously mentioned is not considered practicable.

7.3.7.5 Cost Comparison From Cost Summaries

Between mudcapping and hydraulic breaker
 Reduced cost = $\frac{\$77,460.83 - \$10,605.00}{\$77,460.83}$
 = 86.31%

Between blockholing and hydraulic breaker
 Reduced cost = $\frac{\$99,507.19 - \$10,605.00}{\$99,507.19}$
 = 89.34%

The cost differential of these boulder breaking methods is remarkable. With the many advantages of a hydraulic breaker, the only item that probably prevents its being considered is the initial capital cost and the extra maintenance required.

The safety difference between two component explosives and EBW caps and dynamite and E-B caps is very difficult to quantify, but is a factor in its adoption at several operations.

8.0 FUTURE APPLICABLE TECHNOLOGY

Ongoing research in demolition may one day be applied to safe, economical boulder breaking. Presently the methodology is cost prohibitive or not developed to its full potential and therefore limited to small scale use. A literature search in this area defined two basic categories of future applicable technology: explosive and non-explosive, where the latter is the larger group. A number of systems are presented here but only as food for thought.

8.1 Explosives Methods

8.1.1 Energetic Explosives

The term energetic explosives refers to a high brisance, high velocity explosive. Brisance describes the ability of an explosive to shatter and fragment steel, concrete, and other very hard materials. A good example of a commercially used energetic explosive is the cast primer used to initiate blasting agents. Some of these high brisance explosives are TNT (trinitrotoluene), PETN (pentaerythritol nitrate), RDX (cyclotrimethylene trinitramine or cyclonite), and tetryl.

Energetic explosives can be used in smaller amounts to replace dynamite in "bombs" for unconfined boulder blasting where no specific or special order of explosives would be needed, or in mudcapping to decrease the amount of explosives used.

8.1.2 Ribbon Explosives (Military)

Ribbon explosives, sometimes called Flex-X, (Figure 27) is a military explosive. It is made from 63% PETN, 8% nitrocellulose, and 29% elastomeric binder. The M186 roll demolition charge, as the military identifies it, is 3 in wide, 1/4 in thick, and 50 ft long so it can be cut to any length. This ribbon explosive is backed with pressure sensitive tape and can be shaped and contoured to most any object. The ribbon could also be shaped around suspected weakness zones in a boulder and distribute the explosive power to that weakness zone. Ribbon explosives are designed for cutting through steel but they lack the mass concentration necessary to break boulders provided they are just laid on top of the rock. For the ribbon explosive to have a shattering effect, the length over thickness ratio must be greater than 2.5. This ratio will permit the explosive to reach steady state velocity, however, the diameter of the explosive will probably be too small to deliver a damaging blow to the rock.

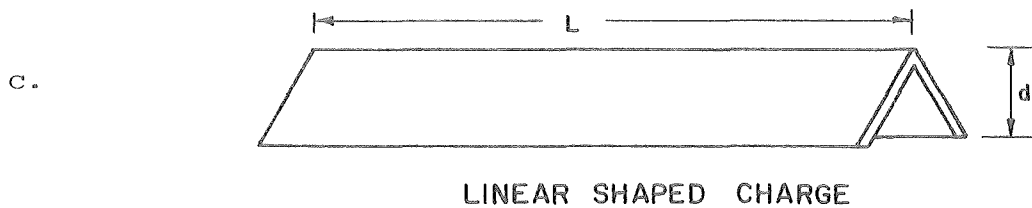
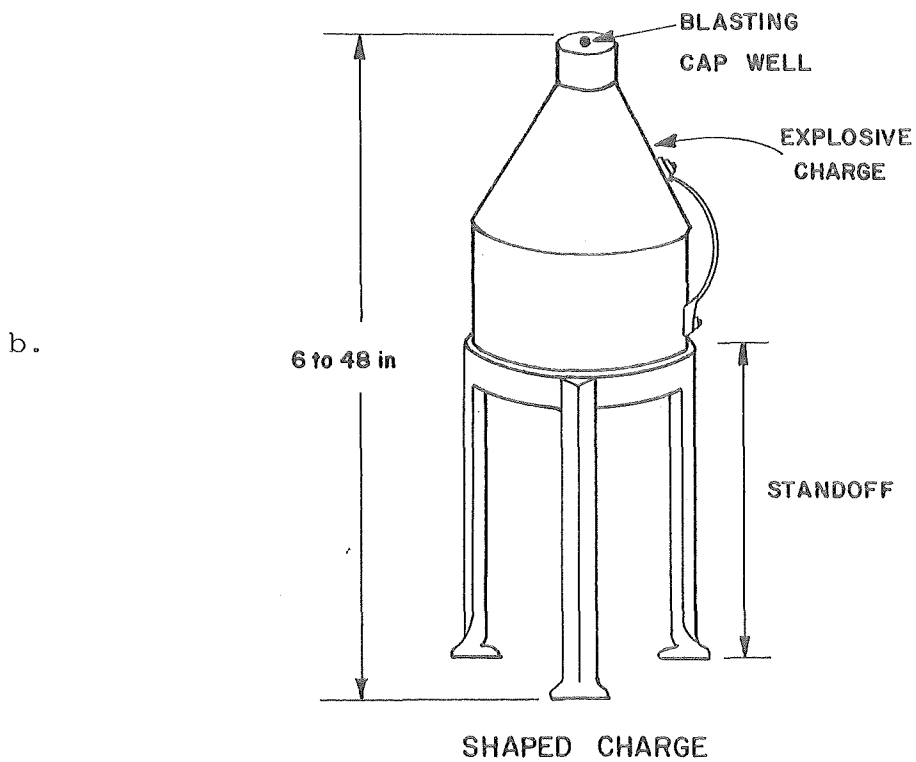
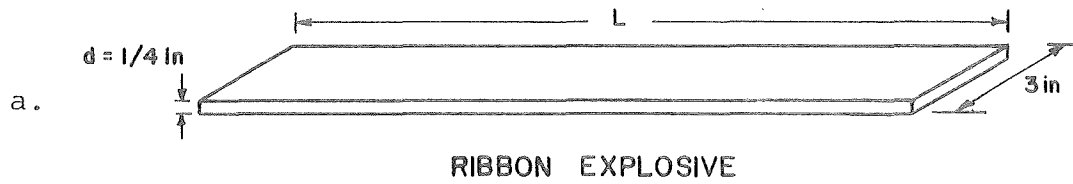


Figure 27 - Military Explosives and Ordnance Applicable to Boulder Breaking.

8.1.3 Shaped Charges

A shaped charge is an explosive contained in a case so shaped as to concentrate the power of the explosion in one small area (Bureau of Mines, 1980). A shaped charge looks like an inverted cone with legs (see Figure 27).

Shaped charges are very effective for cutting holes through reinforced concrete thereby making shaped charges extremely useful in military operations and may have some application to boulder blasting but use in crushers is questionable. The biggest disadvantage of shaped charges are the flyrock potential and the high noise level.

8.1.4 Linear Shaped Charge

A linear shaped charge is a combination of ribbon explosives and a shaped charge. A linear shaped charge is similar in appearance to angle iron (Figure 27).

A linear shaped charge is similar to a shaped charge in that the concentration of the force of the explosive is along the line of the explosive; however, a linear shaped charge does not have the concentrated mass necessary, due to the large length to thickness ratio, to create a shattering effect. Consequently the explosive force would tend not to penetrate the rock. Another disadvantage of linear shaped charges is that a worker must go into the crusher area to place the explosive thus increasing the accident potential.

8.1.5 Contained Projectile

A contained projectile is an unconfined shaped charge with a projectile in contact with the bottom of the explosive (Figure 28). The projectile and explosive would stand a few inches above the boulder with the aid of legs supporting the unit. At the time of initiation a shaped charge concentrates the explosive force onto the boulder at a very high velocity creating a shock wave that breaks the boulder.

This method of boulder blasting has potential because it is a fast method and allows placement of explosives without being in the crusher mouth area. The addition of a projectile amplifies the cutting force of the shaped charge into a shattering force necessary to break boulders, however the potential for crusher damage is high.

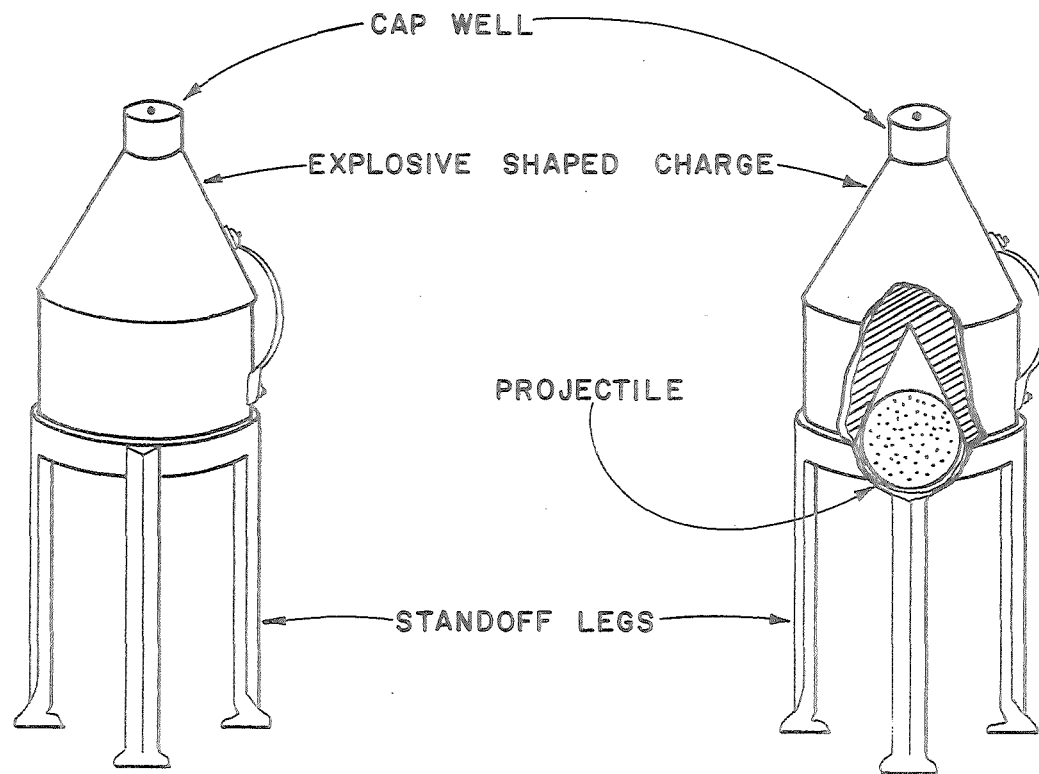


Figure 28 - Contained Projectile Charge.

8.2 Non-explosive Methods

8.2.1 Electron Beam

An electron beam is a device which utilizes a dense stream of high-velocity electrons to impact and melt rock. The electron beams are produced from high voltages (30 to 200 kv) which accelerates the electrons traveling between two electrodes. The electrons are focused by a magnetic lens located close to one of the electrodes. Aligning coils are used for fine focusing of the beam (Maurer, 1979), Figure 29.

The electron beam has potential for being a boulder breaker, however, the x-rays given off make the electron beam a health hazard. Very little work has been done to test the potential of the electron beam as a boulder breaking method.

8.2.2 Spark

The spark method of breaking rock utilizes high-voltage capacitors discharging across two or more electrodes Figure 30, to produce shock waves which crater the rock (Maurer, 1979). Even though the spark creates a high enough temperature to melt the rock, it cannot, because the spark is of such short duration, usually 1 to 50 microseconds.

The spark method of rock breaking has great potential in deep hole drilling, but as yet to be tested for boulder breaking.

8.2.3 Flame Jet

A flame jet is a rock cutting method which uses a high-velocity flame powered by air or oxygen enriched air oxidized with fuel oil, as shown in Figure 31 (Maurer, 1979). The heat from the jet flame weakens the rock structures while the high velocity aids cutting through the rock. Abrasives such as sand can be added to the jet to increase the density and cutting ability.

A flame jet in 15 minutes, can cut a kerf 1 3/4 ft deep x 4 in wide x 2 1/2 ft long in Barre Granite. This rate can be greatly increased with the use of abrasives. The flame jet can be used to cut enough rock off the boulder so as to fall into the crusher mouth.

The advantages of using a flame jet for boulder breaking is the elimination of both dangerous flyrock and the need for personnel to be in the crusher area. The

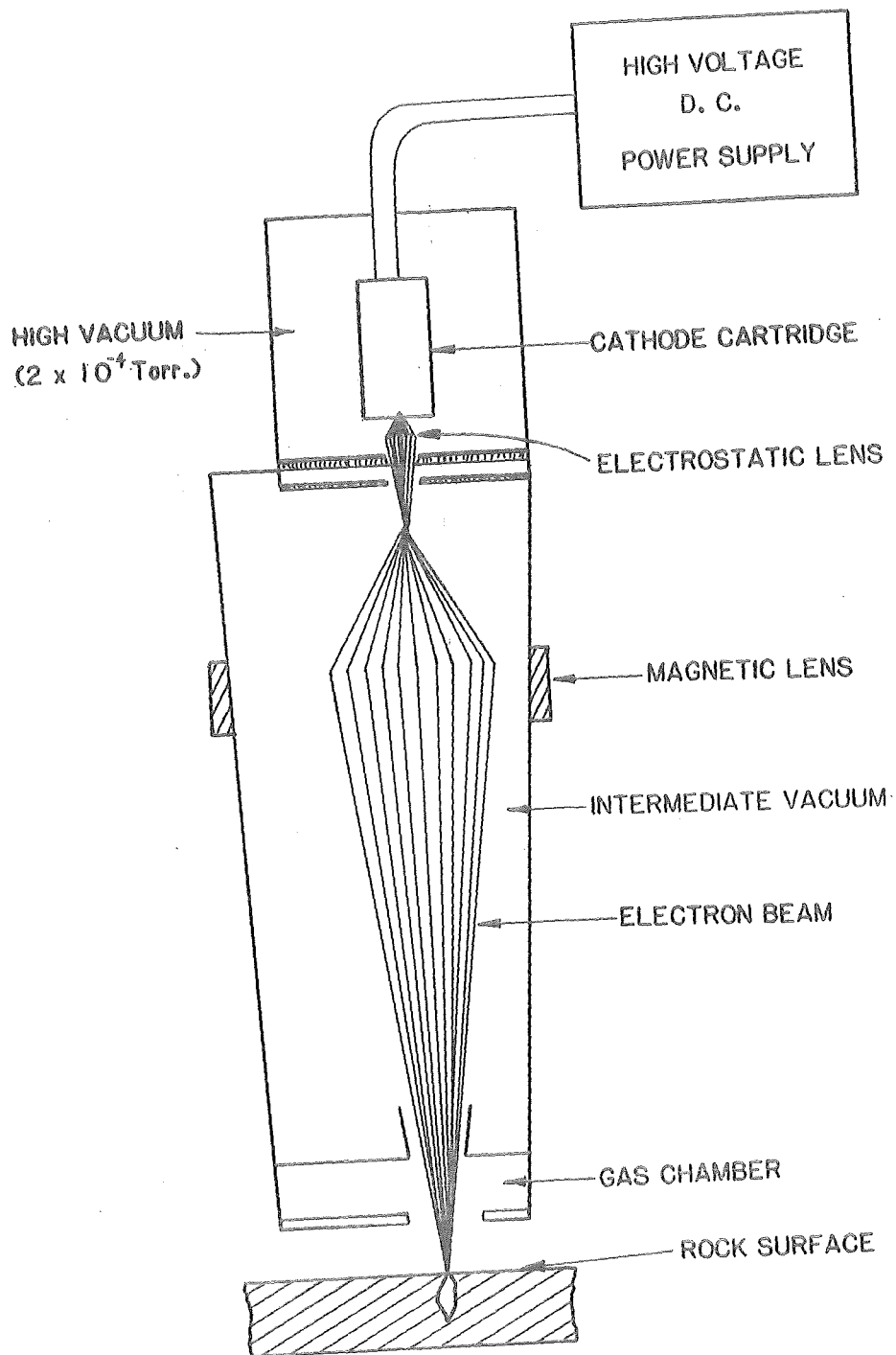


Figure 29 - Electron Beam Rock Breaker
(After Schumacher, 1969)

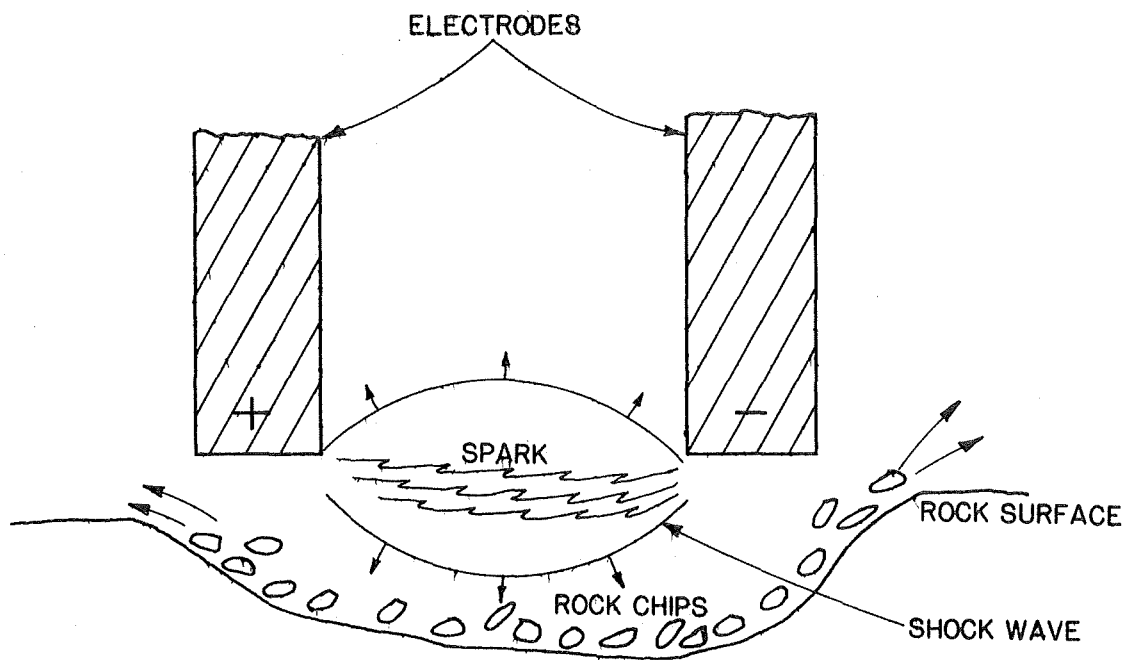


Figure 30 - Spark Rock Cratering Mechanism
(After Maurer, 1969)

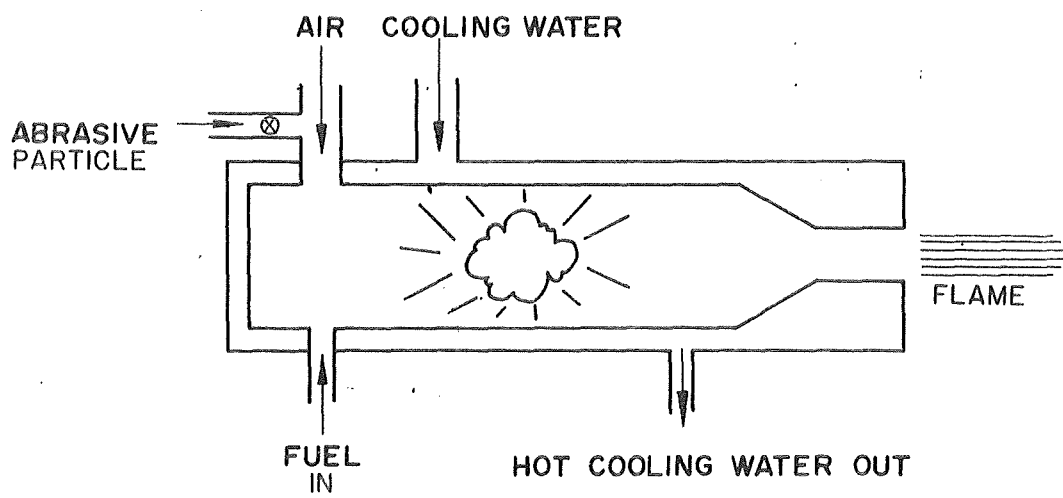


Figure 31 - Flame Jet Burner (After Carstens, 1968)

disadvantages include the dangers of combustible material and noise from the jet. The flame jet has some potential as a boulder breaking method but needs further testing.

8.2.4 Burning Bar

The burning bar method for boulder breaking burns or melts the boulder into smaller pieces. The Nordberg crusher manufacturer recommends this method for many of their crushers. A burning bar is a butane or propane fueled stick-shaped burner. When a boulder needs to be broken the burn bar is placed at the desired location and allowed to burn through the rock.

This method will not harm crusher parts but it is slow in reducing boulder size.

8.2.5 REAM Projectile

The REAM projectile method of rock breakage uses concrete projectiles fired from a cannon (Maurer, 1979). The system has been developed as the REAM tunneling system (Rapid Excavation And Mining) where 8.5 to 10 lb concrete projectiles are fired with velocities up to 64 ft per second at the rock to be broken.

Sixty-two tests have been tried with this technique as a secondary breakage method. Boulders ranging in size from 2 tons to 45 tons were used. The projectile kinetic energy required for breakage ranges from 55,320 ft-lb for a 1 ton boulder to 2,950,400 ft-lb for the 10 ton boulders. The standoff distance, or the distance from the cannon to the boulder, ranged from 50 to 200 ft. Figure 32 shows a REAM cannon mounted near a crusher in an idealized working position. Caution is needed in the use of REAM projectiles for secondary breakage because excessive impact energy will result in flyrock. There is also a danger to the crusher if the projectile misses its mark and hits the crusher.

8.2.6 Electrical Disintegration

An electrical technique for fragmenting rock, called Electric Disintegration, has been developed (Maurer, 1979).

Electric disintegration passes an electric current through the rock to heat and thermally fracture the rock. The thermal stresses produced in the rock are the result of:

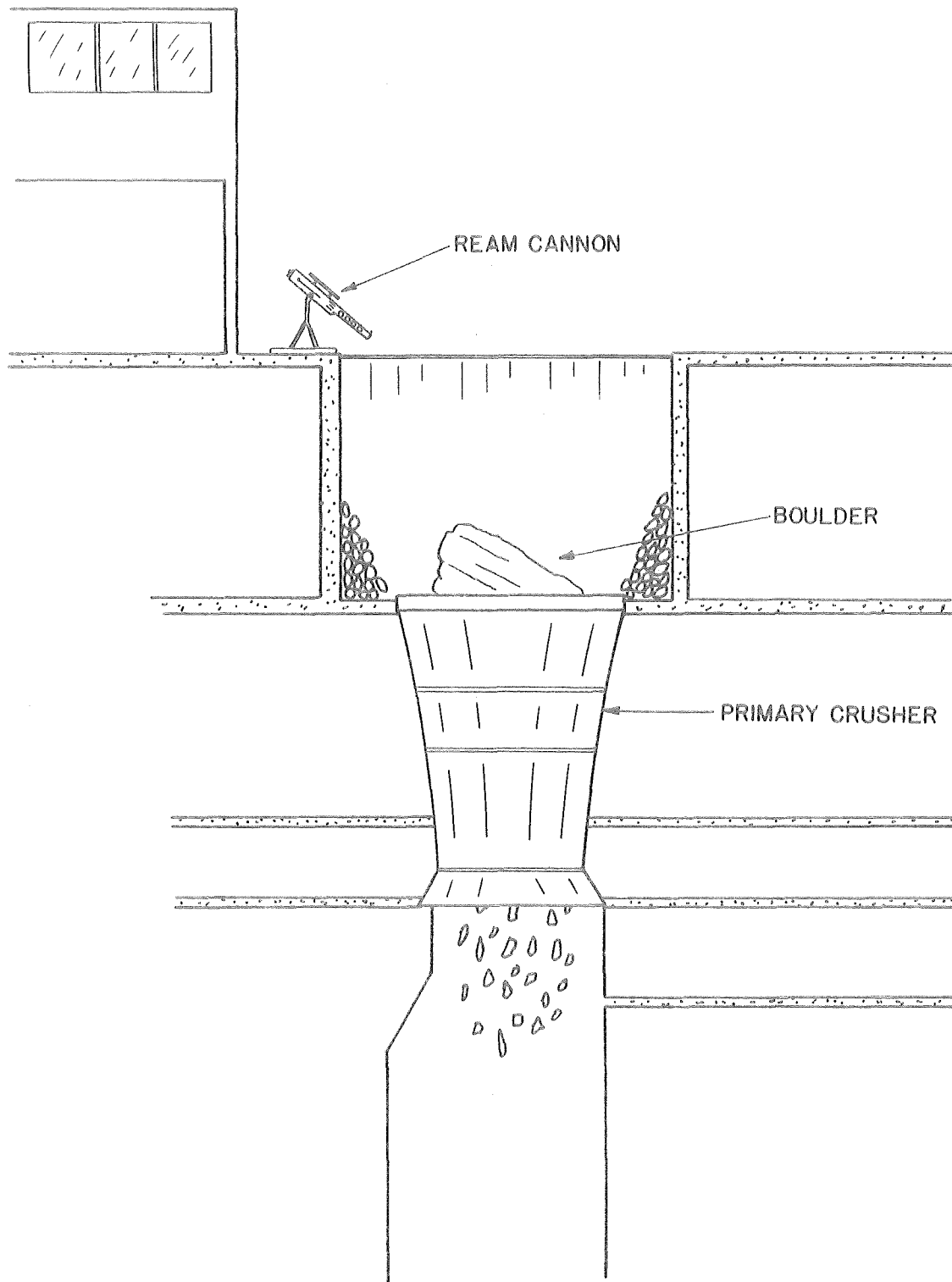


Figure 32 - REAM Cannon Installation in a Crusher Area.

- differential thermal expansion of constituent minerals
- chemical decomposition of rock components
- expansion of gas and moisture
- phase transition of minerals

Electric disintegration has good potential for boulder breakage. In tests, four ton blocks of ore were shattered after only 2 to 3 minutes exposure to the electrical current (James and Hertel, 1967).

Peak power outputs of 445 kw were used during the test with electrode potentials of 100 to 600 volts. The electric disintegration method of breakage can be used both on the surface or underground by attaching the mechanism to a pivotal boom as in Figure 33. This method is both fast and easy; however the initial cost is high and without trained personnel the electrical hazard could be very dangerous.

8.2.7 Water and Air Jets

Water and air jets are high pressure, high velocity narrow sprays, which are able to produce a high strength cutting force. These sprays exit the nozzles, Figure 34, at pressures up to 1,000,000 psi with a velocity up to 12,000 ft per second.

The jet spray can be continuous or pulsating. A single pulse from pulsating water jet can penetrate a 5 in thick piece of copper or a 1 1/4 in thick piece of steel. Water jets tend to be more effective than air because of the higher density of water compared to air. The impact force of a water jet can be improved by adding solid particles to the water, thus increasing the density which increases the impact force of the jet spray.

For boulder reduction in the crusher, water jets would be used to cut the boulder instead of breaking it with a shattering force. There could be a noise problem with the uses of water jets due to the noise developed from high speed motion; however, further testing of boulder breaking by water jets will be needed.

8.2.8 Breakage by Expansion

A chemical method of breaking rock by expansion exists but is not very practical for breaking boulders in crushers to date. The product is Bristar, manufactured by the Onoda Cement Company, Ltd. of Japan. This product is a non-explosive demolition agent made from a special silicate and organic compound that need only be mixed with water.

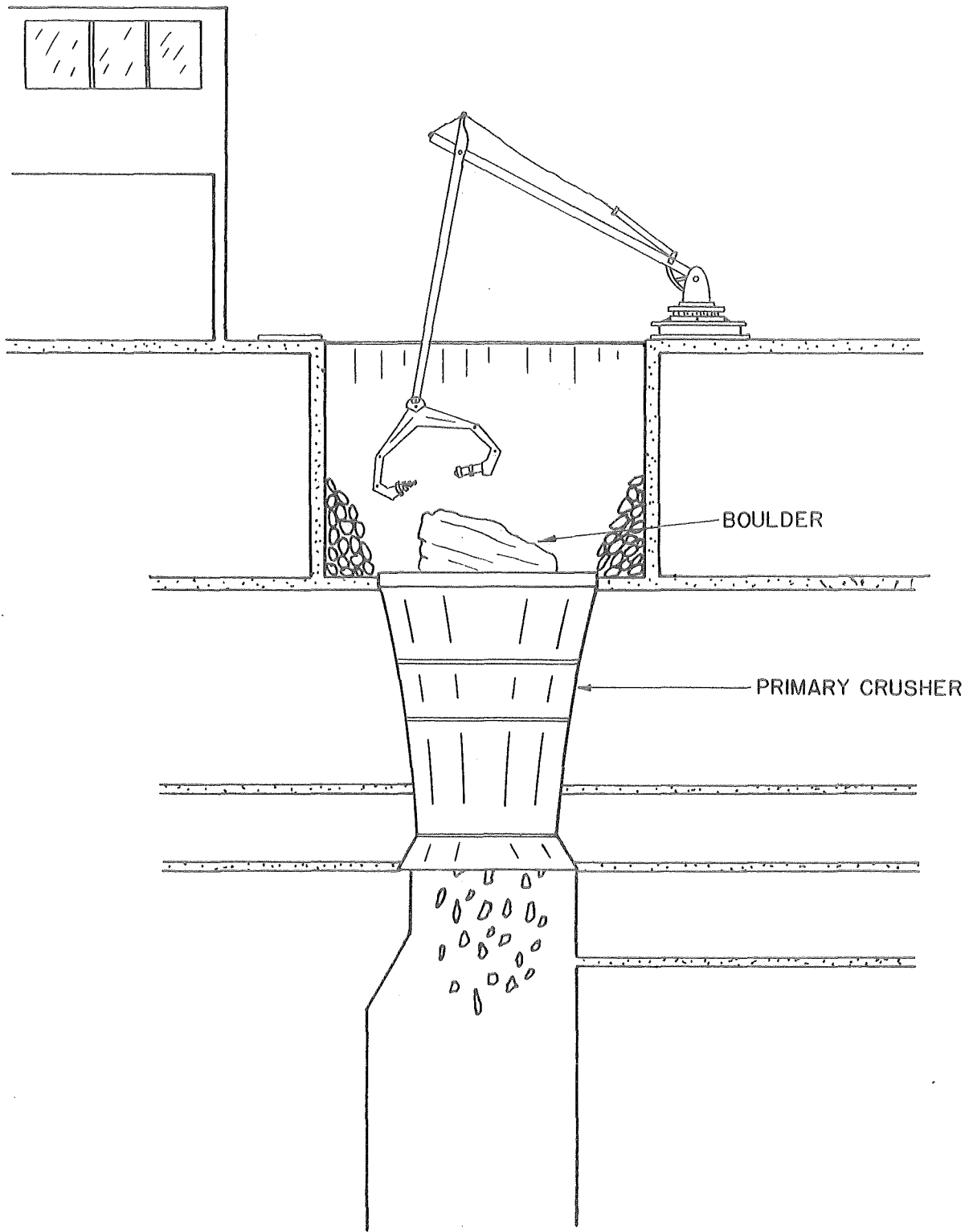


Figure 33 - Electrical Disintegration Method
Installed in a Crusher Area.

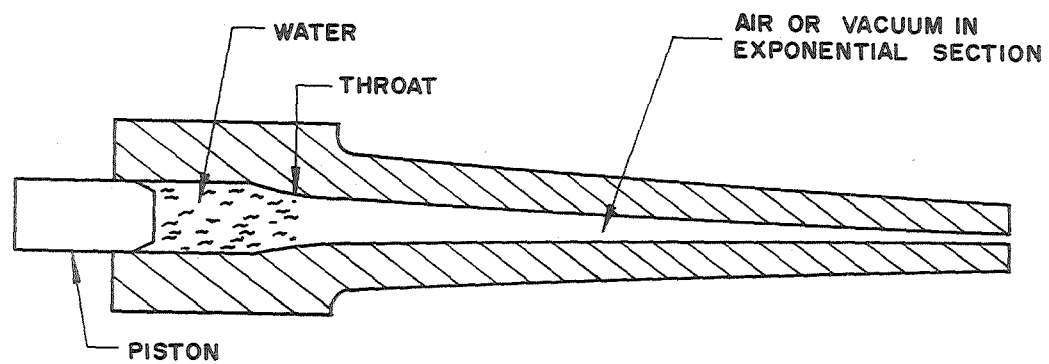


Figure 34 - Examples of an Exponential Type Pulsating Jet Nozzle

To use the product, first a hole of 36 to 52 mm must be drilled to 2/3 the depth of the boulder. The amount of Bristar needed is mixed with water in parts of 5 kg Bristar with 1.5 l of water. This slurry must then be poured into the hole within 15 minutes, and it must completely fill the hole. One 5 kg bag is enough to fill eight feet (2.4 m) of 1 1/2 inch (38 mm) hole. In time, expansion stresses of 3,000 t/m² build up to promote crack initiation, crack propagation, and an increase in crack width. Within 10 to 20 hours, cracks develop having widths of 10 to 30 mm (0.4 to 1.2 in.) making the rock easily picked apart. Performance is based primarily on hole depth.

Advantages of this method are similar to other non-explosive techniques. No licensing is required and no flyrock, dust, or noise will exist. The procedure requires very little training, and unlike other expansion techniques, there is no danger of having to plug the hole top and have the plug fly loose from pressure buildup of the chemical reaction as for example quicklime and water.

Disadvantages include very long action time, the necessity of drilling a hole, and the great dependence of performance on rock temperature. Colder temperatures lengthen the cracking time.

This particular method is mentioned not for its applicability of breaking boulders in crushers, but because it may evolve into a very practical method in the future; particularly if performance times can be reduced from twelve hours to twelve minutes. Present applications can replace secondary blasting of boulders in a quarry pit.

9.0 RECOMMENDATIONS FOR SAFER PRACTICES

Of course the simplest and most effective remedy to the problem is to never deliver an oversized boulder to the crusher. This requires care in primary blasting, and knowledgeable loader operators.

9.1 Improved Accessibility

From accident data investigations and field visits it is apparent that poor access to boulder blockages is a major contributor to injuries. Figures 35 and 36 show access to two different gyratory crushers. The access in Figure 35 utilizes a steep ladder leading to an unconsolidated rockpile. The workman could easily slip on the ladder or while walking on the loose rockpile to the crusher. Figure 36 also uses an access ladder to the crusher, but a hand rope is added near the bottom ladder section suggesting that the travel is difficult. The platform or catwalk above the crusher is covered with material that can contribute to injury. To aid in the safety of this area, a safety line must be required for any traveling to descending levels by ladder. Also, no attempt should be made to travel unless at least two persons are available; one to venture to the crusher mouth, and one to aid his travel, or be available for rescue. A cage surrounding a ladder, as recommended by OSHA would also improve safety as well as a platform to step on to rather than a rockpile.

To prevent accidental dumping of rock in the crusher when personnel are present, warning systems are necessary. A lighting arrangement works well, and an example is shown in Figure 37. A green light could mean dumping is allowed; and red lights will prohibit dumping.

9.2 Formal Adopted Procedure

Whatever arrangement is made for dealing with boulders, the plan should be well outlined and all personnel made aware of the plan. Good communications and procedures can prevent machinery starting when workers are in the crushers, accidental dumping of rock, people walking in on blasting, and so on. If an adopted procedure requires that workers enter the crusher area, then a procedure to carry out the work should be defined. The plan should include the responsibilities of all mine personnel in the area, and should be approved by the mine engineer, supervisors, and mine management. The plan should include all procedures and responsibilities of personnel from the time a boulder is hung up, to the time the crusher is cleared.

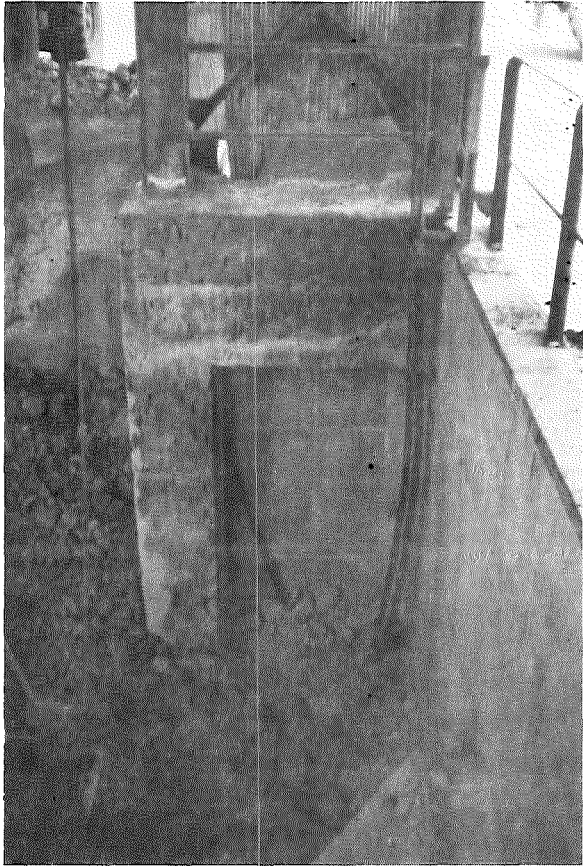


Figure 35 - Steep Access to Crusher Mouth

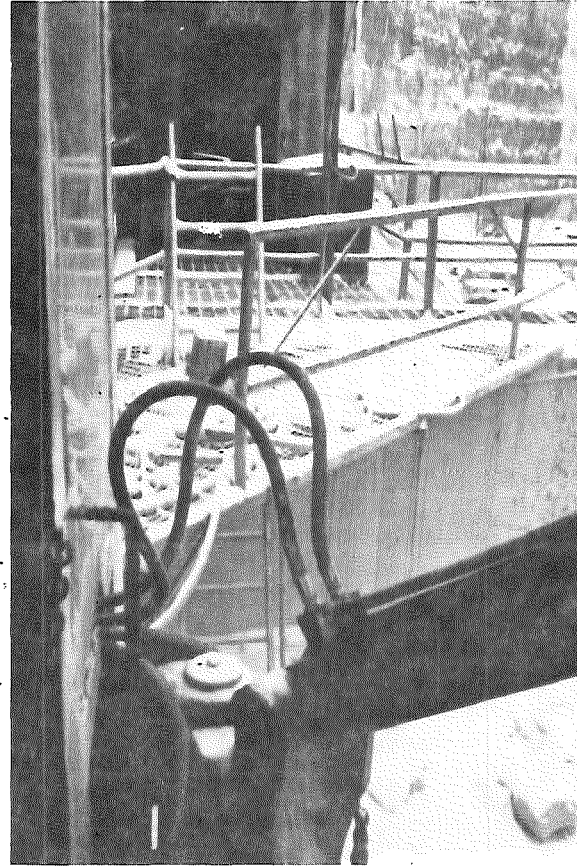


Figure 36 - Cluttered Access to Crusher Mouth

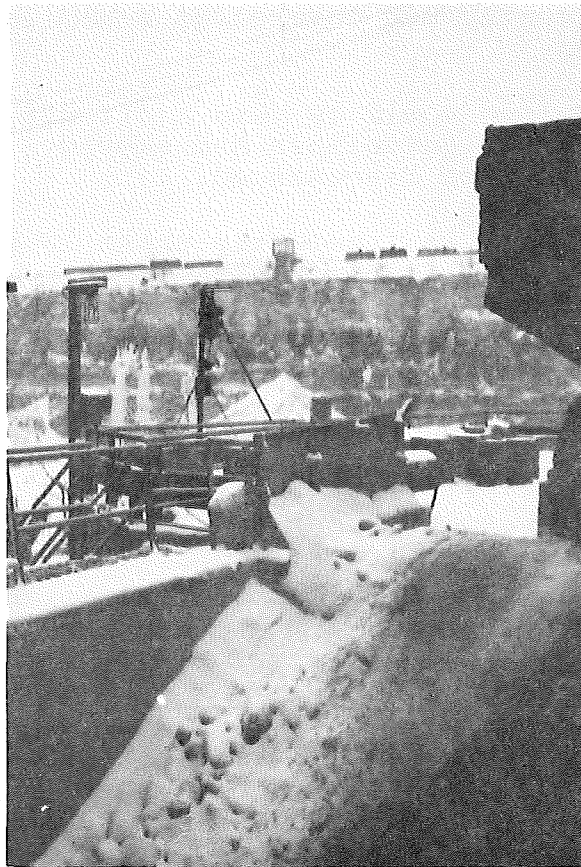


Figure 37 - Crusher Dump Warning Light

9.3 Improved Blasting Methods

Because of crusher damage, insufficiently trained persons, and general blasting hazards, blasting of boulders in crushers and grizzlies is to be discouraged. However, there may be situations where it is justifiable. In these cases the following is recommended:

- Persons should not enter upon or in a crusher unless for scheduled maintenance. Explosive charges should be placed by means of a pole or stick and subsequently mud covered in a similar fashion.
- Blockholing would be very difficult under these guidelines and should, therefore, be discouraged.
- Because of the inherently unstable situation of a bridging or hanging rock, insensitive products should be used so that a falling or shifting rock would not cause a detonation. Safety fuse caps, electric or nonelectric caps, and detonating cord may all detonate under impact and in turn detonate the explosive. Two component explosives and exploding bridgewire caps will minimize this problem as well as minimize magazine problems.
- Personnel handling explosives should be well trained in their use, and use only proper explosive devices for their initiation.
- When vibrating grizzlies are used to feed a crusher, every effort should be made to blast the boulder while on the grizzly rather than after it has entered the crusher mouth.
- A standard operating procedure should be adopted and cover the following operations as the minimum:
 1. Turn on "No Dumping" light to warn haul units that work is being done in the crusher area.
 2. Stop and lock out crusher, feeder, and conveyors so that the equipment cannot be started when

personnel are in the crusher mouth.

3. Examine the boulder blockage; use safety harness if necessary to prevent serious falls when traveling between levels.
 4. Notify certified blasting personnel to design the blasting approach thereby eliminating the condition in the safest manner.
 5. Obtain the blasting cables, machine, etc. and place the charge where desired.
 6. Take a head count of personnel in the area and sound a blast warning signal to assure no personnel stray into the blast area.
 7. Test the electrical connections to assure continuity and initiate the charge with approved equipment.
 8. Examine the blast results to see if the boulder was sufficiently broken, and that there are no undetonated explosives, or misfires.
 9. Sound the "All Clear" signal so that personnel can prepare to resume duties.
 10. Start electrical equipment and turn off the "No Dumping" lights.
- Blasting plan should be developed by a knowledgeable person, reviewed by the crusher manufacturer, reviewed by MSHA and state authorities, taught to personnel, and posted in a conspicuous place.

By following these simple guidelines, along with a definite plan with clearly defined responsibilities and procedures, blasting can be done in crushers if done very carefully with considerable forethought.

9.4 Other Considerations

The hazard analysis has placed explosive methods, manual methods, and mechanical methods in perspective in regard to safety. Economic judgements must of course be weighed by individual operators. However, boulder hang-ups can be reduced by:

- Better primary blast design to reduce boulders
- Loader operator training and experience to prevent loading of boulders

If blasting is the chosen method for handling boulders in crushers, a number of things can be done to reduce accident potential. Normal safe practices are necessary when storing and handling explosives and only experience, certified personnel should be allowed in the boulder blasting area. The incorporation of blast shelters as required in several state regulations could reduce injuries from flyrock and permit a head count of all people prior to blast initiation. A signal plan should be incorporated in to the procedure so as to warn all personnel who may come into the area. Safety blasting procedures such as these are common in any type of blasting. However, materials that are particularly applicable to boulder blasting exist and can further aid in accident prevention.

Boulder blasting in crushers implies that the surrounding area contains many electric lines leading to many types of equipment. This condition suggests that stray currents can be present and therefore pose a threat to premature detonation if electric initiation systems are used. Exploding bridgewire caps, as discussed earlier, successfully combat stray current initiation. Although more expensive, EBW caps provide a great safety advantage in transportation, storage, and use. The infrequent use of boulder blasting can also detract from the high EBW cost disadvantage.

Further safety can be obtained in congested areas of crushers by using a nonelectric system as discussed in Section 5.2.3. These systems are slowly gaining in popularity throughout the mining industry. Nevertheless all explosive work should be done by certified personnel, and with approved apparatus including lead wire and blasting machine. Previous discussion alluded to inclined grizzlies leading to the crusher mouth, and these grizzlies had to first be cleared of debris wedged between the bars before personnel could enter the crusher area.

One operator utilized a home-made grizzly cleaner that sped the cleaning process. The cleaner, illustrated in Figure 38 is moved by an overhead crane. Basically the cleaner is made from wide flange beams forming a frame, and railroad rail is laid across both sides so that either side can be used to clean. Grating is placed on one side so that occasionally the device can substitute for a work platform. The cleaner is slid down the grizzly and the railroad rail forces rock through the grizzly bars, or dislodges them so they can tumble to the crusher. Obviously the cleaner can save many man-hours of prying rock loose and can also improve safety by eliminating the need for workers to enter the area for cleaning grizzlies and steep incline.

9.5 Recommendations for Further Research

9.5.1 Home-Made Devices

A universal complaint of small mine operators is that they lack enough capital to obtain time saving and safer devices. Most equipment dealing with boulders does require power sources, booms, or elaborate overhead cranes. It would be beneficial to explore inexpensive home-made devices that can alleviate boulder hangups.

9.5.2 Explosive Use Research

The project included an economic and hazard analysis of common boulder blasting techniques such as mudcapping and blockholing. Another technique which may have promise is air gap blockholing as shown in Figure 39. This allows less explosive to be used compared with blockholing, but the air gap provides a cushioning affect which greatly reduces the violence of the blast.

Blasting boulders in crushers is much different than blasting in a quarry pit and therefore powder quantities and placement for effective use may not apply because of excessive explosive force that could result. The actual explosive forces delivered to a crusher under a variety of situations should be investigated. It would be beneficial to determine, under controlled conditions, the minimum amount of explosive per cubic yard of boulder.

9.5.3 Economic Study

Most operators do not know how often or how long it takes them to eliminate a boulder problem with their chosen method. A comprehensive time study of the many methods presented here can better help to determine, in an economic sense, the practical value of one boulder handling technique over another. It does appear from results obtained that if sufficient data were collected and then distributed to industry, blasting would become an extremely rare occurrence.

GRIZZLY CLEANER

1 in=3 ft

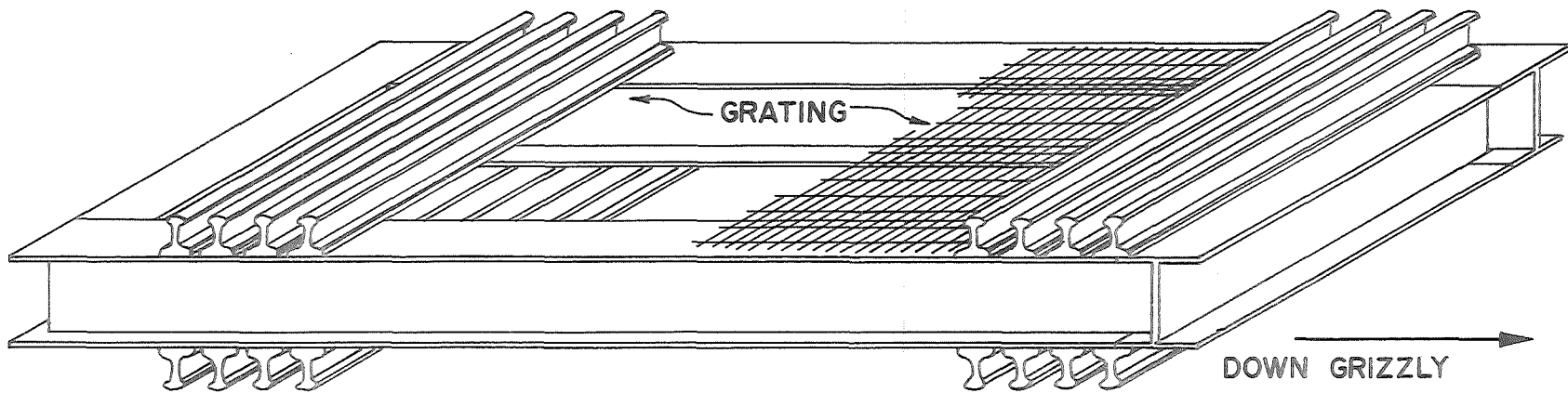
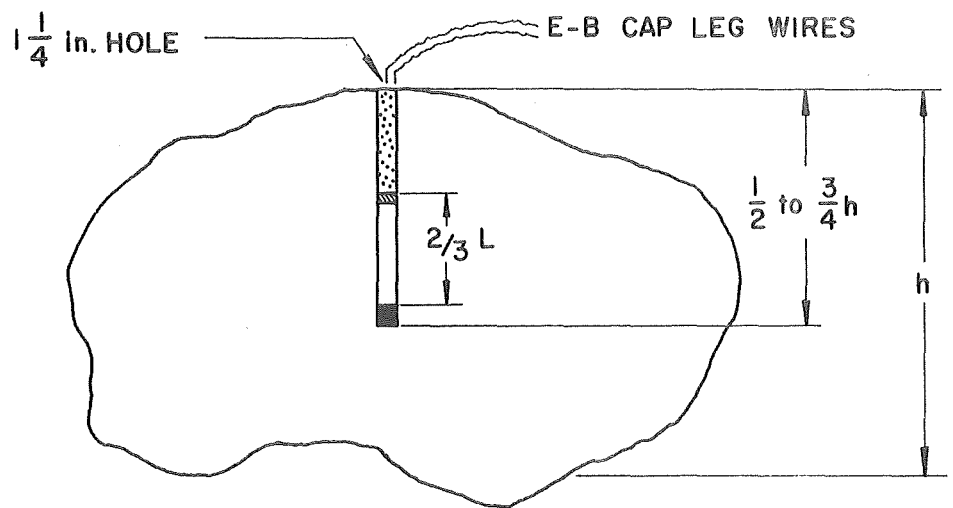


Figure 38 - Home-Made Grizzly Cleaner.



LEGEND

- 40 % DYNAMITE (0.25 lb.)
- ▨ STEMMING (-1/4 in. chips)
- ▩ NEWSPAPER
- AIR GAP

Figure 39 - Air Gap Blockholing Technique.

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