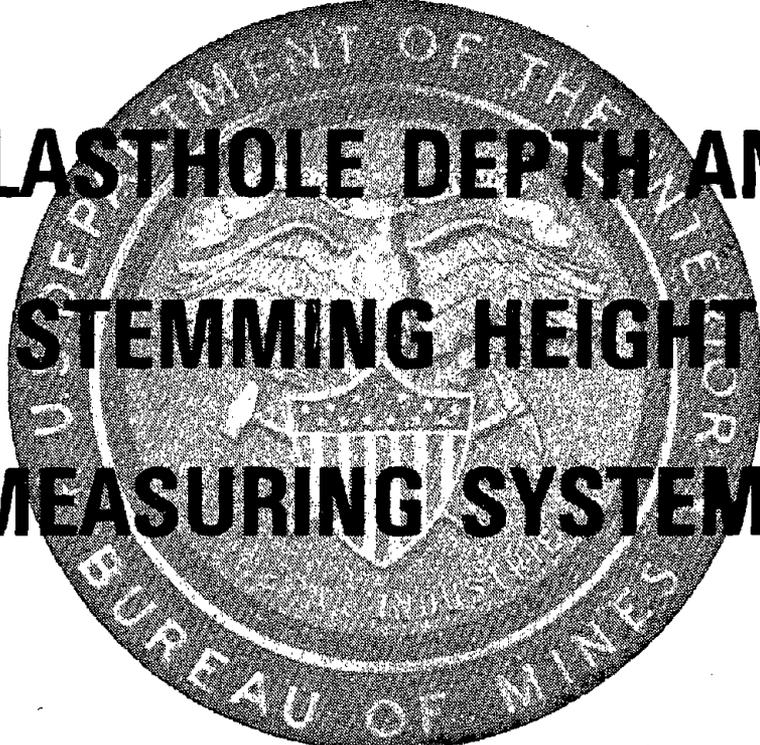


**A minerals research contract report
June 1981**

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**BLASTHOLE DEPTH AND
STEMMING HEIGHT
MEASURING SYSTEMS**

Contract J0208022
Intercontinental Development Corporation

Bureau of Mines Open File Report 4-84

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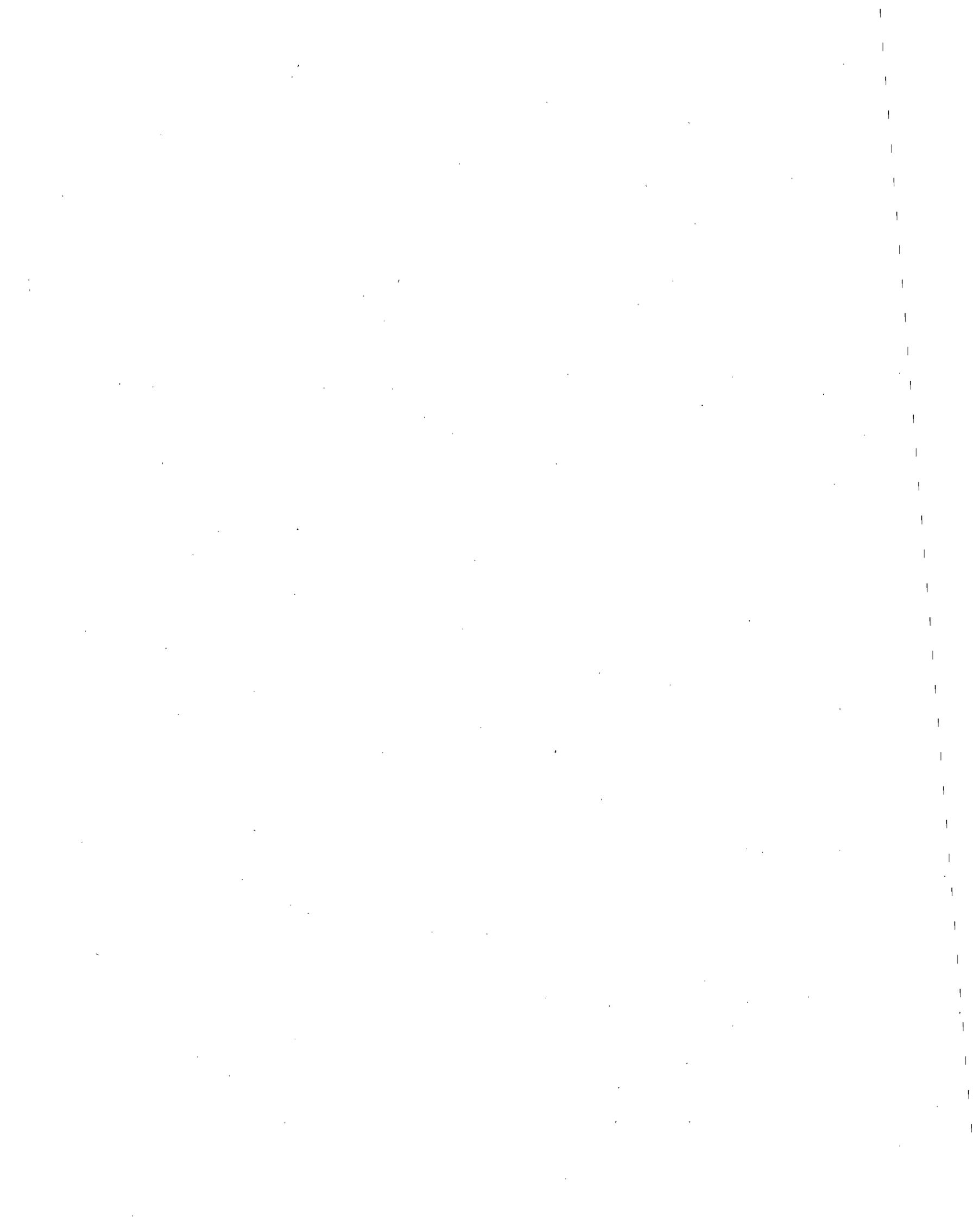
BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR
Minerals Health and Safety Technology

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FOREWARD

This report was prepared by Precision Blasting Services, a division of the Intercontinental Development Corporation of Montville, Ohio under USBM Contract number JO 208022. The contract was initiated under the Mineral Health & Safety Technology Program. It was administered under the technical direction of the USBM Twin Cities Mining Research Center with Mr. Dennis D'Andrea acting as Technical Project Officer. Mr. Larry Anderson was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period September 17, 1980 to June 15, 1981. This report was submitted by the authors on June 15, 1981.

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INTRODUCTION

Private industry has used its capital and ingenuity to develop improved explosives and blasting agents for rock breakage. Development has been rapid and pervasive in caps, electronic delays, primers, and boosters as in other areas of blasting technology including hydraulics, pneumatics, drilling bits, holders and rigs. These developments have been assisted by greatly improved blasting design research, insights, and equations. The advances have been timely because they came in time to offset partly a rapid rise in costs of equipment and supplies, labor, and capital brought on in part by foreign energy suppliers and in part by an inflationary psychology. New regulations for air blast, ground vibration, and fly rock have also intervened.

Problems such as air blast and fly rock resulting from blow-outs seriously affect the safety of workers in surface metal and non-metal mines and the lives of nearby residents and passers-by who might be in the vicinity of blasting operations.

The net effect is rising costs for blasting accompanied by improved technology to meet or offset them. Yet, clever design, advanced formulations, and sophisticated equipment can easily be rendered useless by lack of accurate and precise measurements of borehole depth, water depth, and stemming height.

Improper blasthole depth and stemming height measurements can result in blastholes being either under- or over-loaded or premature loss of confinement during the blasting process.

PROBLEM DEFINITION

This report seeks to describe current borehole measurement techniques as used in various segments of the non-coal mining industry. Also included are measurement techniques for water depth and stemming height. Potentially useful ideas for improving measurements will be suggested and their implementation briefly outlined. Further work will be defined for developing improved blasthole measurement technology.

METHODOLOGY

Measurement techniques currently used in the mining industry in the U.S. and in some foreign countries were defined after a review of the current literature and after surveys were made of a number of mines and quarries. Advantages and disadvantages of the techniques were described. Ideas were generated by the contractor's staff seeking new technical principles and methods of their application. Novel ideas were given a preliminary evaluation and rank-ordered in summary form for future research and development.

The work determined what measurement capability exists and is being used in copper and iron mines, as well as in quarries. Current technology was evaluated for safety, cost, and reliability. Care was taken to uncover deficiencies in present practice. Some deficiencies were found and new principles and procedures were reviewed so that a program of research and development could be undertaken which would lead to improved depth measurements in boreholes.

SECTION I

LIBRARY SEARCH AND LITERATURE SURVEY FOR BLASTHOLE, WATER, AND STEMMING LENGTH MEASUREMENT METHODS

INTRODUCTION

The project needed to determine what methods of measurement have been used for blasthole, water, and stemming lengths. Some mines and quarries were contacted in the mine survey, but a more general information source was sought.

PROCEDURE

The effort employed computer search technology. Search of the Ohio network showed all information available in the state under selected headings. Included were university and public libraries along with Battelle Memorial Institute, federal libraries, and Chemical Abstracts holdings.

In addition, selected publications were searched for the years 1971-1981 and included: Pit and Quarry, Rock Products, Engineering and Mining Journal, Mining Congress Journal, Mining Engineering Science, Iron Age, and AIME Transactions.

Further search encompassed the "Index to Periodical Literature" and books of various titles from pertinent subject areas. Finally, the search covered abstracts of graduate research theses.

FINDINGS

The Battelle Memorial Institute library did not provide pertinent information. Under headings pertinent to blasting procedures, the computer search and the Index to Periodical Literature provided 59 titles of a level of interest adequate to motivate accession and reproduction.

The articles were reviewed in detail, but none described measurement methods adequately for use in this study. Most of the interest centered on design effects such as pattern, hole size, water condition of hole, stemming, and other technical information.

The computer search and the Index to Periodical Literature yielded 47 titles under headings pertaining to borehole or underground measurements. None of the references provided information extensive enough to be suitable for inclusion in this study.

Books of considerable interest were discovered. These included:

1. Mining Engineers Handbook
2. Surface Mining, Mudd Series
3. Society of Explosives Engineers Conferences on Explosive and Blasting Techniques from 1975 - 1980
4. E/MJ Operating Handbook of Mineral Surface Mining and Exploration
5. Reference books on blasting

The books provided information on blast designs and on current design data from non-coal mines, some of which are included in Appendix A (1, 2).

Other sources tended to be concerned with environment, vibrations, breakage or some of the more theoretical aspects of blasting. Still others were product descriptions and comparisons.

DATA ANALYSIS

No useful information on borehole measurement methods resulted from the library search. The library search, however, did produce valuable information on blasting parameters used at copper and iron mines, both in the United States and in foreign countries. Information such as borehole depth and borehole diameter could be used in this study.

COPPER MINES

Thirty-three separate copper operations where blasting was employed were identified from the literature search (2). Borehole depth data, borehole diameter data, and water condition data were available for all 33 mines. The depth-diameter data is tabulated in Table 1.1 and plotted in Figure 1.1. To aid in the analysis of the blasthole diameter versus blasthole depth data, a reference line was introduced on the graph. This line represents the condition where the blasthole depth to burden ratio is approximately two.

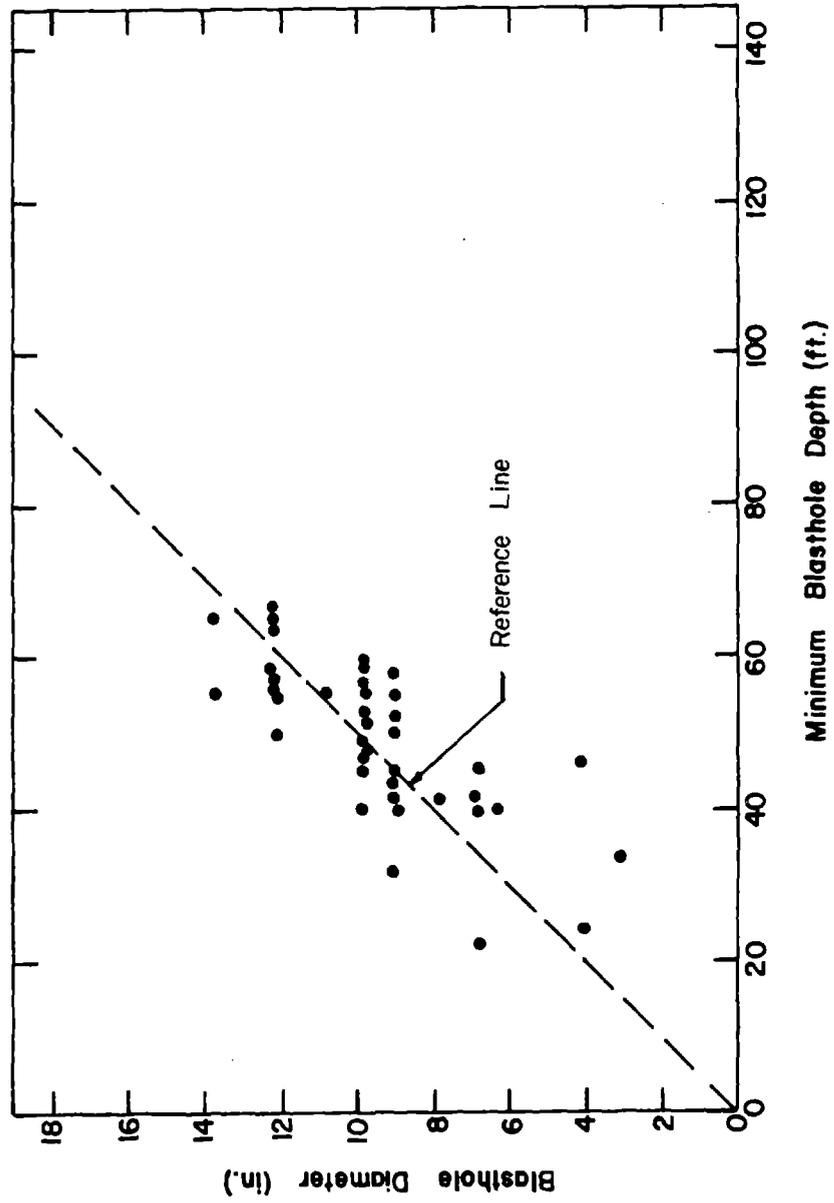


Fig. 1.1: Blasthole Diameter vs. Blasthole Depth for Copper Mines (Pre-1970)

Table 1.1
 Blasthole Diameter and Depth
 for Representative Copper Mines (2)

<u>Mine Number</u>	<u>Diameter (in.)</u>	<u>Hole Depth (ft.)</u>
1	9	32
2	9, 12 1/4, 13 3/4	55
3	9 7/8	49
4	9 7/8	40
5	9	45
6	9	40
7	9	44
8	10 7/8, 12 1/4	55
9	6 7/8, 9	42
10	9 7/8	57
11	6 3/4	45
12	9 7/8	51
13	9	58
14	6 3/4	22
15	9 7/8	55
16	9 - 9 7/8	52
17	9	50
18	12 1/4, 9 7/8	58
19	12 1/4	65
20	12 1/4, 13 3/4	65
21	12 1/4	64
22	12 1/4	50
23	9 7/8	45
24	7 7/8	41
25	9 7/8	48
26	4	24
27	9	52
28	4	46
29	9 7/8, 12 1/4	58
30	9 7/8, 12 1/4	57
31	9 7/8	45
32	3	34
33	6 1/4, 6 3/4	40

The reference line can be used for comparison of similar data gathered in the mine survey as compared to Figure 1.1 from published data on pre-1970 mining operations. Not all data collected in the literature search could be used on Figure 1.1 since much of the data did not list names; the report used data for which redundancy could be eliminated. A summary of the data used in this report is given in Appendix A.

IRON MINES

The literature search revealed data on borehole diameter and depth from 29 iron mines, both foreign and domestic (1, 2). This data is tabulated in Table 1.2 and plotted in Figure 1.2. The reference line is also plotted on this graph. The literature search in iron and other minerals did not produce any valuable data from a standpoint of measuring techniques used to measure borehole depth or stemming.

A comparison of the data from the iron mines versus the data obtained from the copper mines indicates that in general, iron mines use larger diameter, shorter blastholes than copper mines.

Table 1.2
 Blasthole Diameter and Depth
 for Representative Iron Mines (1, 2)

<u>Mine Name</u>	<u>Hole Diameter (in.)</u>	<u>Hole Depth (ft.)</u>
Reserve	9, 11, 12 1/4	38
Erie	9 7/8 - 12 1/4	40
Minntac	12 1/4	45
Butler Tac.	12 1/4, 9 7/8	35
Hill Annex	6 1/2	30
Eveleth	9 - 18	44
Empire	9 - 12 1/4	50
Republic	9 - 9 7/8	43
Groveland	8 - 13	44
Benson	7 7/8	55
Lone Star	5	20
Iron Springs	7 3/8 - 9	30
Eagle Mountain	6, 9, 9 7/8	60
Schefferville	9 7/8 - 10 5/8	41
Labrador City	9 7/8 - 10 5/8	50
Marmora	7	60
Moose Mountain	9 7/8	49
Adams	9 7/8	45
Caland	7 7/8	34
Quebec, Canada	12 1/4, 9 7/8	44
El Pao	6 1/2 - 7	38
Marcona	9	45
Questa (MD)	9 7/8	47
South Agnew	9	35
Algoma	7 1/2	25
Humbolt	9	46
Lindsay	7 3/8 - 9	21
French	9 7/8	35
Smallwood	9.5 - 10	40

WATER CONDITIONS IN BLASTHOLES - LITERATURE SURVEY

The literature survey indicated that water conditions in copper and iron mines were somewhat similar. In both instances, a very small percentage of the holes are dry and the remainder vary in number of holes which are wet and the amount of water in wet holes. The data from the iron mines indicated that approximately 8% of the 24 mines surveyed were totally dry. The remainder, 92%, had varying amounts of water. Twenty-one percent of these mines indicated that they had slight water problems, while 71% indicated that their problems were moderate to severe. Approximately 50% of the mines reported that their water problems were moderate.

Data from the copper mines indicated that 6% of their blastholes were dry. This is based on a survey of 35 different mines. Approximately 31% of the copper mines indicated that they had slight water problems and the remainder, or 63%, indicated that their problems were moderate to varied.

SECTION 2
MINE SURVEY

METHODOLOGY

Current practice in measurement of borehole and water depths and stemming height was determined by gathering information from mines and quarries both foreign and domestic. This information was obtained from our company files and by personal contact with colleagues in the mining industry. The information consisted of the location of the operation, the rock type mined, the hole depth measurement method, the hole depth in feet, the blasthole diameter, the stemming length measurement technique, the stemming length in feet, water conditions in the blasthole, and the method by which the powder load was determined and measured.

Results were tabulated by copper mines, iron mines, and quarries. The blasting procedures from 30 copper operations, 11 iron, and 92 quarries were analyzed. A summation of the data is presented in Tables 2.1, 2.2, and 2.3. The results were plotted to show hole depth versus hole diameter relationships in each of the different types of operations; stemming height and hole depth measurement means were analyzed by type of measurement technique. Stemming measurement technique was analyzed and compared to blasthole diameter to see if diameter of blasthole had an influence on the technique selected.

COPPER MINES

Blasthole diameters were plotted versus minimum blasthole depth on Figure 2.1. The reference line as described in Section 1 was added to this figure. If one compares Figure 2.1 with Figure 1.1 which was the pre-1970 data on blasthole diameter for copper mines surveyed versus blasthole diameter, it is evident that, today, operations are using larger holes on shorter benches where precise measurements of stemming height and hole depth are critical.

The data on hole depth measurement techniques indicated that 70% of the operations used a tape to measure hole depth, 23% relied on drill steel alone, and 7% used a knotted rope to measure the total depth (Figure 2.2(a)).

Table 2.1: Copper Data Survey

#	Location	Depth	Measure Load	Stem	Depth (ft.)	Dia. (in.)	H ₂ O Cond.
1	Arizona	Cloth Tape	Bulk Truck-Meter & Cloth Tape	Cloth Tape	57	9 7/8	35% H ₂ O
2	Arizona	"	"	"	53	12 1/4	10% H ₂ O
3	Arizona	"	"	"	47	9	20% H ₂ O
4	Arizona	"	"	"	47	12 1/4	25% H ₂ O
5	Arizona	"	"	"	47	9	20% H ₂ O
6	N. Mexico	"	"	"	57	13 3/4	20% H ₂ O
7	Arizona	"	"	"	47	9	20% H ₂ O
8	S. Africa	"	"	"	56	9 7/8	60-70% wet 26-33' H ₂ O
9	S. Pacific	"	"	"	56	9 7/8	90-100% wet 33-40' H ₂ O
10	Utah	"	"	"	60	7 7/8 9 7/8 12 1/4	30% wet 10' H ₂ O
11	N. Mexico	"	"	"	45	7 7/8	10% wet 5' H ₂ O
12	Arizona	"	"	"	50	12 1/4 9 7/8	20% wet 10-15' H ₂ O
13	Chile	"	"	"	150	11	50% wet 23-27' H ₂ O
14	Arizona	"	"	"	52	12 1/4	35% wet 6' H ₂ O
15	Arizona	"	Tape Column Rise	Tape	50-65	12 1/4 13 3/4 15	10% wet
16	Utah	"	Calc. on ANFO Tape	None	55	12 1/4	6% wet
17	Montana	"	"	Ct.	48	9 7/8	40% wet 12' H ₂ O
18	Nevada	Drill Steel Tape	"	"	55	9, 12	5% wet 26' H ₂ O
19	N. Mexico	Tape	Bulk Truck-Meter Weight	"	55	9 7/8 12 1/4	30% wet 15' H ₂ O
20	Arizona	Drill Steel	"	None	60	9	10% wet
21	Arizona	Steel	Weight	None	60	10 5/8 9-10 5/8	3' H ₂ O 20% wet 4' H ₂ O
22	Arizona	"	"	"	60	9-10 5/8	1% wet 1' H ₂ O
23	Arizona	"	"	"	30	9	30% wet 6' H ₂ O
24	Arizona	Tape	Tape	Tape	24	9 7/8	Dry
25	Hungary	"	Cartridge	Pole	20-40	3-4	20% wet 6' H ₂ O
26	Arizona	"	Tape	Tape	57	9 7/8	22% wet 27' H ₂ O
27	Arizona	Steel	Count	None	50	6 3/4	Dry
28	Tennessee	"	"	Tape	34	9	5% wet 26' H ₂ O
29	Arizona	Knotted Rope	Weight	Knotted Rope	50	9	25% wet 6' H ₂ O
30	Arizona	"	"	"	48	9	30% wet

Table 2.2: Iron Data Survey

#	Location	Depth	Measure Load	Stem	Depth (ft.)	Dia. (in.)	H ₂ O Cond.
1	California	Cloth Tape	Bulk Truck Meter-Tape	Cloth Tape	60	13 3/4	Dry
2	Michigan	"	"	"	50	12 1/4 15	30% wet 7-8' H ₂ O
3	Michigan	"	"	"	50	12 1/4	20% wet 5-7' H ₂ O
4	Michigan	"	"	"	45	12 1/4	40% wet 5' H ₂ O
5	Wisconsin	"	"	"	38-40	12 1/4	90% wet 15' H ₂ O
6	Minnesota	"	"	"	45	12 1/4 13 3/4 15	50% wet 20' H ₂ O
7	Canada	"	"	"	50	12 1/4 13 3/4	60-70% wet 20-24' H ₂ O
8	Minnesota	"	"	"	40	14-16	60% wet 20' H ₂ O
9	Minnesota	"	"	"	45	15 & 12 1/4	30% wet 20' H ₂ O
10	Minnesota	"	"	"	45	12 1/4 & 15	30% wet 20' H ₂ O
11	Minnesota	"	"	"	45	12 1/4 & 15	30-40% wet 20' H ₂ O

Note: Some mines still use jet pierce, therefore their diameter measurements would be highly variable

Table 2.3: Quarry Survey Data

#	Location	Depth	Measure Load	Stem	Depth (ft.)	Dia. (in.)	H ₂ O Cond.
1	Alabama	Cloth Tape	Cloth Tape	Cloth Tape	24	6 1/2	70% wet 8' H ₂ O
2	Illinois	"	"	"	40	"	90% wet 40' H ₂ O
3	Tennessee	"	"	"	40	"	100% wet 20' H ₂ O
4	Wisconsin	"	"	"	40	5"	95% wet 40' H ₂ O
5	Wisconsin	"	"	"	35	5"	90% wet 35' H ₂ O
6	Alabama	"	"	"	50	6 1/2	30% wet 4' H ₂ O
7	Texas	"	"	"	52	4	None
8	Texas	"	"	"	52	4	None
9	Texas	"	"	"	60	6 3/4	50% wet 10' H ₂ O
10	Tennessee	"	"	"	80	6 1/2	100% wet 40' H ₂ O
11	Illinois	"	"	"	80	6 1/2	90% wet 80' H ₂ O
12	Alabama	"	"	"	85	4	70% wet 20' H ₂ O
13	Illinois	"	"	"	142	6 1/2	90% wet 135' H ₂ O
14	Alabama	"	"	"	170	6 1/2	70% wet 10' H ₂ O
15	Alabama	"	"	"	185	6 1/2	50% wet 15' H ₂ O
16	Alabama	"	"	"	210	6 1/2	30% wet 4' H ₂ O
17	Tennessee	"	"	"	40	6 1/2	30% wet 10' H ₂ O
18	Florida	"	Slurry Counter	"	60	4 1/2	100% wet 60' H ₂ O
19	Michigan	"	"	"	24 & 50	3	100% wet 30' H ₂ O
20	Florida	"	"	"	60	4 1/2	100% wet 60' H ₂ O
21	Pennsylvania	"	Tape	"	55	6 1/4	10% wet 10' H ₂ O
22	Pennsylvania	"	"	"	50	6 1/4	50% wet 10' H ₂ O
23	Tennessee	"	"	Pole	40	4	5% wet 10' H ₂ O
24	Tennessee	"	"	"	50	6	20% wet 10' H ₂ O
25	Georgia	"	"	"	110	6 1/2	50% wet 20' H ₂ O
26	Florida	Drill Steel	Count Sticks	Subtract	50	4 3/4 (2" load)	100% wet full
27	Florida	"	Cloth Tape	Pole	50	7 1/4	100% wet full
28	Florida	"	Count	Subtract	50	4 3/4	100% wet full
29	Florida	"	Count & Tape	Pole	50	7 1/2 hole	100% wet full
30	Tennessee	Cloth Tape	"	"	85	6 1/2	5% wet 5' H ₂ O

Quarry Survey Data (cont'd.)

#	Location	Depth	Measure Load	Stem	Depth (ft.)	Dia. (in.)	H ₂ O Cond.
31	Tennessee	Cloth Tape	Count & Tape	Pole	47	6 1/2	10% wet
32	Tennessee	Drill Steel	"	Marked Pole	200	6 1/2	5' H ₂ O 35% wet
33	Alabama	Cloth Tape	"	Cloth Tape	33	6 1/2	50' H ₂ O 10% wet
34	Alabama	"	"	"	70	6 1/2	2' H ₂ O 30% wet
35	Alabama	"	"	"	94	6 1/2	3' H ₂ O 80% wet
36	Pennsylvania	"	"	"	56	6	15' H ₂ O 40% wet
37	Maryland	"	"	"	55	4	20-30' H ₂ O 50% wet
38	Maryland	"	"	"	48	6 1/4	15' H ₂ O
39	Pennsylvania	"	"	"	55	6	Variable
40	Vermont	"	"	"	30	2 3/4	50% wet
41	R.I.	"	"	"	40	3-3 1/2	10' H ₂ O Dry
42	Massachusetts	"	"	"	70	6	90% wet
43	Vermont	"	"	"	55	6 1/4	5-10' H ₂ O 100% wet
44	N. Carolina	"	"	Marked Pole	53	6 1/2	10' H ₂ O 20% wet; 3' H ₂ O
45	N. Carolina	"	"	"	35	3 1/2	15% wet; 15' H ₂ O
46	Maryland	"	-	Tape	40-50	4	20% wet
47	Illinois	"	-	"	39	4 3/4	5' H ₂ O 100% wet
48	Pennsylvania	"	-	"	20	3 1/2	8-30' H ₂ O 100% wet
49	Pennsylvania	"	-	"	44	6	2' H ₂ O Variable
50	Pennsylvania	"	-	"	24-30	6 1/2	35% wet
51	Pennsylvania	"	-	"	55	6 1/4	0-8' H ₂ O 50% wet
52	Indiana	"	-	"	26	6	0-6' H ₂ O 50% wet
53	Maryland	"	-	"	65	6 1/4	10-15' H ₂ O 100% wet
54	Pennsylvania	"	-	"	30	4	80% full
55	Maryland	"	-	"	57	6	50% wet
56	Colorado	Drill Steel	Fill to Stemming	Notched Tamping Pole	15-38	4-6	15-40' H ₂ O 100% wet
57	W. Virginia	Cloth & Metal Tape	Tape	Pole Tape	30, 40 & 80	6 1/2 & 3 1/2	4-17' H ₂ O 100% wet
58	California	Tape	Count Bags	Pole	42.5	6 1/4	9-30' H ₂ O 65% wet
59	Iowa	"	Weigh Slurry	"	20-65	6 3/4	0-full H ₂ O 95% wet
50	Maine	"	"	Tape	50-30	6 1/2	1% wet

Quarry Survey Data (cont'd.)

#	Location	Depth	Measure Load	Stem	Depth (ft.)	Dia. (in.)	H ₂ O Cond.
61	Oklahoma	Tape	Count	Pole	24, 32, 20	6 1/8	2% wet 5' H ₂ O or less
62	Alabama	Cloth Tape	Tape	"	35	6 1/2	-
63	Ohio	Steel	"	Tape	15	3	Dry
64	Ohio	Tape	"	"	28	5 5/8	Wet
65	Ohio	"	"	"	33	6 3/4	7' H ₂ O
66	Ohio	"	"	"	52	6 3/4	Wet 7' H ₂ O
67	Ohio	"	"	"	34	6 3/4	Wet 7' H ₂ O
68	Ohio	"	"	"	43	5 5/8	Wet 6' H ₂ O
69	Ohio	"	"	"	11	5 5/8	Wet 3' H ₂ O
70	Ohio	"	"	"	47	6.25	Wet 2' H ₂ O
71	Ohio	"	"	"	80	5 5/8	Wet 1' H ₂ O
72	Ohio	"	"	"	25	6.75	Wet 16' H ₂ O
73	Ohio	Steel	Pole	Pole	11.5	2.5	Dry
74	Ohio	Tape	"	"	20	2.5	Dry
75	Ohio	"	Tape	Tape	29	6.5	Dry
76	Ohio	Steel	Pole	Pole	11	3	Wet 2' H ₂ O
77	Ohio	Tape	Tape	Tape	50	6.5	Wet 3' H ₂ O
78	Ohio	Steel	Pole	Pole	55	1.5	Dry
79	Michigan	Tape	Pole	Pole	12-25	3	10% wet 2' H ₂ O
80	Ohio	"	Tape	Tape	60-80	6 1/4	20% wet 5' H ₂ O
81	Texas	Drilled Steel	"	Pole	20-60	4	Dry
82	Virginia	Tape	Count	Tape	30-60	6 1/2-7 7/8	70% wet 4' H ₂ O
83	Hungary	"	"	Pole	40-140	3	5% wet 3' H ₂ O
84	Hungary	"	Pole	"	80	3	Dry
85	H.C.	"	Count	"	40	4.5	30% wet 2' H ₂ O
86	Georgia	"	Tape	Tape	40-70	5-6 1/4	40% wet 4' H ₂ O
87	Georgia	"	"	"	40	7 7/8	30% wet 6' H ₂ O
88	Georgia	"	"	"	60	6 1/2	30% wet 4' H ₂ O
89	Hungary	"	"	"	100-140	4	10% wet 3' H ₂ O
90	Ohio	"	Count	Pole	60	4	60% wet 20' H ₂ O
91	Hungary	Steel	"	"	180	4	Dry
92	Puerto Rico	Tape	Pole	"	60	4	30% wet 6' H ₂ O

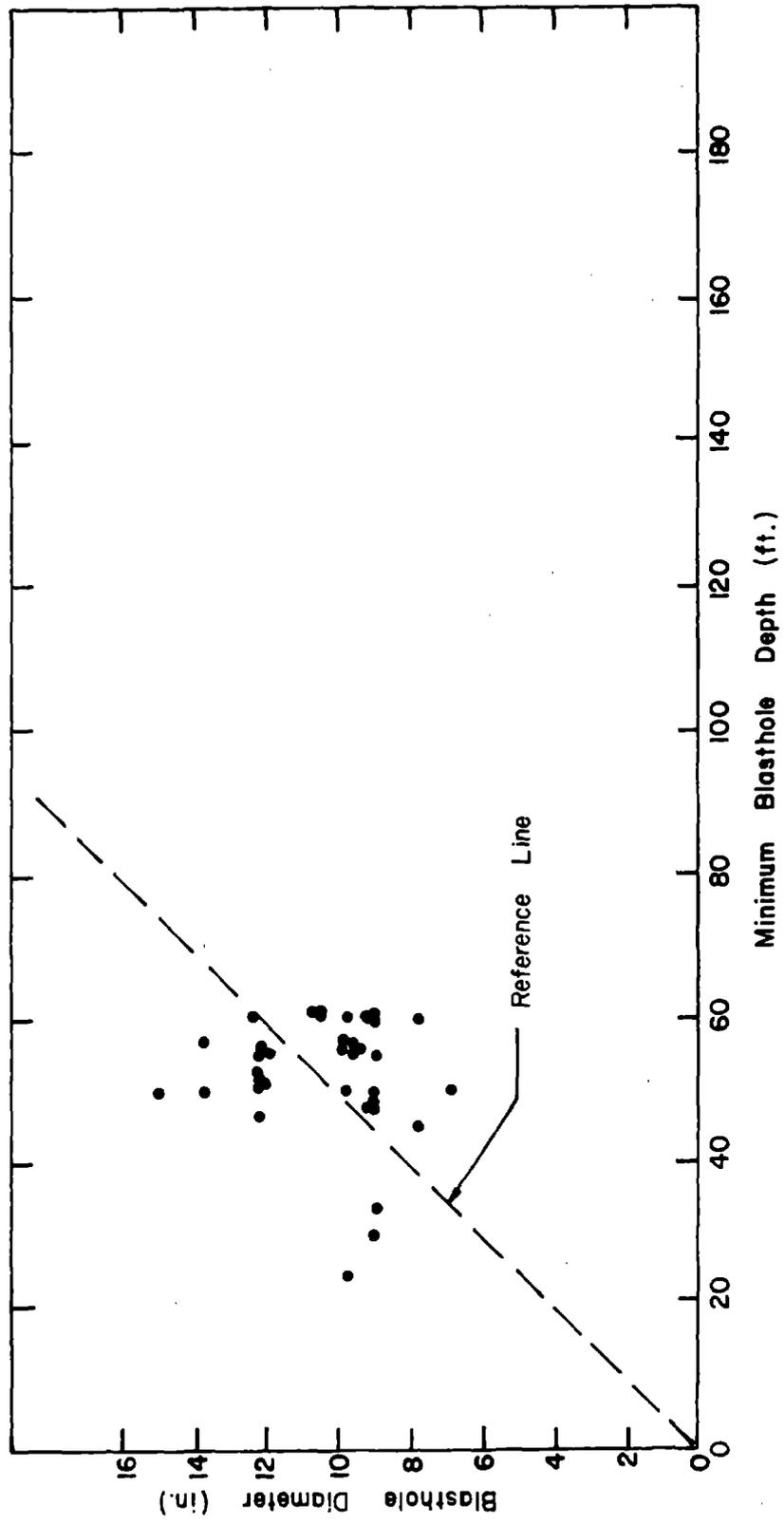


Fig. 2.1: Blasthole Diameter vs. Minimum Blasthole Depth for Domestic Copper Mines (Current)

In stemming height measurements, data obtained from the 30 copper operations indicated that approximately 70% of the operations used a cloth tape for stemming measurement, 3% used a tamping pole, 7% used the knotted rope, and 20% of the operations did not measure stemming length; the reason no stemming length was measured was that a weight or powder load or a cartridge count was used for determining the load in the hole which could be considered a bottom load and thereby operations assumed that more than sufficient stemming would be available above the shot (Figure 2.2(b)).

The measurement technique was compared to the blasthole diameters (Figure 2.3) to determine if there was a correlation between measurement technique and blasthole diameter. Operators used tapes for measuring hole depth in large size blastholes, 12-15" in diameter, and, in blastholes of 9-12" in diameter, tapes were predominately used. As blasthole diameter decreased, the percentage of tape utilization decreased. Either no measurement was taken or some other method was used to measure blasthole depth on smaller diameter holes (Figure 2.3).

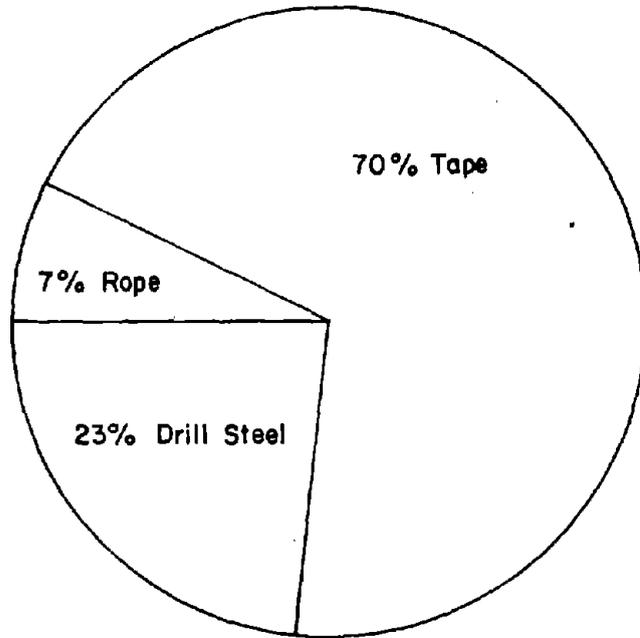
IRON MINES

Blasthole diameter was compared to minimum blasthole depth for iron mining operations (Figure 2.4). The reference line was placed on this figure. Using this line as a reference and comparing data with Figure 1.2, one can see that mines today are using larger diameter, shorter holes than those pre-1970. It can be concluded that the blastholes used today are more broadly dispersed and therefore the stemming height measurements and hole depth measurements are more critical than in the past.

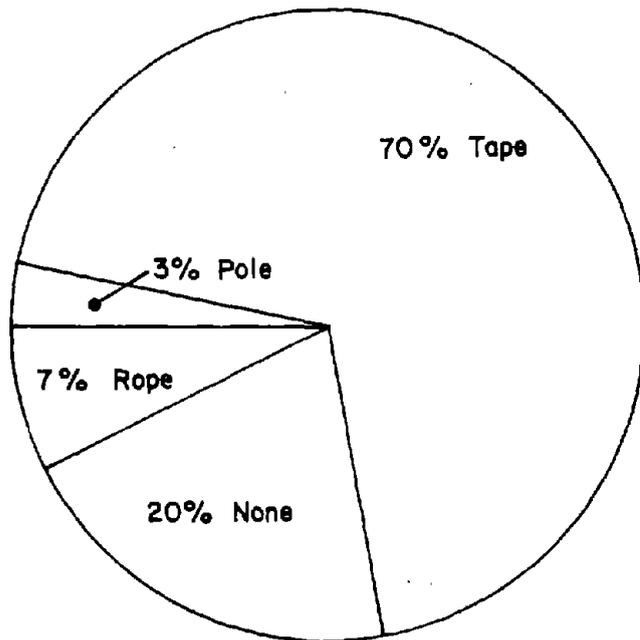
The data from the blasthole depth measurements in iron mines indicated that 100% of the mines used cloth tapes for depth measurement (Figure 2.5(a)).

Data in the stemming height measuring techniques indicated that 100% of the iron mines surveyed used cloth tapes for measuring the stemming height (Figure 2.5(b)).

The data from the iron mines indicated that all mines are shooting at bench height to burden ratios less than two since they are all to the left of the conventional operating conditions line.



a. Hole Depth Measurements



b. Stemming Height Measurements

Fig. 2.2: Statistical Analysis of Measurement Techniques Used in Copper Mines

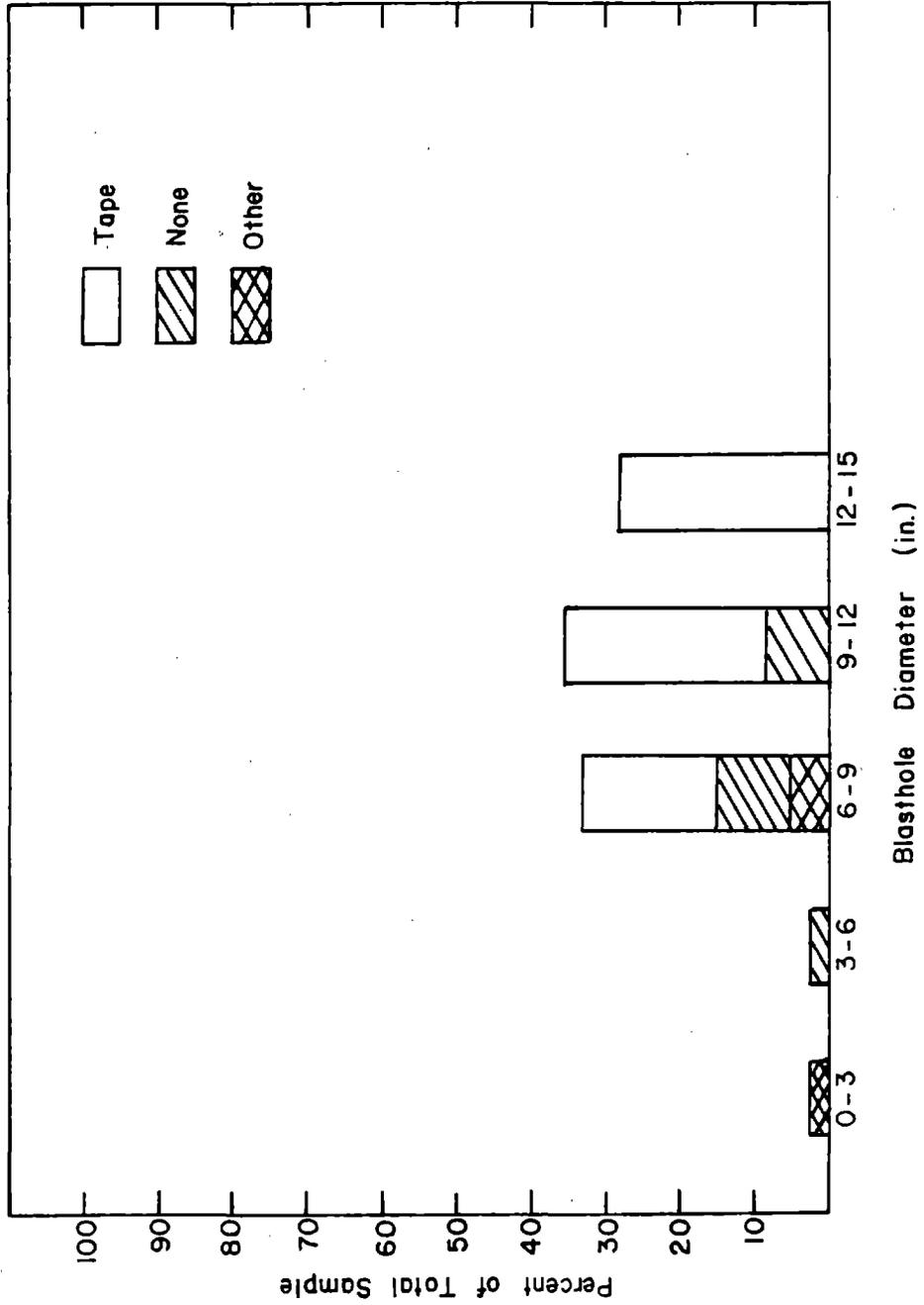


Fig. 2.3: Statistical Analysis of Measurement Technique vs. Blasthole Diameter for Copper Mines

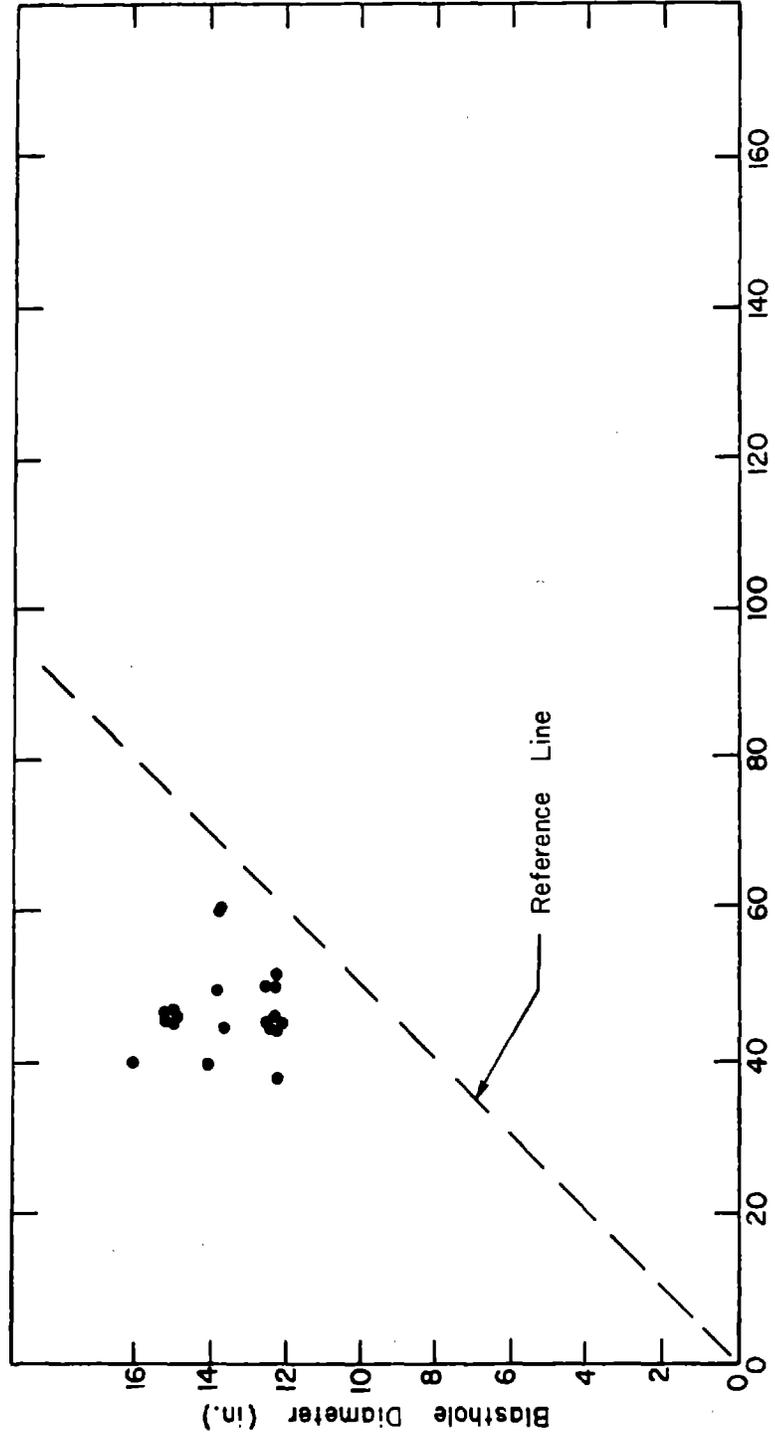
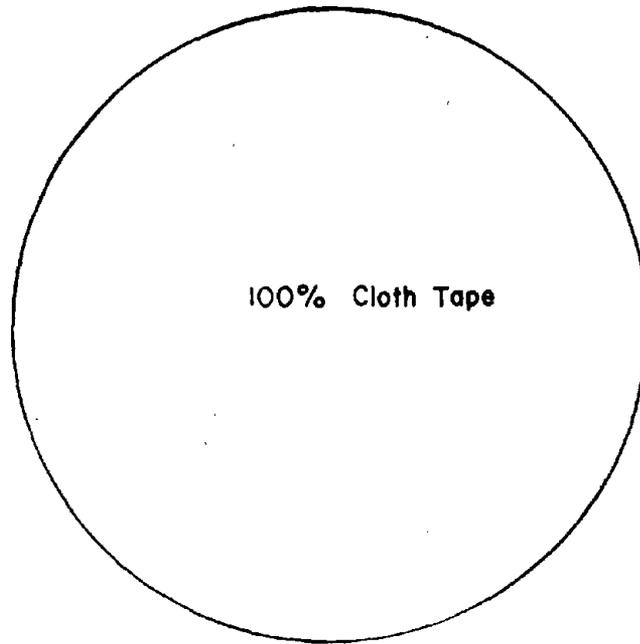
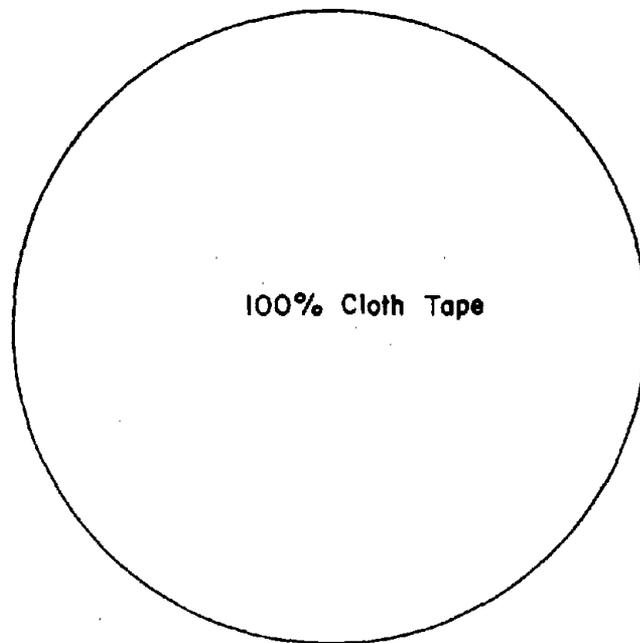


Fig. 2.4: Blasthole Diameter vs. Minimum Blasthole Depth for Iron Mines (current)



a. Hole Depth Measurement



b. Stemming Height Measurement

Fig. 2.5: Statistical Analysis of Measurement Techniques used in Iron Mines

QUARRIES

Blasthole diameter was plotted versus minimum blasthole depth for the 92 quarries surveyed (Figure 2.6). The reference line was placed on this graph as a reference.

Eighty-eight percent of the quarries surveyed used a cloth tape for blasthole depth (Figure 2.7 (a)) measurement; 12% of the quarries relied on drill steel as a measurement tool.

Stemming height measurement in quarries were done with cloth tapes and tamping poles. Seventy-two percent of the quarries surveyed used cloth tapes for stemming measurements, 25% used tamping poles, and 2% used other methods (Figure 2.7(b)).

Measurement techniques were compared to hole depth. Tamping poles were used predominately in holes less than 60 feet long (Figure 2.8). Measurement techniques for stemming were also plotted versus blasthole diameter as indicated in Figure 2.9. The graph indicates that the majority of operations using tamping pole for stemming height measurement were those which had blasthole diameters in the 2-4" range. The graph also indicated that the predominant hole size in quarry operations surveyed was 6-7" in diameter.

WATER CONDITIONS IN BLASTHOLES - MINE SURVEY

Approximately 9% of the iron mines surveyed indicated that their blastholes were totally dry. The remainder, or 91%, of the 11 mines surveyed indicated that some of the blastholes would be wet with varying amounts of water. It could be expected that 20-90% of the blastholes would be wet in the pattern with water depth ranging from 5 to 20 feet.

Of the 30 copper operations surveyed, 7% of the operations reported that they had totally dry blastholes. The remaining 93% of the mines indicated that at least some of their holes are wet some of the time. One mine reported that they had a very slight water problem; only 1% of the holes are wet with water less than 1 ft. deep. The remainder of the mines indicated that at least 5% to 100% of the holes in a pattern could be wet with water ranging from 3 ft. to 27 ft. in depth in the hole.

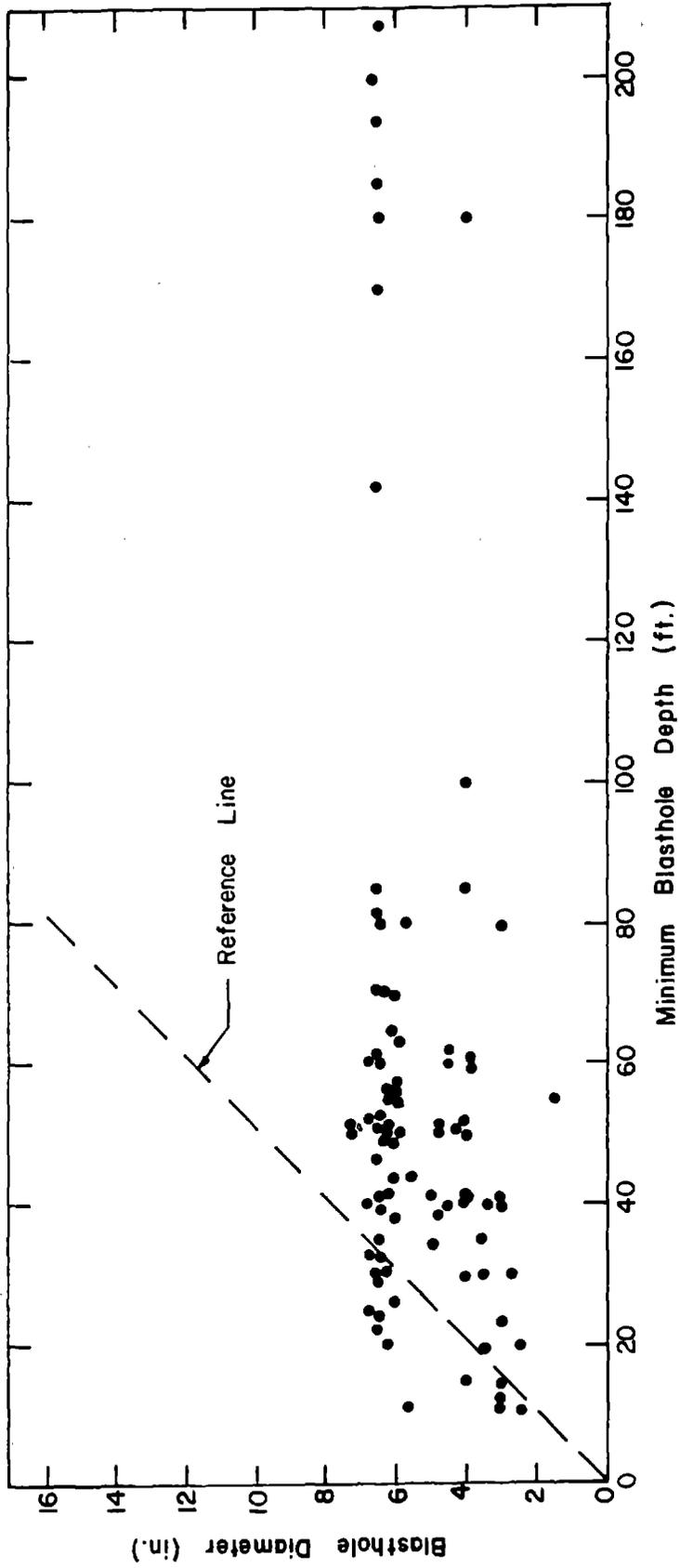
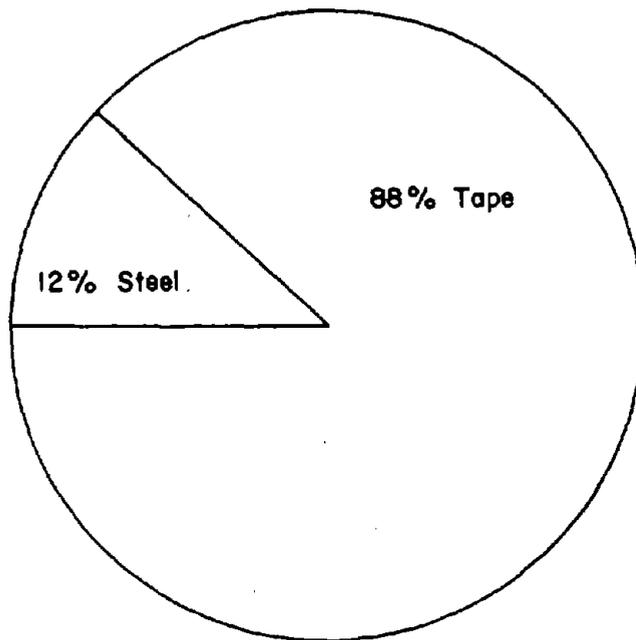
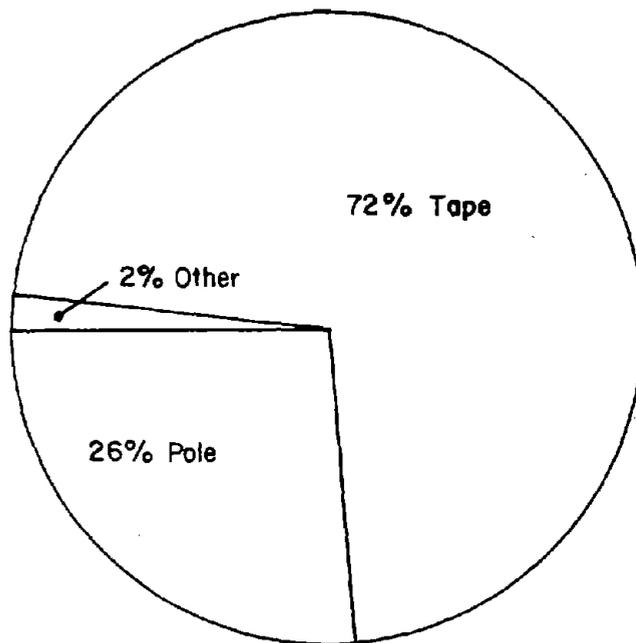


Fig. 2.6: Blasthole Diameter vs. Minimum Blasthole Depth for Quarries (current)



a. Hole Depth Measurement in Quarries



b. Stemming Height Measurement in Quarries

Fig. 2.7: Statistical Analysis of Measurement Techniques Used in Quarries

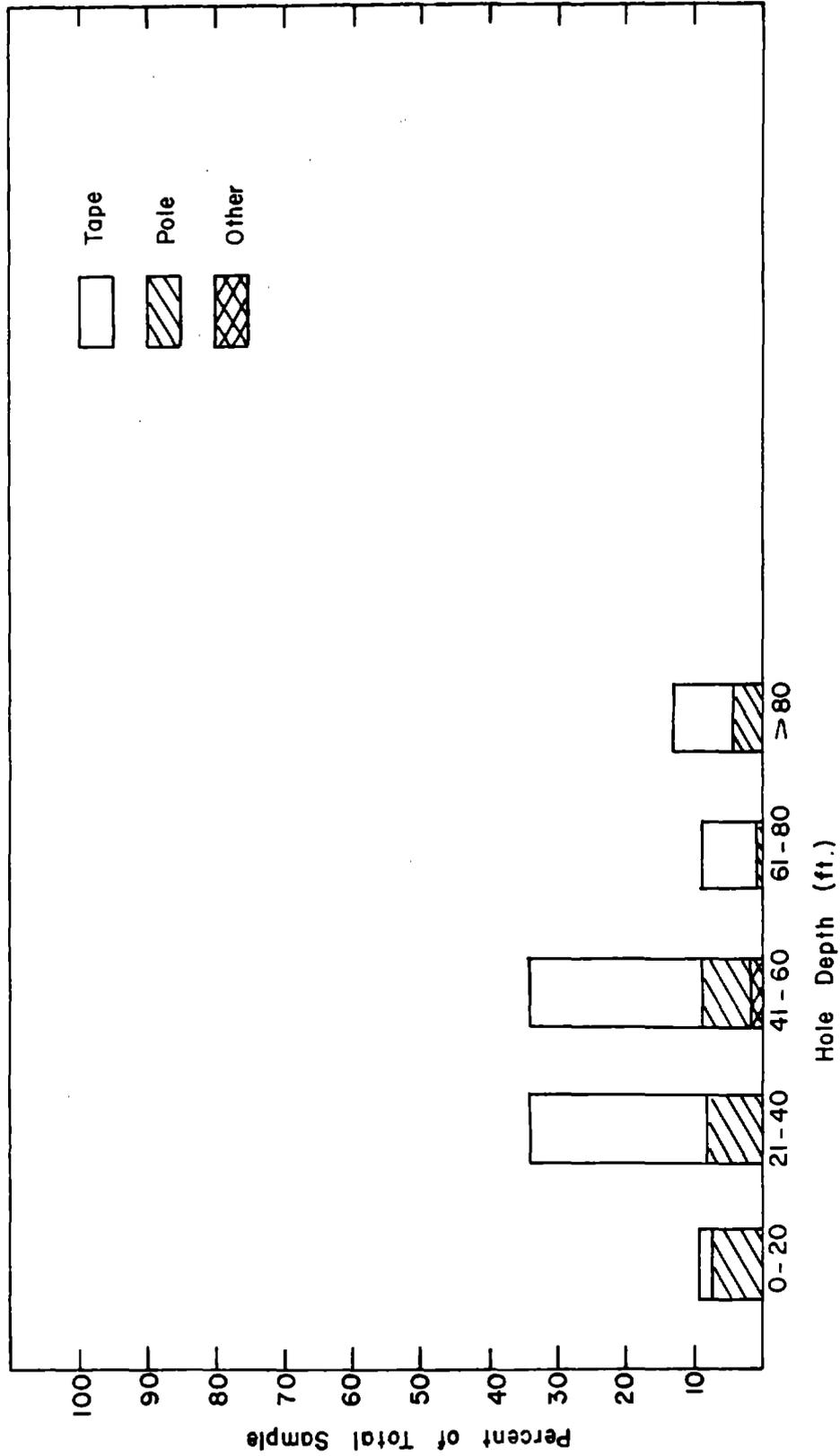


Fig. 2.8: Statistical Analysis of Stemming Measurement Techniques vs. Hole Depth in Quarries

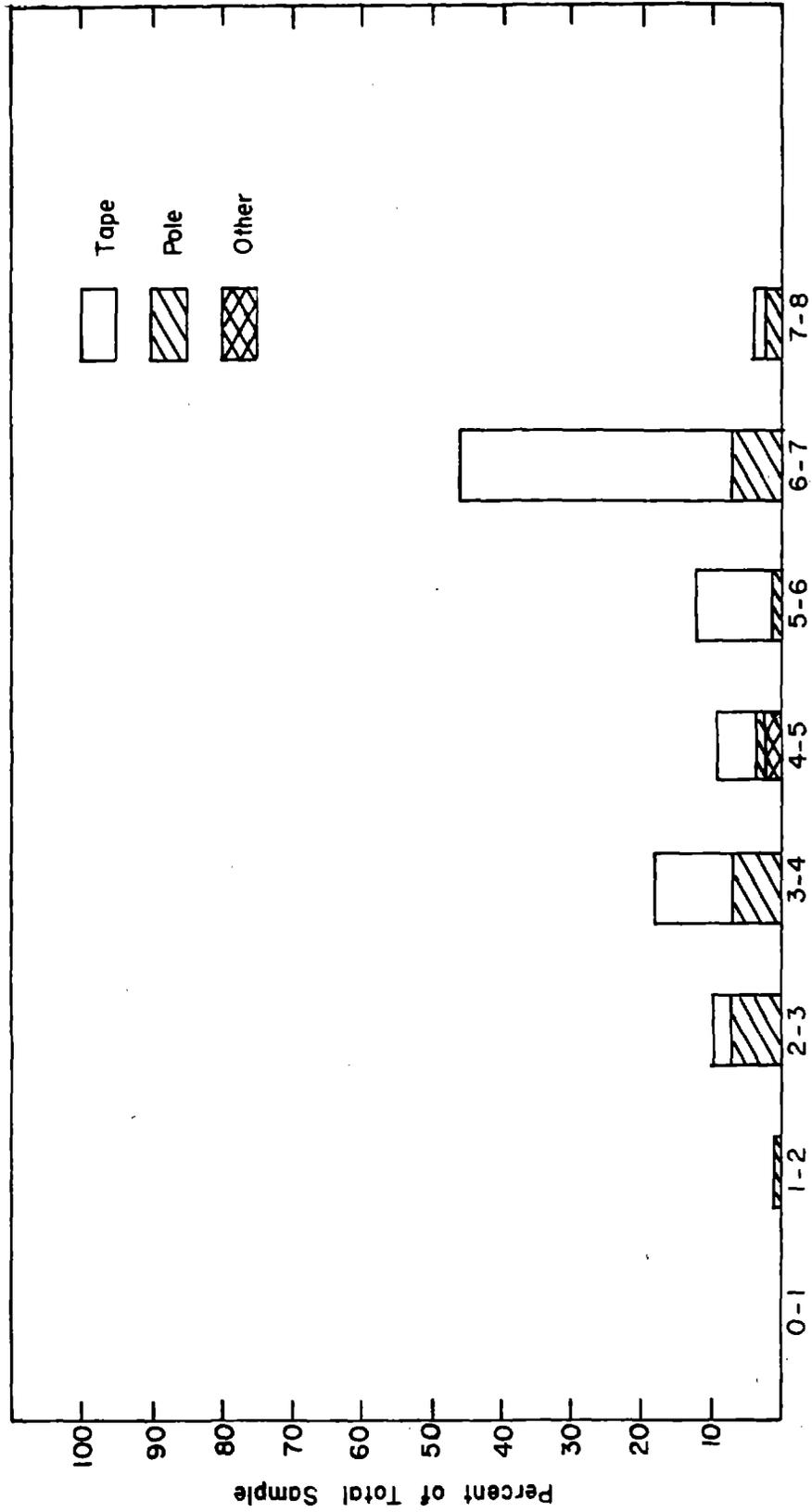


Fig. 2.9: Statistical Analysis of Stemming Measurement Techniques vs. Blasthole Diameter in Quarries

A survey of water conditions in blastholes in quarries produced similar results to those found in iron mines and copper mines. The data from the quarries revealed that 12% of the mines had totally dry blastholes. The remaining 88% of the mines contained some water in some of the holes in the pattern. The water conditions varied from a few wet holes to 100% of the holes in the pattern containing water. The depth of the water could range from 1 to 60 ft. or to water-filled blastholes.

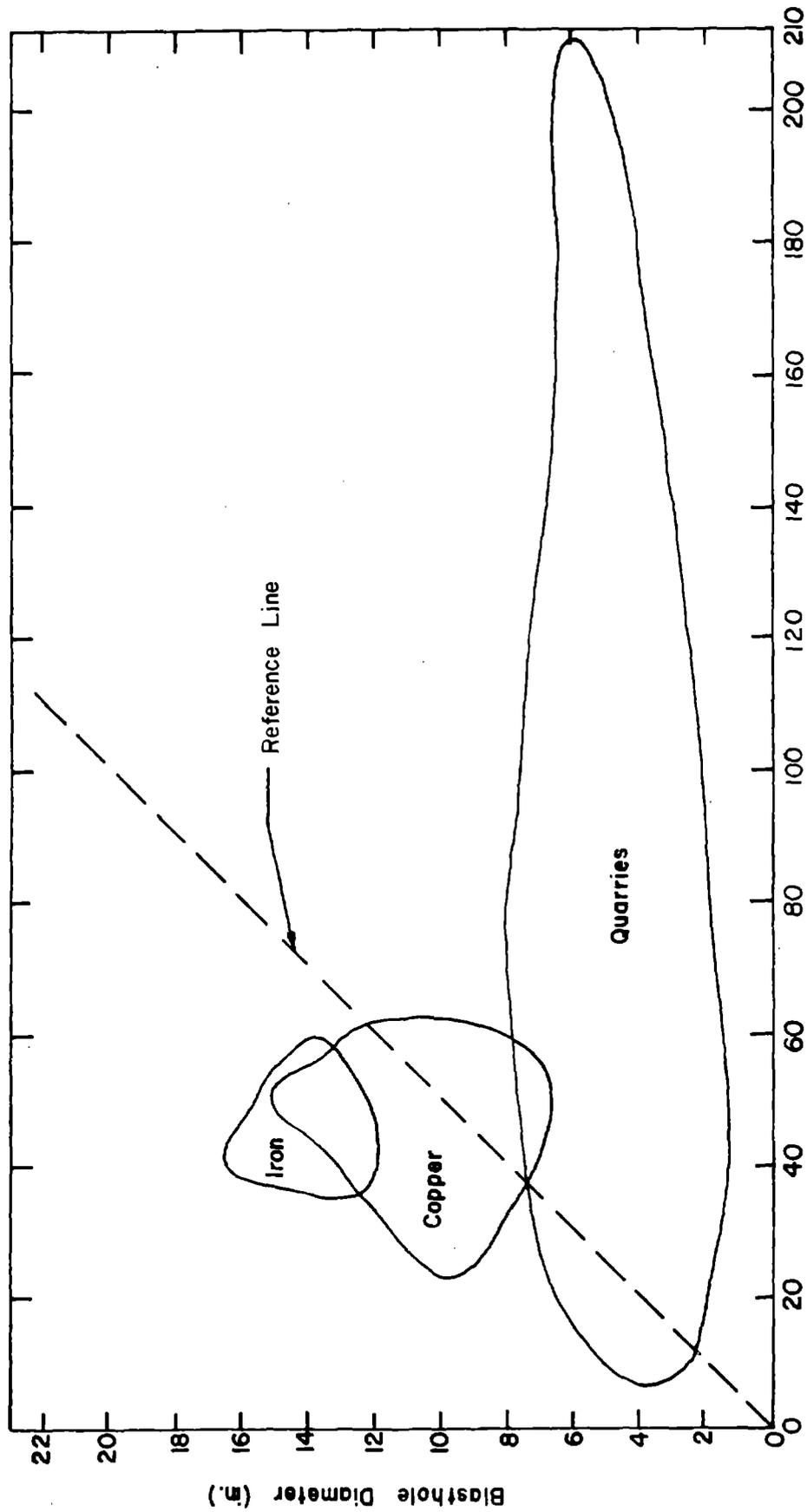
As a result of the study of the water conditions in iron mines, copper mines, and quarries, it is obvious that most operations can expect to have at least some holes in the pattern containing water. Any device that would be considered for measuring blasthole depth must work equally well in dry or water-filled holes. It should be pointed out that measurement accuracy in wet boreholes is more critical than in dry. Wet blastholes, in general, tend to be more violent than dry blastholes. Therefore, if conditions are identical between two different blastholes, the one containing water is more prone to blow-out and production of flyrock and airblast. It can be concluded, therefore, that any borehole depth measurement technique that does not function in water should not be considered further for general application.

The water problem may not be a severe hinderance for stemming height measurement instrumentation. Although blastholes contain water, as indicated in the data, many of the holes are pumped before loading. Therefore, water level would not necessarily be raised by powder fill into the stemming zone. On the other hand, depending on what type of explosive is loaded in the hole, the water could be forced to rise above the explosive column. Bulk slurry loading raises the level of water which appears in the stemming zone.

Water in the stemming zone may affect the measurement technique used. A universally applicable stemming measurement device should work equally well in water-filled or in dry blastholes. However, it may be feasible to develop instrumentation which would only function under dry conditions for use in the operations that had no water problems.

SUMMARY

Blasthole depth measurements in the mines surveyed were accomplished predominantly by cloth tapes and to a lesser extent by drill steel. One hundred percent of the iron mines, 88% of the quarries, and 70% of the copper operations relied on tape usage. Quarries relied on drill steel when tape was not used and copper operations did likewise except for a small percentage which used a knotted rope. Stemming height measurements in the mines surveyed were accomplished predominately with a cloth tape. One hundred percent of the iron mines, 72% of the quarries, and 70% of the copper mines used a cloth tape. The majority of the quarries that did not use a cloth tape relied on a tamping pole whereas the majority of the copper mines that did not use a tape used no stemming measurement system at all and relied primarily on weighted cartridge bottom loads. A comparison of blasthole diameters versus minimum blasthole depths for the three types of operations surveyed is indicated in Figure 2.10. Figure 2.10 contains the reference line. It can be seen from this plot that the majority of the quarries used small diameter, longer holes than did the copper or iron mines. Copper mines in general used smaller diameter holes than iron mines.



Minimum Blasthole Depth (ft.)
 Blasthole Diameter vs. Minimum
 Blasthole Depth for All Mines (current)

SECTION 3

ANALYSIS OF ADEQUACY FOR CURRENTLY USED MEASUREMENT METHODS

INTRODUCTION

In general, the measurement methods used for borehole depths involve comparison by human eye of a physical effect with a standard of length. Such methods are subject to misreading errors of the effect level and of the numerical value of the length standard.

DRILL STEEL

Drilling operations usually provide the first opportunity for hole depth measurement. An operator counts the number of drill steels in the hole at calculated final hole depth. While the primary purpose of drill steel is to load and turn the drill, an important secondary purpose is to provide the first rough basis for measurement. Any error in the rough measurement is not crucial since, customarily, a more careful measurement is made with a weighted cloth tape after the drill steel is withdrawn from the hole.

If a second measurement is omitted, serious difficulty can arise, however, in operator error if a miscount occurs on the number of drill steels. Another source of error is the inadvertant use of drill steels of differing lengths.

Drill steels are durable for their use compared to other measurement devices. They survive as long as the end threads are not stripped or broken and as long as abrasion or rust does not prevent further use. Not often, but occasionally, a drill steel is lost down hole or bent. Longevity is acceptable and a function of use level and of care in use. The steel can also be used to estimate water level in the hole from the length of the wetted tool string.

CLOTH TAPE AND ROPE

The most common method for measuring a completed borehole uses a weighted cloth or rope. The cloth tape has a weight fixed at one end. The weight should be made of non-sparking metal such as aluminum or lead. Sometimes

operators may use a rock or steel bolt for the weight. The weighted tape is dropped to the bottom of the blasthole to indicate the hole depth. The tape is then retracted and the water level is read at the height to which the tape was continuously wetted. The devices are cheap and, with care, reasonably durable. Accurate measurement depends on dropping the tape to hole bottom and having a complete length of tape. The figures on the tape should not be abraded away or covered with mud. Ends break off on occasion and corrections are carried in the memories of the operators. Memories may fail and a misread borehole-depth reading ensues. Even worse, a broken end may not be noticed by individual operators and no correction is made.

Cloth tapes may be stuck downhole by a rock fall in the hole. Even though the end may not be broken off, the tape may be stretched in extrication attempts. Erroneous readings follow.

Sometimes the level of water is difficult to ascertain from a tape as oil level in a car engine is sometimes hard to read on a dipstick. Part of the difficulty may arise if the tape is not re-reeled between readings because of mud or dirt or to avoid time loss. The tape is strung out on the ground and becomes even dirtier or abrades from footsteps or from tire wear when run over by a truck.

A tape is durable for the price and is reliable with reasonable care. The time in service for a tape was found to vary widely depending on intensity of use and level of care. Operators do not worry about tape life or replacement costs because tapes are cheap. No records are kept, therefore, on loss or purchase frequency. Any sizeable operation will maintain several active tapes on site and the supervisor or foreman will try to keep an extra one in his pickup.

Some few operators use a knotted rope to measure depth of a finished borehole. One knot is tied at the length desired and drilling discontinued when the full rope length extends from the knot at the surface to the bottom of the hole. As with tape, lost ends can yield misleading readings. Any common measurement method can accommodate an overdrilled hole by backfilling to the desired weight.

WEIGHED LOAD

The level of powder fill can be determined by counting bags or cartridges or, in the case of slurry, metering a predetermined volume or weight into the bottom of the borehole. The count can be in error and truck meters can lose calibration with wear or temperature changes. Turbines lose fit; valves and meters malfunction. If weight alone is measured, a caved or otherwise obstructed hole can prevent bottom filling and bring about excessive top filling. Room at the top is too confined for adequate stemming and blowout occurs.

TAMPING POLE

A secondary measurement is frequently run during and after powder loading. The weighted tape may be used or a notched or taped pole inserted to the top of the powder or slurry. Error and reliability of tape measurement methods have been treated above. The notched or taped pole can be inserted wrong end up; the tape may fall off. If poles of several lengths are available, the wrong one may be selected.

MEASUREMENT SYSTEM SPECIFICATIONS

The main difficulty with devices used solely for measurement is that they take valuable time and may be used haphazardly or not at all. Blast-int technology is too important to rely on slipshod operation. Labor and powder costs are too high and potential damage associated with bad blasting operation is too great. Opportunity clearly exists for greatly improved technology. Since increasing speed is the benefit most sought, special need exists for safe, remote and reliable measurements at low cost. Measuring system specifications are given in Table 3.1. While any new device proposed for development need not meet the full range of measurement system specifications described in Table 3.1, the device should satisfy the needs for measurement in a particular set of circumstances.

Table 3.1: Measurement System Specifications

<u>Category</u>	<u>Range</u>	<u>Specifications</u>
Linear Measurement		
A. Hole Depth	0-200 feet	Depths 0-200 feet (\pm 0.5 ft. accuracy)
B. Stemming Height	0-40 feet	
C. Water Depth	0-200 feet	Measures water depth 0-200 feet
Blasthole Conditions		
A. Diameter	2-18 inches	Fits 2-18 inch dia- meter blasthole All materials
B. Material	Rock, earth, clay. Weak, strong, stable or unstable.	
C. Water	Empty to full	Measures underwater Line of sight un- necessary.
D. Deviation	May exceed one diameter	
Environmental Conditions		
Terrain	Flat to rugged	Small, lightweight
Temperature	-500 F to 1300 F	Unaffected by temper- ature (-500 to 1300 F)
Immediate surrounding	Explosive, detonators	Safe
Mud	Severe - absent	Works in mud
Lighting	Good - poor	Easily readable
Sound	Quiet - noisy	No audible signals
Operator Qualifications		
A. Education	Elementary - advanced	Easily operated
B. Work habits	Careful - careless	Rugged
Potential Abuse	Abrasion; physical shock	Durable, reliable

SECTION 4

COMMERCIALY AVAILABLE MEASUREMENT DEVICES

TRANSFER FROM OTHER APPLICATIONS

Many techniques have been developed to measure in areas of application other than blasting. Some may be transferred unmodified into use for blasthole, water depth or stemming height measurements. Others require some modification. The devices are listed; their possible blasting application described, feasibility estimated, and obvious modification needs flagged.

DEVICES

Devices listed are commercially available in the U.S. Their development has presumably required investment of capital and time. A very large advantage for blasting application would be a possible cost reduction since research and development costs are already paid off or such costs would be paid off faster with the expected increase which blasting provides to total market. Time to the stage of full development and commercialization would be shortened also since much of the work is done. Finally, any such transferrable device should be debugged for its present use and as a result be far more accurate and reliable in blasting applications.

Devices in commercial use elsewhere permit distance measurement by determining the time interval for reception of a sonic echo from the hole bottom, the water surface, or powder surface. Commercially available are an instant camera focussing device and an echo-detecting instrument specifically appropriate for distance measurement. A borehole measurement device was manufactured for underground use in the early 1970's based on the echo detecting system (3). The device is no longer in production.

Working on a different principle sludge level indicators can also be used on water in a borehole. A well-water depth indicator on a cable can also measure water depth (4, 5). The study identified 81 companies which market water level indicators and sensors.

Similarly, ground radar (6, 7) can detect subsurface voids and might measure borehole and water depths even though application to powder-filled spaces might prove to be hazardous. Subsurface electrical resistivity devices, theoretically capable of recording spaces underground, similarly risk powder detonation.

Down-hole, petroleum-well logging devices use the entire range of radiation frequencies, particle types and intensities for measuring reservoir characteristics. Well-depth is determined from a reel odometer tracking the cable or a wire which is run to bottom hole from the surface. Corrections for stretched cable are not usually made, although in principle, hole depth is greater than cable length measured at the off-reel. More detail follows.

SONIC ECHO DEVICES

Section 3 of this report listed features essential to the successful application of sonic echo principles to blasthole measurements. The instant camera device and the sonic tape instrument utilize similar principles and technology. Use is simple; the device is reasonable in cost considering the opportunity for repeated use and read out is digital to reduce likelihood of transcription error. Energy level is low so that premature ignition should not be a problem. The device seems appropriate for use on blasting sites. The problem with reflectance at water level in a wet hole would be suitable for research and development. A sonic tape is commercially available (8). It has the capability of measuring distance from 2.7 feet to 60 feet with an accuracy of \pm one inch.

FLOAT LEVEL INDICATORS

A large number of float level indicators is available from the chemical processing industry or, in the case of sludge level indicators, from the pollution control industry. Any of these could, by invasive methodology, be used to measure either slurry level or water level as well as hole depth. One device uses an infra-red source and beam whose interruption is recorded as water or sludge level (9). Float level or sludge

level indicators could presumably be used without development. Cost effectiveness: investment and repair seem to render the system non-feasible.

RADAR

Numerous devices have been developed for void detection underground by use of radar (6, 7). These are commercial but tend to show high initial and maintenance costs. The prospect of igniting a powder column prematurely with microwave radiation through the ground or the blasting initiation wire grid is not attractive.

ELECTRICAL RESISTIVITY

Electrical resistivity devices seem to provide the same advantages and suffer the same disadvantages as radar devices.

DISPOSABLE MEASURING DEVICES

Several disposable measuring devices are commercially available. These devices could have application in measurement of blasthole depth or stemming height. A disposable tape is available and is used by plumbers.

A number of different types of cloth "chains" are also used for distance measurements in the mining industry. These devices function by counting the length of thread removed from a container. The thread can be cut and the counter reset for the next measurement. The counters hold from 6,000 to 15,000 feet of thread. Measurement accuracy is claimed to be 99.9% (10).

SUMMARY

Each of the devices is currently available for any required research and development effort. As with devices which are only potentially valuable in borehole measurement applications, commercial devices of special

interest include those which are invasive as with the well-logging cable odometer or those which use relatively low energy for remote sensing as the sonic echo measuring devices.

SECTION 5

POTENTIAL METHODS OF BLASTHOLE DEPTH, WATER AND STEMMING LENGTH MEASUREMENTS

MEASUREMENT AND PROCEDURE

All possible methods of hole depth, water and stemming length measurements may be divided into two broad categories: invasive and non-invasive. The invasive methods lower something into the hole; most commonly, a weighted measuring tape. The non-invasive methods are also referred to as remote sensing methods. In these methods some form of radiation which is most probably but not necessarily transmitted and received by a device on the surface, is used to gauge the depth of the hole. Electromagnetic radiation is one possibility. The specific types, depending on frequency, include both light beams and microwaves. Acoustic waves might also be used. A third possibility is radiation from a radioactive source.

The present study endeavored to look at a broad spectrum of invasive and non-invasive types. The effort considered physical principles first and possible methods of implementation second. This approach has resulted in a wide variety of ideas. Many of these ideas are impractical by reason of high cost, excessive complexity, questionable safety or low reliability. However, several show definite, practical possibilities. The low-priority methods are discussed first in the following paragraphs. Later, methods of greatest potential are presented in more detail.

INVASIVE METHODS

IRRETRIEVABLE

Invasive methods using modifications of the existing disposable tape or cloth string chain discussed in Section 4 could be developed. However, practical water depth measurements would not result. Although invasive methods are usually variations of the measuring tape, they could include one of the remote sensing methods. In the latter case, a small transmitter placed at or dropped to the bottom of the borehole would permit calculation of depth from the transmission-path properties from hole

bottom to a receiver on the surface. Either the transmitting device would have to be disposable at very low cost, or the device would have to be recovered after each measurement. The recovery device would have to be lowered on a cable and the cable itself could as well be used as the measuring device. A levitating transmitter is difficult to visualize. A small radioactive source was considered briefly as a possible disposable transmitter but was rejected as unsafe since the radioactive material would be widely scattered by blasting. Another problem was deemed as important for transmitters of other non-reflected radiation as for optical methods: the hole may deviate from straightness and a radiation beam from the bottom would not be visible from the surface.

RETRIEVABLE

Weighted Tapes

From a practical standpoint, invasive methods seem to be limited to the tape measure or a variation.

Tape readout could be automated by storing the tape on a small hand-wound or electrically operated winch connected to a counting device calibrated to read directly in depth. The device could be completely encased with a tape slot and clear dial protector. A switch on the weight at the end of the tape could be used to sense the bottom of the hole and stop the winch automatically. The same switch would activate a counter. The same switch could be activated at water depth by a float and indicate water depth. However, this would require electric circuit conductors in the hoisting cable, which adds to the complexity of the cable and increases cost while reducing reliability. Another method would use a spring-loaded, idler pulley on the winch. The pulley would sense reduced tension when the weight reached the bottom of the hole and could operate a microswitch to stop the winch. This method could be used for holes partially filled with water. If the weight were partially hollow, buoyancy could be adjusted to produce a measurable reduction in cable tension when the weight enters the water. A second depth-indicating counter could then be controlled by another microswitch sensitive to this change in tension. One counter would then read the depth to water while the other read the

total depth. A problem with wall friction interferences would require a solution. A tape system utilizing fiber optics to activate counters is also conceivable.

A practical refinement to such a system would be some means of cleaning the tape exiting the hole. The tape would pass through a washing tank and between brushes; then over a squeegee to remove the excess water before reaching the tension sensing pulleys and the take-up reel. Although the term tape is used, a wire cable would do as well since no markings are required on the tape itself. A cable would be easier to handle and cheaper to replace than a tape.

Stretched Tape

Another possible method of measuring depth, using an unmarked tape or wire, makes use of the modulus of elasticity of the tape. The tape, with a heavy weight attached, is first lowered to the bottom of the hole. The measuring device at the surface then applies sufficient tension to take up any slack without lifting the weight. The tension is then increased by a known amount. The tape will stretch to a new length depending on the modulus of elasticity and the original length of tape being stretched, which is the depth of the hole. The stretch would be measured on a gauge calibrated to read directly in depth.

A variation of this system would use a disposable tape to eliminate the problem of tape cleaning. The same concept obviates the need for tape removal and reinsertion after powder loading. The tape would first be lowered to the bottom of the hole and the initial depth measured as already described. Explosives, or other filling material, would then be added leaving the tape in place. The measuring device would then be reattached to the tape and a new measurement taken. The method assumes that the fill will pack sufficiently so that the tape is effectively held at the top of the filling and only the portion of the tape above the powder column will stretch. There may be some filling materials for which this method would not be satisfactory.

A good deal depends on the properties of the tape. A tape would be preferable to a wire for this application since it would provide a larger surface area for frictional contact with the fill material. The tape surface

should also be rough for the same reason but not so rough that there would be significant drag on the sides of the hole, above the fill, if the hole is not perfectly straight. The modulus of elasticity of the tape should also be such that tape of adequate measuring length will stretch an inch or two when a tension of five to ten pounds is applied. A plastic tape or a reinforced impregnated paper would seem suitable. The weight used with the disposable tape would itself have to be disposable and the combination be of high uniformity and low cost. High uniformity is needed to prevent necking in the tape and yielding false values.

Others

Other invasive methods considered were an electrically resistive tape, a microwave twin-wire transmission line and a pressure transducer on the end of a cable. The first of these would employ a tape whose electrical resistance per foot was known. The tape would be lowered into the hole with an end weight designed to make electrical contact with the bottom. The depth would be shown by a resistance measurement between the top end of the tape and ground, using low level currents. The tape would be disposable. With water in the hole the resistance would indicate the depth of the water or, with slurry, depth to the top of an explosive slurry. The idea was set back in priority because of uncertainty about the contact resistance at the end of the tape and the possibility of errors if the tape came in contact with the wet sides of the hole.

Twin-Wire Transmission

The twin-wire transmission line should be considered. The system would consist of a length of the 300-ohm twin lead popular for connecting TV antennas. One end of the line would be attached to a weight and lowered into the hole as before. The two wires would be connected together where they are attached to the weight. The end at the surface would be connected to a time-domain reflectometer type of cable tester. A matching transformer would be required at the point of connection. The instrument transmits a low voltage step with a fast rise-time down the line and displays any re-

sulting reflections on a CRT display. A strong reflection would be observed from the far end of the line where the wires are short circuited. Dials and scales on the instrument allow the distance to this reflection, and hence the depth of the hole, to be read directly.

If the hole were partly filled with water a reflection would be observed from the surface of the water because of the difference in dielectric constant between water and air. UHF and microwave signals, such as are present in the pulse, are absorbed rapidly in water so that reflections would not be seen from anything more than a few inches below the water surface. Thus the method could not determine the initial depth of a hole partly filled with water unless the length of cable used were measured directly.

If the cable were left in the hole and explosives were then added, the top of the explosives would give rise to a reflection which would permit the new depth to be measured. This method depends on the velocity of the pulse on the cable. With the cable in the center of the borehole this should be close to the velocity in the air. The main drawback with the system is that the cable would certainly be in contact with the wall of the hole in some places. While these places would probably be visible as reflections, they would also cause an unknown pulse velocity whose size would be difficult to determine and which would be a potential source of error. Cost of cable is not low.

Pressure Transducer

A pressure transducer can be used as a very sensitive altimeter to determine depth. However, a very sensitive instrument is also prone to damage. Unless disposable, not connected, and in radio contact, a transducer is redundant and a supporting cable may be used also as the measuring device. A pressure transducer would work very well to measure the depth of water in the hole since the pressure under water would be much greater. However, the device would still have to be lowered or dropped to the bottom of the hole.

Electrically Conductive - Water

Another invasive method can be used which includes a cloth or plastic tape. Bare electrical conducting wires are woven into the tape. The conducting wires are shorted by water standing in the borehole. A tape operating as is currently done or under one of the modifications described earlier would add to its capabilities an easy measurement of water depth by means of a resistance gauge in the reel. The length of wire determined from its total resistance as far as the water level would give distance downward. Alternatively, the amount of wire shorted out by water could be indicated after the weighted end touched hole bottom and the water depth calculated within the reel. Read out would be indicated on a liquid crystal display, LED, or printed out strip on a tape. Some operators might try to use the device on a hole with a live powder charge. The advisability of using even slight currents in the hole under such circumstances requires serious thought.

Water-Sensitive Dye

A dye is sometimes used in dessicants to indicate by color change when saturation occurs. The usual change is from blue to light pink. A conventional or novel measuring tape would have a water sensitive dye bonded to its surface. When the tape reaches hole bottom, the part wetted would change color and be observed after the tape is retrieved. Measurement could either be visual or colorimetric. Repeated measurements may be a problem. Additional research would be needed to determine if this system is feasible.

Mud-Resistant Fiber

A tape could be woven of a fiber which resists soiling. One such fiber is Teflon - a fluorinated polyethylene. The tape could also simultaneously incorporate a set of bare resistance wires or could be covered with dye to provide means of water-depth measurement. Teflon tape is currently manufactured.

Heat Sensors

Hole depth measurements based on a known local geothermal gradient could be conceived because of the relative ease and low cost of very precise temperature difference measurement. However, after drilling, time is needed to re-establish steady state geothermal temperatures. Ground or surface water could also enter to yield temperature, and therefore depth values which were incorrect and either too high or too low. The heat sensor may have application in determining water depth within a blasthole. The method does not seem suitable for the pace of drilling, measuring, loading and blasting which are currently employed.

NON-INVASIVE METHODS

RADIATION SOURCES

Remote sensing methods are obviously very attractive. Many advantages in speed and low expense accrue with remote measurement. However, the remote methods suffer their own drawbacks. The three forms of radiation which may be used for this purpose are light beams, microwaves and sound waves. Unfortunately two out of these three may be rather quickly rejected. Light offers a potentially very precise means of measuring distance. Laser range finders are available commercially and operate on the same principle as radar. The time for a pulse to travel to a distant target and back is used to measure distance. These devices would be excellent for the present application provided the boreholes were always straight. However, if the bottom is not within line-of-sight from the surface, the method is inappropriate.

MICROWAVES

Except for the case of a metal-cased hole, microwaves are equally handicapped. For the sake of completeness, microwaves will be mentioned. The problem with trying to transmit microwaves down an air-filled hole bored in rock or other dielectric material is that the energy is not confined in the hole but spreads into the surrounding medium.

The energy reflecting from the bottom of the hole and returning for detection to the source will be too small to detect easily. A surface wave could be transmitted along the wall of the hole, using a specially designed antenna. If the energy could be largely confined to the wall of the hole, it might be possible to obtain good reflections from the bottom of the hole or a water interface. Loss in the material surrounding the hole would be prohibitive if moisture is present as is frequently the case. The energy would only travel a few feet. An uncertainty results also as to the dielectric constant of the rock and hence, the wave velocity. The method might have limited application in dry ground where the dielectric constant is known or where the dielectric constant could be determined. One hole could be measured by more conventional means and the dielectric constant and wave velocity assumed to be the same for neighboring holes.

ACOUSTIC WAVES - RESONANT

Acoustic waves offer the greatest promise for a single remote sensing method of hole-depth measurement. The resonant properties of organ pipes are well known. A borehole may be treated as an organ pipe and its depth determined from its resonant frequency. The fundamental frequency would be very low, for example about 2.8 Hz for a 100-ft. hole. However, higher harmonic resonances could be used at which it would be easier to determine the point of resonance. A simple loudspeaker, of suitable weatherproof design, would be mounted in a flat plate placed over the mouth of the hole. The speaker would be driven by a variable frequency oscillator. A phase meter, monitoring the relative phase of the voltage and current being fed to the speaker, could be used more accurately than the ear of the operator to determine resonance. Two adjacent harmonic resonances would be located from which the depth of the hole could be determined. The frequency control could be calibrated directly in feet.

Such a method depends on the velocity of sound which is a function of both temperature and humidity. The humidity effect is quite small and fortunately the temperature below ground is normally fairly constant. Humidity and temperature variations should not be serious factors unless non-uniform heating occurs at the sides of the hole during the drilling process.

If moisture and temperature were a problem, a slightly-invasive hygrometer and a thermocouple could be used to compensate.

ACOUSTIC WAVES - REFLECTED

An alternative to the resonant frequency method is to use a sonar system. This is similar to radar in that a pulse of energy, microwave or sound is transmitted and the time for a reflection from a distant object, in this case the bottom of the hole, to return to the source point is measured. The same loudspeaker arrangement could be used. A pulse generator would be used to drive the loudspeaker. The same speaker, connected to an amplifier through a directional coupler, could be used to receive the reflected pulse. The transmitted and received pulse would be used as start and stop signals, respectively, for a digital timer. Such timers are commercially available and operate by counting cycles of a crystal controlled oscillator. For example, sound travels about 560 ft. round-trip in one second. If a 560-Hz oscillator were used in the timer, the count would be directly in feet. A 5600-Hz oscillator would count in tenths of feet. A small microprocessor could be used to control the pulse transmission and counting sequence. Temperature compensation could be added by suspending a small temperature sensor a few feet below the loudspeaker, to measure the temperature of the air in the hole, and using this information to make a final adjustment in the oscillator frequency. A similar device is available on an automatic focussing, instant camera.

Either of the acoustic methods described would measure the depth to the bottom of a dry hole or to the water surface of a wet one. Water depth would be difficult to measure accurately this way because the high contrast between air and water both in density and modulus of elasticity results in high energy loss from interface reflection. The resonant frequency method would be very difficult to adapt but the sonar method with high gain amplifiers and range gating might permit detection of a reflection from the hole bottom below the water. There is a further problem below the water, however; the density and bulk modulus of elasticity of water are much closer to those of the surrounding earth than are those of air. This will increase the rate of transfer of sound energy to the

surroundings with the result that the depth range which is measurable below water would be severely limited. Further study and tests would be required to determine if acoustic methods could be applied to a water-filled hole.

An underwater acoustic transducer, in place of the surface loud-speaker, would eliminate the losses caused by the air-to-water interface. Such transducers are used in echo-sounders and the popular fish-finders. However, such a transducer requires a radio capability which is expensive or would have to be lowered into the hole until it reached the water which puts it back into the class of invasive methods. This system would be subject to the same attenuation losses as the former in the water-filled portion of the hole. Thus, while acoustic methods are ideal for measuring the depth of dry holes or the depth to the water surface of partially filled holes, their use underwater is more difficult to visualize. Perhaps a limited application in a rock-lined, water-free hole would be suitable if not when the surrounding medium is porous and largely water-filled.

NEW METHODS CONSIDERED FOR DEVELOPMENT

Several of the proposed methods possibly could be developed into practical instruments. The following paragraphs show how development might proceed. The new methods considered do not include such items as disposable tapes, cloth chains, sonic tapes, or sludge guns which are currently available and could be adopted with slight modifications.

AUTOMATIC WEIGHT-AND-LINE SYSTEM

The method illustrated in Figure 5-1 is a variation with advantages of the weighted measuring tape. The method reduces some tape-handling problems. Kinking is reduced and dirty tapes are avoided as are tape stretching and the errors involved. Wire length is remeasured during each use. Cleaning water could be recycled through a small filter or replenished at lunch break or more often if needed.

The partially hollow weight shown in Figure 5.1 is attached to a stainless steel wire. After use, the wire passes first through a washing tank to remove any mud acquired in the hole and then over a spring-loaded pulley, designed to sense tension; another pulley coupled to two electronic counters, calibrated in feet of wire travel; and finally to a take-up reel driven by an electric motor. In operation, the device is placed over the hole with the weight at the surface. An electrical control system, not shown in the figure, starts and resets both counters. A winch lowers the weight into the hole. If there is water in the hole, the weight experiences buoyancy significant because of a partially hollow construction. The buoyancy reduces tension in the wire. The spring contracts slightly, operating one of the microswitches (S1), which in turn stops one of the counters and records the depth to the water surface. The tension is further reduced when the weight reaches the bottom of the hole. Contact with bottom operates the second microswitch (S2), stopping both the second counter and the winch motor. The second counter shows hole depth. The winch is reversed and the wire rewound. A third microswitch, not shown, senses the arrival of the weight at the top of the hole and stops the winch. The two readings remain on the counters until reset. The system operates from a rechargeable battery.

DISPOSABLE ELASTIC TAPE SYSTEM

This system avoids the need to recover the tape and obviates the cleaning problem. The tape remains in the hole permanently, and is used for depth and stemming length, thus saving some time compared to several measurements in the same hole. The key to the system is a special tape with a known Young's modulus. The system is illustrated in Figure 5.2. Tape from a supply reel is lowered into the hole with a disposable weight on the end. When the weight reaches the bottom of the hole, the tape is cut off the reel leaving a few feet excess. The free end should be pegged to the ground to prevent its being lost down the hole before attachment. The tape would be consumed in the blast; contribute energy to break rock and not provide debris in the muck pile.

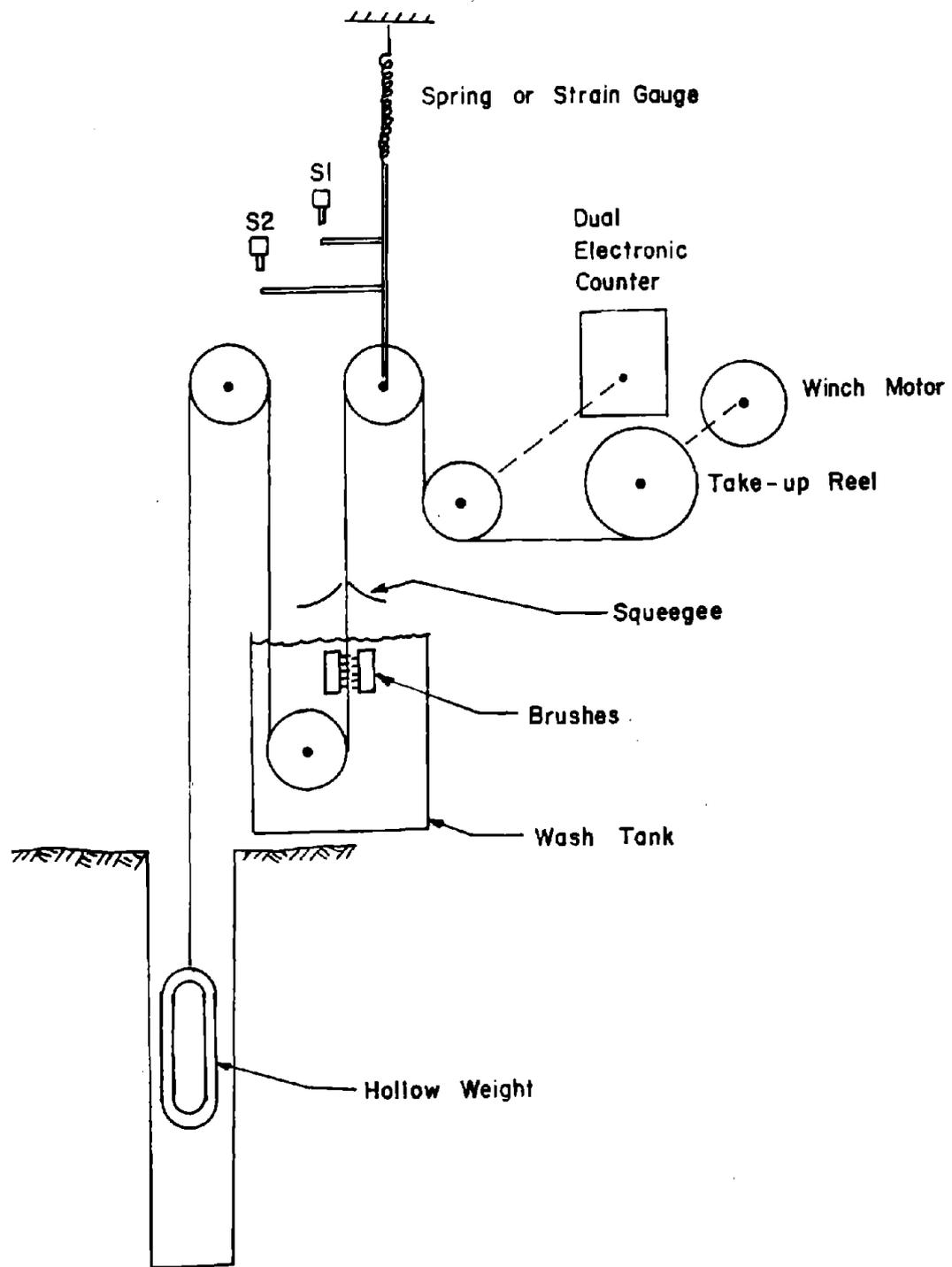


Fig. 5.1: Automatic Weight-and-Line System

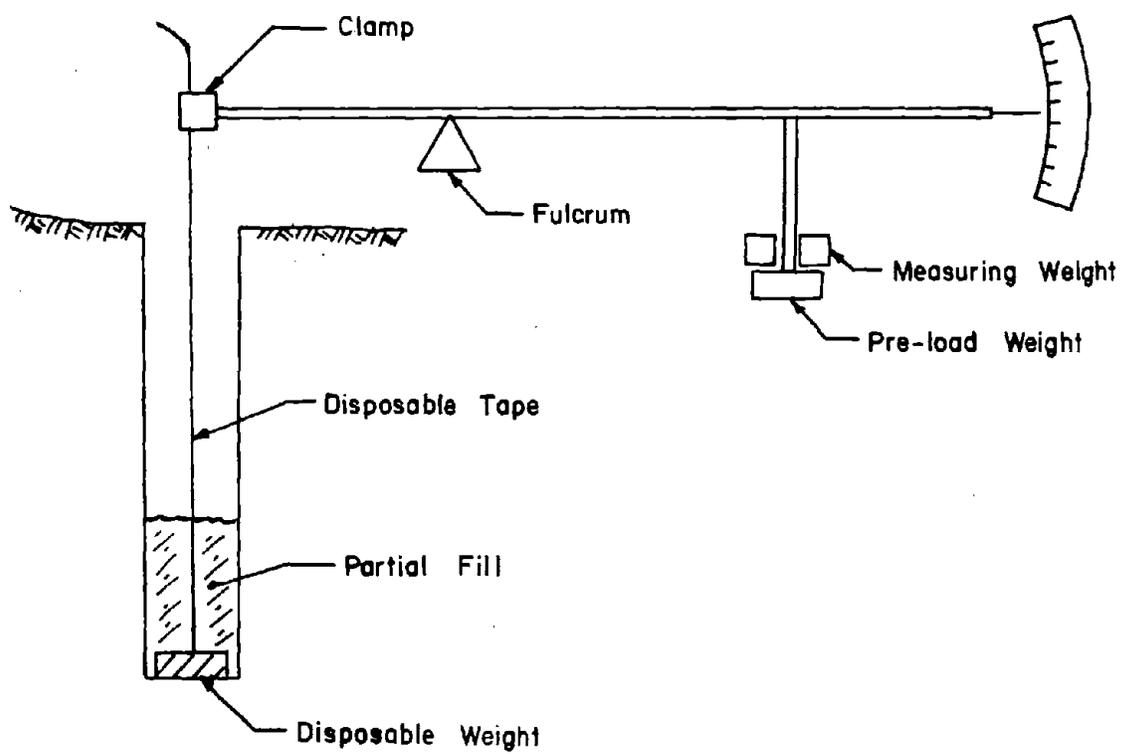


Fig. 5.2: Disposable Elastic Tape System

To take a measurement, the balance (or strain gauge substituted for balance) shown in Figure 5-2 is brought to the hole with the clamp over the hole and the fulcrum, which would be some form of tripod, on the ground. The measuring weight is removed; the beam is held approximately horizontal; the tape is held taut and the clamp is secured to the tape. The scale shown in the figure is moveable. It is adjusted until the pointer is on zero. The measuring weight is then added to stretch the tape and allow the pointer to move over the scale. The amount of stretch depends on Young's modulus of the tape and on its length. Since the modulus is designed into the system, stretch is proportional to hole depth. The scale is calibrated directly in depth.

After the measurement of hole depth is completed, the clamp is released and the balance removed. Powder and, later, stemming material may be added to the hole. When it is desired to take another depth reading, to determine the new depths, the previous procedure is repeated. Success relies upon fill packed tightly enough to grip the tape so that only the part above the fill stretches. A reduced length will stretch less and hence give a smaller depth reading to top of the powder column. The remaining hole depth is available for stemming.

ACOUSTIC RESONANCE

This is the most promising non-invasive method and is illustrated in Figure 5.3. The hole is resonated like an organ pipe and the resonant frequency determines hole depth. In this application there will normally be a node at the bottom of the hole and an antinode at the top. Resonances will occur whenever the frequency is such that the depth of the hole is an odd number of quarter wavelengths. Figure 5.3 (a) shows the case for three quarters of a wavelength, the second resonance. The fundamental frequency is very low so higher harmonics may be more convenient in use. It is not necessary to know exactly which harmonics are being used provided an adjacent pair is chosen.

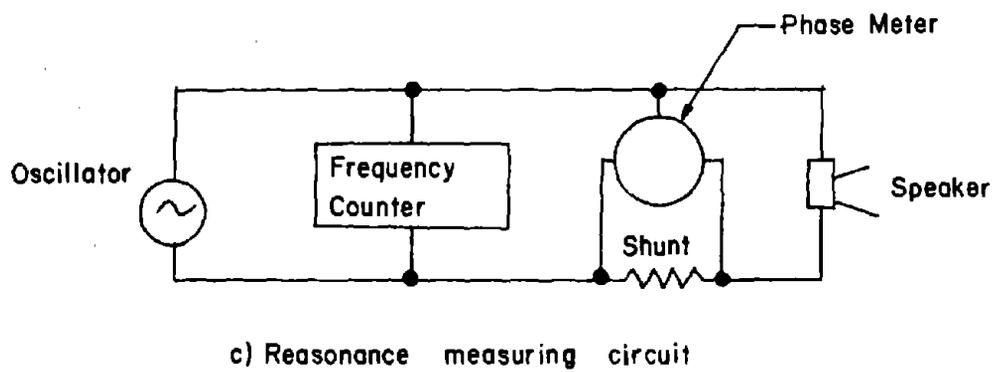
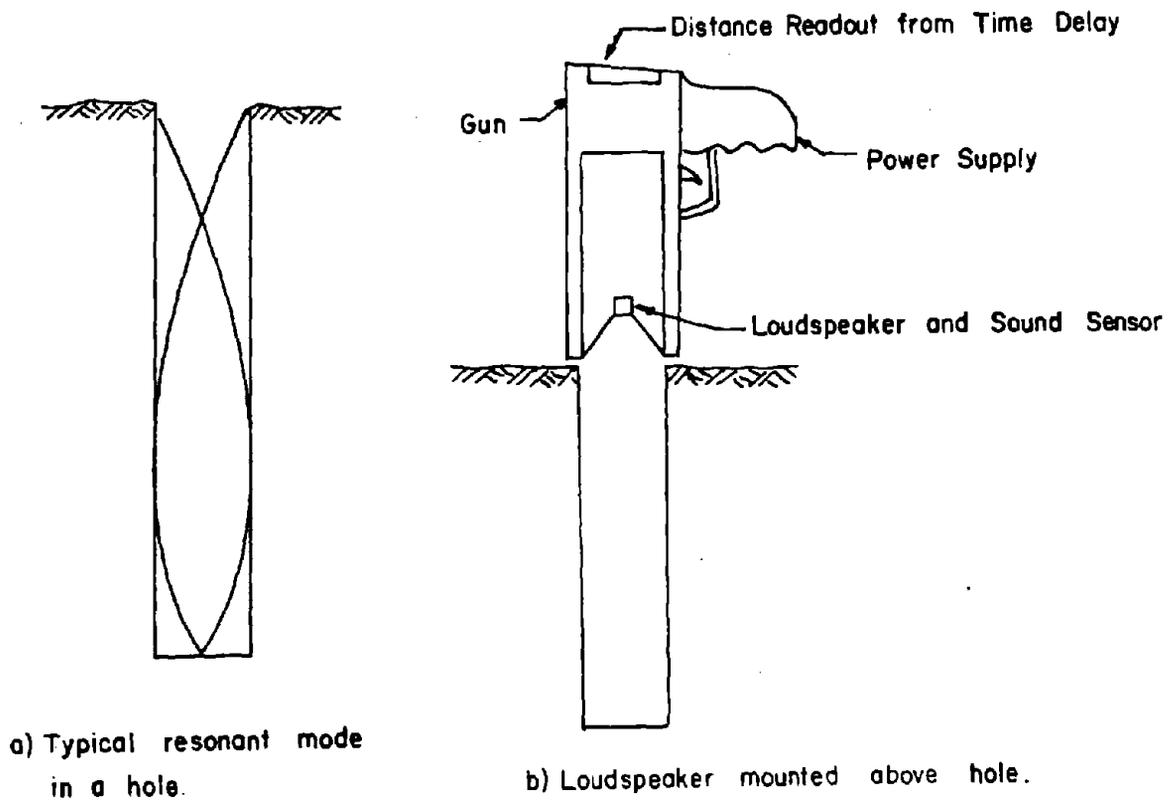


Fig. 5.3: Acoustic Resonance Method

Components

The essential components of this system would be a loudspeaker mounted over the hole and an oscillator to drive it. Figure 4-3(b) shows such a loudspeaker. It would be of a weatherproof type and mounted in a flat plate which would be placed over the hole. A weatherproof housing around the speaker provides protection but is acoustically open at the back. Vents allow free air passage behind the speaker. The speaker is driven by a variable frequency oscillator, Figure 4-3(c). Resonances could be determined by a phase meter. The meter monitors the phase angle between the voltage delivered to the speaker and the current measured across the shunt. The angle approaches ninety degrees at resonance. A frequency counter is the most accurate method of measuring frequency. One resonance would be found and the frequency noted. The next higher resonance would then be located and the frequency read again. The depth could be calculated from these two frequencies. Alternatively a simple integrated circuit, such as those used in pocket calculators, could be incorporated into the system to perform the calculation automatically.

SONAR METHOD

This is not illustrated but the equipment would be rather similar to that used in the acoustic resonance method. The same loudspeaker would serve. The oscillator would be replaced by a pulse generator and the frequency counter by a timer. The general operation of such a method was discussed in an earlier section.

SECTION 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Measurement methods currently employed can be used to provide measurements adequate for blasting applications. Drill steel, weighted tape, notched poles, bag or cartridge count and slurry meters, alone or in combination, provide information on blasthole depth, water depth, powder column height and stemming height with an accuracy which is well within the range of design, geological, and operating variabilities. However, the long time required for a measurement cycle and occasional losses of calibration indicate that development of alternative measurement devices is timely.

The range of variables and of devices currently in use were determined from a literature search and from mine surveys. Results are summarized in Table 6.1. Conditions of use are similarly described and the characteristics or qualities desirable in a measurement device are included.

Boreholes were found to vary greatly in diameter (2-18 inches), length (10-200'), rock type, and water conditions (wet to dry). Powder columns could stretch to 185 feet and stemming heights as great as 35 feet are known.

Field conditions cover the range of continental temperatures and rainfall levels. Measurement devices resist physical abuse and shock and must be operable with little training by busy mine operators whose low profit margin precludes high levels of investment, whether in time or cash. The immediate surroundings are occupied by explosives which can be easily detonated. Data show a movement in time toward larger hole-diameters which increases the risk of blow-out and motivates development of better measuring devices.

A measuring device must be safe, quick, simple-to-operate, accurate (± 6 inches), cheap, durable, rugged, and easy-to-read. The prevalence of dry blastholes or dry stemming zones in some regions may provide an opportunity for dry hole measurement systems of hole depth or stemming height. Most operators, however, do not know in advance that a given hole is dry. This is only determined after measurement. A measurement system, therefore, that would not function in water would not have universal application. A reliable dry hole measurement system may be

valuable, but it will only solve a portion of the measurement problem. The ideal measurement device would work equally well in wet or dry blastholes.

Borehole depth measurement methodologies in current use are low-cost to purchase, simple, durable and readily available. They include weighted tapes, stemming poles, bag counts, slurry metering and drilling steel count. Measurement technologies in present practice are often inaccurate, time-consuming if done properly, and easily influenced by operator error.

The evaluation matrix shown in Table 6.1 summarizes and quantifies relative merits of potential measurement methodologies.

Candidate measuring techniques with best potential for improvement over the present weighted tape method are: disposable tapes, string chains or acoustic resonance methods for dry blastholes, and in addition modified sludge indicators or automated readout tapes. These devices could be used in either wet or dry blastholes.

Table 6.1: Research Evaluation Matrix for Potential Research and Development
(Rating: 5-Excellent to 1-Poor)

<u>Method</u>	<u>System</u>	<u>Technical</u>	<u>Safety</u>	<u>Durable</u>	<u>Underwater Operation</u>	<u>Economic</u>
Invasive	Disposable Tape	5	5	4	1	5
	String Chain	5	5	4	1	5
	Automated Readout Tape	5	5	4	4	4
	Stretched Tape	3	5	3	1	5
	Chemical Dye Tape	1	5	4	3	5
	Resistance Wire Tape	4	4	4	3	3
Non-Invasive	Sludge Level Indicator	5	4	3	5	3
	Sonic Tape	4	5	3	1	4
	Acoustic Resonance	4	5	3	1	3

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Appendix A
Blast Design Data -
Literature Survey

Table A.1: Drilling Data - Copper (1970)

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Mine	Material	No. Drills	Type Drill	Penetration Rate, Fph	Hole Diameter, In.	Advance Blasthole Drilling, No. Holes
1.....	All	1	Rotary	75	9	Nil
2.....	All	4	Rotary	41	9, 12¼, 13¾	NA
3.....	Ore	1	Rotary	85	9¾	25
	Waste	2	Rotary	85	9¾	50
4.....	Ore	NA	Rotary	80	9¾	20
	Waste	NA	Rotary	110	9¾	50
5.....	All	6	Rotary	49	9	NA
6.....	All	2	Rotary	40	9	NA
7.....	All	4	Rotary	46	9	NA
	All	1	Rotary	74	9	NA
	All	1	Rotary	44	9	NA
8.....	All	7	Rotary	48.4	10¾, 12¼	NA
9.....	Ore	1	Rotary	22.8	6¾, 9	NA
	Waste	1	Rotary	24	6¾, 9	NA
10.....	Ore	1	Rotary	30	9¾	245
11.....	All	NA	Rotary	43	6¾	30
12.....	All	2	Rotary	75	9¾	NA
13.....	All	2	Rotary	68.2	9	None
15.....	Ore	3	Rotary and	75	6¾	Minimal
	Waste		DTH	65	6¾	Minimal
16.....	Ore	5	Rotary	48	4¾	NA
	Waste			64	5¾	NA
17.....	Waste	5	Rotary	80.9	9¾	250
18.....	All	5	Rotary	80	9, 9¾	NA
19.....	All	1	Rotary	37	9	NA
	All	2	Rotary	50	9	NA
20.....	All	1	Rotary	60	12¼	NA
	All	1	Rotary	70	9¾	NA
21.....	Waste	7	Rotary	37.5	12¼	NA
	Leach	1	Rotary	50.0	12¼, 13¾	NA
	Ore	1	Rotary	56.3	13¾, 15	NA
	Flux	1	Rotary	22.0	7¾	NA
22.....	All	5	Rotary	90.0	12¼, 13¾	160
23.....	Waste	NA	Rotary	37.5	12¼	15
	Leach	NA	Rotary	45	12¼	15
	Ore	NA	Rotary	34.45	12¼, 10¾	65
24.....	All	4	Rotary	NA	12¼	NA
25.....	All	4	Rotary	35	9¾	NA
26.....	All	3	Rotary	45	7¾	45
27.....	Ore	4	Percussion	53	2¾	NA
28.....	All,	4	Rotary			
	15-20,000 psi,			49.2	9¾	100
	50,000 psi			29.4	9¾	1,000
29.....	All	2	Percussion	24.6	4	NA
30.....	Ore	2	Rotary	45	9	NA
	Waste	2	Rotary	70	9	NA
31.....	Ore	2	Percussion,	52	4	NA
	Waste	2	DTH	23	7¾	NA
32.....	All	2	Rotary	53	9¾, 12¼	NA
33.....	All	5	Rotary	45	9¾, 12¼	NA
34.....	All	4	Rotary	50	9¾	45
35.....	All	3	Percussion	65	3	NA
36.....	All	2	Rotary	40	6¼, 6¾	0

Data from: Cummins, A. B., Given, I. A., SME Mining Engineers Handbook, Vol. 2, AIME, New York, 1973

Table A.2: Blast Design Data - Copper (1970)

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Mine	Material	Pattern*	No. Holes	Rows	Spacing, Ft.	Burden, Ft.	Tons Blasted	Powder Factor, Lb per Ton	Explosives Used†	Ore Density, Cu Ft per Ton	Bench Hr., Ft.	Subgrade Drilling, Ft.	Stemming, Ft.	Water Conds.
1	All material	17 F	150	8-10	15	7.5	100,000	0.78	ANFO	18.0	25	7	12	Mod.
	Ore									25	7	12		
	Waste									25	7	12		
2	All	1 H	20	1	27	2,200	84,000	0.67	ANFO & MS	12.4	50	5	28	Mod.
	Waste					ea yd								
3	All	5 F	40	2	24	24	80,000	0.80	ANFO & S	11.5	40	9	23	Mod.
4	Overburden	16 B	50	3	20	NA	NA	0.35	ANFO & S	11.5	40	9	23	Mod.
	Waste	16 B	40	3	18	NA	NA	0.35	ANFO & S	11.5	40	9	23	Mod.
	Ore	16 B	20	2	18 x 20	NA	NA	0.325	ANFO & S	11.5	40	9	23	Mod.
5	All	1 C	8-10	1	21	21	24-30,000	0.18	S & C	12.0	33	7	20	Mod.
6	Ore	6 F	14	4	32	16	28,000	0.453	ANFO & S	12.0	40	5	24	Mod.
	Ore & waste	6 F	14	4	36	18	28,000	0.388	ANFO & S	12.0	35	5	15	Mod.
7	Seismic velocity:									NA	35	5	16	Mod.
	0-2400 fpa	5 F	40	4	36	30	121,000	0.38	ANFO	12.9	25	9	25	None
	2,500-4,000	5 F	40	4	30	27	91,000	0.50	ANFO	12.9	35	9	25	None
	4,100-6,000	5 F	40	4	24	21	66,000	0.81	ANFO	12.9	35	9	25	None
	6,100-15,000	5 F	40	4	21	18	42,000	1.08	ANFO	12.9	35	9	25	None
8	Ore													
	Waste													
	Altered rock	1 H	100	1	22	30	260,000	0.256	ANFO	12.2	49	6	30	Varied
	Porphyry	1 H	100	1	18	30	240,000	0.263	ANFO	12.2	49	6	30	Varied
	Contact zone	1 H	100	1	15	30	220,000	0.288	ANFO	12.2	49	6	30	Varied
9	Ore	14 E	21	3	16	15	27,300	0.40	MS	7.0	49	6	30	Mod.
	Waste	14 E	24	3	20	20	30,061	0.82	MS	7.0	49	6	17	Mod.
10	Ore	4 E	80-100	2-5	33	26	NA	0.66	S & MS	12.2	36	6	17	Mod.
11	Overburden	15 D	70	4	16	16	150,000	0.15	ANFO & S	12.2	49	6	5	Mod.
	Leach	15 D	70	4	14	14	140,000	0.15	ANFO & S	12.2	49	6	27	Slight
	Ore	15 D	70	4	12	12	129,000	0.15	ANFO & S	12.2	49	6	27	Slight
12	Overburden	6 H	100	4	25	25	NA	0.25	ANFO & S	12.5	40	5	27	Slight
	Rock	6 H	100	4	23	23	200,000	0.45	ANFO & S	12.5	45	6	22	Mod.
13	Soft	3 A	5	1	25	45	40,000	0.167	ANFO & S	12.4	45	6	22	Mod.
	Medium	3 A	5	1	22	40	22,000	0.182	ANFO & S	12.5	50	8	26	Slight
	Hard	3 A	6	1	20	45	30,000	0.200	ANFO & S	12.5	50	8	26	Slight
15	Ore	5 C	24	2-3	14	14	11,400	0.37	ANFO & MS	11.8	50	8	26	Slight
	Waste	5 C	18	1-2	12	12	4,800	0.50	ANFO & MS	11.8	20	2.5	12	Slight
	Waste	5 C	18	1-2	14	14	8,800	0.35	ANFO & MS	11.8	20	2.5	12	Slight
16	Sandstone	NA	20	3	17.8	17.8	NA	NA	ANFO	11.8	20	2.5	12	Slight
17	Waste	6 H	40-70	2-4	40	32	Up to 240,000	0.24	S	14.7	NA	NA	NA	None
18	All	4 F	40	4	26	12	94,000	0.30	ANFO & S	12.8	60	5	28	Slight
19	All	14 C	21-30	2-3	10	10	NA	0.34	ANFO, S, MS	12.6	40	12	27	Mod.
20	All	6 E	60-80	2	22-28	26-22	192-204,000	0.50	ANFO & S	12.5	40	10	25	Varied
21	Soft	3 D	Varies	1	45	21	360,000	0.85	ANFO & coal	12.0	60	8	26	Mod.
	Medium	3 D	Varies	1	39	21	240,000	0.80	ANFO & coal	12.0	60	15	35	Slight
	Hard	3 D	Varies	1	36	21	160,000	0.80	ANFO & coal	12.5	50	15	35	Slight
22	All	2 F	18	1	39	32	160,000	0.18	ANFO & MS	12.3	60	15	34	Slight
23	Hard	2 F	15	1	21	10	45,000	1.00	ANFO & S	12.5	50	14	32	Mod.
	Soft	2 F	15	1	24	12	50,500	0.75	ANFO & S	12.5	50	14	32	Mod.
	Medium	2 F	15	1	24	12	51,750	0.875	ANFO & S	12.5	50	14	32	Mod.
24	Ore	3 F	15	1	33	21	55,000	3.8	MS	12.5	40	10	32	Mod.
25	All	14 G	48	3-4	28	22	48-86,000	0.56	ANFO & S	7.7-11.8	40	5	15	Mod.
26	All	NA C	30	2-3	20-27	18-20	38,000	0.32	S	12.8	33	8	18	Mod.
27	Ore	NA	180	3	6	6	15,000	0.45	ADY	8.4	NA	NA	NA	Mod.
28	-10,000 psi	14 D	200	7-10	28	24	12,700,000	0.50	S	10.0	41	7	15	Slight
	15-20,000 psi	14 D	100	3-5	24	22	31,500,000	0.61	S	10.0	41	7	15	Slight
	50,000 psi	14 D	30	3-5	24	24	32,100,000	0.67	S	10.0	41	7	15	Slight
29	Limestone	14 C	18	3	12	12	NA	0.20	ANFO	12.5	20	4	8	Slight
30	All	4 E	25	2	21 x 18	9	60,000	0.43	ANFO	11.7	40	12	22	Slight
31	Ore	9 D	40	3-6	7-8	6-7	9,000	0.80	ANFO, ADY	11.0	40	4	9	Mod.
	Waste	9 D	30	3-4	22-24	11-12	28,000	0.45	& MS	11.0	40	4	9	Mod.
32	Ore	5 E & F	40	4	40	20	109,650	0.45	ANFO & S	12.0	50	8	32	Mod.
	Waste	5 E & F	28	5	36	18	83,710	0.40	ANFO & S	12.0	50	8	32	to
	Overburden	5 E & F	20	4	44	22	58,050	0.18	ANFO & S	12.0	50	8	32	Reverse
33	Ore	17 H	60	2	25	12	156,000	0.32	ANFO & S	12.5	60	7	30	Mod.
	Waste	17 H	60	2	30	15	200,000	0.32	ANFO & S	12.5	60	7	30	Mod.
34	Ore	17 E	90	6	32	16	180,000	0.35	ANFO & MS	12.0	40	5	18	Slight
	Leach	17 E	60	5	35	25	180,000	0.30	ANFO & MS	12.0	40	5	18	Slight
	Waste	17 E	90	6	32	16	180,000	0.35	ANFO & MS	12.0	40	5	18	Slight
35	Ore	5 B	240	6	3	10	1,300	0.22	ANFO & GDY	NA	28	6	4	Slight
36	Ore	14 F	18	2	21	18	24,000	0.24	ANFO & S	12.3	33	7	16	Mod.
	Ore	14 F	17	3	23	20	22,000	0.22	ANFO & S	12.3	33	7	16	Mod.
	Waste	14 F	25	3	25	21	33,000	0.15	ANFO & S	12.3	33	7	16	Severe

* Patterns not to scale.

† Explosive used: ANFO, ammonium nitrate and fuel oil; GDY, gelatin dynamite; ADY, ammonium dynamite; S, slurry; C, carbomite; AGY, ammonium gelatin dynamite; MS, metallized slurry.

‡ G, gyratory crusher; J, jaw crusher.

Data from: Cummins, A. B., Given, I. A., SME Mining Engineers Handbook, Vol. 2, AIME, New York, 1973

Table A.3: Blast Design Data - Iron (1967)

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Mine			Drilling				Typical Blast			
No.	Name	Material (See Table 13.4-1)	Drill & Type	Bit Type (1)	Hole Size (in.)	Penetration Rate (fph)	Pattern (2)	Powder Factor (lb/ft.)	Explosive Used	Primer
1	Reserve	Ore Waste	JET		9	20	7L	0.8	ANFO, S	
2	Erie	Ore Waste	JET ROTO		9 12½	20	7	0.5-0.8	ANFO, S, MS	
3	Sherman Group	Ore Waste	ROTO ROTO	3C-CI 3C-CI	9-9½ 9-9½	60 45-60	8D 7D	0.3 0.5	ANFO, LVBA ANFO, S, MS	HDP-1 HDP-1
4	South Agnew	Ore Waste	Churu	Blade	9	5-10	7D	0.3	HVBA	HDP-1
5	Hill Annex	Ore Waste	DTH DTH	CI CI	6½ 6½	43 23-36	6D 8D	0.3 0.3	ANFO EL 654	HDP-1 HDP-1
6	Algoma	Ore Waste	DTH DTH	X X	7½ 7½	20 20	7D 7D	1.1 1.1	S ANFO	Titan Titan
7	Empire	Ore Waste	ROTO & DTH ROTO & DTH	3C-CI 3C-CI	9-9½ 9-9½	18.6-14.6 18.6-14.6	7E 7E	0.44 0.45	ANFO ANFO	Titan 500 Titan 500
8	Humboldt	Ore Waste	JET ROTO	3C-CI	9 9	11.2 14.7	7E 7E	0.7 0.7	S S	Booster Booster
9	Groveland	Ore Waste	JET DTH	DTH Br.	8-13 7½	21 15-20	8E 8E	0.5 1.0	ANFO, S, MS ANFO, MS	HDP-1 HDP-1
10	Benson	Ore Waste	ROTO ROTO	3C-CI HH-IJ	7½ 7½	50 45	6D 6D	0.59 0.59	FRBA FRBA	HDP-1 HDP-1
11	Atlantic City	Ore Waste	ROTO ROTO	CI CI	9½ 9½	11.5 18	6E 6E	0.17-0.39 0.12-0.28	ANFO, MS ANFO, MS	PETN PETN
12	Lone Star	Ore Waste	ROTO ROTO	BD 600 BD 600	4½ 4½	40	1C 1C	0.1 0.1	Nitro Starch 40% Nitro Starch 40%	None None
13	Lindsay	Ore Waste	ROTO ROTO	HF HF	7¾-9 7¾-9	48 58	1C 6C	0.27 0.25	ANFO ANFO	Stick Stick
14	Eagle Mountain	Ore Waste	ROTO ROTO	IR & W7R IR & W7R	9 9	35-45 25-35	5D 5D	0.42 0.35	MS MS	Cart Booster Cart Booster
15	French	Ore Waste	ROTO ROTO	TC TC	9½ 9½	60 50-70	7C 7C	0.246 0.246	ANFO ANFO	Pentomex #1

Data from: Pfleider, E. P., (ed), Surface Mining, AIME, New York, 1968.

Table A.3 (cont'd.)

Typical Blast (cont.)											Changes	Mine No.
Detonator (4)	Holes	Rows	Bench Height (ft)	Sub-Grade (ft)	Spacing (ft)	Burden (ft)	Tons per Blast (1 X 10 ³)	Water Condition	Crusher Opening (in.)	% Secondary Breakage	Recent and Proposed Future	
PC	350	8-10	35	2	21	21	325	Moderate	G60	2%	Metallized slurry; pump truck, loading & slurries, pump truck column loading larger waste removal equip.	1
PC	400	4	35	5	26	18	800-900	Moderate	G60		Plant-mix ANFO	2
PC-EBC	60 60	3 3		5 8	24 24	24 21-24	90 80-90	None to Severe	J48 X 60	0	Expanded spacing; metall. slurries (MS); New explosives—spacing	3
PC	8-12	2	30	5	18-21	35	5-8	Severe	Box 42	0	Powder characteristics & packaging—DTH (1966)	4
PC PC	50 50	3-4 3-4	27 27	3 3	18 16-18	18 16-18	30 30	Moderate	G60	0		5
PC PC	15 15	3 3	20 20	5 5	12 12	20 20	3 3	Severe	J36 X 40	5%	15 ft to 12 ft centers	6
PC PC	95 100	7 6	45 45	5 5	20 X 18 13	20 15	142.5 82.8	Severe	G60	10	105T end-dump trucks (1965)	7
PC PC	50 50	5 5	43 43	3 3	19 17	14 15	65 53	Severe	G48	1%		8
WPC WPC	70 50	7 5	35 35	3 3	22 18	22 18	120 50	Slight	G54	3-5%	MS & pump trucks	9
EBC WPC EC WPC	10-30 10-30	2-4 2-4	30 30	5 5	18 15	19 15	15-45 10-30	Slight	G54	1%	Reduced pattern; increase ANFO; decr. MS	10
PC EBC PC EBC	100 100	6 6		7 7	18 22	18 22	140 150	Slight	G54	2		11
PC, #6 PC, #6	20 40-100	2 4-8	12	0	12	12	3.65	Slight	R30 X 60	0	9 yd d.l. to reduce no. of units Conveyor vs. large truck for long haul being studied	12
EBC EBC	40-100	1 4-8	18 18	4-5	16 18	14 18	10 8	None	J48 X 60	10		13
PC PC	30-40 40-70	1-2 2-4	22 20-22		22 20-22	22 20-22	80-120 80-140	None	G60		Expanded drill spacing; hot solution—pump trucks	14
PC, EBC PC, EBC	60-88 54-60	6-7 6	32 28-32.5	3 3	33-39 35-42	24-29 25-28	148-350 45-87	Severe	J42 X 48	1	Staggered pattern; MS; expanded spacing	15

Table A.3 (cont'd.)

No.	Mine Name	Material (See Table 13.4-1)	Drilling				Typical Blast							Typical Blast				Water Condition	
			Drill & Type	Bit Type (1)	Hole Size (in.)	Penetration Rate (fph)	Powder Factor (lb/ft ³)	Explosive Used	Primer	Detonator (4)	Holes	Rows	Bench Height (ft)	Sub-Grade (ft)	Spacing (ft)	Burden (ft)	Tons per Blast (1' X 10')		
16	Smallwood	Ore Waste	JET & ROTO ROTO	TC TC	9.5-10 10	20-25	7D	0.85	MS	Process #1½	WPC	140	4	35	5	23	23	350	Slight
17	Marmora	Ore Waste	DTH DTH	CI-X CI-X	7 7	12 12-33	2A,C 9A,C	0.34 0.29	ANFO, LVBA ANFO, LVBA	Pentomex "	PC PC	12 12-36	1-4	55 55	5 5	18 19-24	18 20-24	25-30 25-70	Moderate
18	Moore Mountain	Ore Waste	ROTO ROTO	TC TC	9½ 9½	14.5 16	7D 7D	0.6 0.6	MS SBA	Pentomex #2 "	WPC WPC	30 30	6 6	31 31	4½ 4½	24 27	24 26	62 67	Moderate
19	Adams	Ore Waste	ROTO ROTO	CI CI	9½ 9½	27 23-27	8E 8E	0.6 0.6	ANFO, S, MS ANFO, S, MS	H, Det H, Det	PC PC	88 Var.	6		5	22 22-23	22 22-23	85 Var.	Moderate
20	Caland	Ore Waste	ROTO ROTO	TC & CI TC & CI	7½ 7½	30-120 45-270		0.35 0.35	ANFO-HVBA ANFO-HVBA		PC, WPC, EBC PC, WPC, EBC	5-40 5-40	1-4 1-4	30 30	4 4	18 15-18	18 15-18	4-35 4-35	Moderate
21	Quebec-Carter	Ore Waste	ROTO ROTO	TC TC	12½ 9½-12½	14.5 16	7G 7G	0.70 0.70	ANFO, S, MS ANFO, S, MS	¼"/hole ½"/hole	WPC, EBC WPC, EBC	85-100 85-100	5-6 4-6	40 40	4 4	23 24-30	23 24-30	200-300 100-600	Sev.-S, Sl.-W
22	El Pao	Ore Waste	DTH DTH-Churn	CI CP	6½-7 6½-9	22.6 42.3-15	2E 10E	0.24 0.18	MS ANFO	HDP-1 HDP-1	WPC WPC	15 15-24	1 1-2	33 33	5 5	15 16-20	17 20-22	30 22.5-35	Slight
23	Marmora	Ore Waste	ROTO-DTH DTH-ROTO	CI-X CI-X, 3G	7 7-9	17-14 20-28	9D 9C	1.30 0.35	ANFO, HVBA ANFO	HDP-1 HDP-1	EBC EBC	20 14-20	2 2	45 45	3 3	16 16-22	14 16-22	26 13-27	None
24	Moat Bay (Ni)	Ore Waste		None required					None required—occasional	ripping of hard crust at surface.									
25	Quanta (Mo)	Ore Waste	ROTO ROTO	TC TC	8 9	65 65	8D 8D	6.48 0.48	ANFO ANFO	HDP-1 HDP-1	PC, EBC PC, EBC	50 50	5-6 5-6	40 40	7 7	20 20	20 20	70 70	Moderate

Table A.4: Blast Design Data - Iron (1970)

Data from: Cummins, A. B., Given, I. A., SME Mining Engineers Handbook, Vol. 2, AIME, New York, 1973

Mine			Drilling				Typical Blast			
No.	Name	Material (See Table 17-24)	Drill & Type	Bit Type (1)	Hole Size, In.	Penetration Rate, Fph	Pattern (2)	Powder Factor, Lb per L4	Explosive Used	Primer
1	Reserve	Ore Waste	Jet & Roto		9-11 12 3/4	20	7L	0.8	MS, ANFO, S	
2	Erie	Ore Waste	Jet Roto	SC, CI	11 9 3/4-12 3/4	18 17	8M-F 8M-F	0.3-1.3 0.3-0.7	ANFO, S, MS ANFO, S, MS	3-C 3-C
3	Minnac	Ore Waste	Roto Roto	SC-SI SC-SI	12 3/4 12 3/4	23 24.5	8D 8D	0.55 0.55	ANFO, S, MS ANFO, S, MS	HDP-1 HDP-1
4	Butler Taconite	Ore Waste	Roto Roto	TC TC	12 3/4 9 3/4	45 50	7D 7D	0.5 0.45	ANFO, S ANFO, S	HDP-1
5	Hill Annex	Ore Waste	DTH DTH	CI CI	6 1/2 6 1/2	43 23-26	6D 6D	0.3 0.3	MONSANTO 506	HDP-1 HDP-1
6	Eveleth Taconite	Ore Waste	Jet Jet		9-18 9	21 21	8K 8K	0.4-0.5 0.4-0.5	ANFO, MS ANFO, MS	Cast. 140s Cast-140s
7	Empire	Ore Waste	Roto Roto	SC-CI SC-CI	9 12 3/4	35 35	7E 7E	0.48 0.48	ANFO, MS ANFO, MS	Procure 3C & 48
8	Republic	Ore Waste	Jet Roto		9 9 3/4	11.2 14.7	7E 7E	0.7 0.7	S S	Booster Booster
9	Groveland	Ore Waste	Jet Roto		9-13 9 3/4	17 16-20	8E 8E	0.75 0.5	ANFO, S, MS ANFO, MS	HDP-3 HDP-3
10	Beacon	Ore Waste	Roto Roto	SC-CI HH-1	7 3/4 7 3/4	65 65	Var. Var.	0.71 0.71	ANFO, MS, NCN ANFO, MS, NCN	HDP-1 HDP-1
11	Atlantic City	Ore Waste	Roto Roto	CI CI	9 3/4 9 3/4	18 24	6E 6E	0.17-0.39 0.0-0.28	ANFO, MS ANFO, MS	PETN PETN
12	Lone Star	Ore Waste	Roto	BD 600	6	80	3C	0.1	Nitro Starch 40%	None
13	Iron Springs	Ore Waste	Roto Roto	HF HF	7 3/4-9 7 3/4-9	48 55	6C 6C	0.43 0.84	NCN NCN	Stick Trojan #12 Trojan booster
14	Eagle Mountain	Ore Waste	Roto-DTH Roto-DTH	X, CI, HF X, CI, HF	6, 9, 9 3/4 6, 9, 9 3/4	35-45 25-60	7D 7D	0.42 0.35	MS MS, ANFO	Cast booster Cast booster
15	Schefferville	Ore Waste	Roto Roto	TC TC	9 3/4-10 3/4 9 3/4-10 3/4	60 50-60	7C 7C	0.45 0.56	MS, ANFO, S MS, ANFO, S	Procure #1 Procure #1
16	Lahaska City	Ore Waste	Roto Roto	TC TC	9 3/4-10 3/4 9 3/4-10 3/4	60 80-80	7D 7D	0.85	MS	Procure #1

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Table A.4 (cont'd.)

Typical Blast (cont.)											Changes	
Detonator (4)	Holes	Rows	Bench Height, Ft	Sub-grade, Ft	Spacing, Ft	Burden, Ft	Tons per Blast, 1×10^4	Water Condition	Crusher Opening, In.	% Secondary Breakage	Recent and Proposed Future	Mine No.
PC	250	8-10	35	3 0	31	21	400	Moderate	G60	0-1%	Metallized slurry; pump truck, loading & slurries, pump truck column loading larger waste removal equip.	1
WPC, PC, EBC	250	4	35	5	20-28	20-28	250-750	Moderate	G60	1%	Dewatering Drill Holes	2
WPC, PC, EBC	180	4	35	5	24-40	20-28	300					
PC-EBC	100	4	40	5	28	28	500-1000	Moderate	G60	<1%	Expanded spacing; metall. slurries (MS)	3
	200	4	40	5	28	28	400-700				New explosives—spacing, larger holes	
PC	100	5	30	5	24	24	10	Moderate	G60	0		4
PC	100				28	28						
PC	30	3-4	27	3	18	18	20	Severe	G60	0	Increase no holes/blast	5
PC	30	3-4	27	3	16-18	16-18	20	Severe				
PC	300	4	42	2	10-35	12-35	400	Moderate	G54		Expanded patterns	6
PC	300	4	42	2	10-35	12-35	400					
PC	76	6	45	5	28	28	200	Severe	G60	1%		7
PC	76	6	45	5	18	18	200					
PC	50	5	40	3	19	14	65	Severe	G48	1%	Drop 100T trucks; return to 75T.	8
PC	50	5	40	4	26-30	20	100					
WPC	200	7	40	4	22	22	350	Severe	G54	1%	MS & pump trucks	9
WPC	176	5	40	5	24	24	300					
EC, EBC, RPC	50	4	50	5	20	11	50	Moderate	G54	1%	Reduced & elongate pattern; increase ANFO; decr. MS	10
EBC, EC, RPC	50	4	50	5	20	11	50					
PC EBC	100	6		7	18	18	140	Slight	G54	2		11
PC EBC	100	6		7	22	22	150					
PC, #6	20	2	20	0	14	14	7.0	Slight	R30 X 60	0	Large trucks for long & short haul being considered	12
EBC, PC		1	25	4-5	11	11	10	Slight	J48 X 60	2%		13
EBC, PC	8-100	4-8	25		13	13	8					
PC	20-40	1-2	45	15	18-12	18-22	35-100	None	G60	1%	Higher penetration rate through drill-foot modification	14
PC	40-80	2-4	45	15	20-24	20-24	70-200					
PC, EBC	90-100	6-7	37	3-4	22-32	22-34	218	Severe	J42 X 48			15
PC, EBC	90-100	6-7	37	3-4	22-32	22-34	177		R48 X 72 R36 X 72			
WPC	140	4	45 & 65	5	24	4	350	Slight	G60 X 89	5	Increased space & burden; MS reduced blast depth	16

Table A.4 (cont'd.)

Mine			Drilling				Typical Blast				
No.	Name	Material (See Table 17-24)	Drill & Type	Ra Type (1)	Hole Size, In.	Penetration Rate, Fpb	Pattern (2)	Powder Factor, Lb per L _t	Explosive Used	Primer	
17	Marmora	Ore	DTE	Carbide	7	14	BE†	0.38	MS, HCN MS, HCN	Pentamer Pentamer	
		Waste	DTE	Butam-Bit	7	12-18	BE†	0.43			
18	Moose Mountain	Ore	Roto	TC	9 3/4	22	7D	0.6	MS MS	Pentamer † Pentamer †	
		Waste	Roto	TC	9 3/4	23	7D	0.6			
19	Adams	Ore	Roto	CI	9 3/4	18-25	8E	0.6	ANFO, S, MS ANFO, S, MS	H, Det H, Det	
		Waste	Roto	CI	9 3/4	19-32	8E	0.5			
20	Caland	Ore	Roto	TC & CI	7 3/4	30-80		0.35	ANFO-HVBA ANFO-HVBA		
		Waste	Roto	TC & CI	7 3/4	43-120		0.35			
21	Quebec-Charlem	Ore	Roto	TC	12 3/4	22	7, 8 8	0.65	ANFO, S, MS	1 1/2 hole	
		Waste	Roto	TC	9 3/4-12 3/4	22	Modified B, D, E	0.65			
22	El Pao	Ore	DTE	CI	6 1/2-7	22-6	2E	0.34	MS	HDP-1, Titan 225 HDP-1	
		Waste	DTE	CP		42.3-15	10E	0.18			
23	Marcona	Ore	Roto	SC	9	35	7D	0.63	ANFO, HVBA ANFO	HDP-1 HDP-1	
		Waste	Roto	SC	9	38	7D	0.50			
24	Questa (Mo)	Ore	Roto	TC, CI	9-9 3/4	40-70	8D	0.35	ANFO, S ANFO, S	IRECO-SC IRECO-SC	
		Waste	Roto	TC, CI	9-9 3/4	55-100	8D	0.41			

* Revision of Table 13.4-2, Surface Mining.

† Square pattern used.

Typical Blast (cont.)										Changes		
Detonator (4)	Holes	Rows	Bench Height, Ft.	Sub-grade, Ft.	Spacing, Ft.	Burden, Ft.	Tons per Blast, 1 X 10 ³	Water Conditions	Crusher Opening, In.	% Secondary Breakage	Recent and Proposed Future	Mine No.
WPC, PC, EBC	1	1	55	5	08	08	25-60	Moderate	G48		10ST End-dump trucks (1970)	17
WPC, PC, EBC	Var.	Var.	35	5	19-24	20-24	Var.					
WPC	60	6	45	4 1/2	26	26	75-100	Moderate	J86 X 94	0-1		18
WPC	80	6	45	4 1/2	27	27	75-100					
PC	88	6	40	5	12-23	24-25	85	Moderate	G542	1-2	Reduced spacing Bulk slurry & pump trucks	19
PC	Var.				23-24	25-26	Var.					
PC, WPC, EBC	50-100	1-4	30	4	18	18	36-72	Moderate	J86 X 4	<1	Bulk drill truck	20
PC, WPC, EBC	50-100	1-4	30	4	15-18	15-18	36-72					
WPC, EBC	85-100	5-7	40	4	26-30	26-30	200-500	Sev. S. SI-W	J86 X 84	1-2		31
WPC, EBC	85-102	5-7	40	4	26-30	26-30	100-600					
WPC	16	1	33	5	15	17	20	Slight	J84 X 84	6	Chambering—experimental MS for top load in ore & hard waste	32
WPC	16-34	1-3	33	5	18-20	20-22	22.5-55					
PC	100	5-6	40	5	14	14	75-100	None	G48 & J86 X 84	1-2		33
PC	100-200	5-6	40	5	20-24	20-24	100-200					
PC, EBC	60	5-6	40	7	20	20	70	Moderate	G48	1		35
PC, EBC	60	5-6	40	7	25	20	70					

