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OPERATING GUIDELINES FOR DRAGLINE STRIPPING OPERATIONS; ANALYSIS OF TANDEM SYSTEMS

FINAL TECHNICAL REPORT
AS OF
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VOLUME I

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ABSTRACT

Practical guidelines for choice of dragline block length, bench height, pit width, and dig/cast patterns are developed for single seam, dragline-based hillside and hilltop stripping operations in northern and southern Appalachia. They are based on interviews of 45 dragline operators and computer analysis of dragline cycle time data for almost 10,000 cycles for 20 draglines in four states. The factors affecting philosophies and decisions are documented.

Analyses of observed dozer/dragline mining operations determined that the observed operations are not true tandem systems utilizing the production capability of dozers in a systematic manner. Models are constructed to analyze the potential of tandem dozer/dragline systems and tandem loader/truck/dragline systems. Conclusions are that significant productivity and cost benefits may be available with deep dozer benching, particularly for small dragline operations. Loader/truck/dragline systems provide capability for deeper digging than is possible with a dragline alone or with a dozer/dragline system, but do not appear economically competitive within the operating range of a dragline or a dozer/dragline system.

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EXECUTIVE SUMMARY

Previous Department of Energy studies indicated that more than 30% of total Eastern surface coal production is produced by tandem mining systems. The most common system observed utilized one or two dozers and a small- to mid-sized dragline. Another observed system utilized a loader/truck/dragline. Because of the apparent importance in total coal supply of these systems, the Department of Energy commissioned this study to determine operating guidelines for these systems which could be used to improve productivity.

Project Summary

The initial objective of this study was to analyze and develop operating guidelines for dozer/dragline and loader/truck/dragline tandem mining systems. The field data base was 20 randomly-selected mining operations in Northern and Southern Appalachia. Nineteen of the field study operations were dozer/dragline operations. However, none of the 19 operations was a true tandem operation; all were predominantly dragline-oriented operations. Dozers, in all of the 19 operations, were restricted in production largely to benching tasks, both drill bench and dragline bench. In addition, dozers did a significant amount of reclamation work. But dozers operating as part of a stripping team in conjunction with a dragline was not observed to a significant extent.

The remaining field study site was a loader/truck/dragline operation not deemed useful for general analysis because of special conditions prevailing at the operation.

The study objective was changed, therefore, to analyze and develop operating guidelines for dragline-predominant mining systems, and to provide analysis of true tandem mining systems in order to frame an estimate of their value as alternative mining methods.

This report presents operating guidelines for dragline-predominant mining systems. Generally desirable choices for bench height, pit widths, and dragline operating procedures for small- to mid-sized draglines operating in single and multiple seams are provided. The research effort determined that the characteristics of the individual dragline with respect to its ability to perform the several functions of the digging cycle is an important parameter in choosing the optimal operating procedures. Accordingly, guidelines are provided for hoist-limited, matched, and depth-sensitive draglines.

In order to measure the potential value of tandem systems, models were built for a true dozer/dragline tandem system and for a loader/truck/dragline tandem system. Production costs for these tandem systems were compared to the dragline-predominant system for cases utilizing a small (7 yd^3) dragline. The dozer/small dragline tandem system employed in deep overburden appeared to be economically superior to the dragline predominant system commonly employed.

Conclusions

- Dragline time study data should be used to develop operating guidelines for a given dragline.
- In many cases, dozers could be very effectively used as part of a true dozer/dragline mining system.
- For operations employing small draglines, a loader/truck/dragline tandem system does not appear economically competitive to a dragline-predominant system. However, this tandem system can be used in deeper overburden than either the dragline-predominant or dozer/dragline systems.

Recommendations

It is recommended that the following research programs be sponsored to provide coal companies with information on equipment that can be used to improve productivity and costs:

- Demonstration of the effects of using machine- and site-specific operating guidelines for a dragline-predominant operation.
- Demonstration of the effects of a site-specific engineered dozer/dragline tandem system.
- Development of methods and equipment specifications to improve productivity in two-seam stripping.
- Documentation and evaluation of alternative dragline operating philosophies.

ACKNOWLEDGMENTS

Both volumes of this report were organized and typed by Carol Rossell. Drawings were done by Steve Applegate. Appendices J and K are based on working papers prepared by George Smrikarov. Appendix L is based on a working paper prepared by Attilio DiMarco. All dragline production rate estimates were derived using a computer program developed and validated by Attilio DiMarco.

We gratefully acknowledge the help and friendship of the engineers and operators in six cooperating coal companies. The field work at their mines was the best part of this project.

1. INTRODUCTION

1.1 From the Log of a Time Study Engineer

June 1978, Mine A: It was something, alright. Watching the dragline operator dig hard sandstone 50 feet above the bench. After having heard for years that it couldn't ... or shouldn't ... be done.

"We know that we don't get a good bucket fill scalpin' like this," the operator said, "but we're doin' it here because it's the best way for this area.

July 1978, Mine B: "Once you have to build out, go as wide as you can," the superintendent was saying as we looked down into the 200-foot-wide cut. He was referring to a common rule-of-thumb in deep stripping. If you need an extended bench, carry a wide pit to minimize rehandle.

August 1978, Mine C: "I like to take a real long move and throw the bucket out to dig," the operator said. "Then I can work a whole shift without movin'."

True, taking a long move cuts down on the non-productive dragline walking time. But what about the increased digging time? And the lost dirt room? What's more important anyhow, cycle time or walking time?

August 1978, Mine D: It was beautiful. Blocking into the hill -- a nice example of true integration of mining and reclamation practices. Gradin and backfilling of the final highwall were kept right up with the active cut by taking short cuts into the hill perpendicular to the cropline. And bonding and backfilling costs were much less than if they had mined along the contour.

But what about stripping productivity? And cash flow patterns? How were they affected? How can you tell when blocking is a good choice?

September 1978, Mine E: "It's too bad you hadda see us side-dippin' like this," the oiler said, apologetically. "We could really make time if we were on the other side."

How right he was. Working the dragline from the high bench in spoil to chop out the parting between the two seams was a notoriously inefficient way to use a dragline. But almost everybody does it that way.

1.2 A Hundred Different Ways

The old-timers know it better than anybody. And they tell you. There's a hundred different ways to strip an area.

Bench with the dragline or with the dozer? High bench or low? Wide cut or narrow? Kick it out or bump it? Two-position block or three? Chop it out or block it?

Are there any general answers to these kinds of questions? Most strip miners would say "No. There are so many variables that each decision must be totally site-specific." Nonetheless, some general answers have evolved for the big mines and machines in the western and midwestern United States.

What about the little 2400 Lima in Ohio? The 7400 Marion in Pennsylvania? The 4600 Manitowoc in West Virginia? The BE 480W in Alabama? They uncover a lot of coal with those small machines. Can enough be learned about the site-specific factors and operating rationales to ferret out some general operating guidelines?

Well, after spending 1,400 hours riding day and night on 20 draglines in four states, and talking with 45 dragline operators having a combined total of over one thousand years of operating experience, and timing almost 10,000 dragline cycles, and analyzing the data by computer, you learn something. And what we learned is presented in this report.

1.3 Study Objectives and Scope

The objective of this study was to develop operating guidelines for dozer/dragline and loader/truck/dragline stripping systems used in hillside and hilltop stripping in northern and southern Appalachia. The guidelines were to be stated principally in terms of recommendations for pit widths, dragline bench heights, block lengths, and dig/cast patterns for different draglines and operating conditions. Deep stripping was of primary interest.

The study was limited to dragline-based surface coal mining operations in Pennsylvania (bituminous), Ohio, northern West Virginia, and Alabama. Both single seam and two-seam operations were included. Draglines with more than 25 cubic yards of bucket capacity were, by design, excluded from the study.

1.4 General Approach

As the study developed, it became clear that true tandem mining systems were not being observed in the survey mines. One of the survey mines was a loader/truck/dragline operation but was judged to be a unique application and of little general applicability because of its specific characteristics. Nineteen other survey mines were dozer/dragline systems, but stripping was done predominantly by the dragline; dozers were relegated to a service function for the dragline: benching and moving cable, as well as performing other functions such as spoil grading and road building. None of the nineteen surveyed dozer/dragline mines was a true tandem dozer stripping and dragline stripping operation.

Consequently, the only real data available from the study was that pertaining to draglines. The general approach was to use this real data for a series of specific draglines operating at specific sites to develop site-specific operating guidelines for each dragline. The resulting site- and machine-specific guidelines were then reviewed to see which, if any, applied in general to all or most of the mines. This was done for 16 different mines.*

Real dragline data was then used as the basis for prototypical analyses of dragline mining compared to two tandem systems employing draglines: dozer/dragline mining and truck/loader/dragline mining. Each of these analyses assumed the same typical northern Appalachia mining situation. From these analyses, certain generalizations regarding dragline mining and tandem systems were made.

1.5 Dragline Study Methods

The techniques used to determine the operating choices that would maximize the production rate for a dragline are shown chronologically in Figure 1. The first step was to conduct field studies at 20 mines to determine operating procedures and rationales, and to collect dragline cycle time data. The types of data collected and the techniques used to collect them are described in Appendix A.

The dragline cycle time data were analyzed using statistical techniques, primarily multiple regression analysis as described fully in Appendix B. Data analysis had the following two objectives:

- To explain as much of the variability in dragline cvcle times as possible, and to develop an understanding of the phenomena affecting cycle times.
- To develop empirical equations, relating cycle time to dragline operating parameters -- primarily swing angle, digging depth, and spoil pile height.

Next, as described in Appendix E, a mathematical model of single seam dragline operations was developed to estimate dragline production rate. The pit geometry portion of the model accepted as input such factors as pit width, bench height, spoil swell factor, and angle of repose. Then, based on assumed dragline operating procedures derived from those observed during the field survey, volumes and average swing angles, digging depths, and spoil pile heights were determined for a series of "digging components."

*The field data for four additional mines were not adequate for analysis.

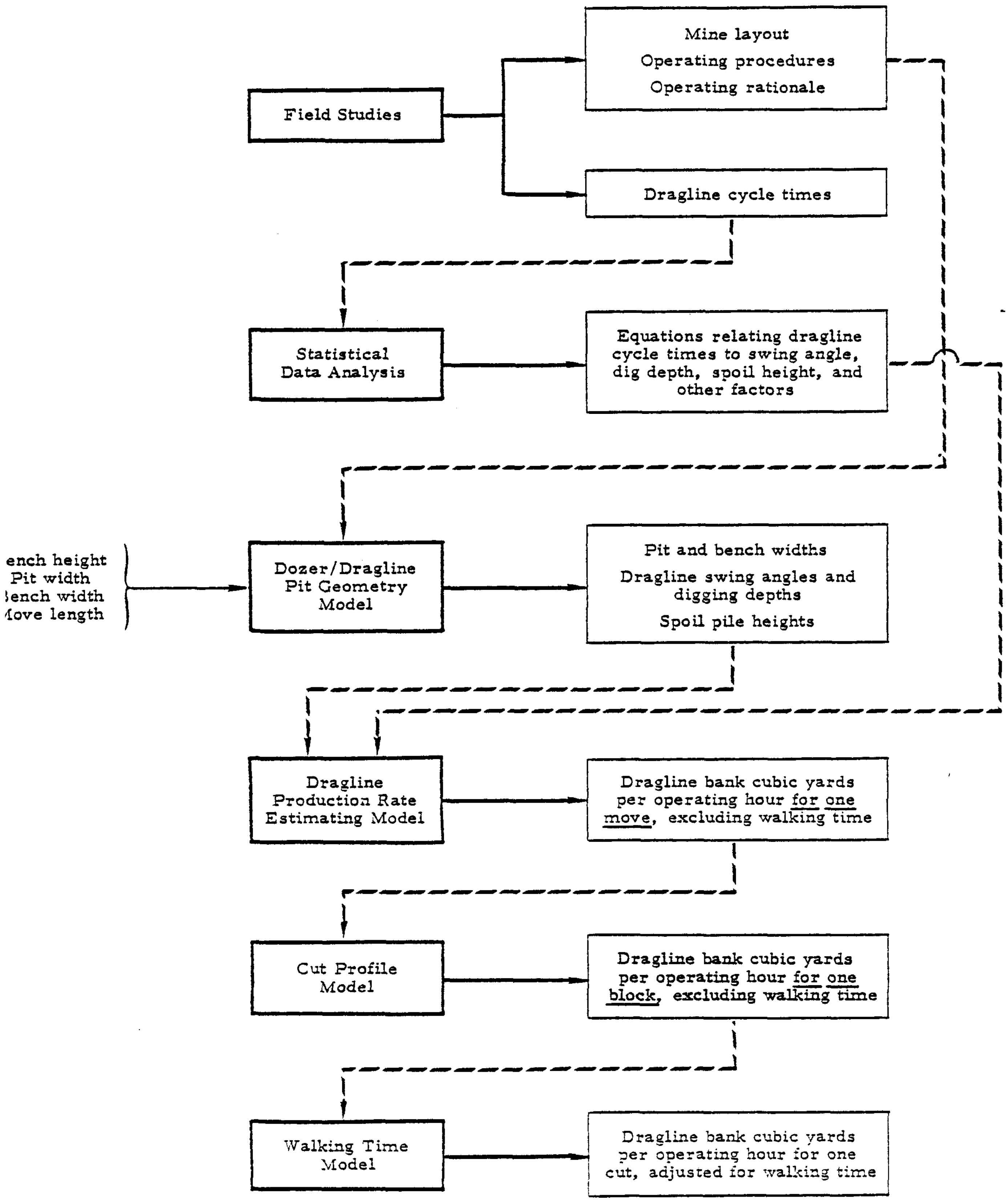

Figure 1. Steps in Estimating Dragline Production Rate

The times to dig each component were calculated using the cycle time equations described above. The result was an estimate of the dragline production rate for a single block, excluding the effects of dragline walking and related activities. Extension of the results to an entire cut was accomplished using techniques described in Appendix M. The effects of dragline walking and related activities were incorporated by reducing dragline operating hours in accordance with procedures described in Appendix F.

For each of a series of overburden depths, the process was repeated for various combinations of bench height and pit width. Results were used to identify the "best" combinations for the specific dragline and operating situation of interest.

The process for two-seam situations was similar, but more restricte Operating procedures were evaluated for two representative case studies.

1.6 Other Comments

Principal study observations, results, conclusions, and recommendations are presented in this, the first of two volumes. The second volume consists of a series of specially prepared Appendices, each describing some technical aspect of the study or providing detailed data.

It is assumed that the reader is familiar with the extended bench method of dragline stripping, although not necessarily with the terminology used in the coalfields of northern and southern Appalachia. For that reason, an illustrated glossary is included at the end of this volume.*

*For a detailed description of the basics of dragline stripping, see U.S. Bureau of Mines Contract Report No. S0144081, entitled, "Evaluation of Current Surface Coal Mining Overburden Handling Techniques and Reclamation Practices," December 1975, available through the National Technical Information Service.

2. TYPICAL DRAGLINE OPERATING PROCEDURES

2.1 Introduction

This chapter has two purposes. The first is to describe the general operating philosophies, equipment, and procedures used at the field survey mines. The second is to describe some typical dragline operating procedures in single seam, extended bench stripping. This is to set the stage for the more detailed descriptions of operating procedures presented later.

2.2 Selected Mine Characteristics

Some characteristics of the principal field survey mines are summarized in Table 1. All were dragline-based hillside or hilltop stripping operations. The draglines ranged in size from a 6-1/2 yard Marion 7200 to a 22-yard Marion 7500. They included diesel and electric machines, and crawlers and walkers. Dragline age ranged from one year to 30 years, and averaged 14 years. Almost all of the dragline operators were very experienced. On the average, they had 19 years dragline operating experience.

Overburden types were varied, ranging from soft shale that required no shooting to hard sandstone and limestone. The types of shooting were also varied -- ranging from very good to poor.

For cycles observed, the dragline cycles per operating hour ranged from 49 to 75, and averaged 61. Although not all of these numbers are averages for a complete block, they do indicate the magnitude of the variability in dragline performance.

2.3 Operating Philosophy, Equipment, and Procedures

All the mines but one were similar to one another in terms of the equipment dedicated to the pit. That equipment consisted of a dragline and one or two dozers -- usually one. A fuel tank had also been installed at each mine. Stripping cuts were generally made along the contour, although one company that operated several mines had hilltop removal and blocking operations as well.

Dozers were little used as stripping machines. Rather, they were utility machines used for benching, grading and backfilling, road construction and maintenance, coal cleaning, and miscellaneous support functions. If relatively deep benching was required for the dragline, the bench was made by the dragline, or, where possible, by shooting the overburden down into the open cut.

Table 1. Summary of Selected Characteristics of Field Survey Mines

Mine No.	Dragline Model	Boom Length (Ft.)	Bucket Capacity (Cu. Yd.)	Dragline Age (Years)	Average Operator Experience (Years)	Type of Overburden	Type of Digging	Ranges of Values Observed			Average Swings Per Hour*
								Swing Angle (Deg.)	Spoil Height (Ft.)	Dig Depth (Ft.)	
1	Confidential	120	9	Not Recorded	Not Recorded	Not Recorded	Not Recorded	45-155	0-55	5-40	65
10	Page 728	150	13	20	30	Sandstone	Some hard digging	30- 90	0-20	5-55	55
11	Marion 7400	160	14	21	28	Clay, shale, & "slate"	Easy-to-hard	30-150	0-40	2-25	75
14	Marion 7400	175	14	9	36	Soft brown shale	Very easy	70-180	0-60	15-65	55
18	Marion 183	130	10	7	12	Dark gray shale	Average	90-190	10-75	10-65	49
23	Manitowoc 4600	120	7	10	11	Limestone & shale	Very hard	80-150	0-10	5-40	65
24	Lima 2400B	120	7	7	5	Light brown sandstone	Hard	50-180	15-40	0-40	63
28	Marion 7400	175	14	20	30	Claystone & shale	Average	50-170	0-75	5-53	65
31	BE 9W	160	10	30	19	Shale & "slate"	Average	50-150	0-50	0-60	59
39	BE 480W (Electric)	175	18	1	20	Limestone & "slate"	Average	30-180	0-60	0-70	56
40	Marion 7400	165	14	Not Recorded	Not Recorded	Not Recorded	Not Recorded	15-150	0-30	5-65	60
46	Manitowoc 4600	120	7.5	14	8	Claystone, shale, sandstone	Some hard digging	30-170	0-25	0-50	68
72	Marion 7200	120	6.5	28	22	Clay & shale	Average	20-100	0-25	5-45	72
75	Marion 7500	200	22	4	9	Sandstone & shale	Hard	50-160	0-90	5-79	57
88	Page 728	150	12	19	27	Limestone & shale	Average	45-180	0-45	0-60	54
99	BE 480W (Diesel)	175	18	10	10	Sandstone	Average	70-150	0-70	5-55	56

*

Chronologically, the first step in mining was removal and stockpiling of topsoil, usually by scrapers -- although the scrapers were rarely dedicated to a pit. Next, dozers were used to make a bench for the overburden blasthole drill. The benches were not cut down to rock. Rather, some clay or soft shale was left to hold down the rock during shooting. Ordinarily, no more than five or ten feet of unconsolidated overburden was dozed off to make the drill bench. The bench dirt, after dozing into the open cut, rarely rose up the highwall to the bench level.

Overburden drilling was done using truck-mounted rotary drills, usually contractor-owned and operated, and ranging from about 6-1/4 to 9 inches in diameter. With one exception, overburden was drilled in one lift. Typical drill patterns were 10 x 10 to 15 x 15. Holes were loaded with bulk or bagged ANFO. At one mine where the overburden was deep, and the mine was not near wells or buildings, the shooting was designed to throw the overburden into the open cut. This usually lowered the bench by an average of 30 feet after leveling by dozers. Otherwise, the shots were designed to bump the overburden, leaving it essentially in place.

At many mines, responsibility for specifying drill-hole patterns was not well-fixed. Often the dragline operator did it; sometimes it was the pit boss. Other times, nobody did it formally. One result was frequent occurrence of poor shots, more prevalent with some companies than with others.

After shooting, a bench for the dragline was leveled by dozer. Working from that bench, the remaining overburden was removed by dragline, using two or three sets. Coal was loaded by front-end loader into on-road, contract coal trucks, generally for haulage to a tipple or prep plant. The coal loaders were rarely dedicated to one pit.

Mine planning procedures varied greatly. In some cases, formal cut specifications were provided to the pit bosses; in others, very little formal pre-mining planning was done. Geological characteristics of greatest impact on planning were the nature of the overburden, stripping ratio and overburden depth, and the number of coal seams. The nature of the overburden mainly affected planned drilling and blasting patterns, production forecasts, and cost estimates. Hard rock, such as limestone or massive sandstone, required closer drilling and blasting patterns, higher costs, and usually, lower production estimates. Stripping ratio and total overburden depth largely determined economic feasibility, although the measures of feasibility varied widely from company to company. The existence of two or more seams dictated different mining methods. Dragline mining of more than one seam required adoption of the horseshoe method or the extended bench method of two-seam stripping.

2.4 Typical Dragline Operating Procedure

At most of the survey mines, the overburden was deep enough that an extended bench was needed. A typical extended bench method for uncovering a single seam is described in this section. It involves what is commonly called a "two-set block". The dragline is a 10-yard BE 9W walking dragline with a 150-foot dump radius, operating in 80-foot overburden from a bench 60 feet above the 32-inch coal seam. Pit width is 105 feet.

At the completion of a block, the dragline was in the keyway position. To begin a new block, it was walked ahead 13 steps -- about 75 to 80 feet -- parallel to the pit direction. From this position -- the keyway position for the new block -- a lift about one bucket deep was dug off the surface across the width of the block (Figure 2). Dirt rolled out ahead of the bucket during this shallow digging, forming a large bucket roll on the bench in front of the dragline. The dozer was used periodically to push the roll down.

The spoil from this lift was dumped at 90 degrees into the open cut to begin building the bench extension for the block.

Next, the keyway was dug to establish the new highwall, as shown in Figure 3. Keyway spoil was dumped at 90 degrees to build the extended bench. Occasionally, the keyway was widened at the top to open it up, thereby reducing the hoist distance out of the keyway before swinging, and providing additional spoil needed to extend the bench. Periodically, as the extended bench spoil rose above the level of the dragline bench, the operator used the bucket to pull the spoil back in toward the dragline to help level the spoil.

During keyway digging, a bucket roll again developed on the bench. To keep the drag cable from dragging in the roll, the dragline was walked three steps back up toward the dig face. The roll did not present any problem thereafter.

After dumping a sufficient volume of spoil for the extended bench, the dragline was shut down while leveling of the extended bench was completed by dozer, as shown in Figure 4. This usually took 20 or 30 minutes.

The dragline was then walked out about 18 steps to a position on the extended bench just leveled by the dozer. From that position, a section of the extended bench from the previous move was dug and dumped at 90 degrees, thus beginning to form the main spoil pile. This material was all rehandle.

Still in the position on the extended bench, the dragline dug remaining bank material, facing a little toward the highwall during digging. Spoil was cast on the main pile after swinging through an angle of 125 to 150 degrees, as shown in Figure 6. To finish the block, the dragline was moved back to the keyway position (not shown) to clean up -- that is, to dig rock that had fallen into the open keyway during digging from the extended bench position.

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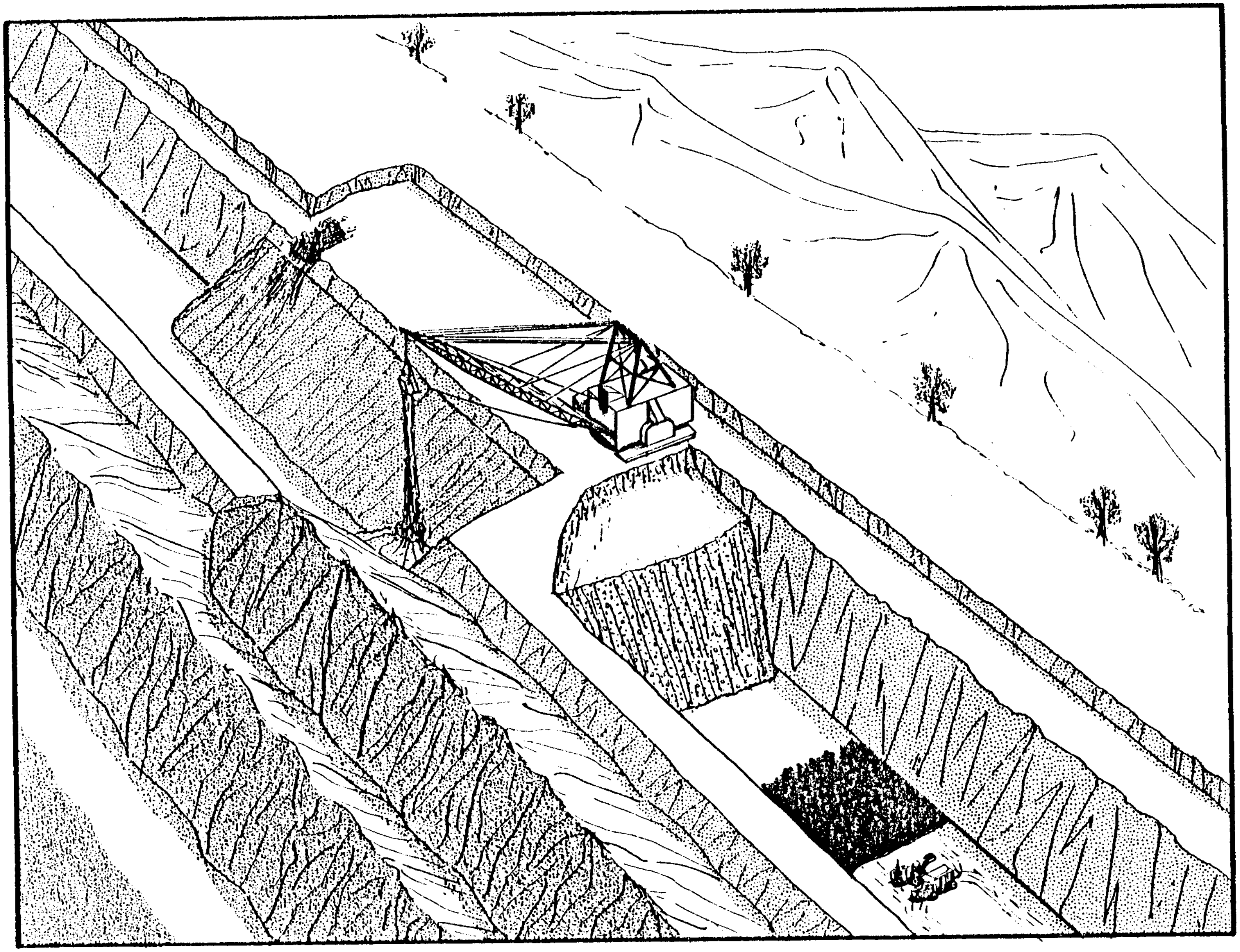

Figure 2. Step 1: Digging a Shallow Lift Off the Block

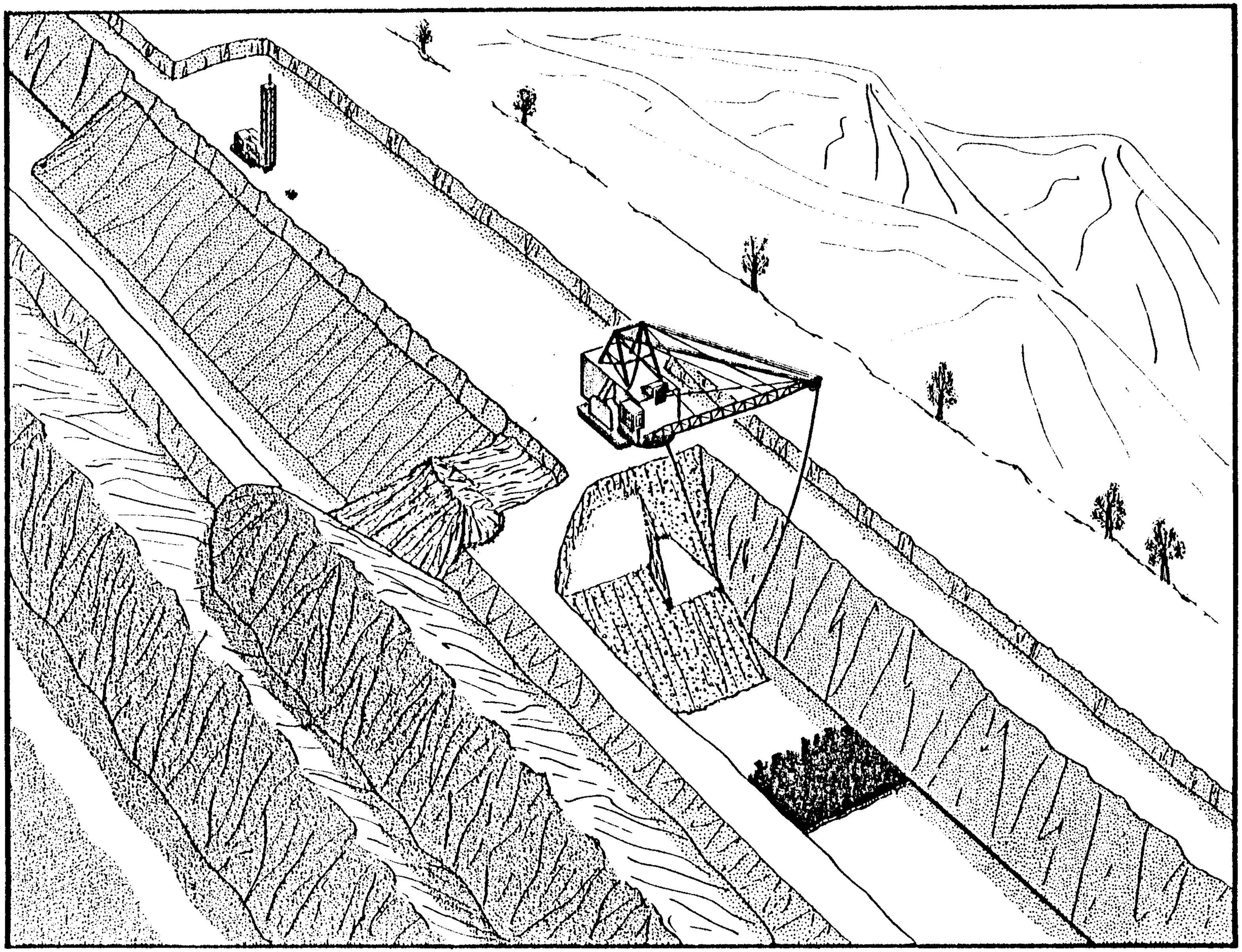

Figure 3. Step 2: Digging and Widening the Keyway and Building the Extended Bench

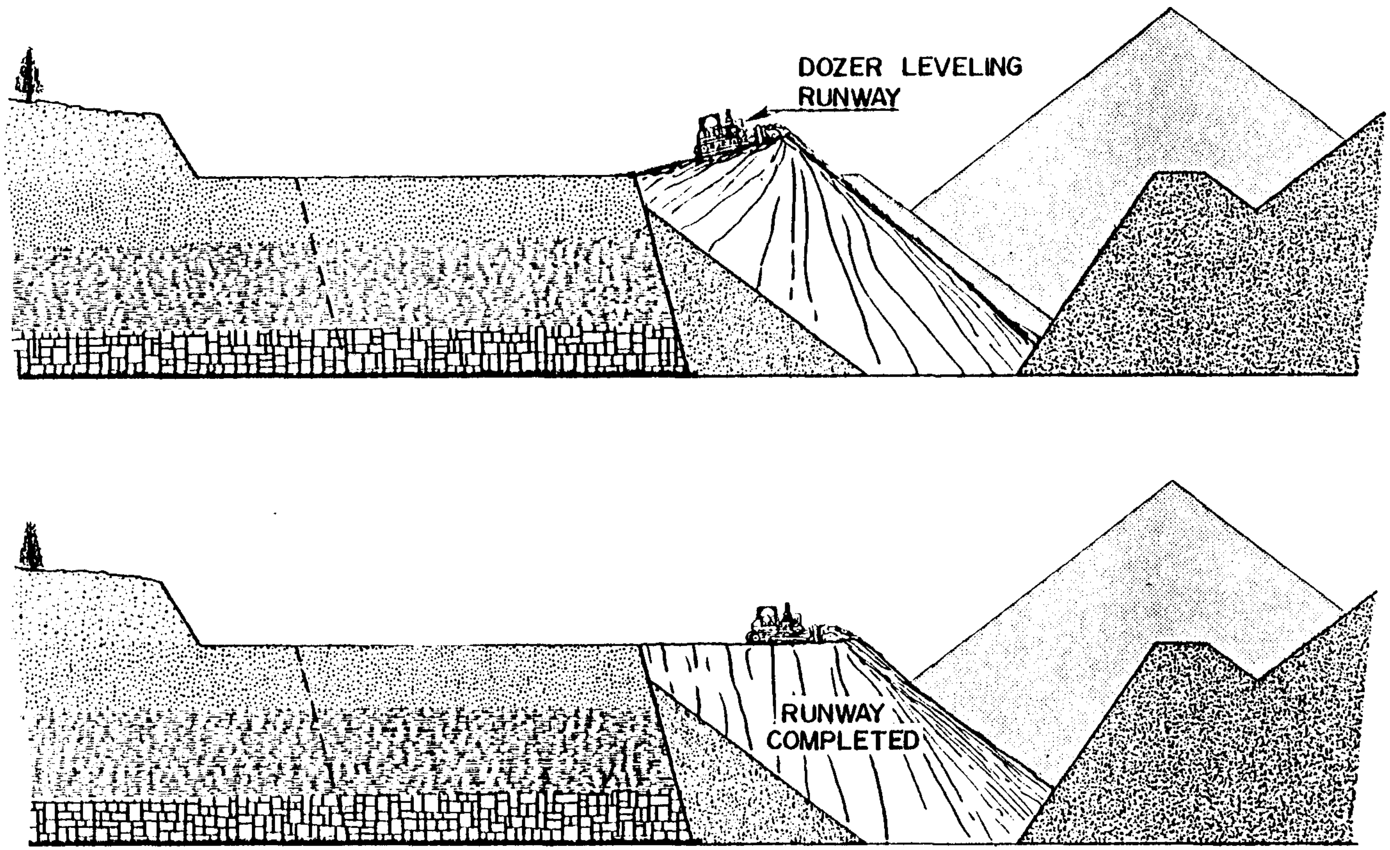

Figure 4. Step 3: Dozer Levels the Extended Bench (Runway)

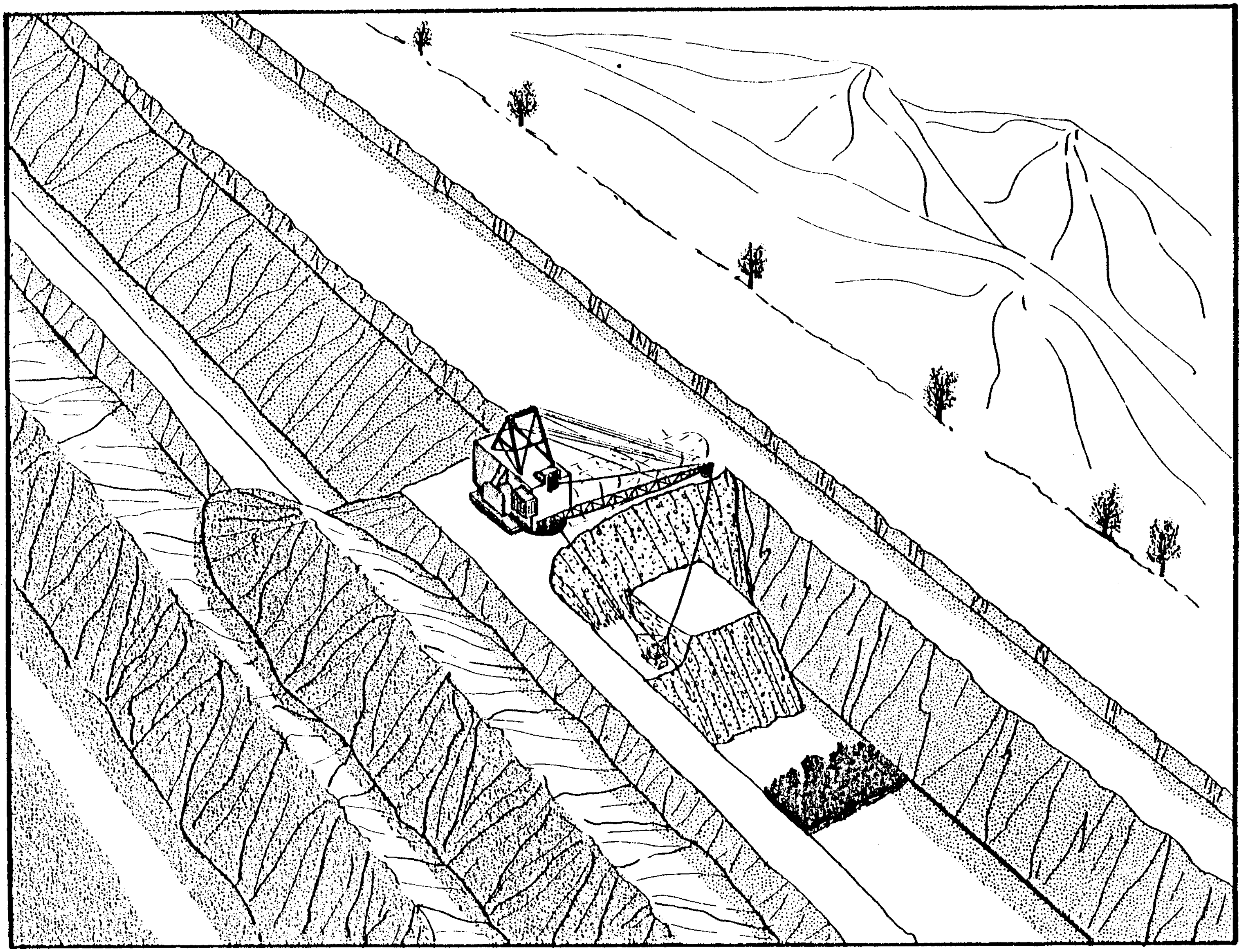

Figure 5. Step 4: On the Extended Bench, Digging the Rehandle Section

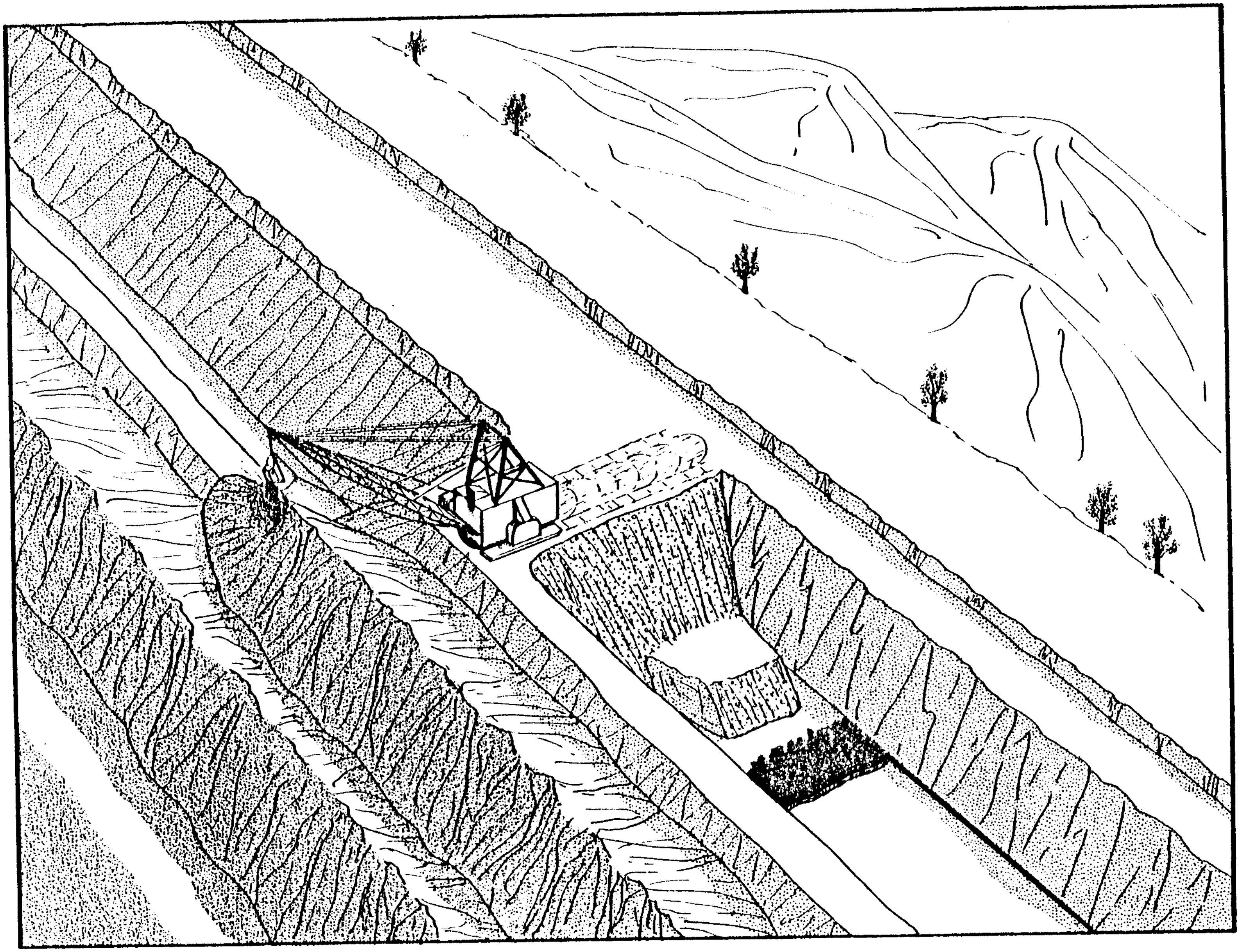

Figure 6. Step 5: Digging the Remaining Bank From the Extended Bench Position

2.5 Components of the Dragline Cycle

Each cycle of the dragline had the following components, starting the cycle at the point at which the bucket was dumped:

- Return swing: This was returning the boom back to the position to dig.
- Bucket positioning: Either during the return swing, or after it had been completed, this was positioning of the bucket to get it into the bank, ready to dig.
- Drag and fill: This was dragging the bucket in toward the fairlead to fill it.
- Drag after fill: This didn't always happen. It was continued dragging of the bucket after it had completely filled.
- Dump: This consisted of swinging toward the spoil pile, hoisting the bucket to dump, and dumping.

2.6 Dragline Operation

All the draglines timed had similar operating controls. Each had two or three hand-operated levers and two foot pedals. If a machine had three levers, one was for swing, the second for drag, and the third for hoist. If the machine had two levers, one was for swing, and the other was for drag and hoist. On all machines, one foot pedal was to operate the drag brake; the other was to operate the hoist brake.

Operating procedures are as follows. To swing the boom, the operator pulls the swing lever forward to swing one way, and backward to swing the other. The swing speed is controlled by the distance that the lever is moved from the center or neutral position. To stop the boom, the operator moves the lever to reverse the direction of swing -- a process that the operators call "plugging it". The machines do not have swing brakes.

At the beginning of a cycle, the bucket has dumped, and is hanging under the boom point, generally at least 20 feet above the bench -- higher if the spoil pile is higher. As the boom is returned to the digging position, the operator lowers the bucket using the drag lever to pull the bucket in toward the fairlead. During this time, he maintains some tension in the hoist cable by using the hoist brake intermittently.

As the boom nears the desired position for digging, the operator plugs it to stop the swing. If the digging is shallow, he may have positioned the bucket in the bank during the return, maintaining drag speed so that the bucket enters the bank digging. For deep digging, the operator generally drags the bucket in to the fairlead during the return swing, using the drag brake to hold it there until the return swing has been completed. Then, once the boom has stopped, the operator releases both the hoist and drag brakes, letting the force of gravity carry the bucket down and out to the digging position. This is called casting or throwing the bucket.

Once the bucket has reached the digging level, further positioning may be necessary. This is accomplished by hoisting or dragging the bucket a little to jockey it into position.

Digging is started by moving the drag lever forward (or backward). In easy digging, full drag speed is generally used. In hard digging, operators rarely use full speed. During digging, the operator uses the hoist brake to keep tension in the hoist cable. If he doesn't maintain enough tension, the bucket will bury itself and stall. If he maintains too much tension, the bucket will come out of the bank too early.

When the operator is ready to hoist the bucket, he puts the drag lever in neutral and initiates the hoist.* At the same time, he starts the swing. While hoisting the bucket, the operator uses the drag brake to maintain tension in the drag cable, thereby preventing the bucket from dumping. The swing speed is controlled so that the bucket doesn't hit anything on the way to dump. Hoist speed is maintained to assist in dumping the bucket. Next, the hoist lever is returned to neutral, the drag motor engaged, and the return swing started.

There are some variations on the types of control used. An example is the interlock on Manitowoc draglines. This is a device that interlocks the hoist and drag drums so that, for example, when the bucket is being hoisted, it is not necessary to hold the drag brake. Rather, the drag cable will pay out, under tension, at the same speed that the hoist cable is being reeled in.

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*On most of the machines timed, the operators always used full hoist speed.

3. CYCLE TIME VARIABILITY

3.1 Magnitude of Variability

Cycle times for a given dragline vary widely. The purposes of this chapter are to show how much and, in a general way, why. Cycle time variations for individual machines and from machine-to-machine are discussed.

Figure 7 shows the histograms of cycle times for two draglines for which large numbers of cycles were timed. The top histogram in the figure is for Mine No. 31, a BE 9W dragline described by coal company personnel as a consistent machine. And, in a relative sense, it is, as comparison with the bottom histogram will confirm. That latter histogram is for a Marion 7400 dragline. The spread or variability for the Marion 7400 is much greater than that for the BE 9W, although it is obvious that the BE dragline is the slower of the two.

The cycle time histograms for two more draglines are shown in Figure 8. The variability in cycle times is roughly the same for the two draglines -- one a Marion 7400 and the other a BE 480W. The Marion appears to be the faster machine.

The histograms show that most of the cycles timed were 30 to 80 seconds long -- a large variation. Additionally, some cycle times were as much as two minutes.

3.2 Summary of Component Time Data

Table 2 contains a summary of the time study data for principal survey mines. The observed average times for the total cycle and for each component are shown. Note that these are averages for the cycles timed and, in some cases, do not reflect the averages for an entire block or set.

The average cycle times for individual machines ranged from 48 to 74 seconds. The average over all machines was roughly 60 seconds. Average return swing times for individual machines did not vary too much, ranging between 12 and 19 seconds, and averaging about 16 seconds over all machines. Average positioning times ranged from one to six seconds, and averaged three seconds overall.

The digging time averages varied greatly from machine-to-machine. They ranged from 13 seconds for a dragline digging soft shale to 30 seconds for machines digging harder shale and sandstone. Averaged over all machines, the digging time was roughly 21 seconds.

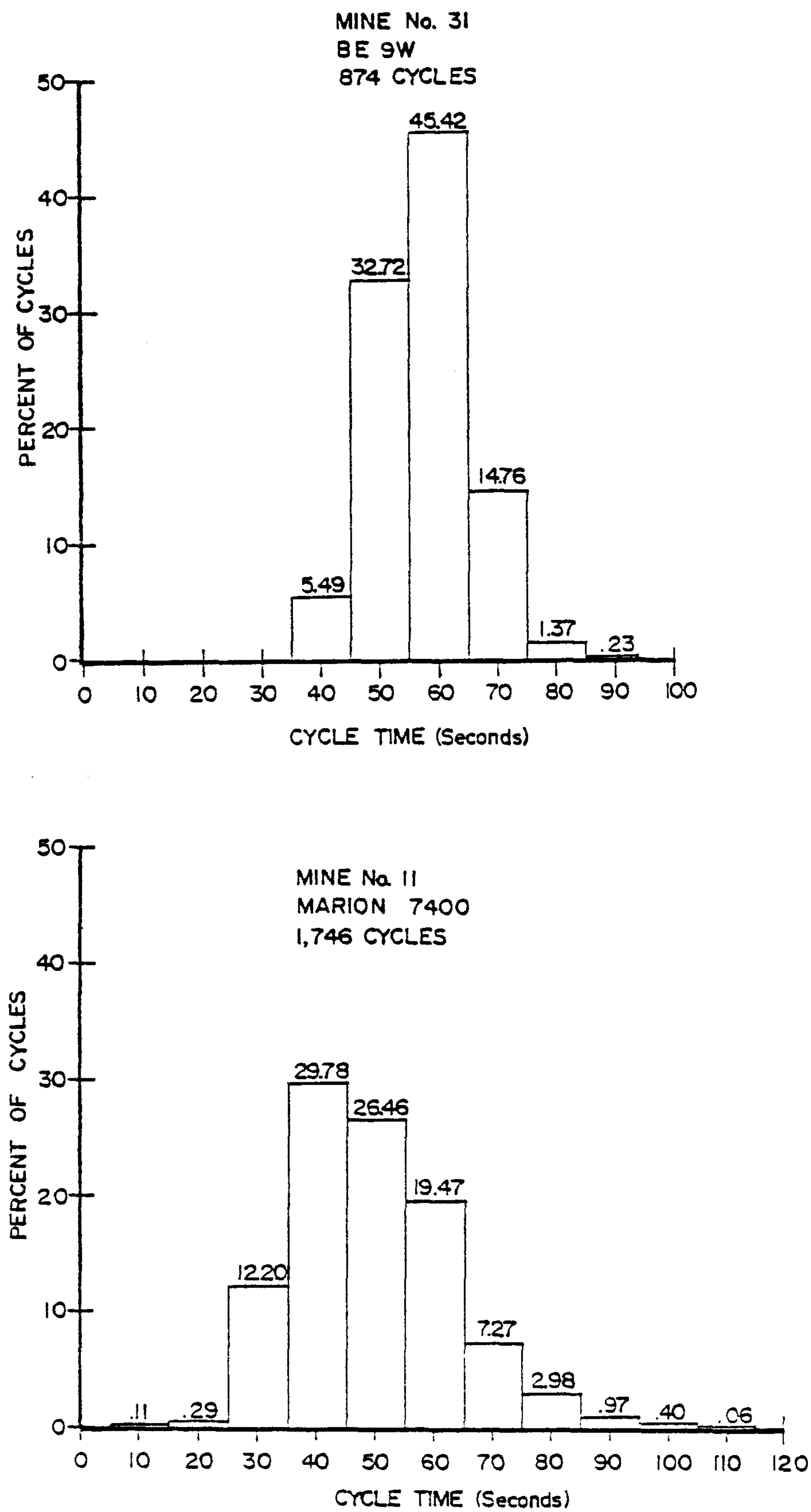

Figure 7. Dragline Cycle Time Histograms for Mines 31 and 11

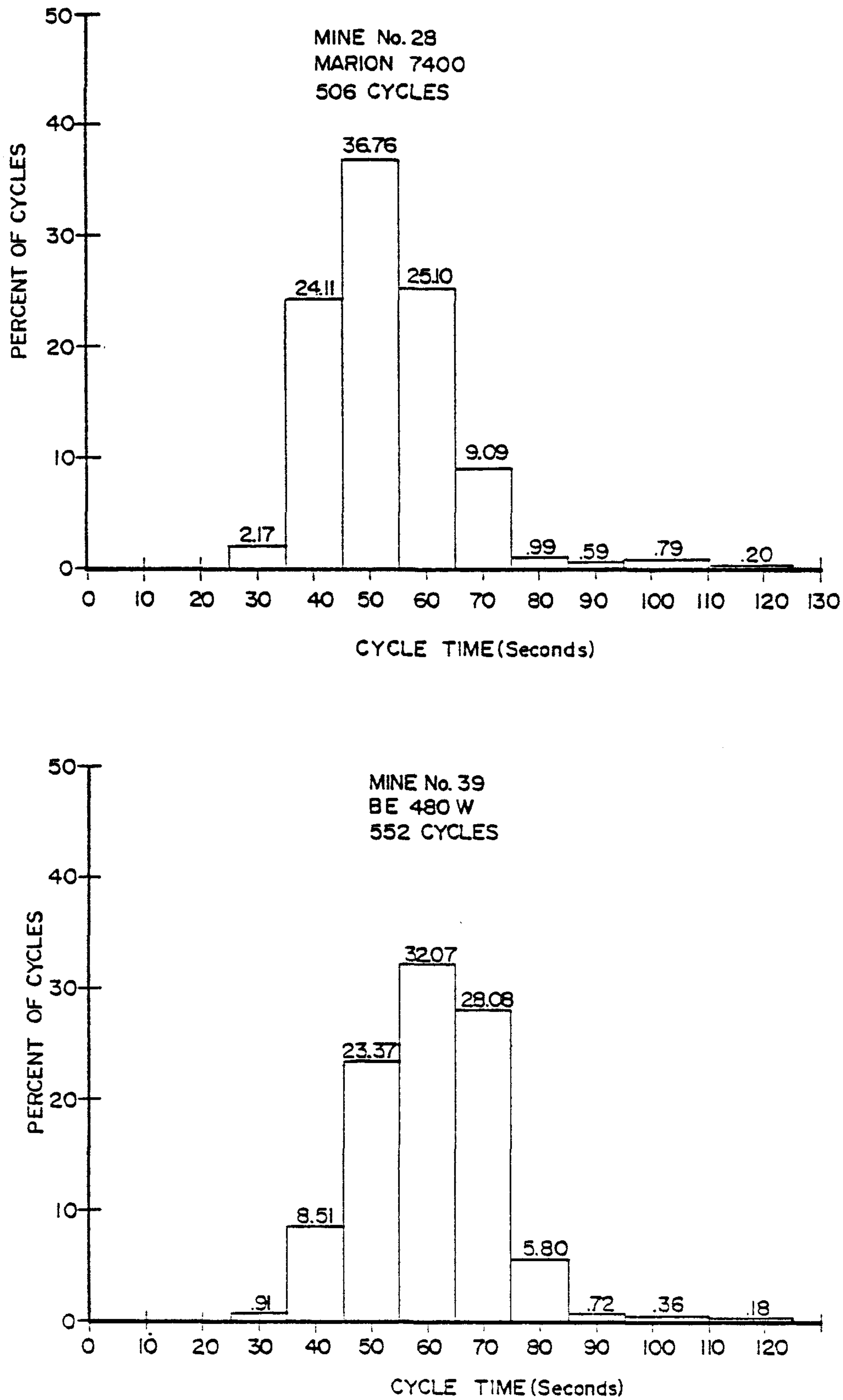

Figure 8. Dragline Cycle Time Histograms for Mines 28 and 39

Table 2. Summary of Time Study Data

Mine No.	Overburden or Interburden	No. of Cycles Timed	Average Cycle Time (Sec.)	Average Return Swing Time (Sec.)	Average Bucket Positioning Time (Sec.)	Average Dig Time (Sec.)	Average Dump Time (Sec.)	Average Swing Angle (Deg.)*	Average Dig Depth (Ft.)*	Average Spoil Height (Ft.)*	Type of Overburden & Digging
1	Overburden	228	55	14	4	17	20	110	28	38	Not noted
	Interburden	74	62	15	6	18	21	111	28	46	Not noted
10	Overburden	320	65	14	3	28	19	60	42	0	Sandstone, avg. digging
11	Overburden	1,074	48	14	1	15	16	76	10	7	Clay, sandstone, shale
	Interburden	672	63	17	3	19	21	124	44	42	Claystone
12	Overburden	106	65	12	3	30	18	93	43	0	Not noted
14	Overburden	375	57	19	1	13	22	122	29	0	Unshot soft shale
18	Overburden	233	74	18	5	30	19	139	40	45	Shale
23	Overburden	271	55	14	2	21	16	97	31	0	Poorly shot limestone & shale
	Interburden	261	70	16	4	28	21	143	26	33	Claystone & shale, poorly shot
24	Overburden	223	57	15	1	20	20	118	26	26	Sandstone, hard digging
28	Overburden	159	62	16	3	26	19	105	16 (above bench)	0	Sandstone, above the bench
	Interburden	347	55	14	3	18	18	95	33	71	Shale, normal digging

*Average swing angles, dig depths, and spoil heights are not averages for a complete block. but rather are averages for cycles timed only.

Table 2 (Cont'd). Summary of Time Study Data

Mine No.	Overburden or Interburden	No. of Cycles Timed	Average Cycle Time (Sec.)	Average Return Swing Time (Sec.)	Average Bucket Positioning Time (Sec.)	Average Dig Time (Sec.)	Average Dump Time (Sec.)	Average Swing Angle (Deg.)*	Average Dig Depth (Ft.)*	Average Spoil Height (Ft.)*	Type of Overburden & Digging
31	Overburden	874	61	17	5	15	23	97	31	4	Shale & "slate"
39	Overburden	552	64	17	4	19	23	98	44	24	Clay, limestone, & "slate"
	Interburden	461	62	18	4	18	20	102	54	32	"Slate"
40	Overburden	304	60	15	4	18	21	76	43	6	Clay & shale
46	Overburden	244	53	12	3	23	14	90	28	5	Claystone (poorly shot), shale, sandstone
72	Overburden	469	50	16	0	17	14	58	19	3	Clay & shale
75	Overburden	645	63	15	1	25	19	99	41	40	Sandstone (hard digging) & shale
88	Overburden	480	67	18	4	22	23	91	45	26	Limestone & shale
99	Overburden	334	64	19	1	19	23	107	23	32	Sandstone
TOTALS & AVERAGES	Overburden	7,237	59.7	15.5	2.7	20.7	19.3	96.2	31.8	18.2	
	Interburden**	1,469	64.2	16.5	4.3	20.7	20.8	120.0	38.0	38.3	
	ALL	8,706	60.5	15.7	3.0	20.7	19.5	100.5	32.9	21.8	

*Average swing angles, dig depths, and spoil heights are <u>not</u> averages for a complete block. but rather are averages for cycles timed only.

**Excludes interburden digging for Mine 28, which was treated as overburden digging.

Average dump times from machine-to-machine varied more than return swing times, but less than the digging times.* They ranged from 14 to 23 seconds, and averaged about 20 seconds overall.

3.3 Cycle Time Equations

Cycle time equations derived from time study data using regression analysis techniques are summarized in Table 3. The equations show that cycle times for all machines were correlated with swing angle. Additionally, for most machines, the cycle times were also correlated with spoil height and dig depth.

For example, the equation for Mine 10, a Page 728 dragline, is:

$$\text{Avg. cycle time (sec.)} = 41.4 + 0.146 \times \text{swing angle} + 0.195 \times \text{spoil height} + 0.323 \times \text{dig depth}$$

where swing angle is measured in degrees, spoil height in feet above the bench, and dig depth in feet below the bench.

The coefficient of swing angle, 0.146, indicates that, on the average, cycle time increased one second for every seven degrees.** Similarly, estimated average cycle time increased one second for every five-foot increase in spoil height, and one second for every three-foot increase in dig depth. This is the kind of information that can be used to estimate the effects on cycle time of lowering the bench or widening the pit.

For Mine No. 10, assuming a swing angle of 60 degrees, a spoil height of zero feet, and a dig depth of 42 feet, the estimated average cycle time is:

$$\text{Est. avg. cycle time (sec.)} = 41.4 + 0.146 \times 60 + 0.195 \times 0 + 0.323 \times 42 = 63.7 \text{ seconds}$$

*"Dump time" refers to the time to swing, hoist, and dump.

**This is found by taking the reciprocal of the coefficient.

Table 3. Summary of Dragline CYCLE Time Equations Derived From Time Study Data

Mine No.	Dragline Model	Coefficients of Linear CYCLE Time Equations					No. of Cycles Timed
		Intercept (a_o)	Swing Angle (Ω)	Spoil Height (h)	Dig Depth (d)	Spoil Height Divided by Swing Angle (h/Ω)	
1	Confidential	13.6	0.133		0.72	18.6	228
10	Page 728	41.4	0.146	0.195	0.323		320
11	Marion 7400	33.6	0.152		0.092	6.69	1,074
14	Marion 7400	21.9	0.180		0.30	19.1	375
18	Marion 183	46.8	0.092	0.16	0.169		233
23	Manitowoc 4600	45.4	0.071	0.086			271
24	Lima 2400B	41.0	0.055	0.28	0.062		223
28	Marion 7400	40.1	0.068	0.044	0.135		347
31	BE 9W	52.2	0.012	0.26	0.15		874
39	BE 480W (Electric)	39.4	0.115		0.265	6.92	477
40	Marion 7400	41.0	0.10		0.271	-8.17	304
46	Manitowoc 4600	31.1	0.118	0.062	0.404		244
72	Marion 7200	38.7	0.145	0.35	0.083		469
75	Marion 7500	34.5	0.107	0.037	0.054		645
88	Page 728	31.7	0.166	0.21	0.33		480
99	BE 480W (Diesel)	41.2	0.132	0.13	0.08		334
"Average"		37.3	0.112	0.112	0.157	2.7	6,898

The actual average cycle time for Mine 10 at the indicated parameter values was 65 seconds. The predicted value, 63.7 seconds, is close to the actual.

For some machines, an interaction between swing angle and spoil height was indicated. The Marion 7400 at Mine 14 is an example. The cycle time equation is:

$$\text{Est. avg. cycle time (sec.)} = 21.9 + 0.180 \times \text{swing angle} + 0.30 \times \text{dig depth} + 19.1 \times \text{(spoil height divided by swing angle)}$$

The last term in the equation is the interaction term. For example, at a spoil height of 40 feet and swing angle of 80 degrees, the term adds 9.5 seconds to the cycle time estimate. For the same spoil height but a swing angle of 160 degrees, the addition would be 4.8 seconds.

Averaged over all machines, the coefficients in Table 3 indicate the following:

- Cycle time increased one second for every nine-degree increase in swing angle.
- Cycle time increased one second for every nine-foot increase in spoil height.
- Cycle time increased one second for every six-foot increase in digging depth.

Estimated average cycle times calculated from the equations for each machine are plotted versus swing angle in Figure 9 for a spoil height of 20 feet and a dig depth of 30 feet. The curves would look much different for other values of spoil height and dig depth. The machine-to-machine variation is quite marked. For a swing angle of 90 degrees, the estimates range from 50 seconds for Mine No. 75 to 67 seconds for Mine No. 10.

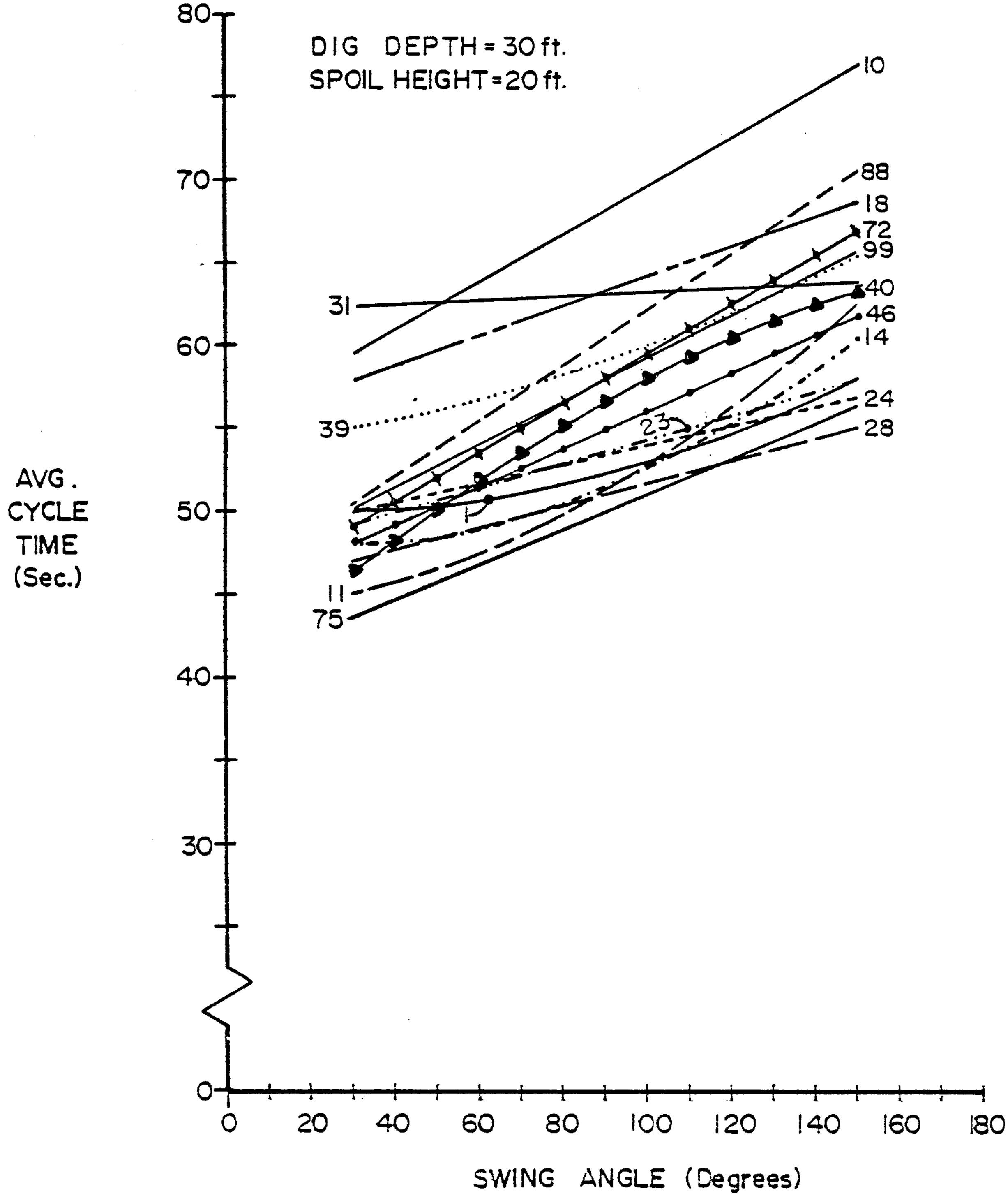

Figure 9. Estimated Average Dragline Cycle Time Versus Swing Angle

4. DIGGING TIME VARIABILITY

4.1 Introduction

Information provided early in the project by the chief engineer for one of the participating coal companies showed clearly that -- for a given dragline -- digging time variability was much greater than the variability for the times for other components of the cycle. For that reason, a principal objective of data analysis was to explain variability in digging times, both for a given machine and from machine-to-machine.

To structure the data collection effort, a series of hypotheses regarding causes of digging time variability were formulated. They are listed below.

4.2 Hypotheses Regarding Dig Time Differences for a Given Machine

4.2.1 Digging Depth

Theory indicates that digging time should increase with increasing depth, for the following two reasons:

- As shown in the upper portion of Figure 10, at shallow depth, the horizontal component of the drag force is large relative to the vertical component. This tends to keep the bucket in the bank. But, as digging depth increases, the vertical component -- which tends to pull the bucket out of the bank -- increases, and the horizontal component decreases. The changing force vectors slow the digging as depth increases.

- At shallow depth, especially when digging shale, common practice is to "layer load". This means dragging the bucket horizontally to peel off the layers along their bedding planes. At greater depth, because of the changing drag force vectors, layer loading is not possible. Digging takes place by cutting across bedding planes. This is more difficult than layer loading.

4.2.2 Multipass Digging

It was expected that making multiple dig passes on a cycle would double the digging time.

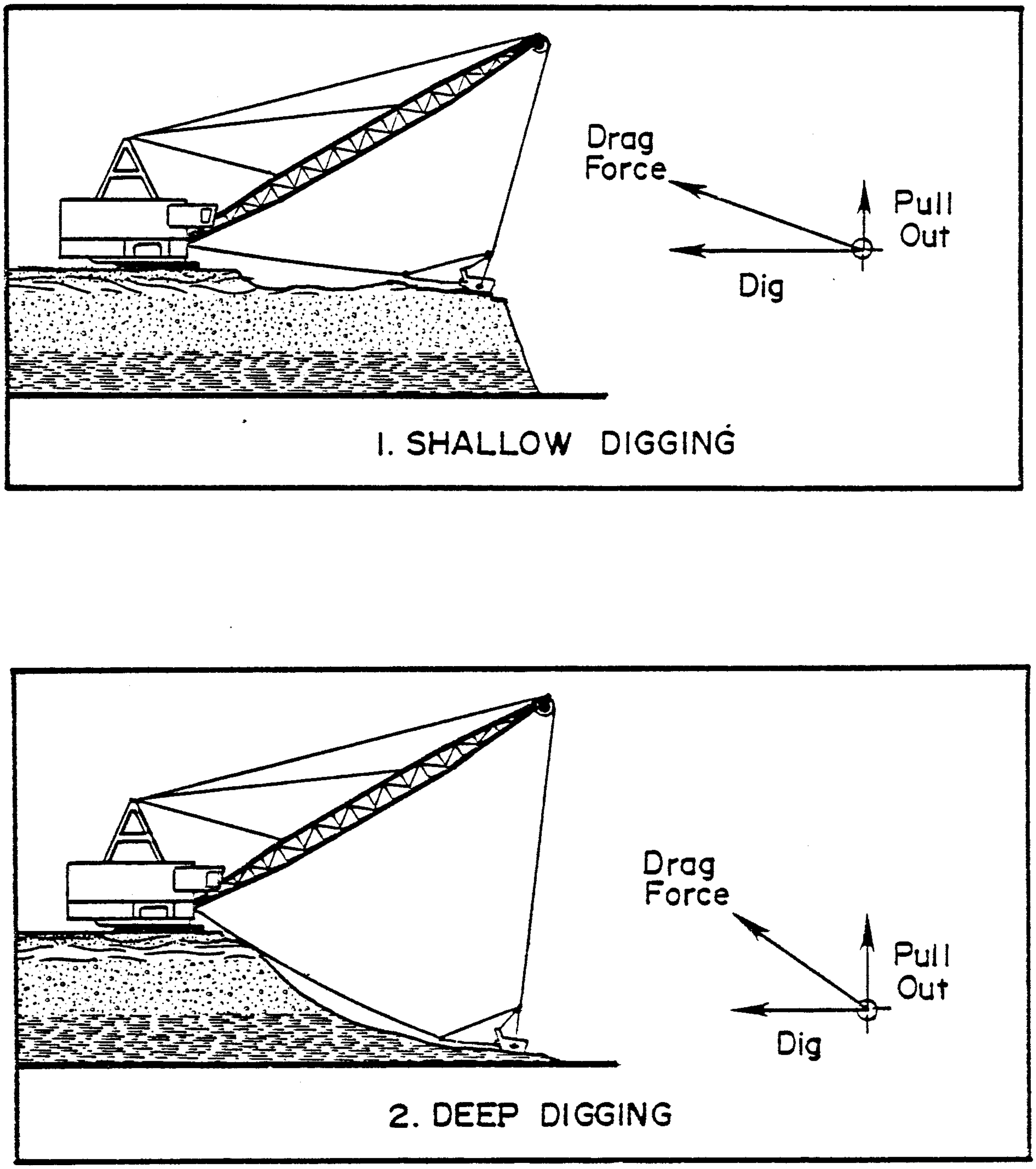

Figure 10. The Effect of Digging Depth on Drag Force Vectors

4.2.3 Block Length

Taking an exceptionally long block is known to increase digging time. The reason is illustrated in Figure 11. For a block of normal length, at the farthest digging point, the bucket is directly under the boom point when digging begins. By the time the bucket has filled, it will be about 1/2 to 2/3 of the way in to the fairlead, and can be hoisted without spilling too much. In contrast, for a very long block, the bucket has to be cast beyond the boom point to dig deep. As a result, it will be under the point or thereabouts when it has filled. But the bucket can't be picked up that far out without tipping and losing load. As a result, the operator will continue to drag the full bucket in toward the fairlead before hoisting. This increases the dig time.

4.2.4 Type of Overburden

Manufacturers' data indicate that sandstone digs slower than shale, adding four to eight seconds to dig time as compared with the times for digging shale. Limestone also digs slower than shale, according to the manufacturers' data.

4.2.5 Type of Shot

A poor shot should markedly increase digging time.

4.2.6 Operator

Some operator-to-operator differences in digging times were predicted, based on anticipated differences in drag times after filling the bucket. If the bucket had a hitch plate, no difference among operators was expected.

4.2.7 Chopping

Previous studies had indicated that chopping, either above the bench or below it, would markedly increase digging times.

4.2.8 Keyway

When digging in a narrow keyway, the bucket gets squeezed as it expands side-to-side while filling. It was thought this might increase digging time.

4.2.9 Rehandle

Rehandle material should dig faster than bank material.

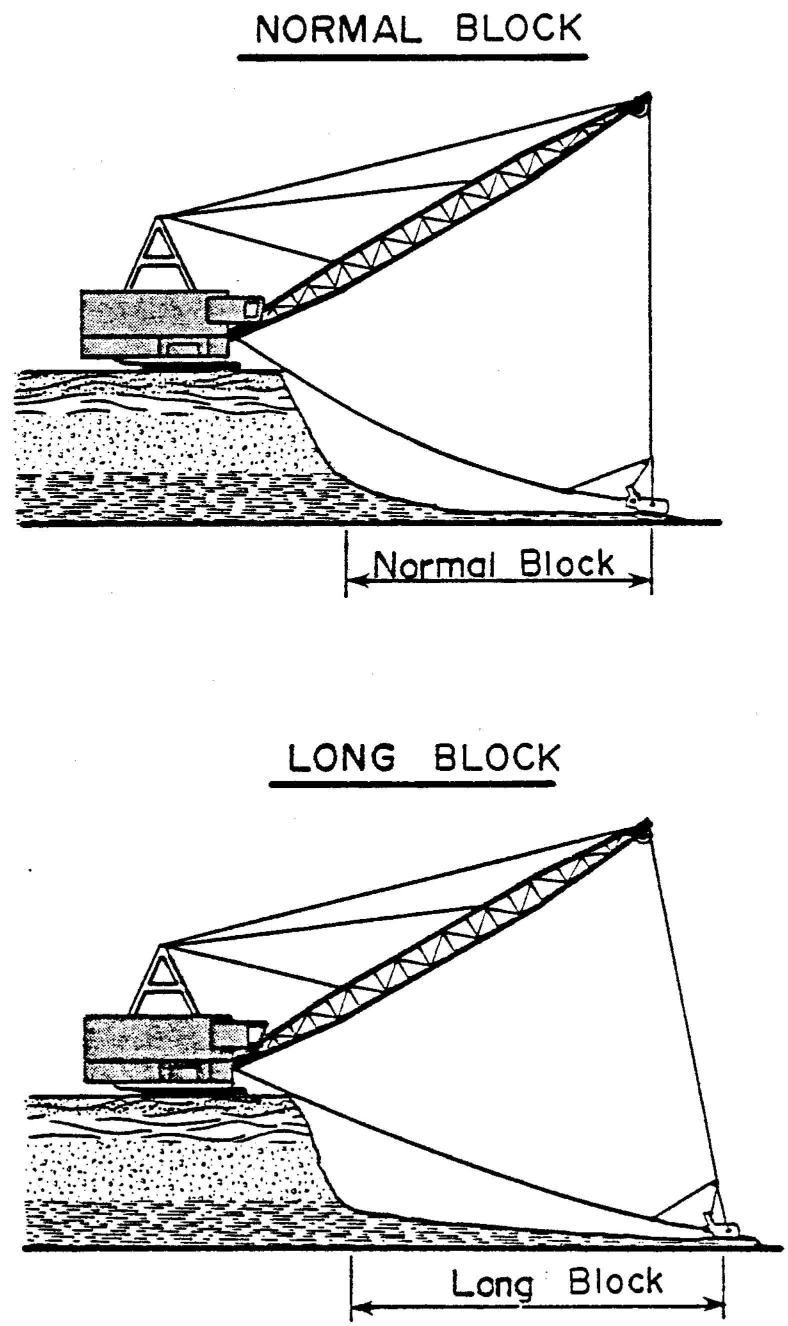

Figure 11. Effect of Block Length on Bucket Position

4.3 Hypotheses Regarding Machine-to-Machine Differences in Digging Time

Statistical testing of hypotheses concerning machine-to-machine differences in cycle times was not part of the project plan and was not done. The hypotheses can be stated, nonetheless. They are:

- Digging time is negatively correlated with the drag motor horsepower per cubic yard of bucket capacity.
- Digging time is positively correlated with the hardness and blockiness of the material dug.
- Digging time is affected by bucket balance and tooth sharpness.
- Within limits, digging time is positively correlated with dump rope length. A short rope allows the operator to pick the bucket up fairly far out without spilling.

4.4 Results for Individual Machines

The results of statistical analyses of digging time data for individual machines are discussed below and compared to the hypotheses.

4.4.1 Digging Depth

Digging time was positively correlated with dig depth for all machines timed, even after adjustment for operator and type of digging.* The coefficients of dig depth in linear dig time equations ranged, for individual machines, from 0.06 to 0.28, and averaged 0.16 over all machines. This is an average increase in digging time of one second for every six-foot increase in digging depth. The kind of result obtained is illustrated in Figure 12.**

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*Complete, detailed results of statistical analyses of digging times are given in Appendices Q and R.

**Two equation forms were fit to the data; one was linear and the other was logarithmic (curvilinear).

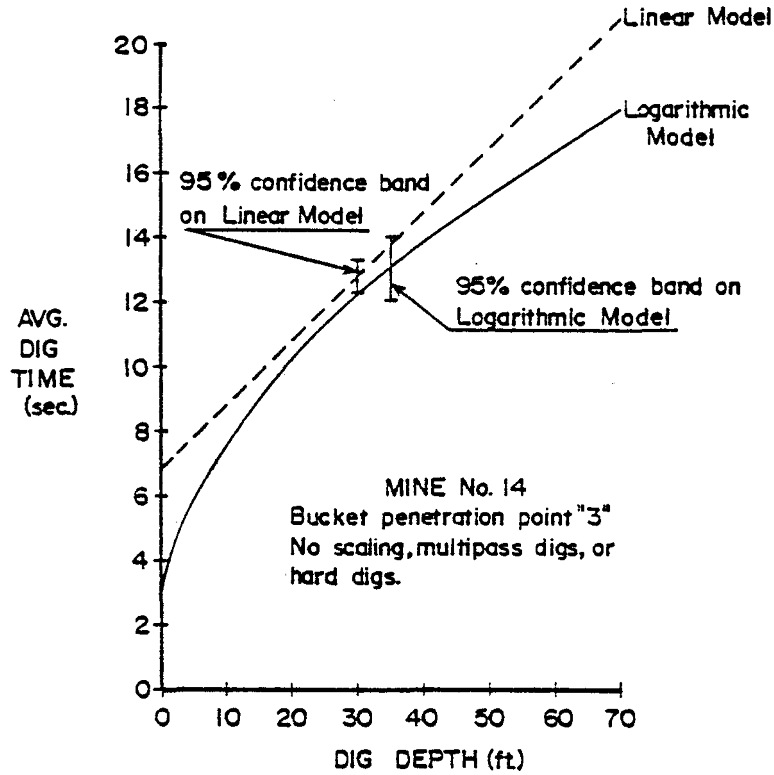


Figure 12. Dig Time Versus Depth for Mine No. 14: Linear and Logarithmic Models

4.4.2 Multipass Digging

For all machines, multipass digging increased digging time significantly. Averaged over all machines, the increase was 19 seconds per cycle; although the averages for individual machines ranged from 8 seconds to 32 seconds.

The observed percentages of dig cycles that were multipass ranged from 0 to 16, and averaged five percent over all machines.*

4.4.3 Block Length

The hypothesis regarding the effects of block length could not be tested because the block lengths for a given machine did not vary during the period of the field survey.

*See Appendix G for more detail.

Bucket penetration point was used as a substitute for block length, and interesting results were obtained, although they were not related to block length. The bucket penetration point was defined as 1, 2, or 3, as shown in Figure 13. Penetration point "3" was what the operators call "digging long". As expected, digging long added to the dig time, relative to shorter digging. On the average, it added five seconds. But the effect of long digging probably stemmed more from overburden hardness than length, because much of the material dug at penetration points 1 and 2 was bucket roll.

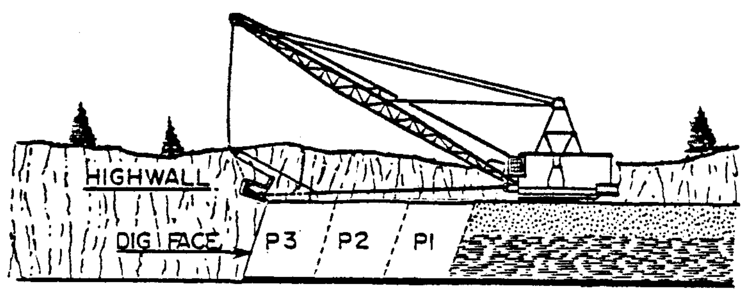
4.4.4 Type of Overburden

The hypothesis regarding the effects of overburden type could be tested only at mines at which markedly different types of strata were dug by the dragline. For the few such mines, digging of sandstone took an average of four- to six-seconds longer per cycle than did digging of shale.

4.4.5 Type of Shot

As expected, poor shots increased digging times.* Poor shots were observed at about half of the field survey mines. Their occurrence is not unusual in strip mining because of the constant experimentation to find better or cheaper shooting methods.

The actual or probable causes of poor shots are shown in Table 4. A frequent cause was failure to drill to the coal, leaving the stratum immediately above the coal unshot.**



LEGEND
P1 = Bucket penetration point "1"
P2 = Bucket penetration point "2"
P3 = Bucket penetration point "3"

Figure 13. Bucket Penetration Points

*Shots were classified as good or poor by the dragline operator, although a poor shot was usually obvious.

**Standard practice is to drill to the coal, then backfill a few feet with stemming to prevent shooting of the coal.

Table 4. Actual or Probable Causes of Poor Shots

Overburden or Interburden	Mine No.	Dig Section or Stratum that was Poorly Shot	Actual or Probable Cause
Overburden	23	Fractured limestone near surface at cropline	Natural fracturing of the limestone made it impossible to get a good shot.
	24	Shale immediately above the coal	Failure to drill to the coal.
	31	"Slate" immediately above the coal	Failure to drill to the coal.
	46	Hard "claystone" near top of bench	(Probable): Benching down to rock left no clay to hold down the hard "claystone" during the blast.
	72	Not determined	Not determined.
	75	Keyway	(Probable): Insufficient loading in inner row of blastholes.
	88	Keyway	(Probable): Insufficient loading in inner row of blastholes.
Interburden	11	Stratum immediately above lower coal seam	Failure to drill to the coal.
	23	All interburden	Failure to detonate ANFO in several holes. Probable causes: not enough detonators in the holes, or rips in plastic bags, causing ANFO to get wet. (Pit was very wet at time of visit.)
	39	Stratum immediately above lower coal seam	Failure to drill to the coal.

Poor shots had three effects, as shown in Table 5 and listed below:

- They increased the frequency of multipass and hard digging cycles. Overall, poor shots affected 26 percent of the dig cycles timed at the subject mines.
- The digging time for cycles affected was increased by an average of 10 seconds per cycle.
- The draglines were frequently idled while the poorly shot material was ripped to make it digable. On the average, idle time was increased by 13 percent.

On average, for the cycles affected by poor shots, dragline productivity was reduced by 36 percent. When all cycles were considered, including those not affected by poor shots, the estimated average productivity loss was 12 percent.*

4.4.6 Operator

There were significant differences between the average digging times for different operators on some machines, after adjustment for the type and depth of digging. They are summarized in Table 6. Overall, the average difference was two-to-three seconds per cycle.**

The differences are attributed to the following causes:

- Dragging the bucket after it has filled: Some operators drag the bucket all the way in to the fairlead on every cycle, regardless of where the bucket fills. This was particularly true for Operator No. 2 at Mine 18. On most cycles after a long cast, he continued to drag the bucket in for an average of eight seconds after it had filled.
- Digging long: Some operators dig long all the time. Others, apparently more systematic, dig short about every third cycle on the average, thereby digging out bucket roll to make room for bucket roll from more long digs.

*Further details are contained in Appendix D.

**Statistical backup for the conclusions in this section is contained in Appendix C.

Table 5. Effects of Poor Shooting on Dragline Productivity: Overburden Only*

Mine No.	Percent of Cycles Affected by Poor Shots	Avg. Increase in Dig Time for Cycles Affected by Poor Shots (Sec.)	Avg. Reduction in Bucket Fill Factor for Cycles Affected by Poor Shots (Percent)	Avg. Increase in Dragline Idle Time for Poorly Shot Material (Percent)	Avg. Loss in Dragline Productivity Due to Poor Shots (Percent)	
					Only Cycles Affected by Poor Shots	All Cycles
23	28	6	18	10	35	11
24	25	7	0	15	24	7
46	22	12	11	20	41	17
72	20	10	28	15	50	12
75	48	14	5	10	31	17
88	15	12	13	10	35	6
Avg.	26	10	12	13	36	12

*See Appendix D for detailed data and calculations.

Table 6. Operator Differences in Average Digging Times*

Mine No.	Dragline	Dragline Age (Years)	Type of Overburden	Approx. Avg. Dig Time, All Operators (Sec.)	ID No. of Operator with Slower Avg. Dig Time	Operator-to-Operator Difference in Avg. Dig Time, After Adjustment for Depth & Type of Digging		Remarks
						Sec.	Percent of Avg. Dig Time	
10	Page 728	20	Sandstone	29	--	0	0	No operator differences detected. Bucket has Miracle Hitch.
11	Marion 7400	14	Clay, shale, and "slate"	16	2 & 3	3	19	Operator No. 1 hoisted the bucket as soon as it was apparent that it wouldn't fill anymore. There were no significant differences among average bucket fill factors for three operators.
18	Marion 183M	10	Dark gray shale	31	2	8	25	Very long drag time after fill for Operator No. 2 when hooking key-way from position on extended bench.
23	Manitowoc 4600	10	Limestone and shale	22	1	2.5	11	Operator No. 1 always dragged the bucket all the way in to the fairlead sheave before hoisting.
28	Marion 7400	20	Claystone and shale	18	1	2	9	No explanation apparent.
31	BE 9W	30	Shale and "slate"	16	1	2	13	Operator No. 1 tended to drag the bucket all the way in to the fairlead before hoisting.
39	BE 480W	1	Limestone and "slate"	18	1	2.5	14	Operator No. 1 had had less drag-line operating experience than the other operators on this machine.
46	Manitowoc 4600	14	Claystone, shale and sandstone	24	2	2	9	No explanation apparent.
72	Marion 7200	28	Clay and shale	18	2	3	16	No explanation apparent.
75	Marion 7500	4	Sandstone and shale	26	--	--	--	Difference not statistically significant.
99	BE 480W	10	Sandstone	19	1	1	5	No explanation apparent.
OVERALL		14.6	--	21.5	--	2.6	12.1	--

*A version of this table showing t-values on average differences is contained in Appendix C.

- Hoist rope tension: The operator must continually work the hoist brake during digging to maintain tension in the hoist cable while digging. Conceivably, there are time differences here due to differences in operator skill.

- Peeling the edge: There are differences in operator philosophy regarding how to dig once the bank has been opened up. Some dig straight ahead, pulling the bucket directly in to the dig face. Others drag the bucket along an edge, peeling the strata off. These practices may account for digging time differences.

4.4.7 Above Bench Chopping

Above-bench chopping ("benching") by the dragline was observed at only two mines. It added several seconds to the average dig time, depending on how high above the bench the digging was. Discussion of below-bench chopping is deferred to a later chapter.

4.4.8 Keyway

On the whole, keyway digging did not significantly affect digging times, unless the keyway had not been well-shot. But the lack of an effect may have been due to the common practice of keeping the keyway opened up. This appeared to be one of the principles of good operating practice.

4.4.9 Rehandle

Surprisingly, digging times for rehandle were rarely significantly different than those for bank material. When they were, there was a positive correlation, meaning that digging times for rehandle were greater on the average than those for bank material. No explanation is apparent.

4.5 Machine-to-Machine Differences in Digging Times

The results of regression analyses of digging times are presented graphically in Figure 14, which shows estimated average digging (drag) time plotted versus digging depth. The machine-to-machine variability is marked. Some inferences about the causes of differences are noted here.

The fastest digging machine was the Marion 7400 at Mine 14. This was the only mine at which the overburden, a soft shale, did not require shooting. The slowest digging machine was the Marion 183M at Mine 18.

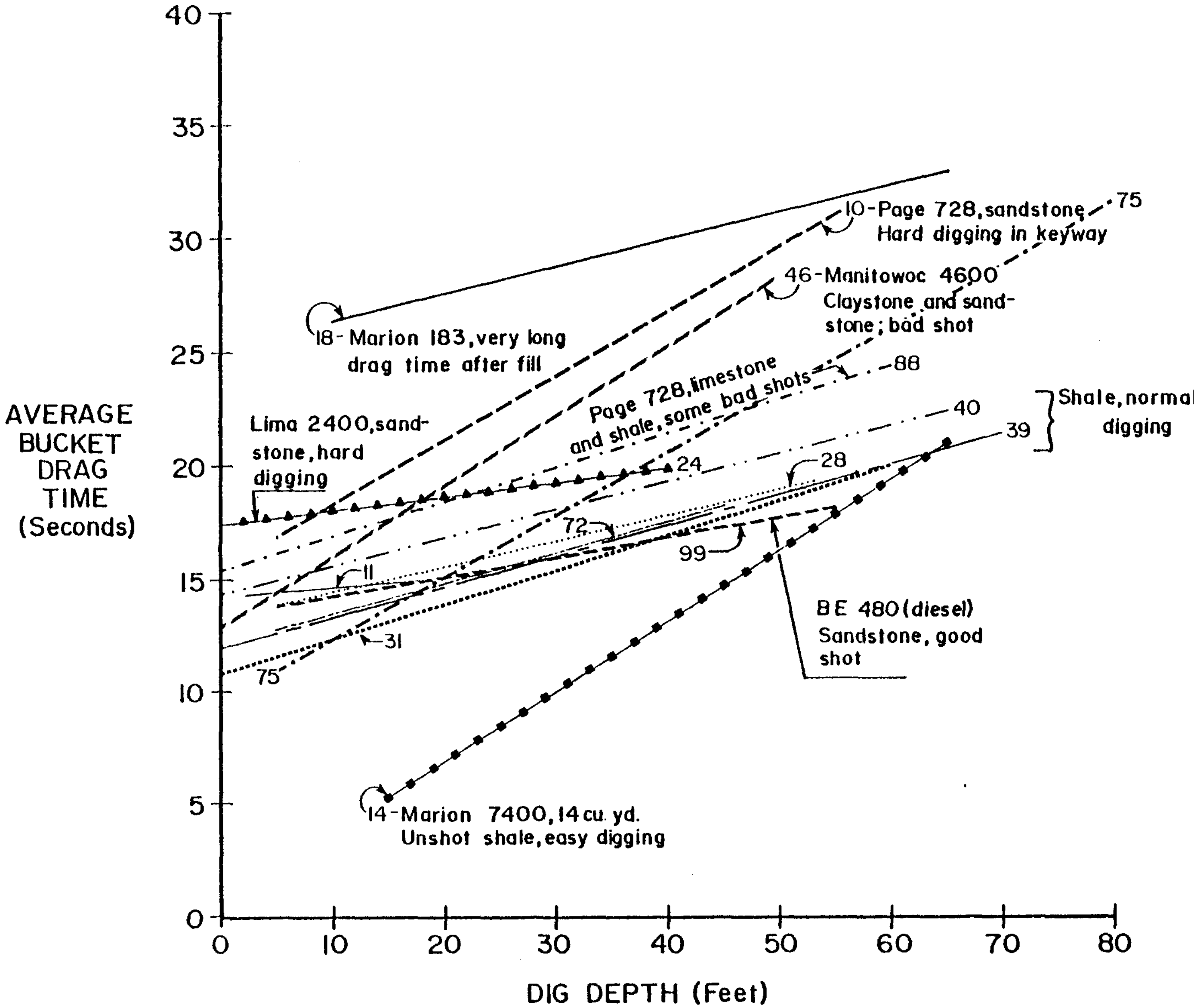


Figure 14. Dragline Digging Time Versus Digging Depth

There, one of the operators continued to drag the bucket for about eight seconds after it had filled on every cycle.

Other slow-digging machines were the following:

- Page 728 at Mine No. 10: An underpowered machine digging sandstone that had not been well-shot in the keyway.

- Manitowoc 4600 at Mine 46: Very bad shot at top of bank near keyway.

Although unable to statistically test hypotheses regarding drag motor horsepower, bucket balance, and tooth sharpness, the operators said that each of these factors has a significant effect on digging times.

4.6 Bucket Fill Factors

Bucket fill factors exceeded 90 percent overall. In general, bucket fill factors were lower than normal in the following circumstances:

- Digging above the bench: For two mines, the bucket fill factor in above-bench digging averaged 70- to 75-percent, markedly less than the fill factor for normal digging.

- Multipass and hard digging: The fill factor was lowered by 5- to 10-percent.

- Digging section: Fill factors in digging keyway and the toe of the old highwall were sometimes 5- to 10-percent lower than other digging.

5. SWING TIME VARIABILITY

5.1 Introduction

As defined in this study, the dragline swing consisted of the following components:

- Return swing
- Bucket positioning
- Dump swing

Similar to the digging component, hypotheses regarding causes of variability in swing times were defined prior to data collection, and then tested statistically after the data had been collected. The hypotheses and actual results are presented and contrasted in this chapter.*

5.2 Hypotheses: Return Swing Time

It was expected that return swing time would increase with increasing swing angle and, possibly, with increasing spoil pile height -- if the operator positioned the bucket during the return swing.

5.3 Results: Return Swing Time

Return swing time was positively correlated with swing angle for all machines. The coefficients of swing angle in linear equations ranged from 0.03 to 0.12, and averaged 0.06 overall. This is equivalent to an average increase of 1 second for every 17-degree increase in return swing angle.

Return swing time was correlated with spoil pile height for 85 percent of the machines, although not all the coefficients were positive. On the whole, spoil pile height was not an important explanatory factor.

It also happened that average return swing time for about half of the machines was greater for keyway digging than for digging the remaining bank or rehandle. The difference, which amounted to one- to two-seconds per cycle, is attributed to bucket positioning during the return swing.

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*Detailed results of regression analyses are contained in Appendix S.

For half of the machines, there were also operator differences that amounted to about two seconds per cycle.

The magnitude of the machine-to-machine variability in return swing time for a given angle can be guaged from Figure 15, which shows the minimum, average, and maximum return swing times plotted versus swing angle. For a given swing angle, the difference between the average return swing times for the fastest and the slowest machine timed was eight seconds.

The results for individual machines are shown in Figure 16. The Marion 7500 at Mine 75 was one of the fastest. Two 4600 Manitowocs were also among the faster machines. The slower machines included a Marion 7200, a BE 480W, and a Page 728.

Although much of the difference among machines is attributable to swing motor horsepower and machine size differences, some is also attributable to operator differences in positioning the bucket. This is illustrated in Figure 17, which shows two curves for each of two draglines -- No. 40 and No. 72. For each machine, one curve is the plot of estimated average return swing time versus angle. The other, for each machine, is the estimated average return and positioning time plotted versus swing angle.

The graph shows that the difference in average return swing times was about five seconds at all swing angles. But the difference between the average times to return and position was only one- to two-seconds. This probably indicates that the operators at Mine No. 72 slowed the swing to position the bucket while swinging.

5.4 Hypotheses: Bucket Positioning Time

After observing dragline operations at a test mine early in the project, the following hypotheses were defined:

- Positioning time decreases with increasing return swing angle. The greater the angle, the more time the operator has to position the bucket during the return swing.
- Positioning time increases with increasing spoil height and digging depth. The sum of spoil height and digging depth is the total distance that the bucket must be lowered to get it into digging position. The greater the distance, the greater the time.
- Positioning time is greatest when the bucket is cast out to dig at depth.
- Positioning the bucket in the keyway takes more time than positioning it elsewhere.

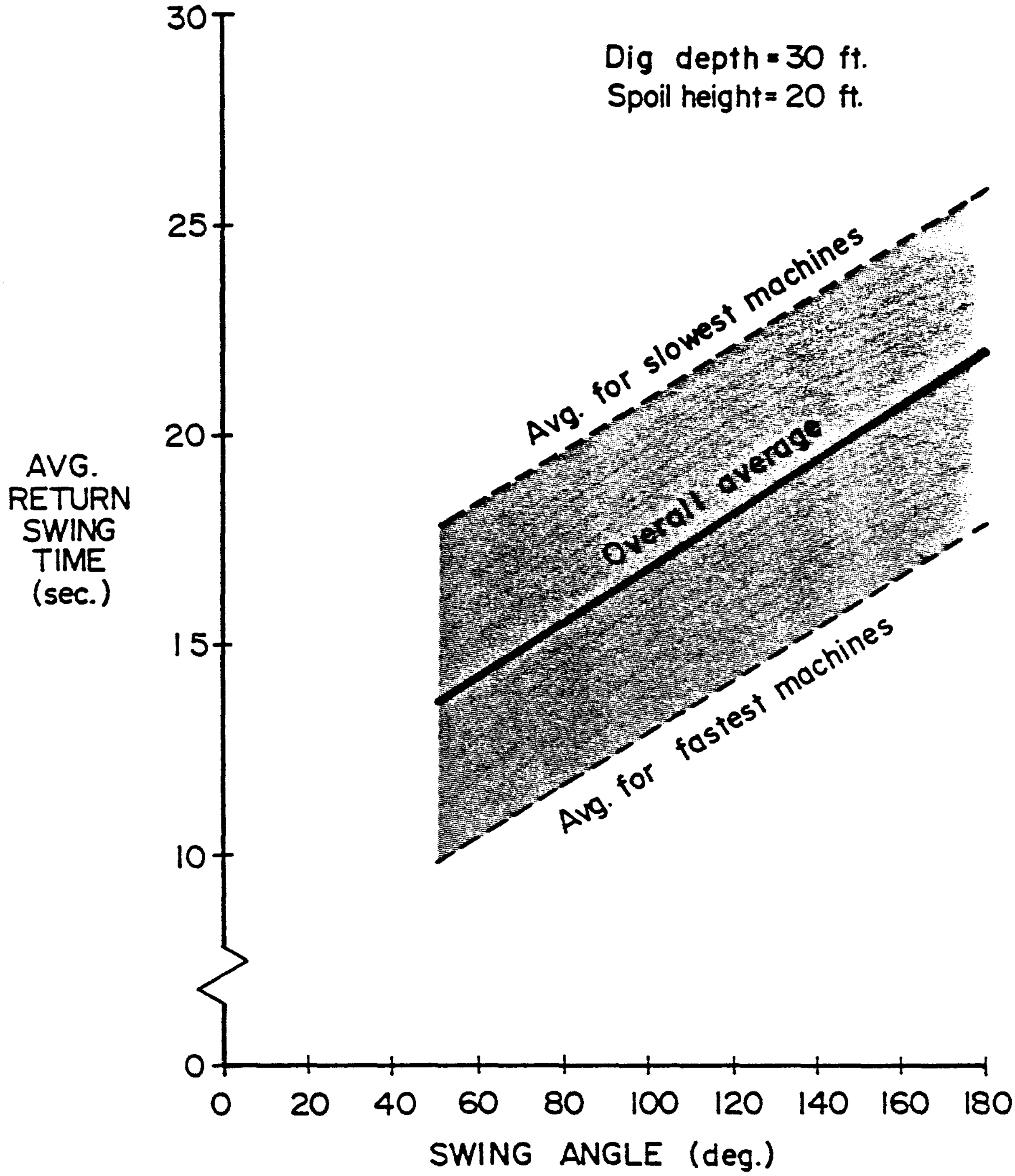


Figure 15. Illustration of Variability in Return Swing Times

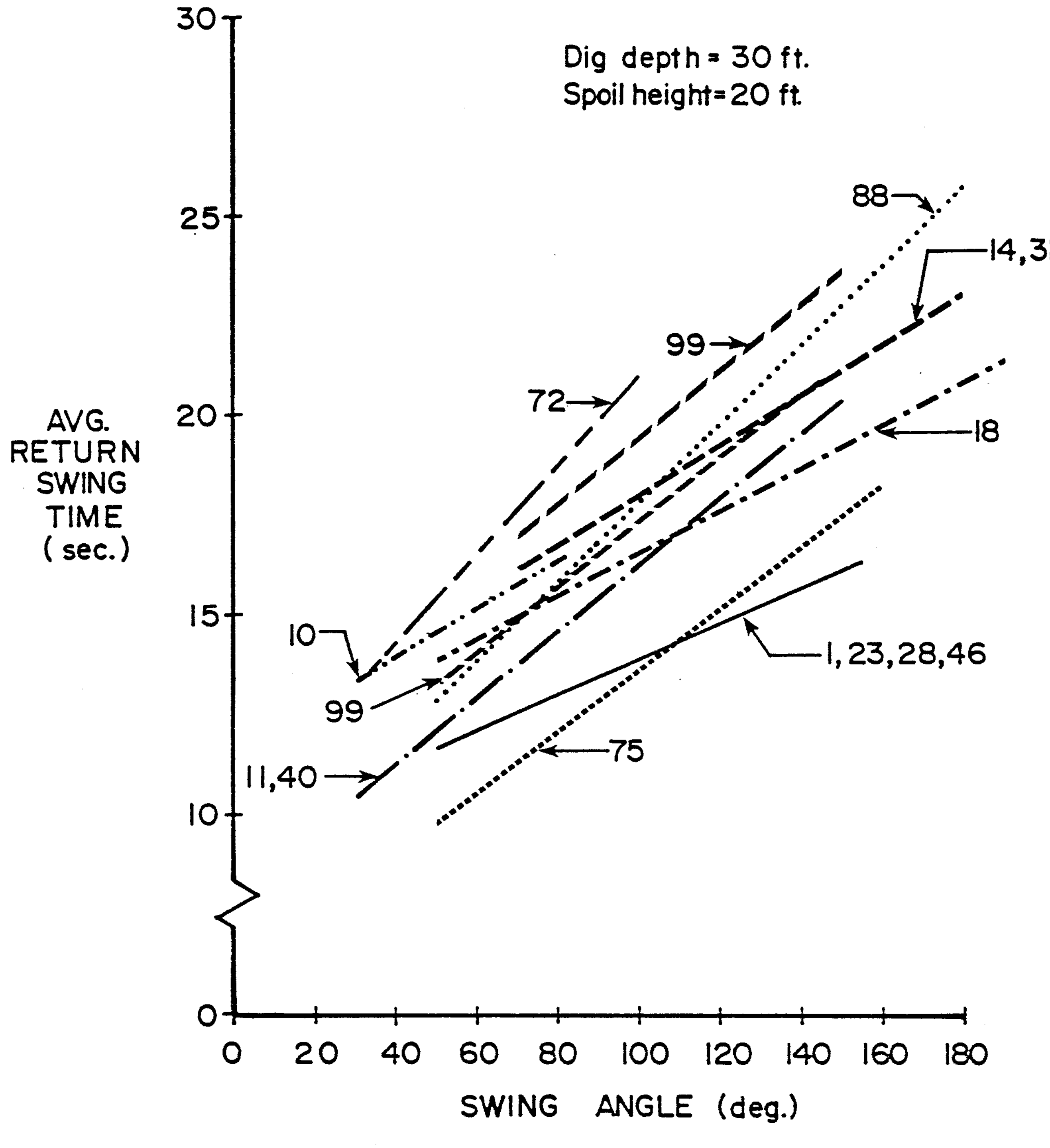


Figure 16. Estimated Average Return Swing Time Versus Angle for Individual Draglines

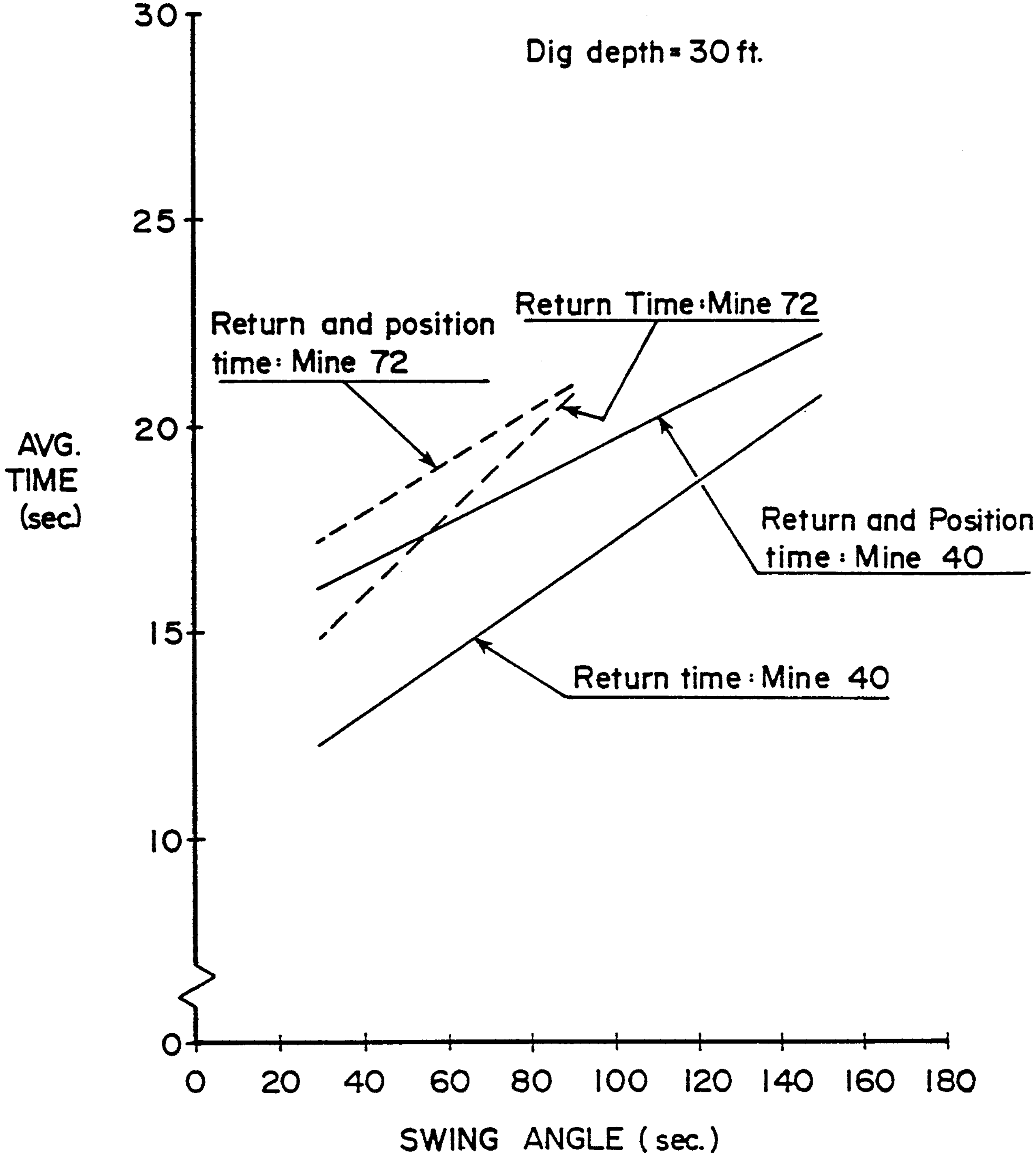


Figure 17. The Effect of Bucket Positioning

5.5 Results: Bucket Positioning Time

Bucket positioning times were, in general, negatively correlated with return swing angle, as expected. The coefficients of return swing angle in linear equations were similar for all machines, averaging -0.03 overall. This indicates a one second reduction in bucket positioning time for every 33-degree increase in return swing angle.

For most machines, positioning time was positively correlated with spoil height. The coefficients of spoil pile height in linear equations ranged from 0.01 to 0.07, and averaged 0.05 overall. This indicates that average bucket positioning time increased one second for every 20-foot increase in spoil pile height.

As expected, positioning time was also positively correlated with depth and bucket penetration point. For cycles on which the bucket was cast to dig, the coefficients of digging depth in linear equations were all about 0.04, indicating a one-second increase in positioning time for each 25-foot increase in digging depth.

Observed average bucket positioning times and 90-percent confidence intervals on the true averages are shown in Figure 18 for individual machines. The averages range from about one- to six-seconds. Most of the differences can be explained by differences in operating circumstances. At Mine 18, for example, extremely deep overburden was being removed by a small dragline. After digging the keyway, the dragline was moved way out onto the extended bench to dig the remaining bank by facing the highwall and hooking the keyway. But the bench was so wide that the operator had to cast the bucket way out to hook the keyway. This caused long positioning times.

5.6 Hypotheses: Dump Time

Hypotheses regarding the causes of dump time variability are listed below.

- Dump time increases with increasing swing angle, spoil pile height, and digging depth.
- The effect of spoil pile height is greater for small swing angles than for large ones.
- The need to hoist out of the keyway before swinging increases dump time.
- For a given swing angle, spoil pile height, and digging depth, dump times are longer when the dragline is positioned on the extended bench than when it is in other positions. This is because of the closeness of the dragline to the main spoil pile.

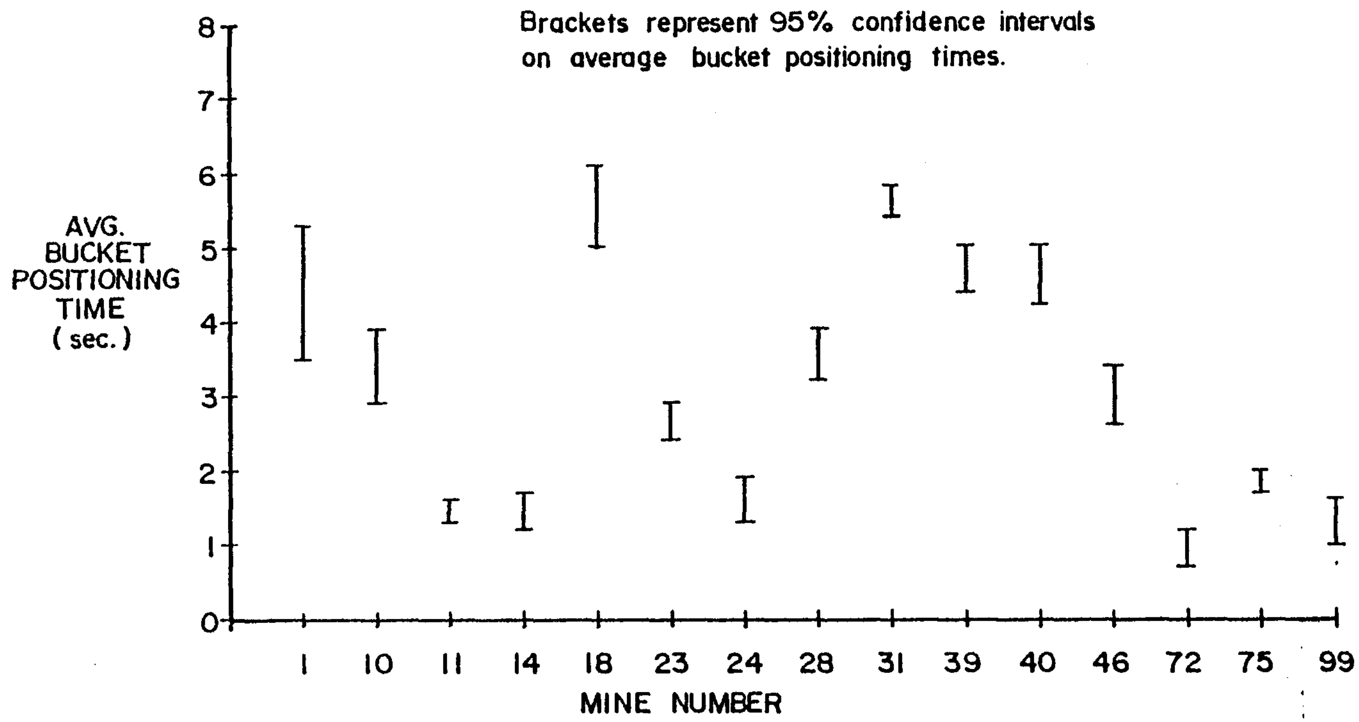


Figure 18. Average Bucket Positioning Times

- Dump times are longer when the bucket must clear the peak of the spoil pile to dump than when spoil is dumped on the side of the pile.

- There are no significant operator differences.

5.7 Results: Dump Time

Dump times were positively correlated with spoil height for all machines. The coefficients of spoil height in linear equations ranged from 0.02 to 0.25, and averaged 0.10 overall. This is equivalent to a one-second increase in dump time for each ten-foot increase in spoil pile height.

The smallest of the foregoing coefficients, 0.02, was for a Marion 7400 that had a button that could be pressed to increase hoist speed by 300 rpm. The operators used it frequently when dumping high. The largest coefficient, 0.28, was for a Page 728 that was underpowered.

Similarly, for all machines, dump times were positively correlated with swing angle. The coefficients of swing angle in linear equations ranged from 0.02 to 0.09, and averaged 0.06 overall -- indicating a one-second increase in average dump time for every 17-degree increase in swing angle.

Dump time was correlated with digging depth for only one-third of the machines. For those machines, average dump time increased one second for every 33-foot increase in digging depth. One reason that digging depth did not have a greater effect is that the bucket usually moves up as well as in during digging. Thus, although the bucket may have penetrated to dig 70 feet below the bench, it might only be 15 feet below the bench when the operator is ready to hoist. So the hypothesis that total hoist distance equals the sum of digging depth and dump height was incorrect.

As expected, there were no operator differences.

Hoisting out of the keyway did increase dump time for about half of the machines. The effect, on the average, was to add one second per cycle. It would have been greater if not for the common practice by operators of keeping the keyway opened up.

Contrary to expectation, dump times were not affected by dumping from a position on the extended bench or having to clear the spoil pile peak to dump.

5.8 Summary of Results: Swing Times

Table 7 shows the swing time equations for individual machines. Inspection of the coefficients in that table give some idea of machine performance characteristics. The BE 9W at Mine 31, for example, was a hoist-limited machine, as evidenced by the large coefficient of spoil height and the small coefficient of swing angle.

Estimated average swing times are plotted versus swing angle in Figure 19 for a spoil height of 20 feet and a digging depth of 30 feet. Plots for different spoil heights or digging depths would look much different than the one in Figure 19. The smaller machines are among the fastest. Examples are the Manitowoc 4600 (23 and 46), Marion 183M (18), and Lima 2400B (24).

The machine-to-machine variability shown is probably due primarily to hoist and swing power differences.

Table 7. Summary of Dragline SWING Time Equations Derived From Time Study Data

Mine No.	Dragline Model	Coefficients of Linear SWING Time Equations					No. of Cycles Timed
		Intercept (a_o)	Swing Angle (Ω)	Spoil Height (h)	Dig Depth (d)	Spoil Height Divided by Swing Angle (h/Ω)	
1	Confidential	6.5	0.133		0.36	18.6	228
10	Page 728	23.9	0.184			16.45	320
11	Marion 7400	19.0	0.152		0.05	6.69	1,074
14	Marion 7400	15.8	0.18		0.06	19.1	375
18	Marion 183	20.2	0.092	0.16	0.067		233
23	Manitowoc 4600	23.5	0.068	0.086			271
24	Lima 2400B	22.4	0.055	0.28			223
28	Marion 7400	25.8	0.068	0.044	0.035		347
31	BE 9W	41.3	0.012	0.26			874
39	BE 480W (Electric)	26.6	0.115		0.13	6.92	477
40	Marion 7400	28.5	0.10		0.147	-8.17	304
46	Manitowoc 4600	16.2	0.118	0.062	0.094		244
72	Marion 7200	21.0	0.145	0.35			469
75	Marion 7500	22.8	0.107	0.037	0.054		645
88	Page 728	14.3	0.181	0.167	0.187	7.1	480
99	BE 480W (Diesel)	26.8	0.132	0.13			334
"Average"		22.2	0.115	0.10	0.074	4.17	6,898

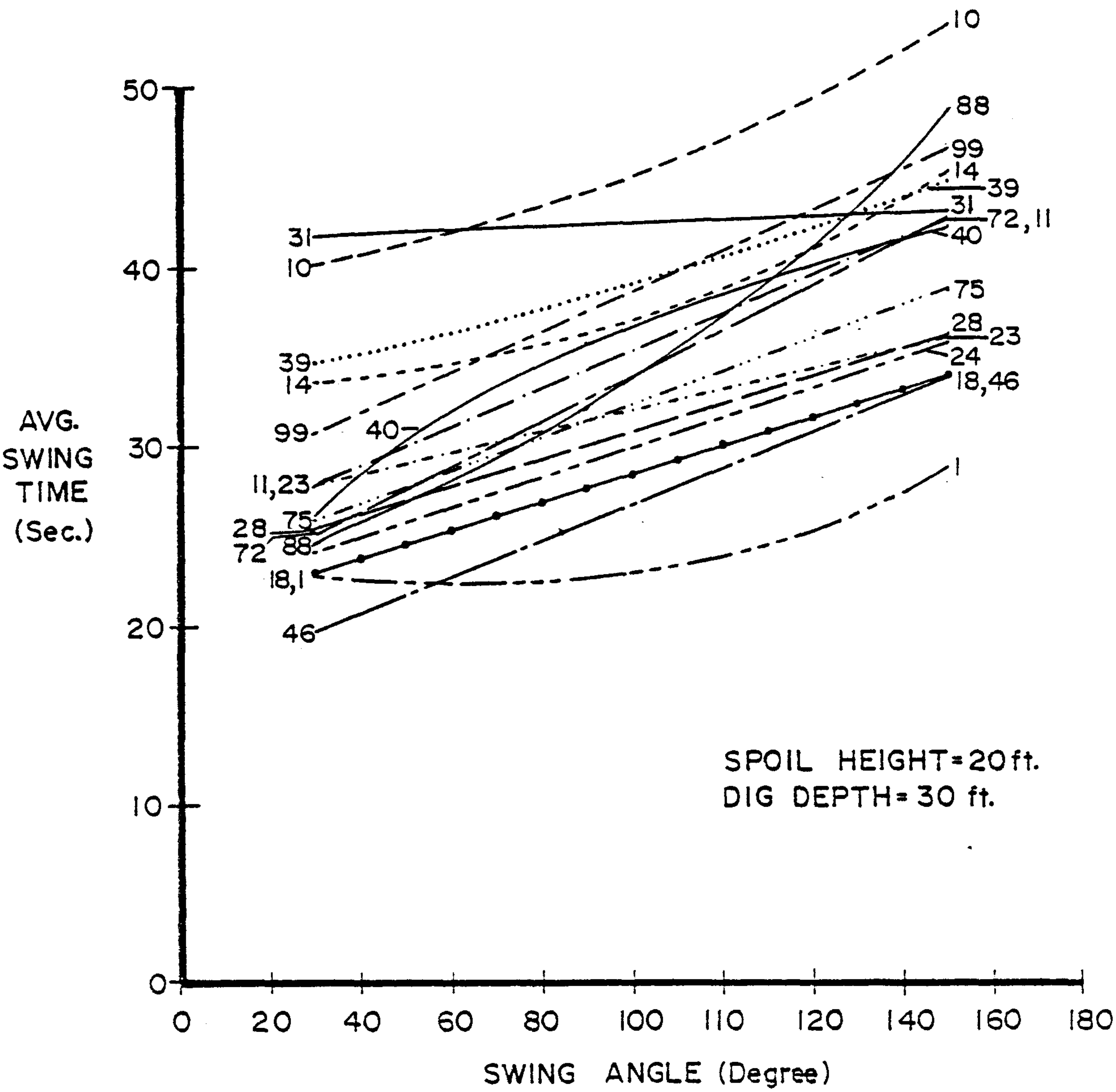


Figure 19. Swing Time Versus Swing Angle for Individual Machines

6. OPERATING DECISIONS

6.1 Reality

"My brother-in-law is an engineer here," the mine superintendent was saying as we looked out at the hilly terrain and meandering pit. "One of these days I'm going to take a handful of spoil, go plop it on his drawing board, and tell him, HERE, LET'S SEE YOU DRAW A STRAIGHT LINE THROUGH THAT!"

Lack of straight lines in real life is not the only problem facing operating people. There's also water, type of overburden, machine breakdowns, and many other factors to complicate life. And there's the fact that all operating choices are compromises involving many interrelated factors. The purpose of this chapter is to describe some of those choices and compromises.

6.2 Definitions

Descriptive phrases such as "deep overburden," "wide cut," and "high bench" are used in this chapter. The definitions are given here.

Pit widths were defined as follows:

- Narrow: 70 to 90 feet
- Moderate: 100 to 130 feet
- Wide: 140 to 160 feet
- Very wide: greater than 160 feet

Bench height definitions were:

- Low or deep: 35 to 50 percent of overburden depth
- Moderate: 20 to 35 percent of overburden depth
- High: less than 20 percent of overburden depth

For example, in 80-foot overburden, a low bench would be 28- to 40-feet below the ground surface, and a high bench would be 16 feet or less below the ground surface.

Overburden depths were categorized relative to the dumping radius of the dragline under consideration. Two classes of draglines were defined. Small machines, such as the Manitowoc 4600 and Lima 2400B, had dump radii less than 120 feet. "Medium-sized" machines were defined to be those with dump radii of 150- to 200-feet. They included the Marion 7400, BE 9W, Page 728, BE 480W, and Marion 7500.

The overburden depth categories for small machines were:

- Shallow: 30 feet or less
- Moderate: 30 to 55 feet
- Deep: 55 feet or more

For medium-sized machines, the definitions were:

- Shallow: 40 feet or less
- Moderate: 40 to 70 feet
- Deep: 70 feet or more

6.3 Operating Decisions

The decisions discussed here concern choices of the following parameters in single seam stripping:

- Dragline block length
- Pit width
- Dragline bench height
- Benching techniques
- Dragline operating procedures

The person or persons that make the decisions vary from mine-to-mine and company-to-company. At many survey mines, particularly those where the dragline operators were very experienced, all of the foregoing decisions were made by the operators. At others, the operators decided on block length and dragline operating procedures, but other decisions were made by the foreman, superintendent, or engineer. An example is specification of the overburden blasthole drill pattern by the superintendent which determines the pit width. Another is specification by the company that deep benching of unconsolidated material is to be done by the dragline, not by the dozer.

6.4 Block Length

Determination of block length is one of the simplest of the operating decisions. At the survey mines, the dragline operators decided the block length. Figure 20 shows how it was done.* To start a new block, the operator moved away from the previous digout position until he reached a point at which the boom point was approximately over the toe of the section to be dug. For the example shown, this results in a 100-foot block if the bench height is 30 feet, and a 60-foot block if the bench height is 70 feet. This shows why the operators "shorten up when it gets deep". It's because use of a long block from a high bench would necessitate long casting of the bucket to dig deep.

There were some operators that liked to take a longer than normal block because they, or their oilers, or both, didn't like to move around a lot. This reluctance, of course, is most pronounced for electric walking draglines. It appeared to be motivated by the operators' desire to keep digging, and not be wasting time moving around.

The long block has one advantage; it reduces the number of blocks per cut, and thus the amount of non-productive dragline movement time per cut. But an overly long block has marked disadvantages. The principal ones are the following:

- The bucket must be cast way out to dig deep. For reasons presented earlier in this report, this increases the average digging time per cycle.
- The ridge line of the resulting spoil pile will be undulating, rather than knife-edge. The spaces between piles are wasted dirt room, and they increase spoil grading costs.

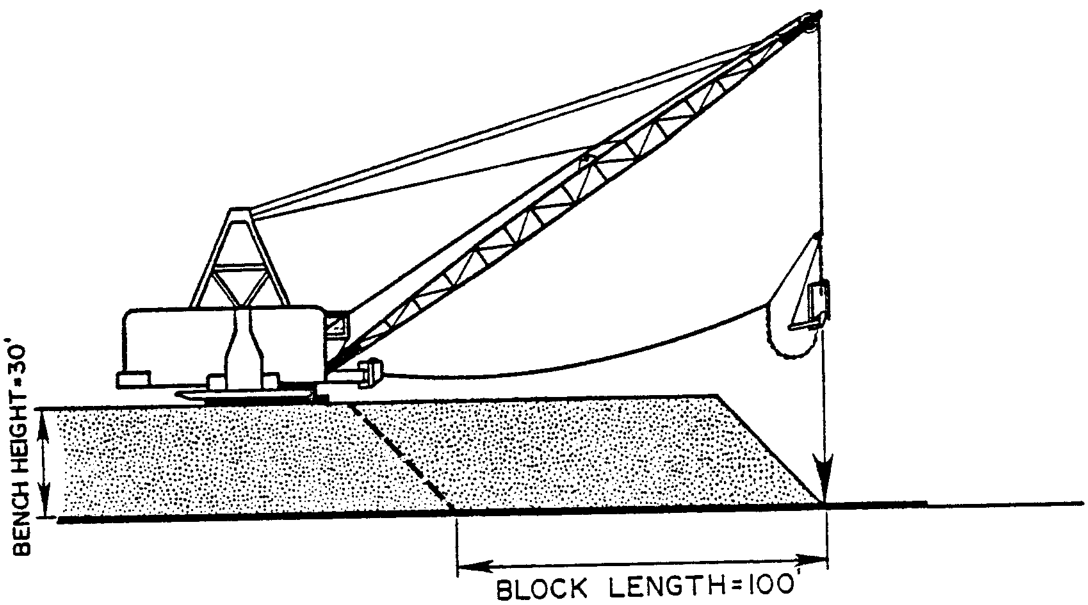
Of course, an overly short block is no good either because it makes it difficult to layer load and to fill the bucket.

Although a relatively simple decision, the choice of block length is nonetheless an important one. The wrong choice could decrease dragline productivity by several percent. Results discussed earlier, for instance, conclude that long digging adds five seconds to digging times.

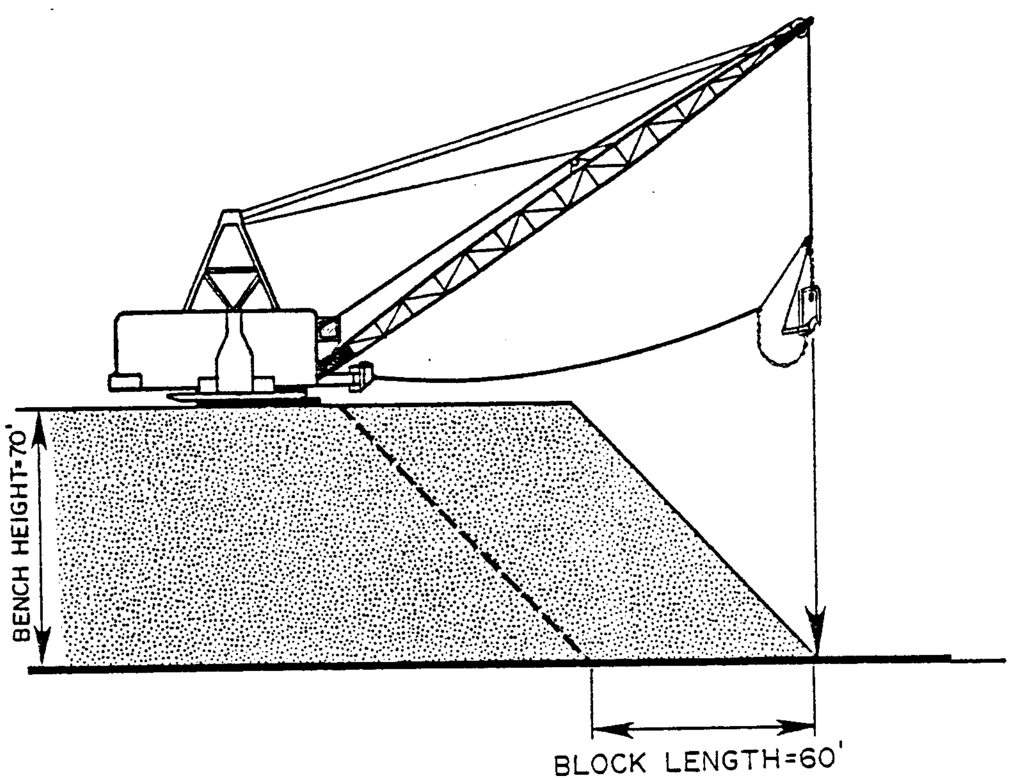
6.5 Pit Width

The choice of pit width is often a controversial one, influenced by topography, dragline range, overburden depth, and pit direction -- among other factors. It is important because it affects average dragline swing

*The figure is for a dragline with a 150-foot dump radius. For much larger draglines, the block length is probably not chosen in the manner shown here.



30-Foot Bench Height



70-Foot Bench Height

Figure 20. Choosing the Block Length for Different Bench Heights

angle and dump height, spoil rehandle percentages, and dragline walking time.

There are many different philosophies regarding pit widths. Some say keep them narrow to minimize swing angles and avoid rehandle. Others like them wide, to make full use of machine range and reduce the amount of non-productive dragline walking time. In general, however, pit widths are moderate, reflecting varying conditions that would make either narrow or wide pits poor choices. Some of those conditions and their effects are discussed below.

6.5.1 Effect on Spoil Pile Height

For a given overburden depth, widening the pit increases the height of the final spoil pile. Under typical operating conditions, each ten-foot increase in pit width will increase the height of the final spoil pile by about two feet. Under normal circumstances, this may not be significant, and probably has little bearing on the choice of pit width. It might be important, however, if the overburden is deep and the bench is low.

6.5.2 Effect on Rehandle Percentage

The effect of pit width on spoil rehandle percentage is significant. In fact, the primary objective of many operating people in choice of pit width is minimization of the spoil rehandle percentage.

In shallow overburden, where dozers are used for benching, this is accomplished by carrying a narrow- to moderate-width pit. If the pit is too wide, keyway spoil may ride up the highwall, causing rehandle even if there is no extended bench.

In deep overburden, where an extended bench is needed, the rehandle percentage decreases as the pit width is increased. This is because, in real situations in northern and southern Appalachia, the rehandle volume is the same for a wide pit as a narrow one. By widening the pit, the rehandle volume as a percentage of cut volume is decreased.

6.5.3 Effect on Swing Angle

As a general rule, widening the pit increases the average swing angle for a block. In very shallow overburden, for example, the whole block can be dug out from the keyway position if the pit is narrow enough. In such a case, the operator would start digging at the old highwall, dumping into the open cut. Average swing angle in this operation would be 45 or 50 degrees. The operator would then dig in toward the keyway, gradually increasing the average swing angle to 90 or 100 degrees.

In shallow and moderate-depth overburden, if the pit is too wide, the operator may have to move away from the keyway position before completing the keyway.* If he does, the remaining keyway material must be chopped out while facing toward the highwall. The swing angle to dump will exceed 90 degrees.

In deep overburden, when an extended bench is needed, narrowing the pit too far may increase the average swing angle. The reason is that the dragline effective spoil radius from the keyway position would be too long to permit building the extended bench next to the current block. In this case, the keyway spoil would have to be "led" -- swung through an angle of 120 to 150 degrees -- to enable dumping near the highwall, thus building the extended bench for the next block, or two blocks hence.

If, however, the pit is wide enough so that the extended bench can be built for the current move, then further widening of the pit will increase the average swing angle for the block, if a two-set block is used. The increase comes during the last dig component on each block, when the bank overburden is dug from the extended bench position.

6.5.4 Effect on Digging Time

For the two-set block, making the pit very wide might increase the digging time when digging bank material from the extended bench position. This is because the bucket would have to be cast far out to hook the edge of the keyway, resulting in drag time after bucket filling.

6.5.5 Effect on Spoil Grading Costs

In research work for the U.S. Bureau of Mines, Jake Howland of Pittsburgh & Midway Coal Company showed that the cost to grade spoil piles with a 120-foot crest-to-crest spacing was roughly twice that to grade piles with 90-foot spacing. Ordinarily, in area mining at least, the crest-to-crest spacing is the same as the pit width, implying that widening the pit increases spoil grading costs. The extended bench methods observed during this project were a little more complex than that, however, because the vee's between spoil piles were sometimes filled when dumping from the extended bench position. So, although widening the pit will probably increase spoil grading costs, the relationship between pit width and grading cost is not well-defined.

6.5.6 Practical Aspects

There are additional factors influencing the choice of pit width. The direction of cuts, for example, is important. In contour mining, the

*This would happen if the keyway spoil began to extend the bench when an extended bench was not needed.

width of a cut generally varies along its length, the result of opening the first cut along the meandering coal seam cropline. Ordinarily, the first cut is made wide to allow for progressive narrowing of succeeding cuts as overburden depth increases. Common practice is also to narrow the cuts at inside curves and widen them at outside curves.

The variation of overburden depth within a cut also influences the choice of pit width. Large variations tend to prevent the use of very wide cuts.

6.6 Bench Height

The choice of bench height is often an important operating decision, affecting digging depth, spoil pile height, rehandle percentage, production rate, and -- if benching is done by the dragline -- swing angle, and bucket fill factor. The effects depend, among other factors, on whether the benching is done by dozer or by dragline.

6.6.1 Effect on Digging Depth

Lowering the bench reduces the digging depth and the average digging time for a block. It also may make it possible to do deep stripping with a dragline that has a small maximum digging reach.

6.6.2 Effect on Spoil Pile Height

Changing the bench height does not, of course, affect the height of the final spoil pile above the pit floor, but it does affect the height above the bench. Lowering the bench increases the average and maximum spoil height above the bench, and therefore increases the dragline dump heights and times.

6.6.3 Effect on Rehandle Percentage

The effect of bench height on rehandle percentage depends primarily on overburden depth and the benching method used. In shallow overburden, if dozers are used for benching, lowering the bench may cause unnecessary rehandle. This is illustrated in Figure 21 for a 20-foot bench in 30 feet of overburden. In this case, the bench dirt extends the dragline bench, causing dragline rehandle that wouldn't have occurred had the bench been higher. *

*A rule-of-thumb is that dozing of half of the overburden into the open cut will extend the bench all the way across the pit.

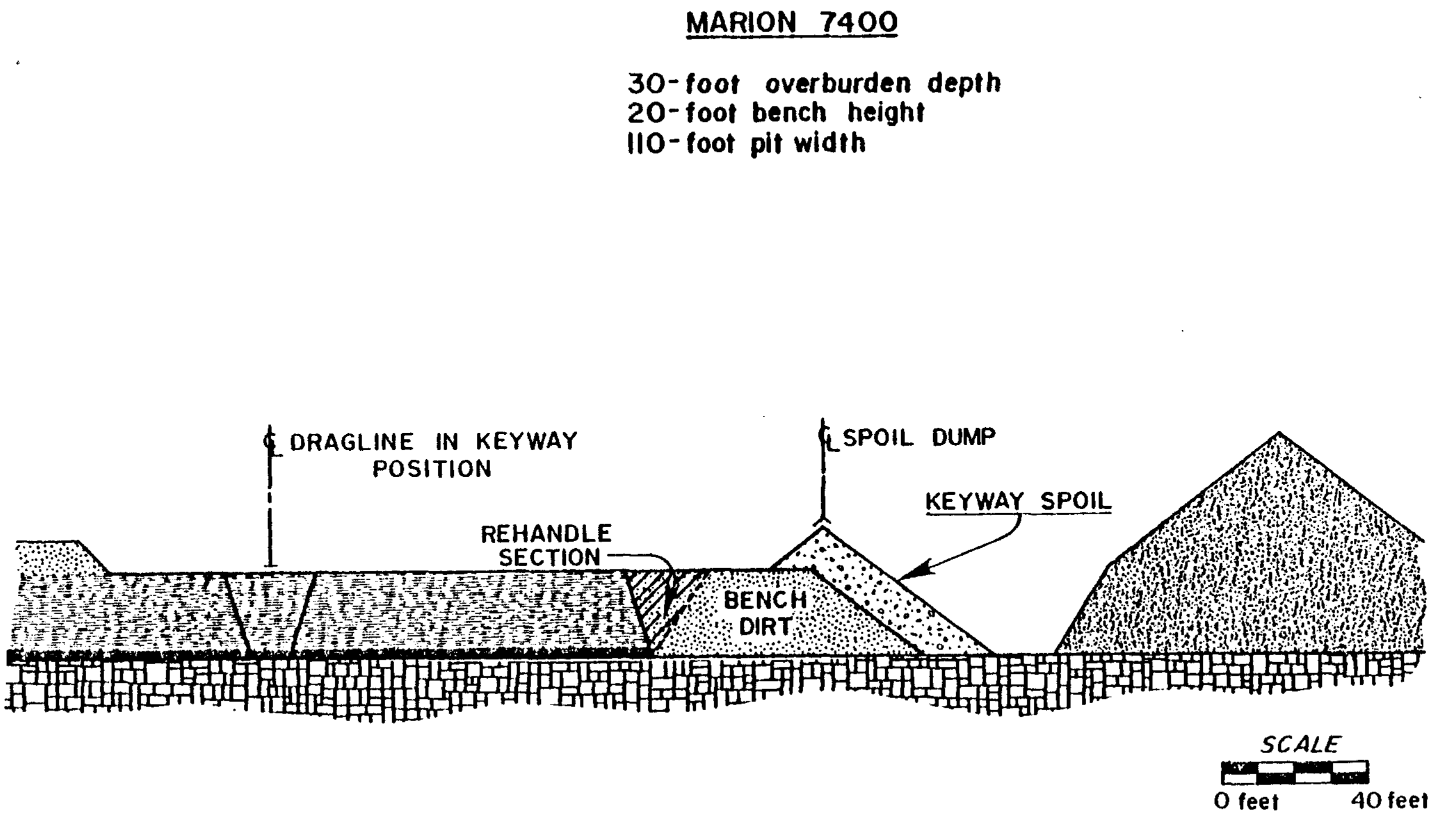


Figure 21. The Effect of Dozer Benching in Shallow Overburden

In moderate overburden, if benching is done by the dragline, lowering the bench may prevent rehandle. This occurs when the overburden becomes just deep enough that an extended bench would be necessary if the dragline worked from a high bench. Lowering the bench may eliminate the need for an extended bench in such a case because lowering the bench extends the effective spoil radius of the dragline. This is because the highwall is not vertical, but rather stands, typically, at an angle of 70- to 75-degrees from the horizontal. For a 70-degree highwall, the edge of the bench moves out toward the pit 3.6 feet for every ten feet that the bench is lowered. In this same situation, of course, deep benching by a dozer would extend the bench.

In deep overburden, where an extended bench is needed, lowering the bench reduces the rehandle percentage, usually substantially. The reason is illustrated in Figure 22, which shows graphically the rehandle sections for high and low benches in deep overburden.

6.6.4 Effect on Dragline Rate of Advance

When benching is done by a dozer, lowering the bench increases the rate of advance of the dragline because it reduces the volume of overburden that must be moved by the dragline per linear foot of cut length.

6.6.5 Effect on Swing Angles

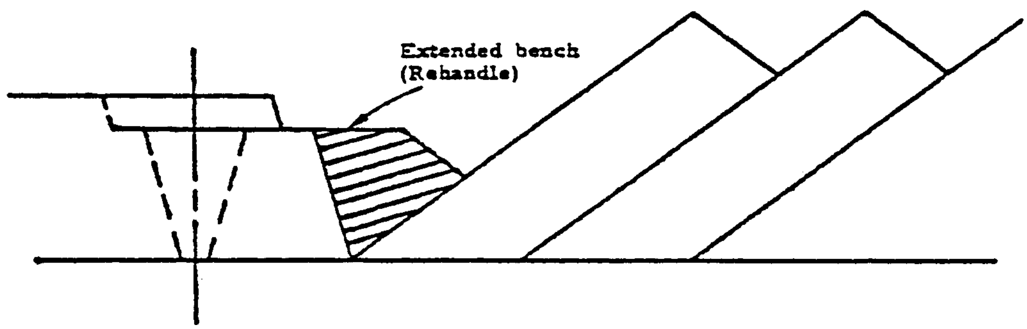
There are two cases in which swing angles are affected by bench height. The first is the case in which deep dozer-benching in relatively shallow overburden fills the pit, taking up dirt room that would have been used for keyway spoil. This may necessitate chopping of some of the keyway section from a dragline position out on the middle of the bench, resulting in swing angles larger than 100 degrees. The alternative is to keep the bench high, as illustrated in Figure 23, digging as much as possible from the keyway position. The average swing angle in this kind of operation would be less than 80 degrees.

The second case is that in which the bench is cut by the dragline, digging above the bench and to the side. The average swing angle to dump side bench spoil usually ranges between 130 and 160 degrees so that increasing the bench depth will increase the average swing angle for the block.

6.6.6 Practical Aspects

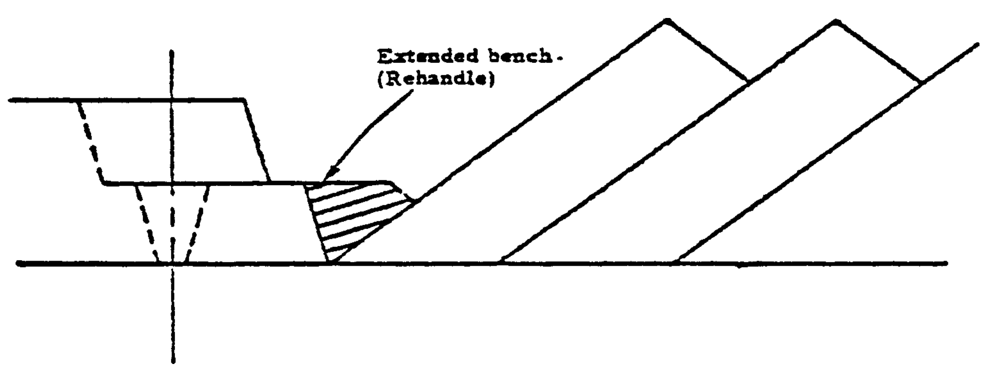
Topography and cut direction also influence the choice of bench height. Where cuts are made along the contour, common practice is to keep the bench at a constant height above the coal for the entire length of the cut. A main reason for doing this is so that the dragline does not have to be ramped up and down from one bench height to another. In hilltop

HIGH BENCH (30% REHANDLE)



1. 100 foot overburden depth, 20 foot bench depth.
Rehandle = 30%

DEEP BENCH (14% REHANDLE)



2. 100 foot overburden, 50 foot bench depth.
Rehandle = 14%

Figure 22. Illustration of Rehandle Percentages for High and Low Benches

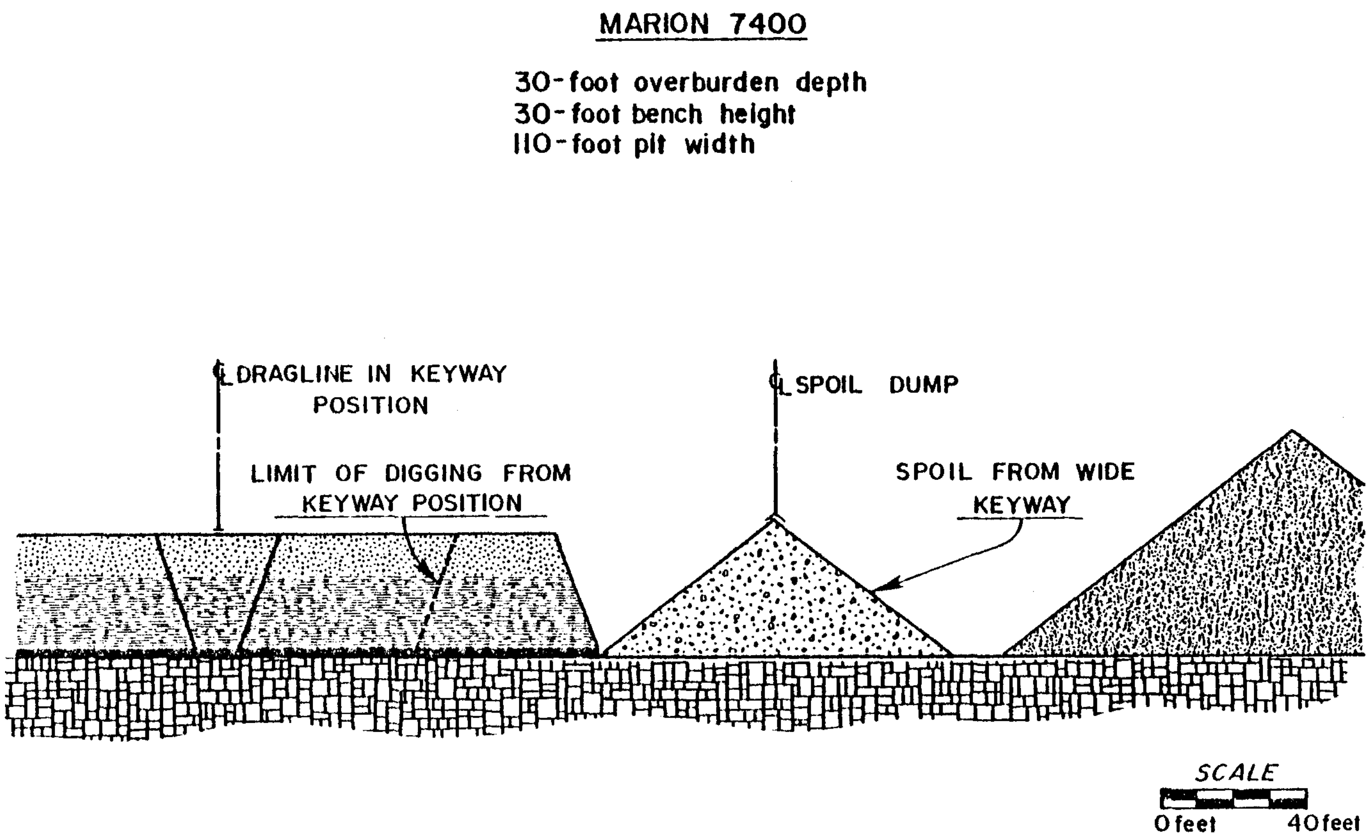


Figure 23. Digging a Wide Keyway in Shallow Overburden

removal and blocking, however, the bench height may vary from block-to-block, depending on the overburden depth. The changing bench heights in a hilltop removal situation are shown in Figure 24.

6.7 Dragline Operating Decisions and Procedures*

Operating decisions and procedures at the survey mines varied with the operator, depth and type of overburden, and pit width, but certain practices were common to most operations.

Moving way ahead and digging a shallow lift off the entire block as the first step on the block is an example. Many operators did this so that they wouldn't be plagued by bucket roll later on.

Sitting over the keyway and digging it out down to the coal was almost a universal practice. It was done for the following reasons:

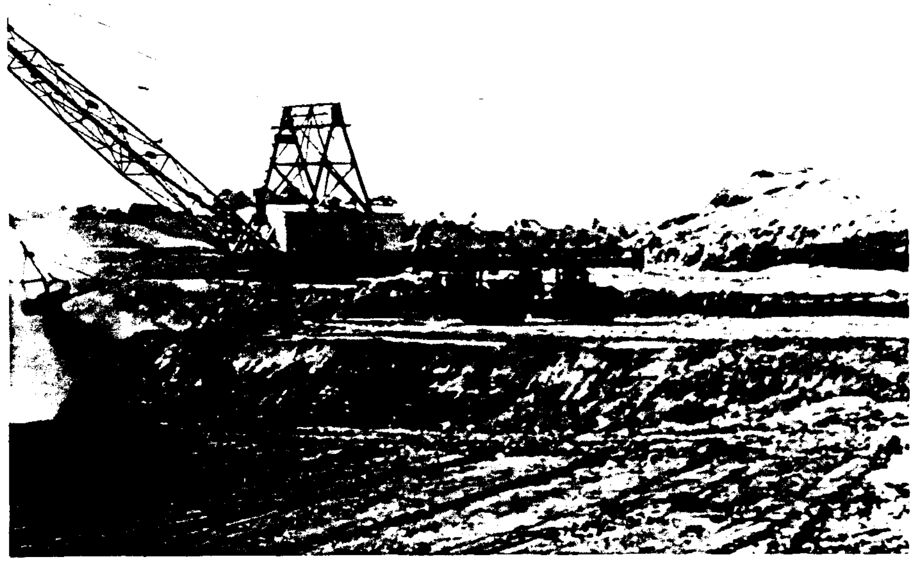


Figure 24. Changing Bench Heights in Hilltop Removal

*Detailed descriptions of dragline operating procedures used at the survey mines are contained in Appendix N.

- To establish a steep, safe highwall. The alternative, chopping the highwall, makes it impossible to get a steep highwall, unless it's squared up by loaders or dozers.

- To open up the bank so that it would not be necessary to chop the highwall when digging from subsequent dragline positions.

- In deep overburden, to make it possible to dump in close to extend the bench, without swinging through a big angle.

Most operators of hoist-limited machines widened the keyway at the top to reduce the distance that the bucket had to be hoisted out of the keyway before beginning to swing. Additionally, at some point during keyway digging, common practice was to move up a few steps toward the dig face to keep the cable out of the roll.

In moderate overburden, where an extended bench was not needed, a two-set block was common -- the first set being the keyway position, and the second being out near the edge of the bench. The bank left after completion of the keyway was dug from the second position.

6.7.1 Shallow Overburden

In shallow overburden, operators must decide how wide to make the keyway. In practice, they tended to make it as wide as possible because the swing angles when swinging from a widened keyway to dump were generally 60- to 85 degrees.

6.7.2 Deep Overburden

When an extended bench is needed, operators must make several additional decisions. One is where to build the extended bench -- for the current block or the next one. For a given dragline, this is largely determined by the pit width, but the operators often still have some discretion.

An example is the case in which the pit is not too wide and the bench extension needed is not too large. Here the operator has two basic choices:

- Build the bench for the current block, in which case it will be wider than necessary.

- Build the bench for the next block, swinging through a large angle, but keeping the bench extension to the needed width.

The effect of the first of these choices is to increase the rehandle volume. This is illustrated in Figure 25 for a Marion 183M operating from the ground surface in 40 feet of overburden with a 70-foot pit width. In this case, the bench extension needed is only five or ten feet. But, operating from the keyway position and swinging 90 degrees, spoil will be dumped 55 feet out from the upper edge of the highwall, resulting in a 55-foot bench extension. This causes extra rehandle, shown cross-hatched in Figure 25.

The effect of the second choice is to increase the swing angle required to build the bench, but the rehandle is held to a minimum. In practice, at the survey mines, the operators carried wider pits than that shown in Figure 25, and built the bench extensions for the current block by swinging keyway spoil through an average of 90 degrees to dump. Nonetheless, this often resulted in a bench extension wider than needed. The extra rehandle that resulted, however, did not generally appear to be large. Additionally, having extra width gave the operators some flexibility in subsequent digging, as discussed below.

After completing the keyway and extended bench, the operator must decide where to sit and where to dig next. At most of the survey mines, the operators moved out onto the extended bench and dug the rehandle. In essence, they dug a second keyway -- this one in spoil. The apparent reasons for this procedure were the following:

- They didn't want to chop to dig the rehandle, so they dug it like a keyway.

- They wanted to steepen (slope) the spoil so that it would stand at an angle greater than the natural angle of repose. This could be accomplished only by sitting over the rehandle section and digging it like a keyway.

- They wanted to "open up" the pit, so that in digging the remaining bank material later on, there would be room to swing while hoisting out of the bank.

When this procedure was used, a vee-shaped section of bank overburden remained after finishing the digging of the rehandle section. The swing angle in digging this remaining section would have been minimized by moving back onto the solid bench to dig it. But, if the extended bench had been made just the right width, or thereabouts, the dragline would not have had adequate effective radius if positioned back on the solid bench. Additionally, although the swing angles were large when the remaining bank was dug from a position on the extended bench, the dump heights were also large. For hoist-limited machines, the large swing angle

MARION 183 M

40-foot overburden depth
40-foot bench height
70-foot pit width

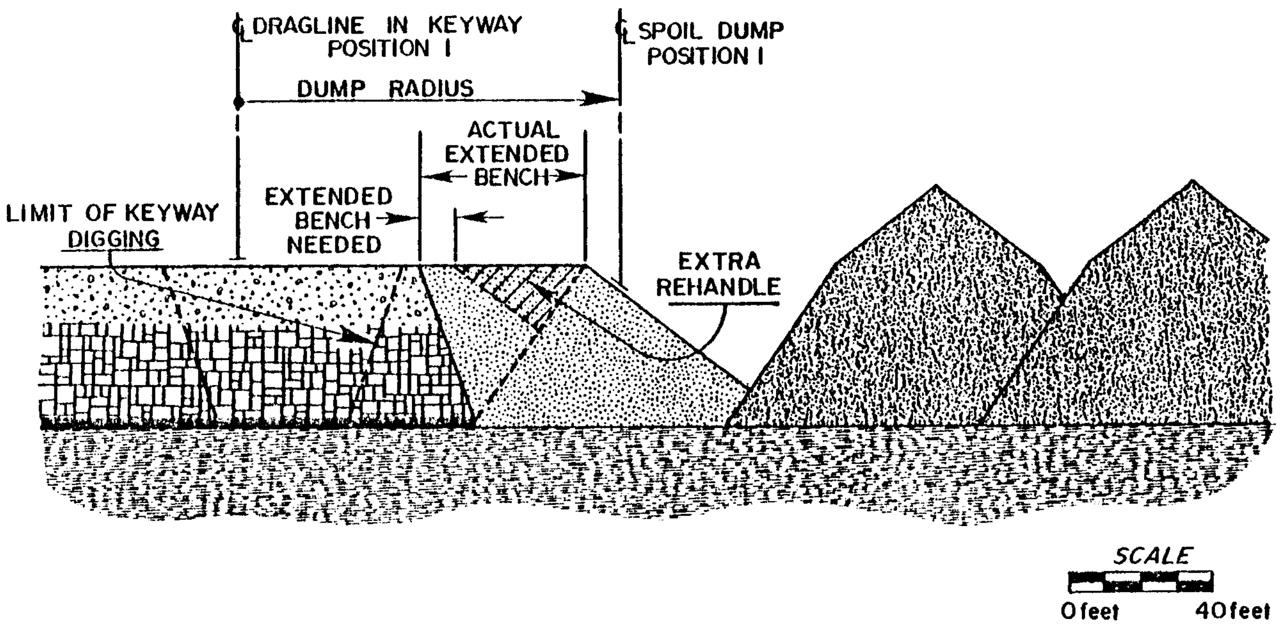


Figure 25. Making an Extra-Wide Bench Extension

probably didn't matter too much. For these -- and possibly other reasons that were not determined -- many operators dug the remaining bank from a position on the extended bench. This was the so-called two-set block.

If the extended bench had been made wider than necessary in the first place, then a three-set block was possible, and, in fact, was used at a few mines. This was because the effective radius of the dragline from the position on the wide extended bench was longer than needed, leaving some "extra" dirt room. In such cases, the dragline was moved back in toward the keyway, but not over it by any means, to dig the remaining bank. Average swing angle from this, the third position, was about 90 degrees. It would have been about 125 degrees if the digging had been done from the extended bench position.

7. OPERATING GUIDELINES: SINGLE SEAM DRAGLINE MINING - MAXIMUM DRAGLINE PRODUCTIVITY

7.1 Introduction

The observed criterion generally used by the surveyed coal companies for "optimal" mining was maximization of dragline productivity as measured in bank cubic yards of overburden removed per operating hour. Dozers dedicated to the pits rarely removed more than 10% of the total machine-moved bank yardage. In most cases, dozers leveled a drill bench and after blasting leveled a bench for the dragline. When blasting did not throw significant overburden into the pit, the resulting dragline bench was substantially the same as the drill bench. When blasting did throw substantial overburden into the pit, the resulting dragline bench was, of course, lower than the drill bench. Mine 18 was the only observed mine blasting in a manner to substantially reduce the dragline bench. At this mine, the drill bench was 95-feet and, after blasting, the dragline bench was 67-feet above the coal. At this mine, also, dozer use after blasting was restricted to leveling the dragline bench.

Based on the criterion of maximization of dragline productivity, guidelines are developed in this chapter for choices of block lengths, bench heights, and pit widths for different mining situations. The guidelines are site- and machine-specific; however, general conclusions are drawn.

7.2 Assumptions

The following assumptions were made in developing the guidelines:

- The effects of block length and pit width on total dragline walking time are insignificant. For example, based on calculations shown in Appendix F, increasing the pit width from 110 feet to 150 feet would increase available dragline operating hours by only one-half of one percent. Increasing the block length from 55 feet to 75 feet would have a similar, small effect.
- The dragline has sufficient capacity to uncover coal at required rates even if all of the overburden is removed by the dragline.

- The width of the cut being made is the same as the width of the adjacent open cut.

- Spoil swell = 23 percent (0.77 cubic yards bank equal one cubic yard loose), angle of repose = 37 degrees, angle of steepened spoil = 55 degrees, highwall angle = 70 degrees.

- The dig face can be steepened to stand at 50 degrees, or more, from the horizontal. This is necessary for feasibility of high benches for certain draglines. The 4600 Manitowoc is an example. If the dig face angle was 40 degrees, the "normal" block length for a bench 70 feet high would be 11 feet. This would obviously be impractical. But if the dig face angle was 50 degrees, the normal block length would be 35 feet.

- A dozer is available to cut varying bench heights as required for analysis.

7.3 Limitations

There are two limitations, neither of them severe, on the analyses done to develop guidelines:

- The effects of block length on digging time were assessed qualitatively.

- For cases in which a high dragline bench is indicated, the extra costs of drilling through unconsolidated overburden that could have benched off were not considered.

7.4 Guidelines for Choice of Block Length

For draglines of the types observed, having dump radii of 100 to 165 feet, the maximum block length should be determined in accordance with the rule given in the previous chapter. For the larger machines, the best block length might be shorter than the maximum.

Longer blocks should be discouraged, for the following reasons:

- The reduction in walking time will be more than offset by the increase in digging time.

- Dirt room will be wasted.
- Spoil grading costs will be increased.

7.5 Guidelines for a Hoist-Limited Dragline

The BE 9W at Mine 31 was a hoist-limited dragline, as evidenced by its cycle time equation, shown below:

$$\text{Est. avg. cycle time (sec.)} = 52.2 + 0.012 \times \text{swing angle} + 0.26 \times \text{spoil height} + 0.15 \times \text{dig depth}$$

The very small coefficient of swing angle in the foregoing equation, and the large coefficient of spoil pile height indicate that hoist distance is an important determinant of cycle time. This machine hoisted very slowly.

The effects of bench height and pit width on dragline productivity in shallow (40-foot) overburden are shown in Figure 26. Bench height is seen to have a very significant effect on dragline production rate, which ranges from 35 bank cubic yards per operating hour per cubic yard of bucket (byc/hr/yd) at a bench height of 25 feet to 45 bcy/hr/yd at a bench height of 40 feet. This is a 28 percent difference. The reasons are clear; dozer benching causes dragline rehandle that would not occur if the bench was near the surface of the ground, and the low bench requires greater spoil height which increases cycle time.

For a high bench, the pit width has little effect on production rate. This is a characteristic of hoist-limited machines; increasing the average swing angle by widening the pit, or decreasing it by narrowing the pit, has little effect on production rate in shallow overburden. At the other extreme, a 25-foot bench height, the production rate for a wide pit is 10 percent greater than that for a moderate-width pit. The reason is the following. At that bench height, the bench will have been extended by dozer spoil, so that rehandle will be necessary. The rehandle percentage is smaller for a wide pit than for a narrow one.

Production rate estimates for moderate-depth (60-foot) overburden are shown in Figure 27. A narrow pit and high bench are seen to be the best choice, offering a production rate 20 percent higher than the closest alternative. The reason for the large indicated difference is the fact that rehandle could be avoided, theoretically, by carrying a narrow pit and minimizing the dozer benching. For wider pits, an extended bench would be needed at any bench height.

Mine No. 31
BE 9W, 10 yard
40-foot overburden

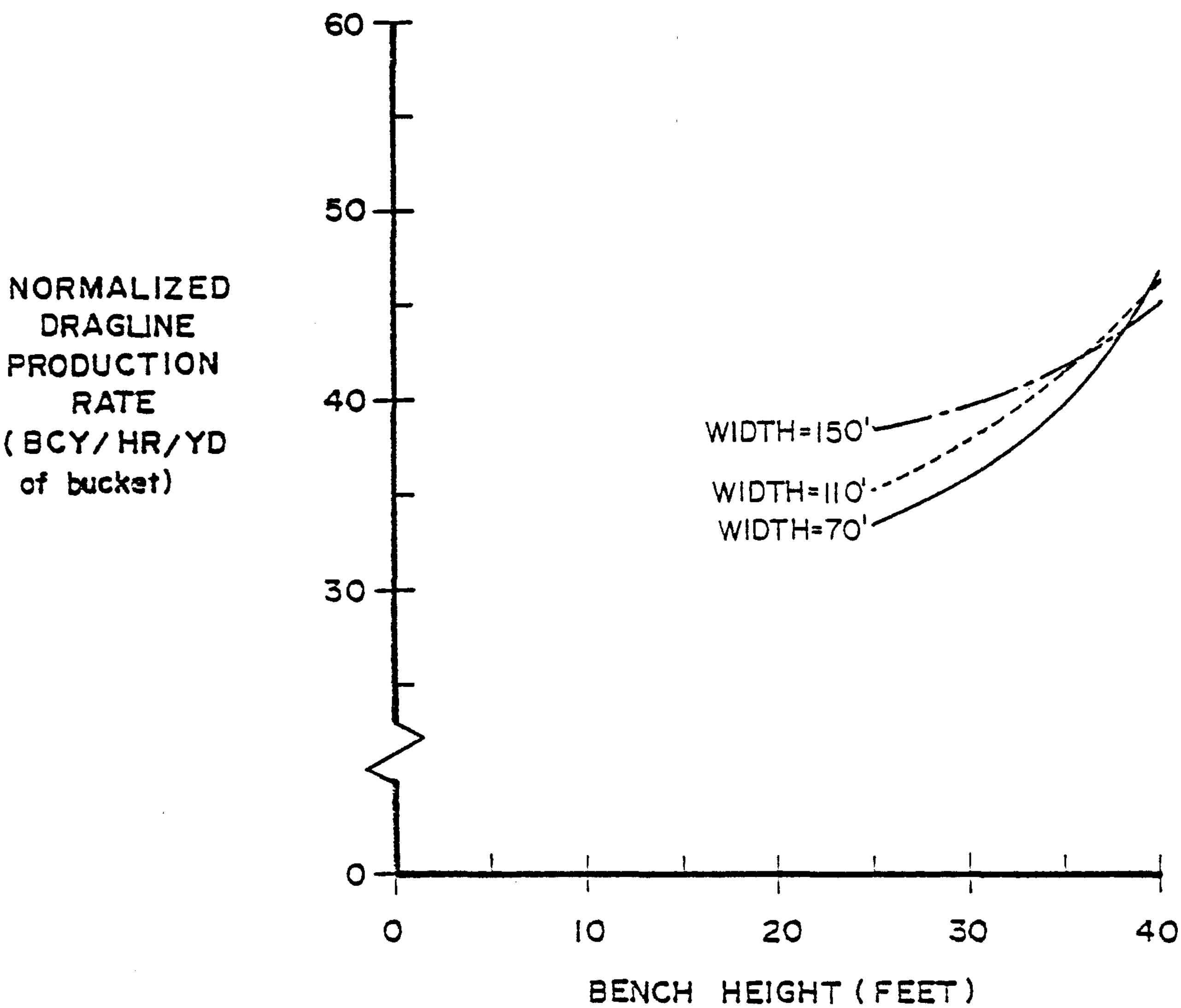


Figure 26. Mine No. 31: Production Rate Estimates for 40-Foot Overburden

Mine No. 31
BE 9W, 10 yard
60-foot overburden

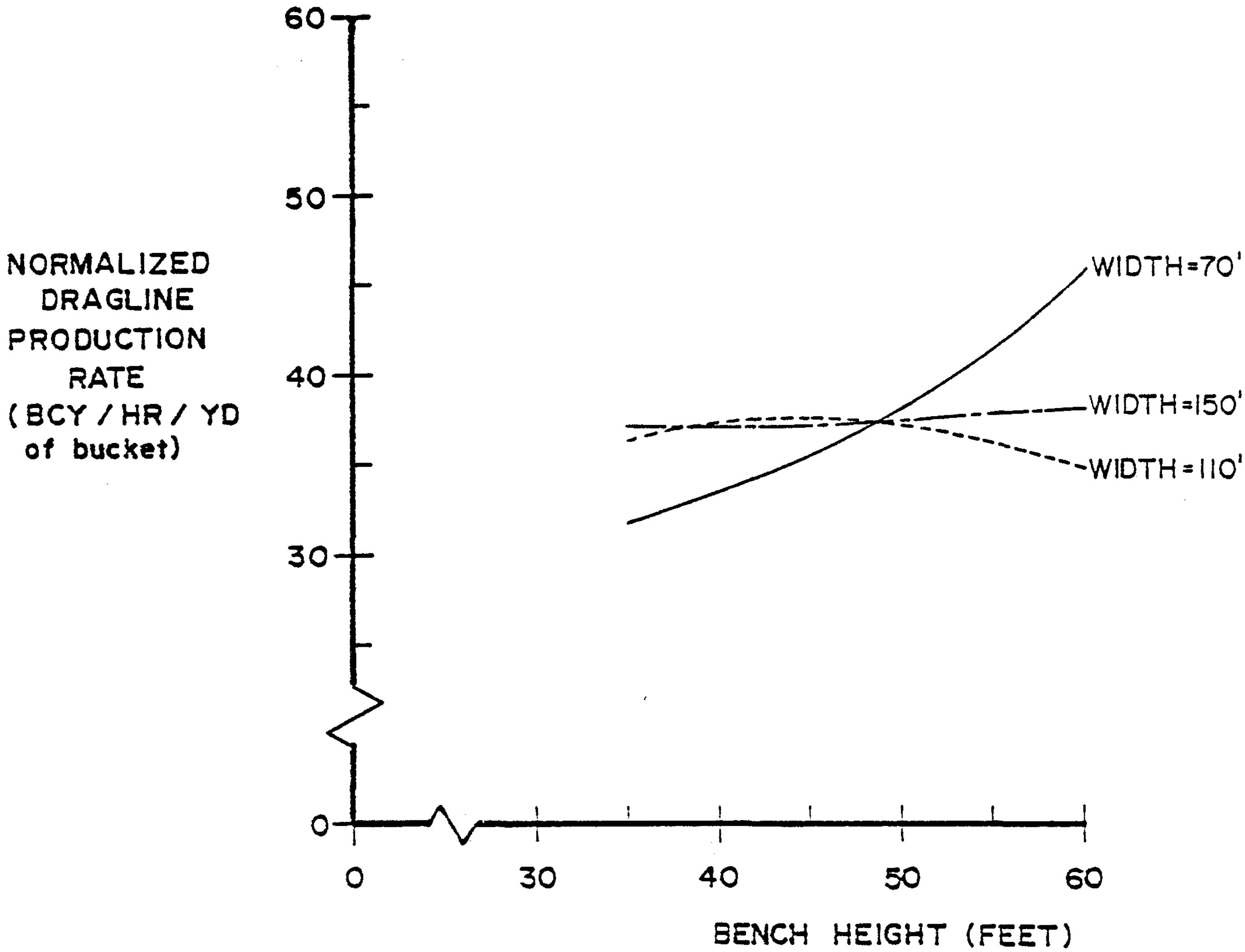


Figure 27. Mine No. 31: Production Rate Estimates for 60-Foot Overburden

This phenomenon is further illustrated in Figure 28, which shows production rate versus overburden depth for 70- and 110-foot pit widths, assuming that there was no dozer benching. For the 110-foot pit width, the production rate is shown to drop sharply at an overburden depth of 57 or 58 feet. This is the depth, theoretically, at which an extended bench becomes necessary. But, for a 70-foot pit width, an extended bench is not needed until overburden depth reaches almost 70 feet. So, at a depth of 60 feet, the production rate would be much higher with the narrower pit. But, referring back to Figure 27 again, if it is necessary to bench down ten or more feet with the dozer, then a moderate-width or wide pit would be the best choice, because the rehandle percentage would be less than that for a narrow pit.

The production rate estimates for deep (80-foot) overburden are shown in Figure 29. In this case, an extended bench would be needed at any pit width or bench height. A narrow pit would be a poor choice because of a high rehandle percentage and a long swing angle to lead the spoil and build the extended bench. Production rates for the moderate-width and wide pits are better than those for the narrow pit. Bench height has little effect, although, for a 110-foot pit width, benching down 20 feet would increase production about five percent over the case in which the dragline worked from the ground surface. In a practical sense, the best choice for this machine in deep overburden is a moderate pit width and bench height.

Summarizing, the operating guidelines for the hoist-limited BE 9W dragline are the following:

- In shallow overburden, keep the dragline bench as high as possible. Recognize that pit width has little effect on production rate.
- In moderate overburden, tend to carry a relatively narrow pit if the bench can be kept high. If some dozer benching is necessary, then carry a moderately high bench and a moderate-width pit.
- In deep overburden, bench down 15 to 20 feet by dozer and carry a moderate to wide pit.

7.6 Guidelines for a "Matched" Dragline

For certain draglines, the hoist and swing power appeared to be well-matched. The Marion 7400 at Mine No. 11 was such a machine. It was neither hoist-limited nor swing-limited. Because it was not hoist-limited, the effect of pit width (swing angle) on production rate should be more pronounced than that for the hoist-limited BE 9W.

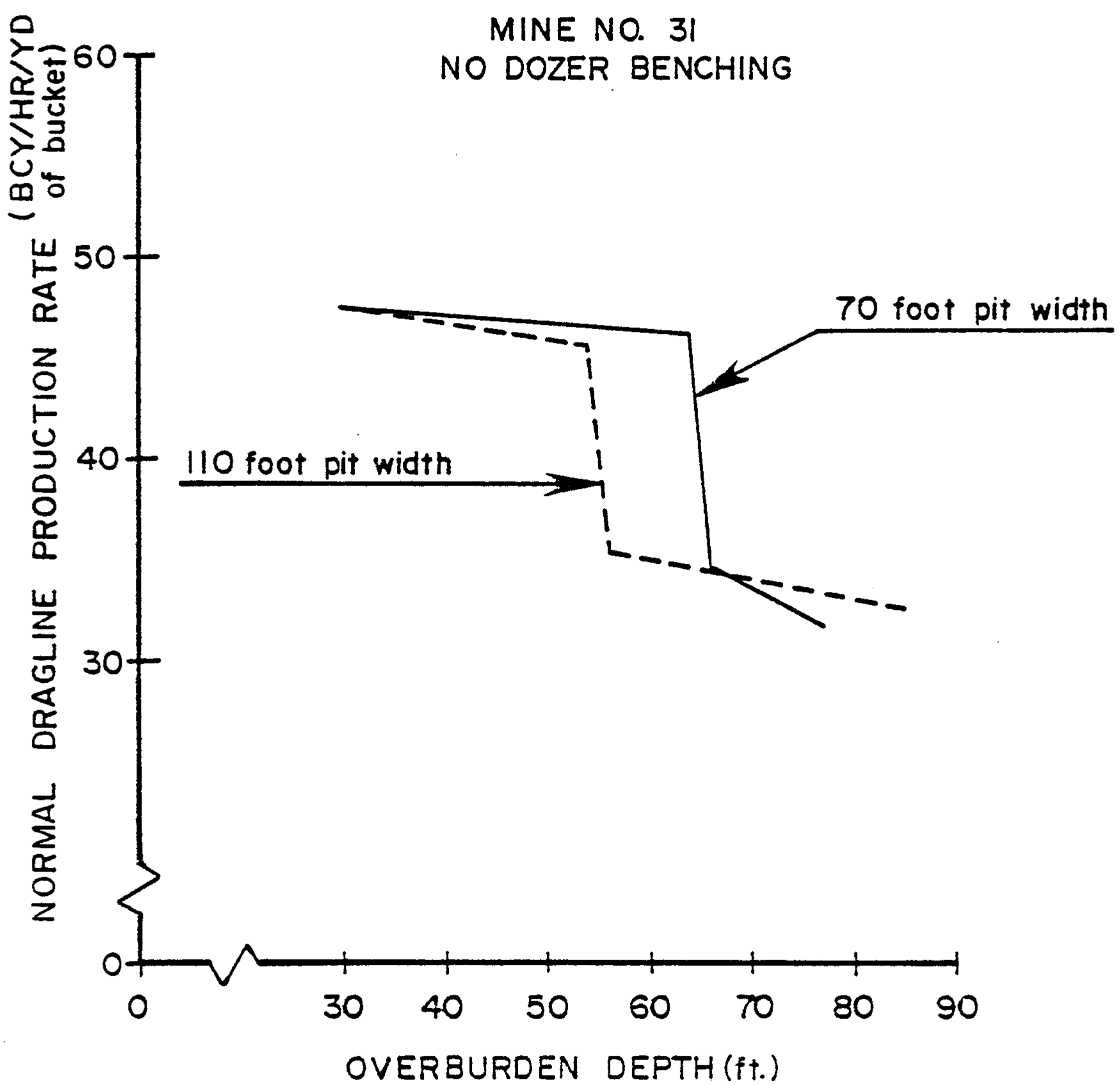


Figure 28. Mine No. 31: Production Rate Versus Overburden Depth for Two Pit Widths

Mine No. 31
BE 9W, 10 yard
80-foot overburden

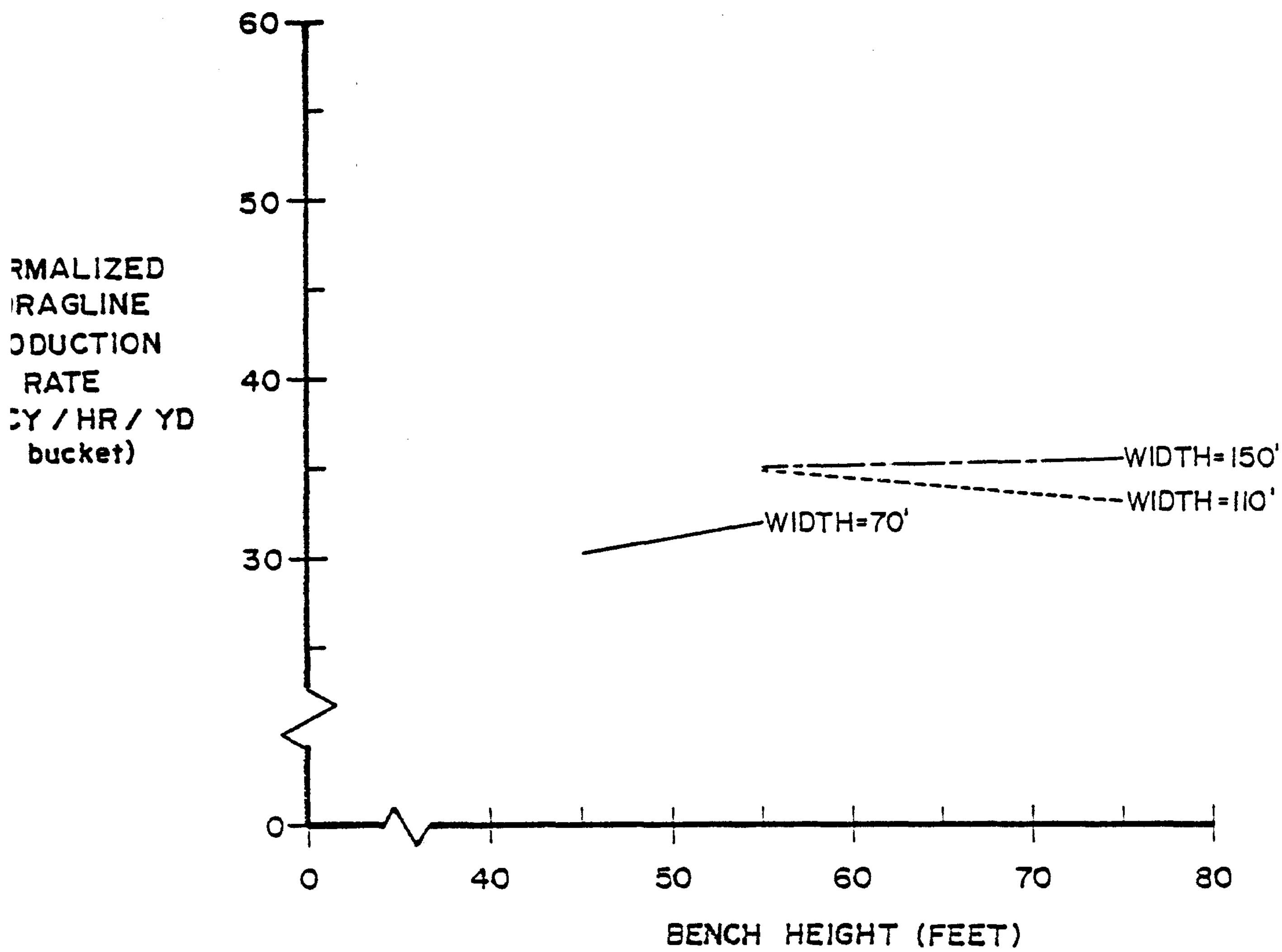


Figure 29. Mine No. 31: Production Rate Estimates for 80-Foot Overburden

Production rate estimates, based on cycle time data for this specific machine, are shown in Figure 30 for shallow overburden. Similar to the BE 9W, production rate increases markedly with increasing bench height. But, as expected for the Marion 7400, the pit width matters, with the narrow and moderate-width pits showing higher production rates than the wide pit.

In moderate overburden, as shown in Figure 31, the effects of pit width and bench height on production rate are similar to those for the BE 9W. Production rate is maximized by a narrow pit and high bench to avoid use of an extended bench. If some dozer benching is necessary, the bench should be high and the pit width moderate.

Results for deep overburden, shown in Figure 32, are again similar to those for the BE 9W. A narrow pit is a poor choice for the same reasons presented for the BE 9W. Production rates are roughly comparable for moderate and wide pits, although bench height also has an effect. At a bench height of 60 to 65 feet, the production rate is near its maximum and is not sensitive to pit width. That bench height range, coupled with a moderate or wide pit would be a good choice.

So, surprisingly perhaps, the operating guidelines for the 30-year-old hoist-limited BE 9W and the 21-year-old, well-matched Marion 7400 are very similar, even though the guidelines for each were based on machine- and site-specific time study data.

A further indication of the generality that is beginning to evolve is given in Figure 33, which shows estimated production rates versus overburde depth for three Marion 7400's -- those at mines 11, 14, and 28. The estimat for Mines 11 and 28 are virtually identical. Those machines were the same age and had similar horsepower. The dragline at Mine 14 was newer, and ha a more powerful drag and hoist motor than the other two. At the time of the field survey, it also was in easier digging.

7.7 Guidelines for a Depth-Sensitive Dragline

The cycle time for the Manitowoc 4600 dragline at Mine 46 is:

$$\text{Est. avg. cycle time (sec.)} = 31.1 + 0.118 \times \text{swing angle} + 0.062 \times \text{spoil height} + 0.404 \times \text{digging depth}$$

The most notable thing about this equation is the large coefficient of digging depth. The coefficient, 0.404, indicates that average cycle time increases one second for 2-1/2-foot increase in digging depth. This should make the production rate for this machine sensitive to changes in bench height.

(Text continued on page 83)

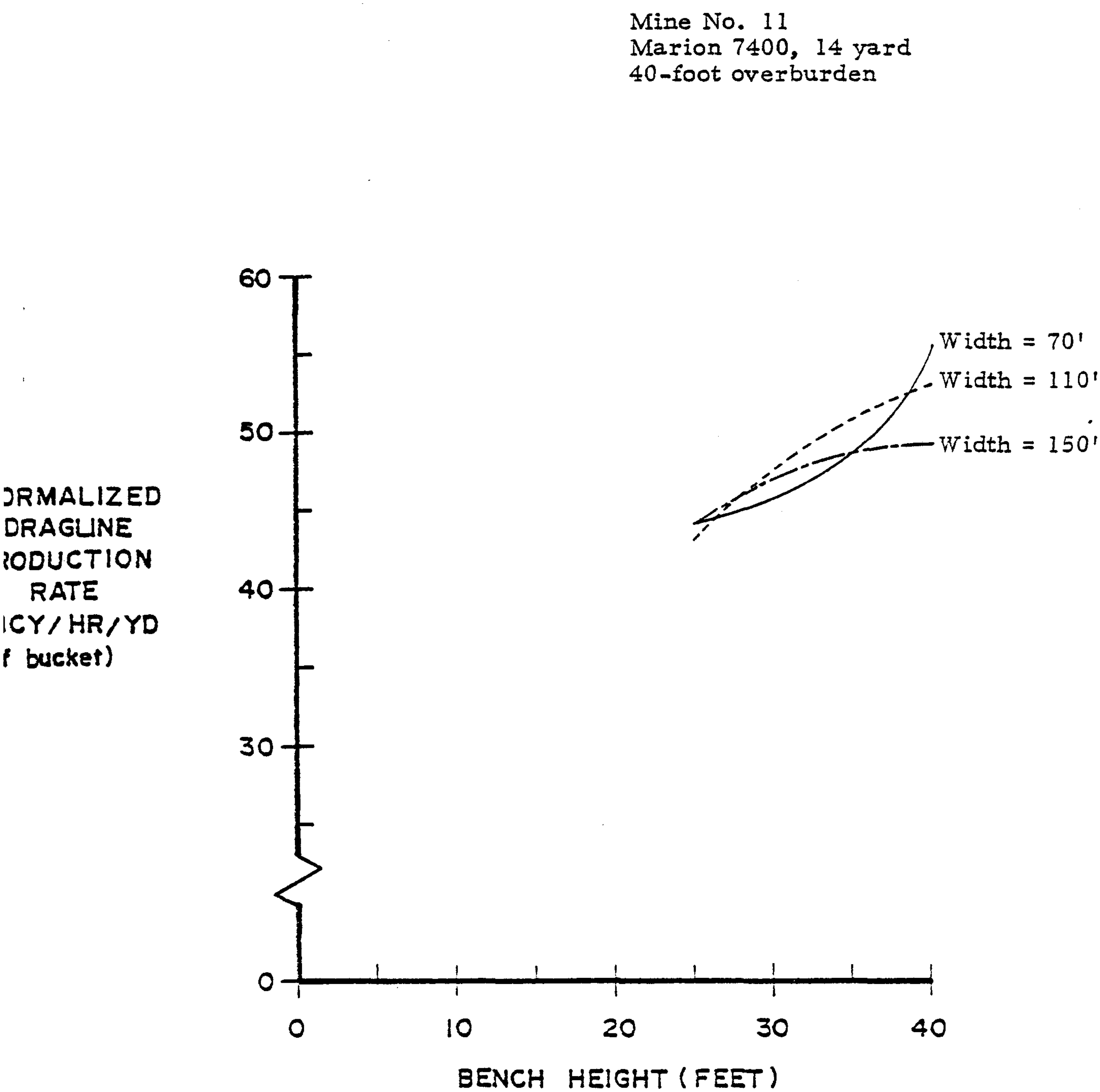


Figure 30. Mine No. 11: Production Rate Estimates for 40-Foot Overburden

Mine No. 11
Marion 7400, 14 yard
60-foot overburden

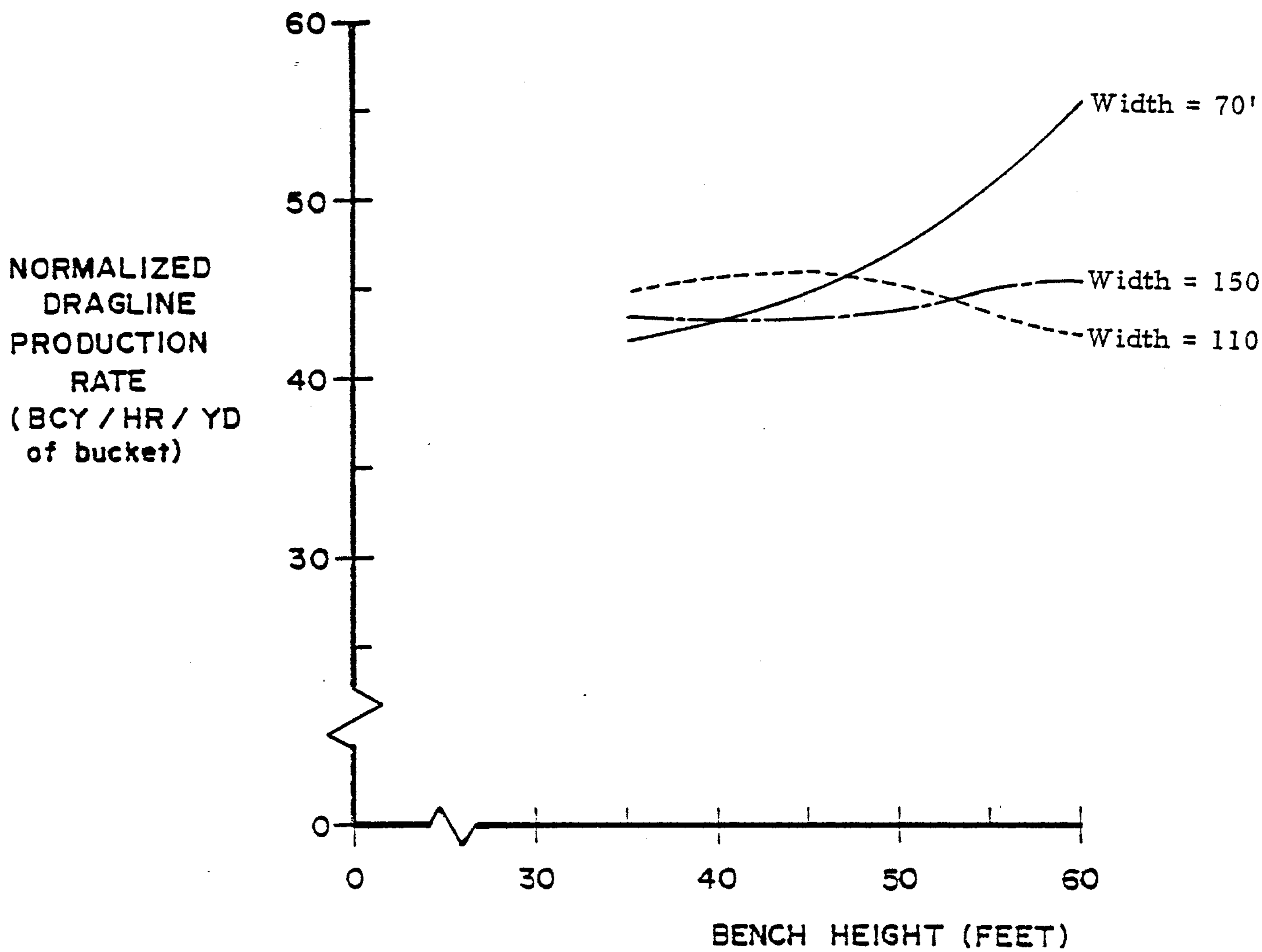


Figure 31. Mine No. 11: Production Rate Estimates for 60-Foot Overburden

Mine No. 11
Marion 7400, 14 yard
80-foot overburden

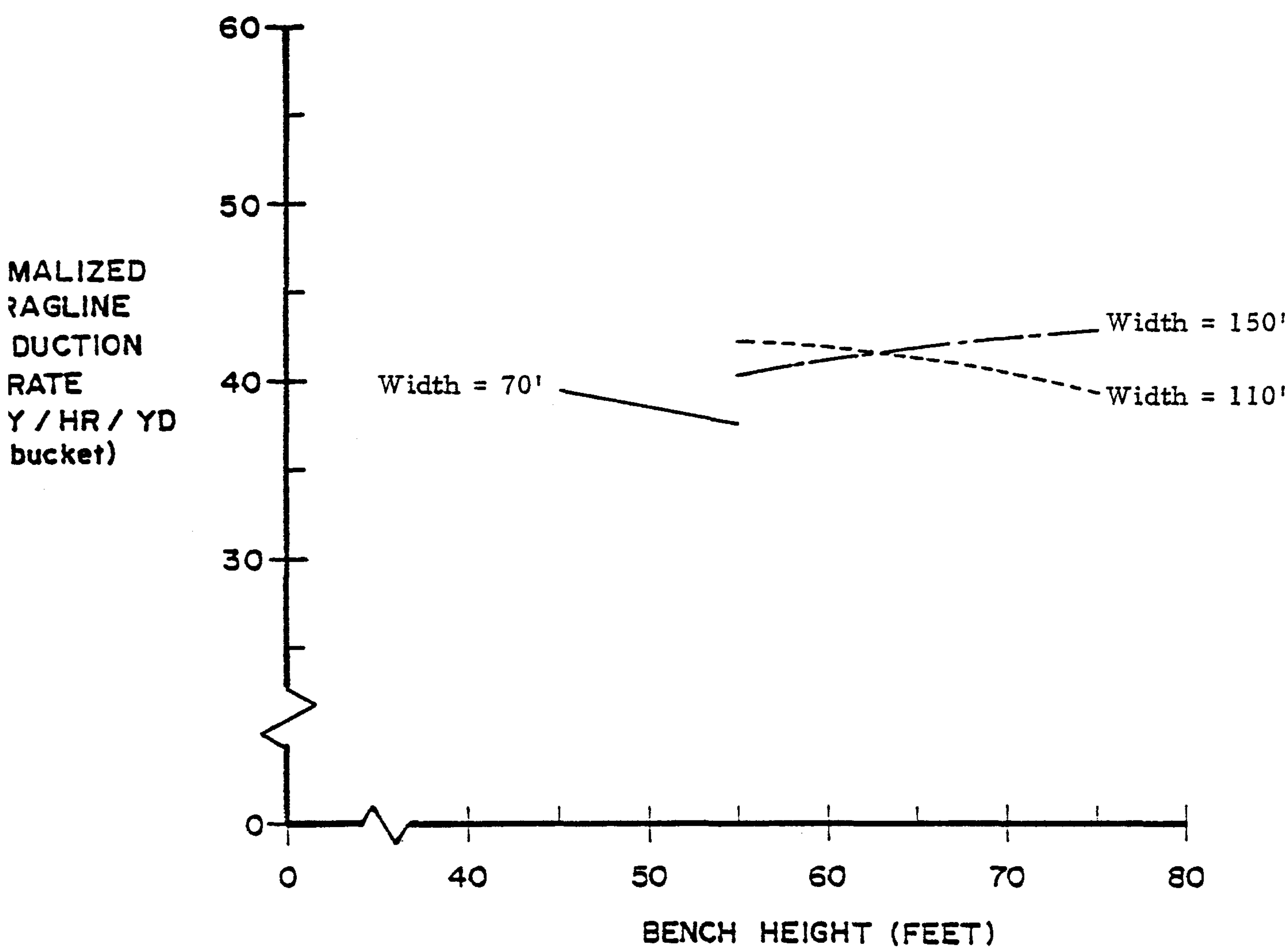


Figure 32. Mine No. 11: Production Rate Estimates for 80-Foot Overburden

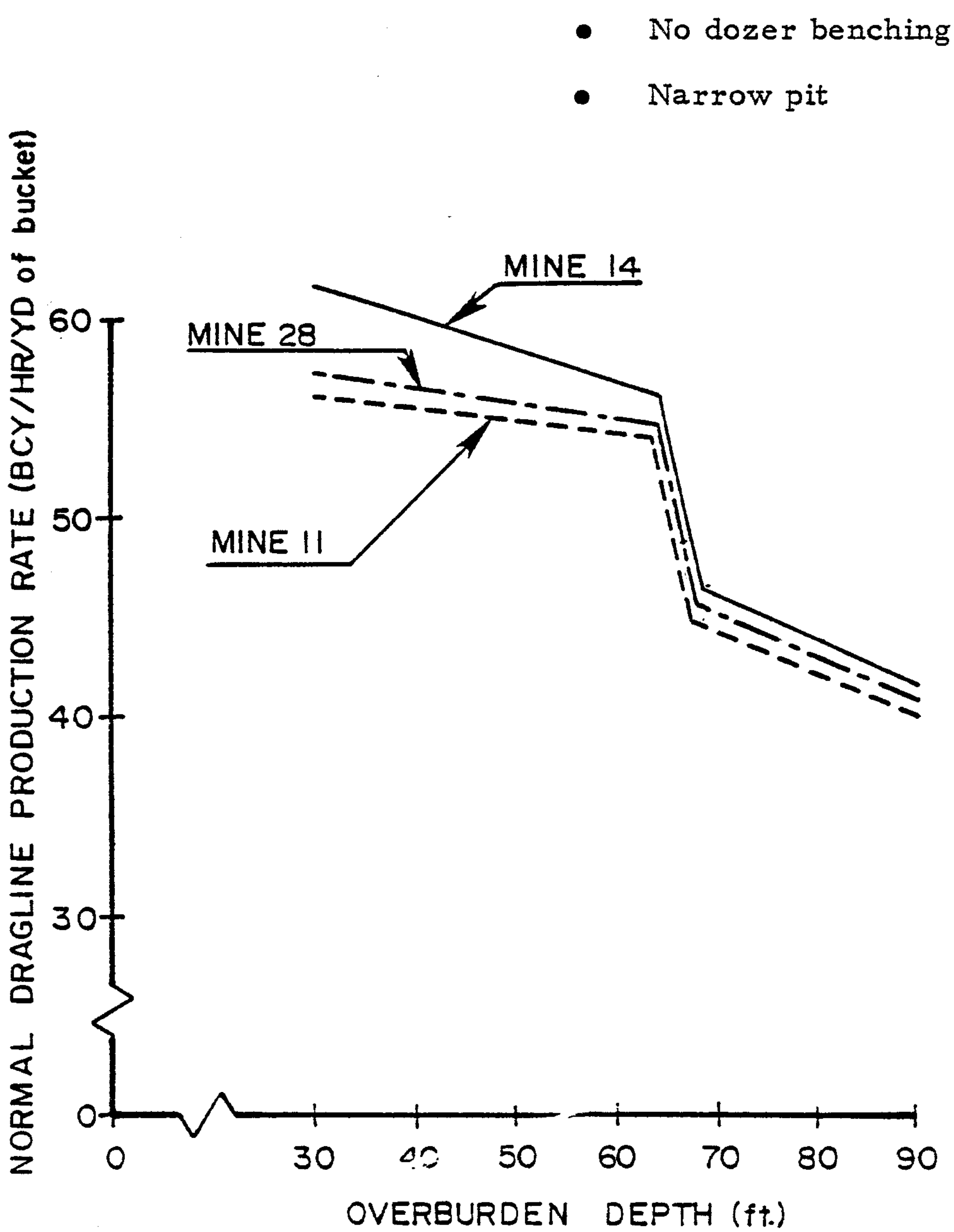


Figure 33. Comparison of Estimated Production Rates for Three Marion 7400 Draglines

In shallow overburden (no graph shown here), the guideline is similar to that for the two previous machines: carry a high bench and a narrow to moderate pit width. In moderate overburden -- which is 50 feet for this small machine -- a relatively wide pit and moderate-to-high bench maximize the production rate, as shown in Figure 34. The best choice probably would be a 40-foot bench height, in part because the pit width doesn't have much effect at that height.

In deep (70-foot) overburden, as shown in Figure 35, a low bench and moderate pit width would be good choices. For example, at a pit width of 90 feet, lowering the bench from 60 feet to 50 feet would increase the production rate by five percent. A narrow pit would be a poor choice since an extended bench is needed. A wide pit could be used only with a high bench, or the spoil pile height would exceed the dump height of the dragline.

7.8 General Guidelines for a Single Block

Machine- and site-specific operating guidelines for the draglines at all of the principal survey mines are contained in Appendix N. A review of those results coupled with the discussion in this chapter reveals that the guidelines for most of the draglines are similar. To reiterate, they are the following:

- In shallow overburden, bench as little as possible with the dozer and maintain a narrow pit.
- In moderate-depth overburden, tend to keep the bench high and the pit width moderate.
- In deep overburden, bench down 15 to 25 feet, and carry a moderate-width or wide pit.

7.9 Guidelines for Contour Mining

Development of operating guidelines for pit widths and bench heights in contour mining is greatly complicated by the increase in average overburden depth from one cut to the next. For example, overburden in the first cut is generally shallow. The guidelines discussed above indicate that a fairly narrow pit should be carried in shallow overburden. But opening up narrow on the first cut would be an error, and it is unlikely that anybody does it. Rather, the rule is to open up wide, allowing narrowing of the cuts when the overburden gets deeper. Development of guidelines for determination of the "best" sequence of pit widths in contour mining was not part of this project. But the previously specified guidelines for block length and bench height are applicable.

Mine No. 46
Manitowoc 4600, 7.5 yard
50-foot overburden

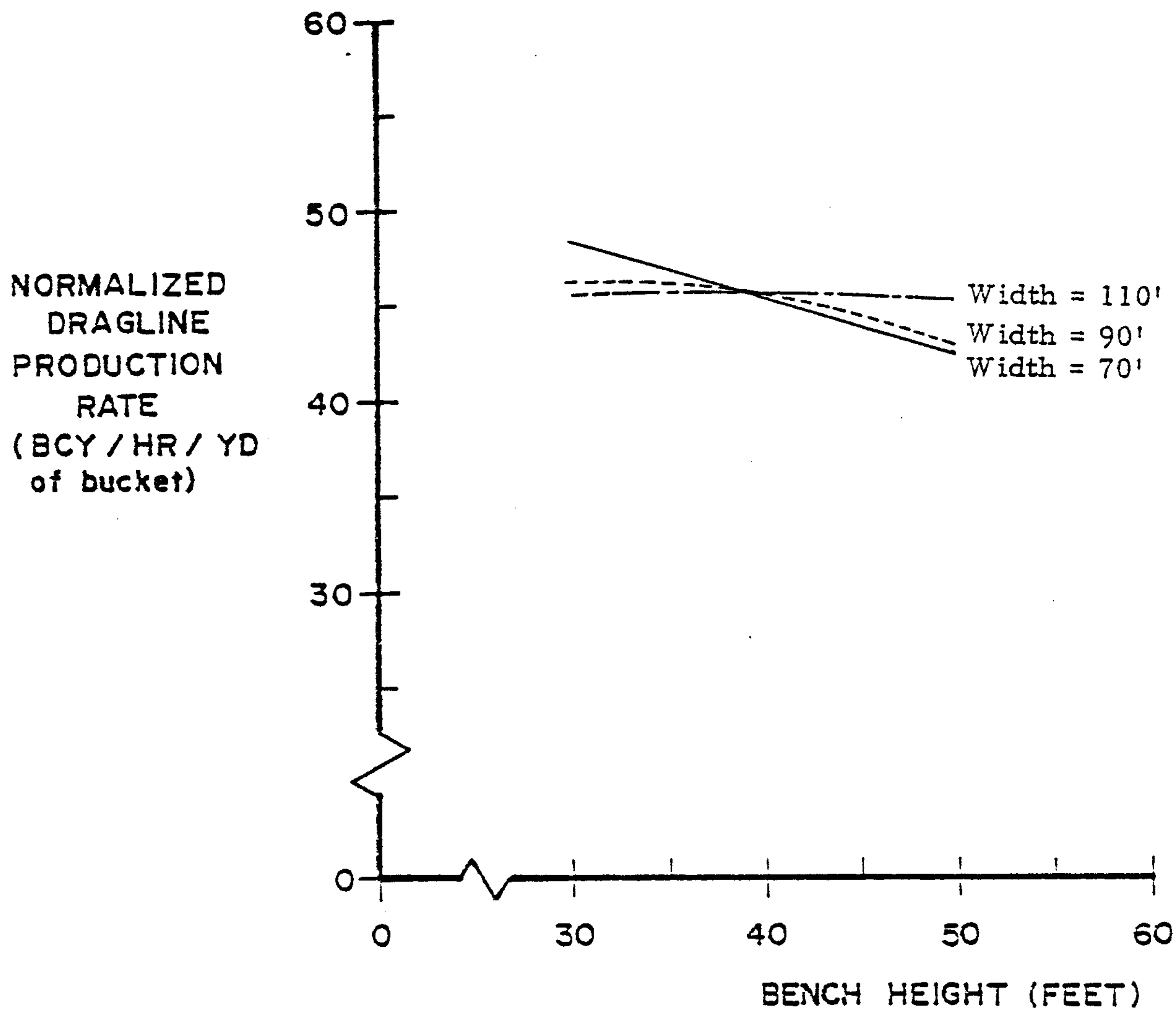


Figure 34. Mine No. 46: Production Rate Estimates for 50-Foot Overburden

Mine No. 46
Manitowoc 4600, 7.5 yard
70-foot overburden

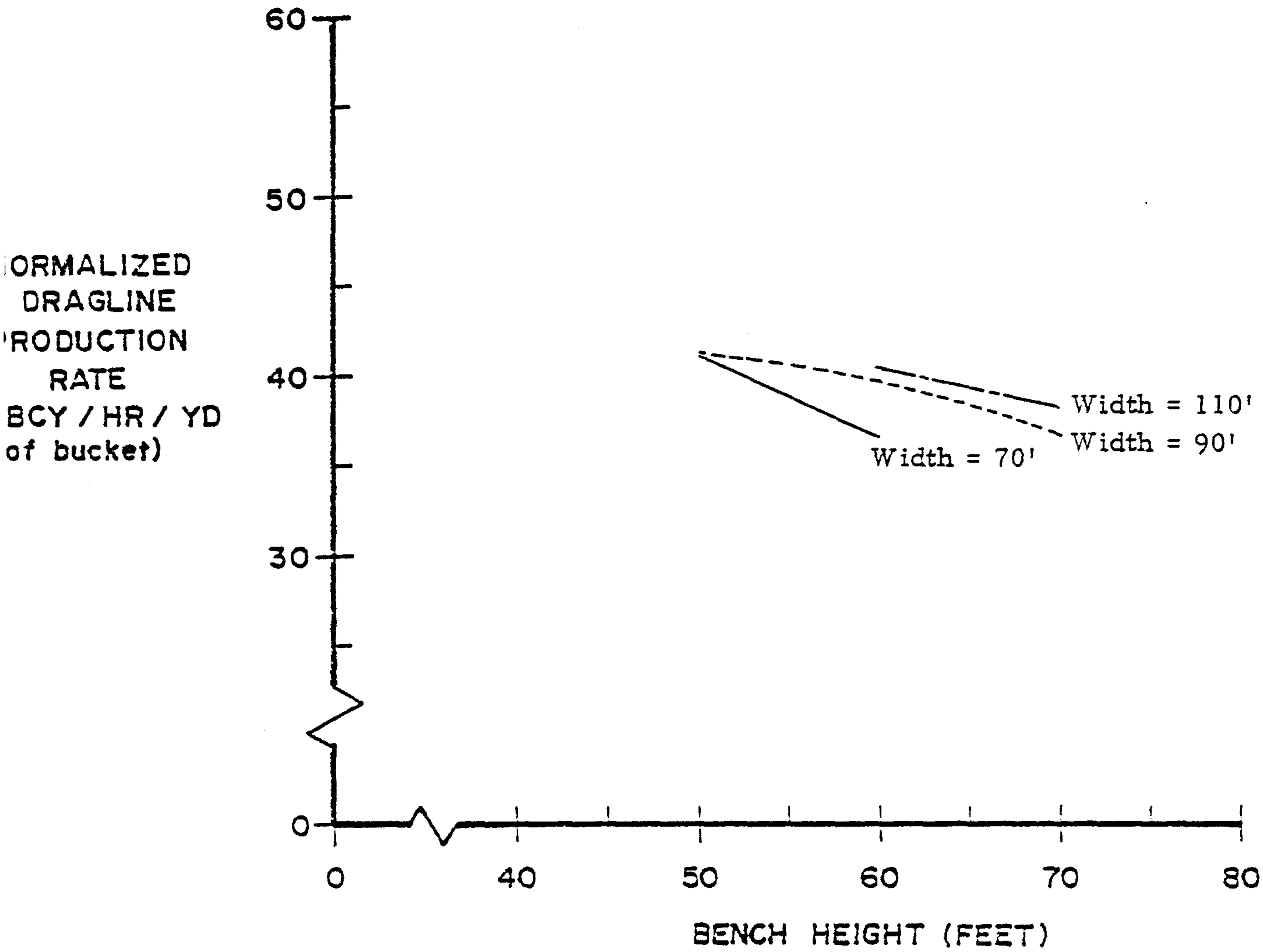


Figure 35. Mine No. 46: Production Rate Estimates for 70-Foot Overburden

7.10 Guidelines for Blocking and Hilltop Removal

At the blocking and hilltop removal operations surveyed, the tendency was to make straight cuts and to move the dragline bench up as the overburden got deeper. The first of these two practices affects the guidelines for choosing pit widths. In blocking, for example, the overburden is shallow at the beginning of each cut and deep at the end. The guidelines for such a case would indicate that the cut should be narrow at the beginning and wide at the end, but this is impractical. Rather some compromise width must be chosen and used for the entire length. Intuitively, this seems likely to mean that pit widths in blocking -- and in hilltop removal -- should be moderate. Additionally, it seems likely that the sensitivity of dragline production rate to changes in pit width will diminish because of averaging of advantages and disadvantages over the length of the cut.

A simplified sample problem was worked to test these hypotheses. Details are contained in Appendix M. It involved a Marion 7400 blocking into a hill with a seven-degree slope, taking ten 60-foot blocks up to a maximum overburden depth of 90 feet. Two extremes of pit width were compared -- a 70-foot pit and a 130-foot pit. The indicated average dragline production rate for the narrow cut was five percent more than that for the wide one. The difference between pit widths of, say, 90 feet and 110 feet would probably be smaller.

It's likely that a narrow pit would be best when the ground slope angle is very gradual and overburden depth doesn't increase too fast. A wider pit would be indicated for steeper ground. But, since blocking is usually restricted to gradually sloping areas, a wide pit is not indicated. The tendency should be to keep the pit width narrow to moderate.

7.11 Guidelines for Dragline Operation

Listed below are some of the guidelines that the dragline operators themselves followed, as a general rule:

- Keep the cable out of the roll.
- Keep the keyway opened up.
- Keep the dump cable a little shorter than the manufacturers' recommendation.
- Keep the bucket teeth sharp.
- Don't dig long on every cycle.

- Sit over the keyway to dig it, dragline range permitting.
- Sit over the rehandle section to dig it.
- In shallow overburden, stay over the keyway as long as possible.
- Don't try to dig hard material too fast.

8. SINGLE-SEAM TANDEM MINING SYSTEMS

8.1 Introduction

The dozer/dragline mining systems observed in the survey mines were primarily dragline stripping systems. Dozers performed support work for draglines and reclaimed land, but did not perform significant stripping. The closest approach to a true tandem system was at one mine where blasting was utilized to throw a top lift from the bench into the open pit. The variability of shot effectiveness from block-to-block was too great to permit adequate analytical study of this blasting/dragline system.

The purpose of this chapter is to discuss an analysis of two true single-seam tandem systems: dozer/dragline, and loader/truck/dragline. In order to analyze these systems, two models were built. The dozer bench production model, described in Appendix L, enables estimation of dozer production for stripping a top lift from a block and simultaneously building an extended bench for a dragline. A loader/truck model, described in Appendix T, enables estimation of loader/truck production for stripping a top lift from a block and carrying it around the pit for placement in the vees of the spoil piles from earlier cuts.

Each of these models when combined with the dragline production model provides the capability of analyzing a tandem system. The dragline model is believed tested and verified. Neither the dozer model nor the loader/truck model has been tested and they therefore are not verified because sufficient observations were not available in the field. Nevertheless, both models are believed basically valid. Any changes in the models that testing and verification might require should not significantly change the conclusions reached in using the models for analysis.

8.2 Assumptions

The general assumptions and limitations stated in Chapter 7 for developing operating guidelines apply here.

For dozer/dragline analyses, specific equipment is selected. A 7-1/2 cubic yard dragline and a 410 horsepower dozer are representative of a large number of mines operating in northern and southern Appalachia. To represent this group, a Manitowoc 4600 dragline* and a Komatsu 355 dozer are chosen based solely on the fact that more information is available to the authors on these machines than on competing brands. Similarly, specific equipment chosen for the loader/truck/dragline analysis are a Caterpillar 992-C 10 cubic yard loader, Caterpillar 773-B 50-ton rock trucks, and, again, a Manitowoc 4600 7-1/2 cubic yard dragline.

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*The cycle time equation for this type dragline at Mine 46 (a depth-sensitive machine) is used for production estimates. See Chapter 7, p. 78.

Relevant production costs are assumed to be those associated directly with the production machines. Exploration, site preparation, drilling and blasting, and spoil grading costs are excluded. Except spoil grading, the costs excluded are essentially the same for dragline mining, dozer/dragline tandem mining, and loader/truck/dragline mining. Spoil grading costs for the three methods will vary but not in a well understood manner. For dragline or dozer/dragline mining, spoil grading costs should decrease as the pit width narrows. For loader/truck/dragline mining, spoil grading costs should be considerably lower than for dragline or dozer/dragline mining because only final grading is needed over much of the mined area and trucks are available to fill the final cut.

8.3 Dozer/Dragline Tandem Systems

Two case studies have been analyzed for dozer/dragline tandem systems: 60-feet of overburden in one case, 70-feet in the other.

8.3.1 Sixty-Feet of Overburden

Table 8 lists component production rates, the percent of total time required for dozer stripping, daily total bank yardage production, and estimated Ownership and Operating costs per bank cubic yard for a Manitowoc 4600 dragline and Komatsu 355 dozer operating in 60-feet of overburden and employing various bench heights and pit widths.

The data of Table 8 indicate that total system production increases substantially with increased dozer stripping and moderately with increased pit width. The increase in production associated with deeper benching has two causes: (1) primarily, greater utilization of the dozer as a production machine, and (2) secondarily, increased performance from the dragline as digging depths are reduced. The latter effect is machine-specific; a matched or hoist-limited dragline might suffer reduced performance as a result of deep benching. The increase in production with pit width is the result of decreased dragline rehandle having greater impact than increased dozer push distances and increased dozer rehandle. In terms of system productivity, maximum productivity is achieved by stripping the maximum feasible amount with the dozer which in this case is 25'. At this level, only a narrow pit is possible. The dragline will be spoilbound if either the pit width is increased or if further dozer benching is attempted. In either case if the dragline is spoilbound, the only available course of action is to push the spoil piles back with dozers. This is both expensive and non-productive.

Table 8 also indicates a significant cost benefit with deeper dozer stripping based on estimated Ownership and Operating (O&O) costs. O&O costs per operating hour for the dragline and the dozer are detailed in Tables 9 and 10. The O&O costs reported in Table 8, and also in Table 11 for deeper overburden, reflect 100% dedication of the dragline to stripping and the required amount of dedication of the dozer. For example, in the most favorable case listed in Table 8 (35' dragline bench height, 70' pit width) the dozer is required to strip 47.3% of the available operating time.

Table 8. Dozer/Dragline Tandem System Production and Costs[1]

Overburden = 60'

Dragline Bench Height		PIT WIDTH 70' Drag	70' Dozer	90' Drag	90' Dozer	110' Drag	110' Dozer
60'	BCY/OP.HR.	277.5	0	298.5	0	312.0	0
	% of Op. Time Dedicated to Stripping	100.0	0	100.0	0	100.0	0
	Total System BCY/Day[2]	4,354		4,688		5,276	
	O&O Cost $/BCY	.322		.300		.266	
55'	BCY/OP.HR.	292.5	653.0	311.3	542.5	320.3	452.1
	% of Op. Time Dedicated to Stripping	100.0	4.0	100.0	5.3	100.0	6.3
	Total System BCY/Day[2]	5,018		5,335		5,485	
	O&O Cost $/BCY	.288		.245		.268	
45'	BCY/OP.HR.	327.0	644.9	326.3	515.1	328.5	419.8
	% of Op. Time Dedicated to Stripping	100.0	16.9	100.0	21.1	100.0	26.1
	Total System BCY/Day[2]	6,844		6,831		6,873	
	O&O Cost $/BCY	.232		.239		.246	
35'	BCY/OP.HR.	339.0	511.7	Infeasible: Insufficient Dragline Dump Height		Infeasible: Insufficient Dragline Dump Height	
	% of Op. Time Dedicated to Stripping	100.0	47.3				
	Total System BCY/Day[2]	9,134					
	O&O Cost $/BCY	.211					

(1) Manitowoc 4600 (7 cubic yards) dragline; Komatsu 355 dozer.
(2) Based on 22 shift hours per day; 1.4 shift hours per operating hour

Table 9. Estimated Dragline O&O Costs - Manitowoc 4600 (7½ cubic yds)

	\$/Operating Hour[1/]
Direct Labor and Fringes	
1 operator @ \$15.00 & 1 oiler @ \$13.00	39.20
Maintenance and Supplies	
\$14.22/op.hr.	14.22
Fuel	
23 gal./op.hr. @ 50¢/gal.	11.50
Depreciation	
\$805,000 less \$150,000 salvage; 15 years; 8,030 sh.hr./yr.	7.62
Interest, Taxes, Insurance	
20% of Average Investment	16.65
TOTAL	\$89.19

1/ 1 operating hour: 1.4 shift hours

Table 10. Estimated Dozer O&O Costs - Komatsu 355 (410 hp)

	$/Operating Hour [1/]
Direct Labor and Fringes	
1 operator @ $14.00	19.60
Maintenance and Supplies	
$18.00/shift hour	25.20
Fuel	
17.4 gal./op.hr. @ 50¢/gal.	8.70
Depreciation	
$300,000 less $50,000 salvage; 4 years; 8,030hr./yr.	10.89
Interest, Taxes, Insurance	
20% of Average Investment	6.10
TOTAL	$70.49

[1/] 1 Operating hour: 1.4 shift hours

Table 11. Dozer/Dragline Tandem System Production and Costs[1]

Overburden = 70'

Dragline Bench Height		PIT WIDTH 70' Drag	70' Dozer	90' Drag	90' Dozer	110' Drag	110' Dozer	130' Drag	130' Dozer
70'	BCY/OP.HR.	Infeasible: Required Extended Bench Exceeds Space Available		276.8	0	287.3	0	291.8	0
	% of Op. Time Dedicated to Stripping			100.0	0	100.0	0	100.0	0
	Total System BCY/Day[2]			4,321		4,488		4,561	
	O&O Cost $/BCY			.324		.312		.307	
60'	BCY/OP.HR.	273.8	645.9	299.2	547.7	304.5	448.9	Infeasible: Insufficient Dump Height	
	% of Op. Time Dedicated to Stripping	100.0	7.1	100.0	9.1	100.0	11.3		
	Total System BCY/Day[2]	5,012		5,458		5,553			
	O&O Cost $/BCY	.295		.275		.275			
50'	BCY/OP.HR.	307.3	638.1	310.0	502.0	Infeasible: Insufficient Dump Height		Infeasible: Insufficient Dump Height	
	% of Op. Time Dedicated to Stripping	100.0	19.3	100.0	24.7				
	Total System BCY/Day[2]	6,758		6,816					
	O&O Cost $/BCY	.239		.246					
45'	BCY/Op.Hr.	323.8	587.7	Infeasible: Insufficient Dump Height		Infeasible: Insufficient Dump Height		Infeasible: Insufficient Dump Height	
	% of Op. Time Dedicated to Stripping	100.0	30.6						
	Total System BCY/Day[2]	7,916							
	O&O Cost $/BCY	.220							

(1) Manitowoc 4600 (7-1/2 cubic yards) dragline, Komatsu 355 dozer.
(2) Based on 22 shift hours per day; 1.4 shift hours per operating hour.

The O&O cost of 21.1¢ per BCY assumes the dozer is not charged to stripping the remaining 52.7% of its available operating time. Other chargeable uses of the dozer are reclamation and drill benching.

If, as an alternative, dozer costs for 100% of the operating time were included in the O&O costs of Table 8, on the basis that a dozer's presence is required to support the dragline, the apparent economic benefit of deeper dozer stripping would increase because proportionately more dozer time would be charged to shallow dozer stripping cases than to deeper cases. Again, as an example, the O&O cost of 32.2¢ per BCY reported in Table 8 for a 60' dragline bench (no dozer stripping) would increase to 57.6¢ per BCY, an increase of 79%. The 21.1¢ per BCY for the case of a 35' dragline bench (25' of dozer stripping) would increase to 27.5¢ per BCY if 100% of the dozer operating time was charged to stripping. This is an increase of only 30%. The data of Table 8, and also Table 11, present the economic benefits of deeper dozer stripping in a conservative manner.

8.3.2 Seventy-Feet of Overburden

For 70-feet of overburden, all parameters are the same as before except overburden is increased 10 feet. Table 11 lists data for this case.

Again, from the standpoint of lowest cost and maximum production, the most favorable strategy is to bench down with the dozer to the maximum feasible amount without causing the dragline to become spoilbound. Although overburden depth has increased 10', it is not feasible to bench any deeper than the previous case. In both 70' and 60' of overburden, the optimum (and maximum) top lift is 25'.

8.4 Conclusions - Dozer/Dragline Systems

In deep overburden, a dozer/small dragline tandem system utilizing maximum feasible dozer benching has been shown to be economically superior. However, the results are site- and machine-specific. There are basically two impacts on costs caused by dozer benching. The primary effect is the cost of dozer stripping. This effect will be positive or negative depending on the relative cost of dozing material off the bench versus digging it with the dragline. In general, the smaller the dragline the more favorable will be the relative cost of dozer benching. A second impact is on the digging cost of the dragline, and the direction and magnitude of this impact depends on the characteristics of the dragline. Benching for a depth-sensitive dragline will tend to improve dragline productivity and reduce dragline costs. Benching for a hoist-limited dragline will tend to decrease dragline productivity and increase dragline costs. For a matched dragline, the costs and productivity effects on the dragline alone are probably slight. In view of the foregoing, the practice of determining "optimal" mining by the criterion of maximization of dragline productivity appears to offer no assurance of achieving the most favorable mining costs for a dozer/ dragline tandem system.

The observed shooting of highwall into the pit below appears, on the basis of the foregoing analysis, to be generally good practice when used with small draglines. In the cases analyzed, overburden thrown into the pit by blasting would be that much less that would need to be dozed. The amount of top lift removed by blasting must be controlled to assure that too much for the given dragline is not taken.

The mine operator faces a bewildering set of variables which must be analyzed rigorously to determine optimum configuration for a dozer/ dragline pit. The cost difference between the best and the worst cases shown in Table 11 is 10.4 cents a cubic yard (or about $1.25 per ton of coal if the stripping ratio is 12:1). Differences of this magnitude are highly significant. Use of accurate cycle time equations with the models developed in this project can be of major assistance to the operator seeking greater productivity and lower cost.

8.5 Loader/Truck/Dragline Tandem Systems

Analysis of a loader/truck/dragline system is complicated by the need for approximate matching of equipment capabilities. If the loader and trucks do not have sufficient overburden committed, they are either forced to accept downtime or must mine a nearby block of reserves. Since a loader/truck mining system is inherently more expensive than dragline mining, it does not normally make sense to dedicate mineable reserves to the loader and trucks that a dragline can mine. The problem of matching capabilities is not a major limitation on a dozer/dragline system because of dozer flexibility. When not stripping, a dozer normally would have several options available to it: reclamation, road building, etc.

Appendix T discusses a loader/truck/dragline tandem system consisting of a Manitowoc 4600 dragline, a Caterpillar 992-C highlift, and four Caterpillar 773-B trucks digging 70' of overburden. Estimated cost of stripping is $.35 per bank cubic yard compared to $.22 for the best dozer/ dragline option and to $.31 for the best dragline alone option. Table 12, which is reproduced from Appendix T, summarizes these data.

In general, the cost differential between a loader/truck system and between either a dozer/dragline tandem system or a dragline-only mining system appears to be of such a magnitude that within the overburden operating range of this dragline, a loader/truck/dragline tandem system will not be economically competitive. Nevertheless, loader/truck/dragline systems will probably develop in the future because they permit use of a dragline in overburden that is too deep for a dragline or dozer/dragline system. A potential application of this tandem system is mountaintop mining in Central Appalachia where dragline use is presently limited.

Table 12. DRAGLINE / LOADER / TRUCK TANDEM SYSTEM PRODUCTION COSTS
OVERBURDEN DEPTH = 70'

DRAGLINE BENCH HEIGHT, FEET	DESCRIPTION	PIT WIDTH, FT. 70 LOADER/TRUCK	70 DRAG	90 LOADER/TRUCK	90 DRAG	110 LOADER/TRUCK	110 DRAG
60	Block, BCY	10,333		13,286		16,240	
	Lift, BCY	1476	8857	1898	11388	2320	13920
	BCY/HR.	464	277	464	299	466	312
	Oper. Hours	3.18	32.0	4.09	38.0	4.97	44.6
	$/Hr.	222.73	80.9	222.73	80.9	222.73	80.9
	$/BCY	0.48	0.29	0.48	0.27	0.48	0.26
	O&O Cost, $/BCY	0.32		0.30		0.29	
50	Block, BCY	11,603		14,918		18,234	
	Lift, BCY	3315	8288	4262	10656	5210	13024
	BCY/Hr.	440	318	440	322	450	340
	Oper. Hours	7.53	26.0	9.68	33.1	11.57	38.3
	$/Hr.	222.73	80.9	222.73	80.9	222.73	80.9
	$/BCY	0.50	0.25	0.50	0.25	0.49	0.24
	O&O Cost, $/BCY	0.32		0.32		0.31	
40	Block, BCY	12,873		16,550		20,228	
	Lift, BCY	5517	7356	7093	9457	8669	11559
	BCY/Hr.	393	418	393	398	393	368
	Oper. Hours	14.1	17.6	18.0	24.0	22.0	31.4
	$/Hr.	222.73	80.9	222.73	80.9	222.73	80.9
	$/BCY	0.57	0.19	0.57	0.20	0.57	0.22
	O&O Cost, $/BCY	0.35		0.36		0.37	

9. THE HORSESHOE METHOD OF TWO-SEAM STRIPPING

9.1 Background

There's a lot of two-seam stripping in northern and southern Appalachia. The prevalent stripping method is the horseshoe method, generally used where the average overburden depth is much greater than the average interburden thickness. It involves using a single dragline to uncover two coal seams in a cut by making two passes in the cut. On the first pass, the dragline works from a bench in overburden and uncovers the upper coal seam. At the end of the cut, the dragline is moved around to the spoil side onto a bench that has been constructed in the spoil pile by a dozer. The interburden is then dug by a process known as side-dipping or sidecutting.

The method is of special interest in a research context because of the low productivity on the interburden pass. It's generally only 1/3 to 2/3 of the productivity on the overburden pass. Various means for improving productivity have been suggested, among them the following:

- Use of a one-pass extended bench method in place of the horseshoe method.
- Design and use of a special chopping bucket on the interburden pass.
- Keycutting of the interburden by dozer or loader to eliminate inefficient chopping of the lower highwall by the dragline.
- Use of a machine other than the dragline for removal of the interburden.

A first step in evaluation of alternatives to the horseshoe method is to develop an understanding of that method -- how it works, and why. That was the objective of the field work and analysis of the horseshoe method conducted during this study.

9.2 Reason for Use

There is a single reason for use of the horseshoe method. It has to do with the limitations on the dragline dump height capability. After the first pass on overburden and removal of the upper coal seam, one possibility for removal of the interburden is to ramp the dragline down to a position on top of the interburden to dig it conventionally. But, if the overburden is deep and the interburden thin, two things happen:

- The spoil pile from the overburden pass is high.
- The top of the interburden is well below the ground surface.

Under these circumstances, it is very unlikely that the maximum dump height of the dragline will be enough to allow it to spoil interburden material if the machine itself is on top of the interburden. This means that the dragline bench for the second pass must be raised above the level of the top of the interburden, usually well above it. The standard method for doing this is to make a high bench in the spoil pile.

9.3 Case Study

Specific operating procedures observed in use at Mine No. 11 are described in this chapter. Production estimates are also presented. Details of the computational procedure are contained in Appendix J.

For the overburden block being dug out at the time of the survey, the overburden was 69 feet deep. The interburden was 22 feet thick. Each coal seam averaged about two feet in thickness. The pit width was 80 feet.

Digging the Side Bench (Figure 36)

On the overburden pass, the dragline worked from a bench 39 feet above the coal, or roughly 30 feet below the ground surface. Benching was done by the dragline as the first component of the block. The side bench material -- old spoil from past stripping of an upper coal seam -- was dug ahead and to the side and swing through an average angle of 90 degrees to dump. The toe of the bench spoil rode all the way up the lower highwall, past the upper coal seam to the upper highwall.

In digging above the bench, the digging times were about five seconds per cycle longer than digging below the bench, and the fill factor was 30 percent lower.

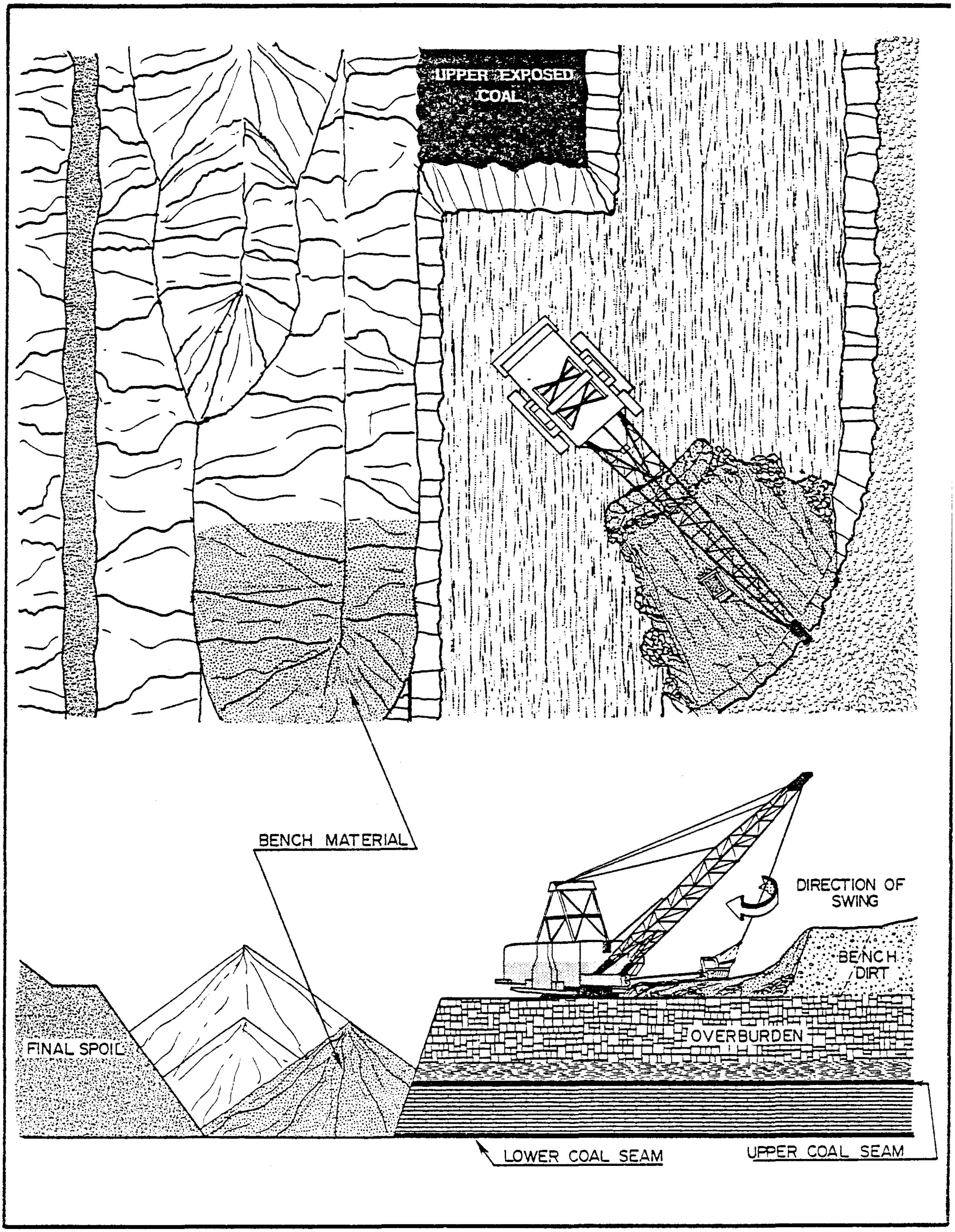


Figure 36. Digging the Side Bench

Digging the Keyway in Overburden (Figure 37)

The second step in overburden removal was to dig the keyway, swinging through an average angle of 90 degrees to dump.

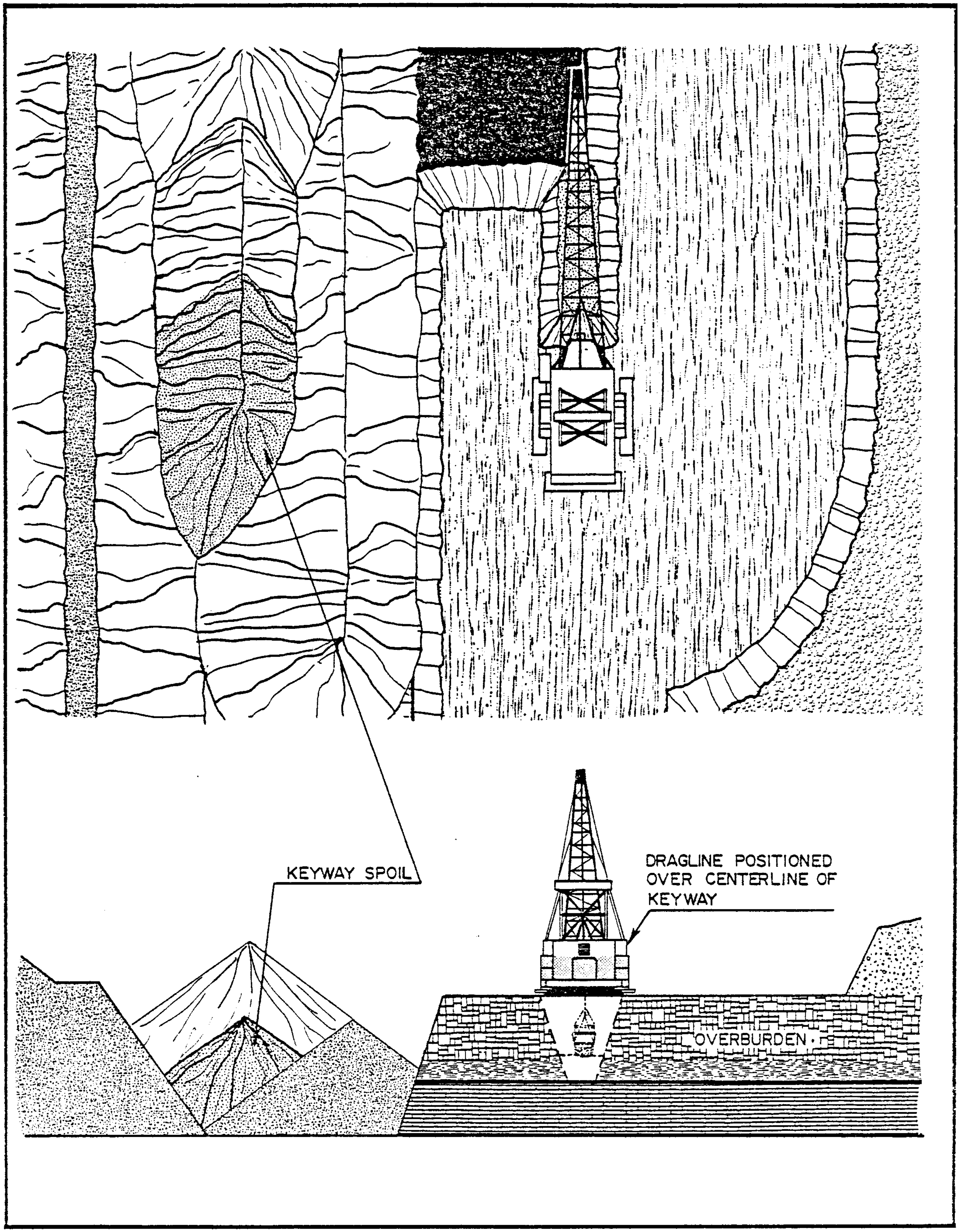


Figure 37. Digging Keyway in Overburden

Finishing the Removal of Overburden (Figure 38)

After completing the keyway, the dragline was walked out to the edge of the bench to dig the remaining overburden. The swing angle in this operation was small, averaging 45 degrees. Dump heights were also fairly small.

After finishing this component, the dragline was moved ahead to begin a new block. Meanwhile, the spoil pile just completed was leveled by dozer, forming the spoil bench for the interburden pass. To level the spoil, the peak was knocked off into the vee between spoil piles.

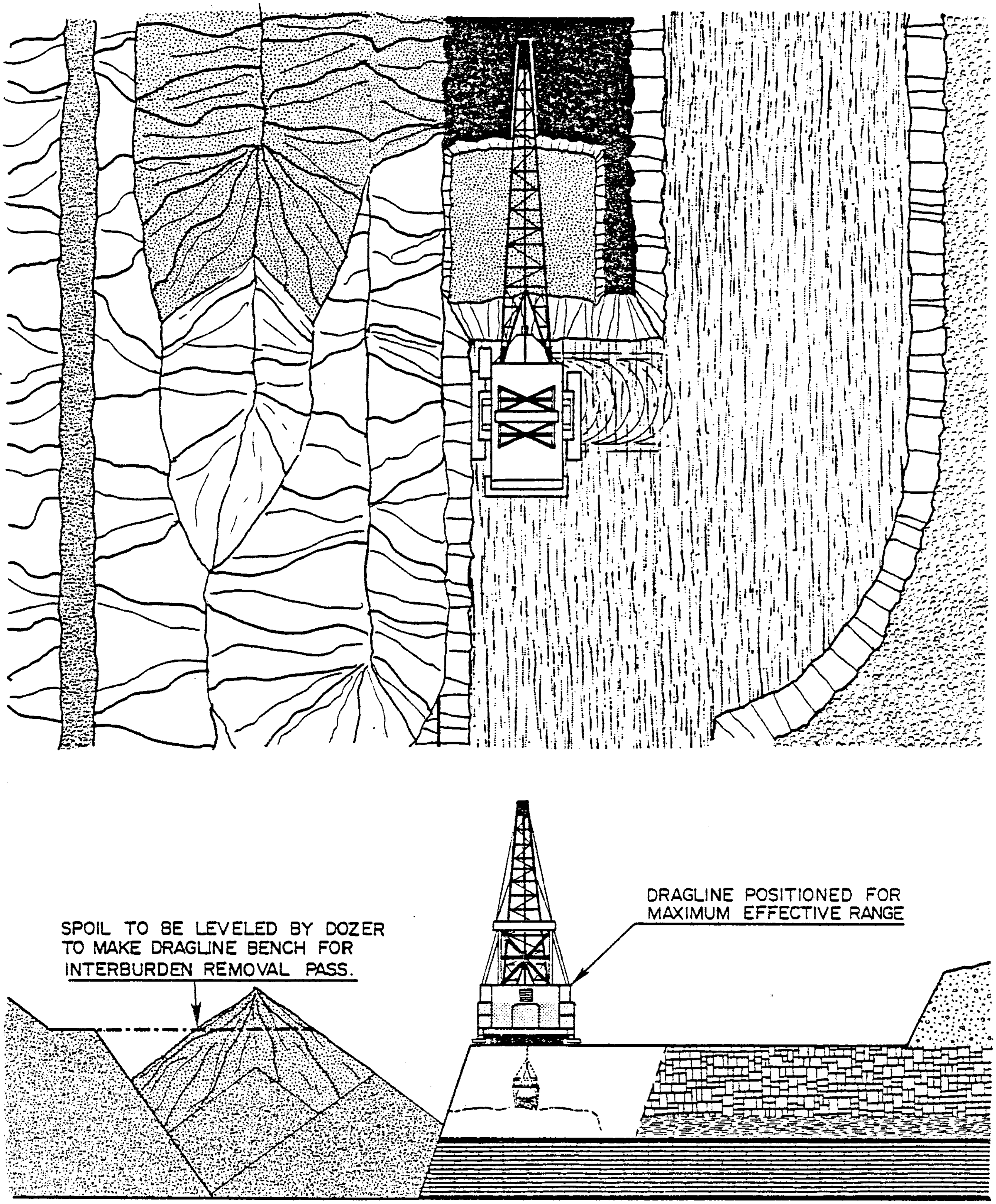


Figure 38. Finishing the Removal of Overburden

Starting to Remove Interburden in a Block (Figure 39)

After removing all of the overburden in the cut, the dragline was walked around the end of the pit onto the spoil bench, and was deadheaded on the spoil bench to the beginning of the cut.

To begin removal of interburden in a block, the dragline was faced perpendicular to the highwall and positioned so that the bucket scaled right down the highwall when hanging vertically under the boom point -- ready to chop. This was possible only because the pit width and spoil bench height had been chosen to make it possible. If the pit had been too narrow, or the bench too low, then the bucket would have had to have been pulled in to chop. Conversely, if the pit had been too wide, or the bench too high, the bucket would have had to have been cast to chop.

The digging procedure about to begin was called "chopping", a procedure in which the bucket was allowed to hang down vertically, and then was dropped onto the surface to be dug. It was an inefficient way to dig, but there was no alternative.

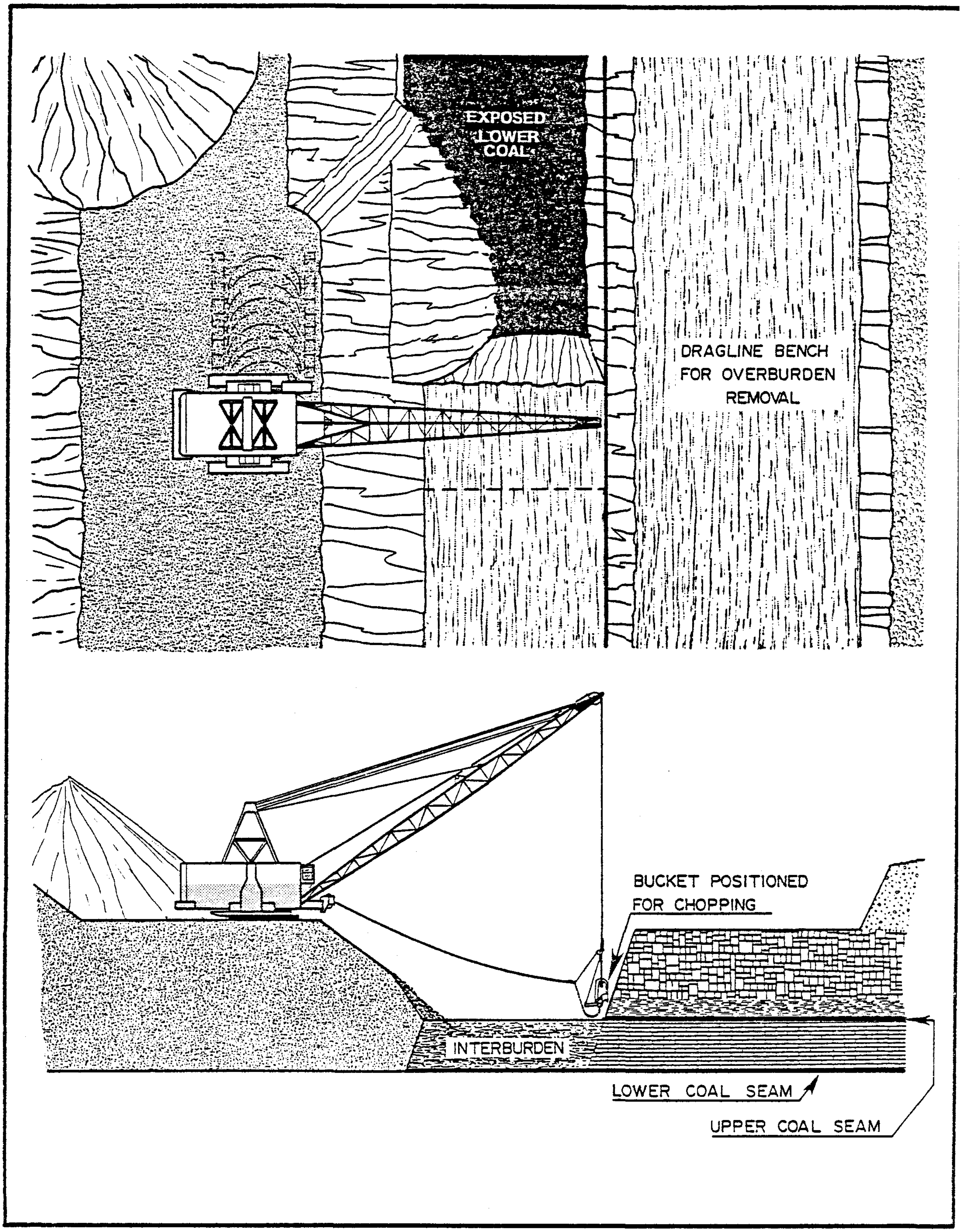


Figure 39. Starting to Remove Interburden in a Block

Chopping the Highwall (Figure 40)

The operator began to dig by chopping the highwall. He dropped the bucket onto the interburden, but didn't get good penetration because the pull plates hit before the teeth. Then he dragged the bucket across the interburden, but it filled only to about 40 percent of capacity. He continued dragging it up the slope to the fairlead, eventually filling it with spoil from the bucket roll.

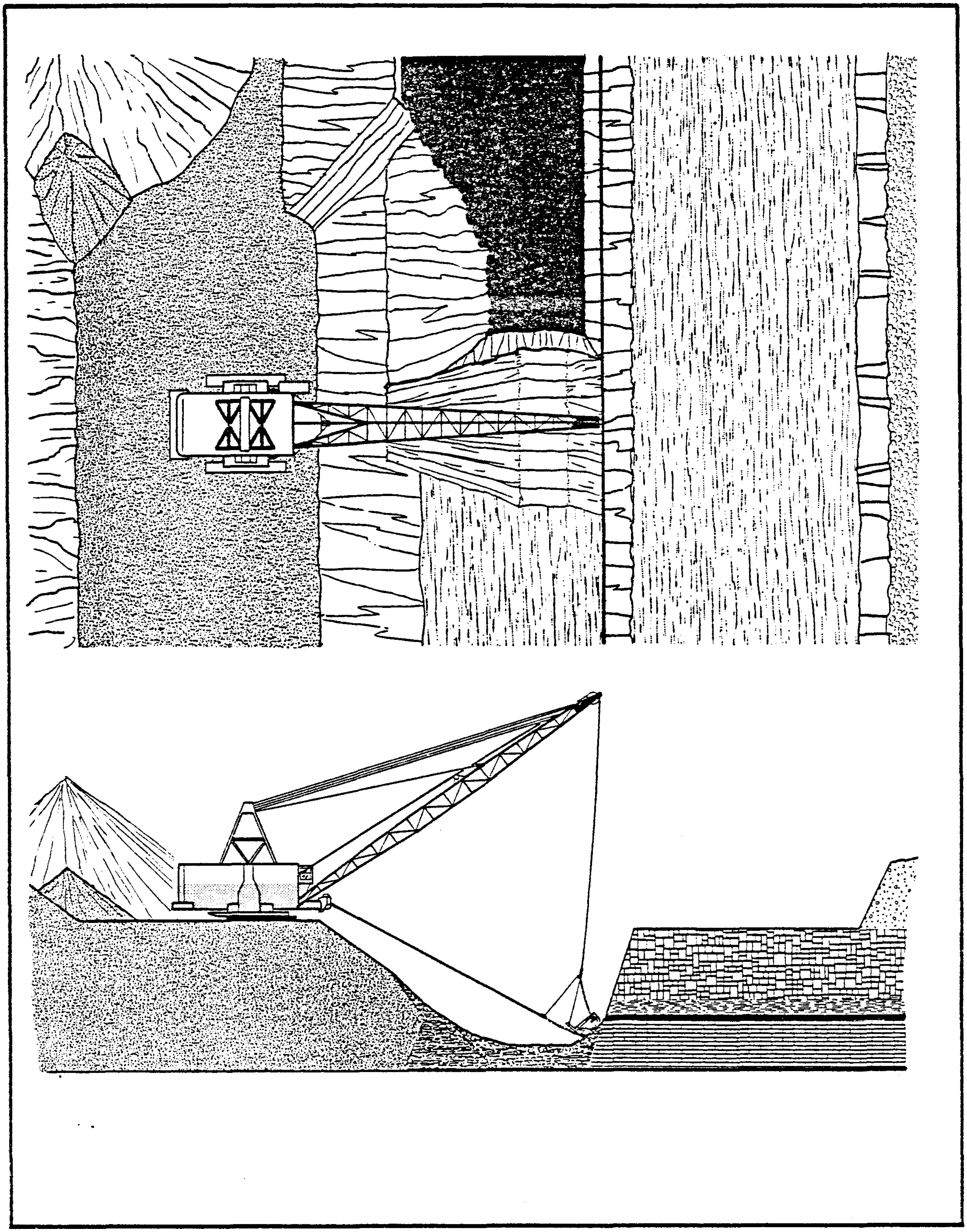


Figure 40. Chopping the Highwall to Dig the Interburden

Finishing the Straight-Ahead Dig (Figure 41)

After awhile, all the chopping was completed, and the operator dug in a conventional manner. Eventually, however, he reached the point where he couldn't dig anymore because the bucket was pulling out of the bank and coming up the dig face slope. That finished the side-dipping part of the block.

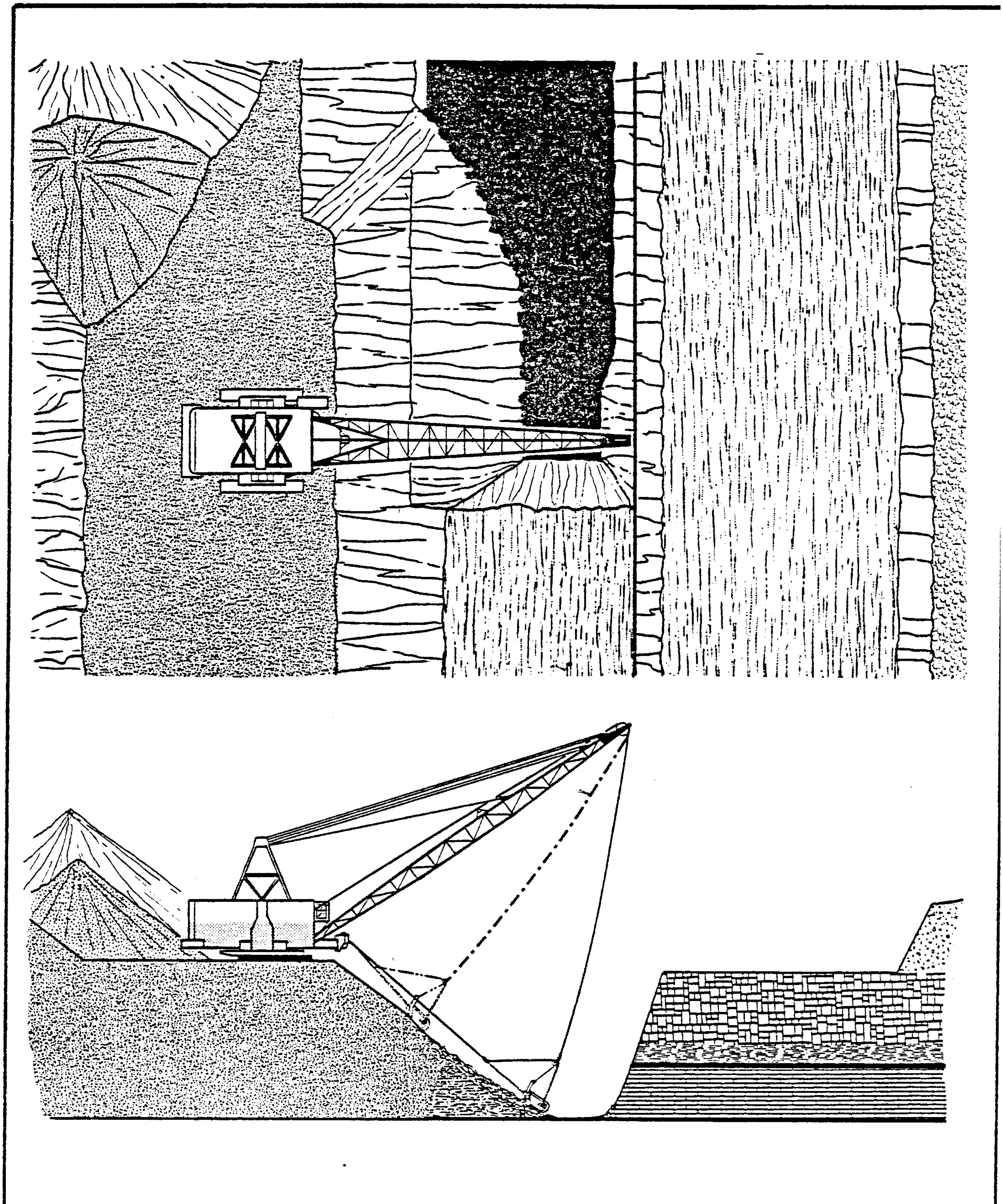


Figure 41. Finishing the Straight-Ahead Dig

Moving Ahead and Sloping the Spoil (Figure 42)

Now, the operator wanted to dig more-or-less parallel to the highwall to clean up the interburden from the previous block that he couldn't get by side-dipping. But he couldn't do it straight-away, because the drag cable would have dragged in the edge of the spoil bench. So, first he moved ahead a few steps parallel to the bench, and dug a section two buckets wide off the edge of the spoil bench, down about halfway to the coal. Then, he moved back up toward the dig face and completed the digging down to the coal. He "got off the edge" by half-a-bucket, meaning that he exposed the edge of the coal seam plus a few feet to spare.

The operator said that he always dug a section two buckets wide off the edge of the spoil bench, and that this was necessary for drag cable clearance.

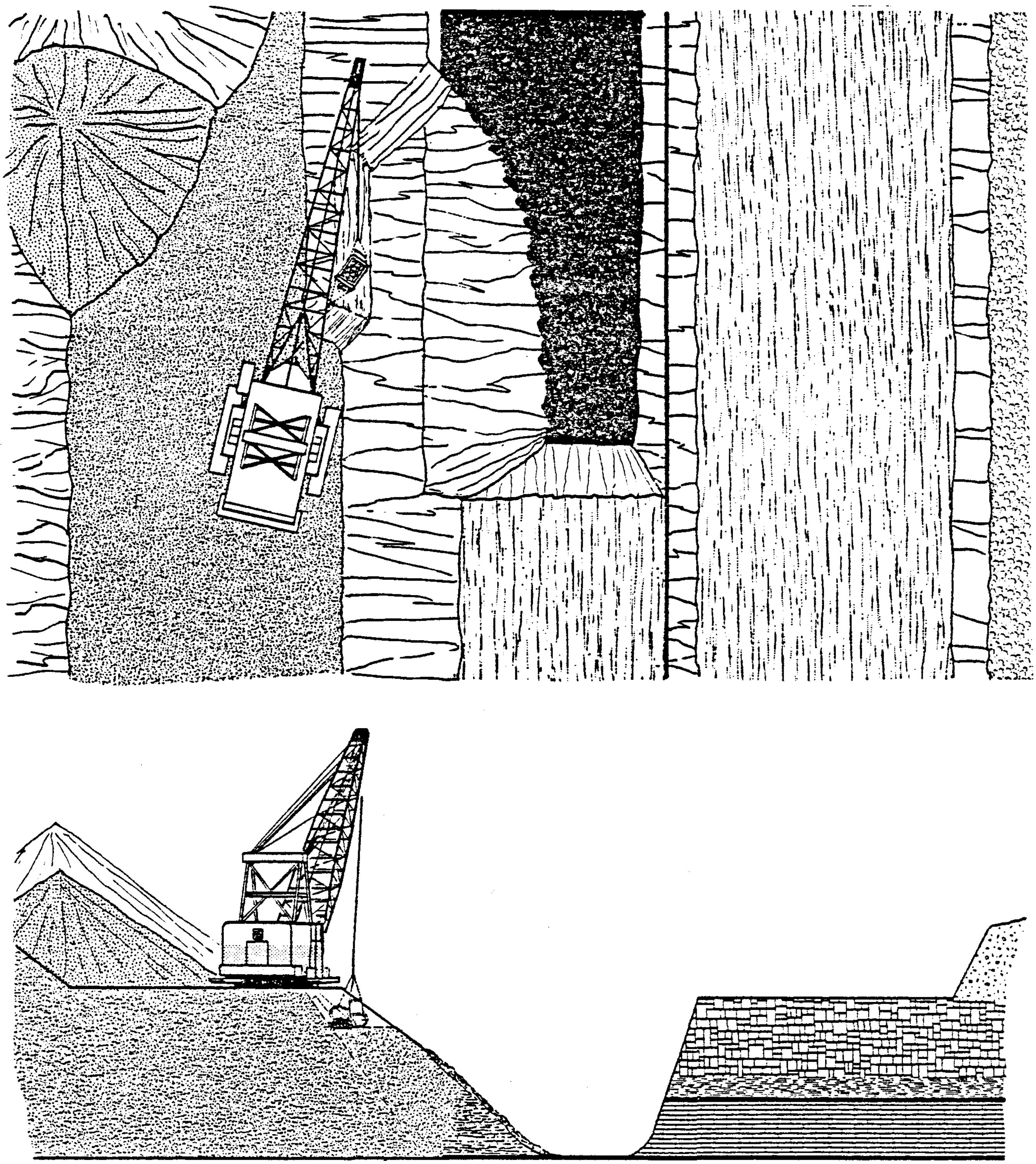


Figure 42. Moving Ahead and Sloping the Spoil

Digging Diagonally to Finish the Block (Figure 43)

The last component of the block was digging diagonal to the pit and cleaning up the interburden material left from the previous block.

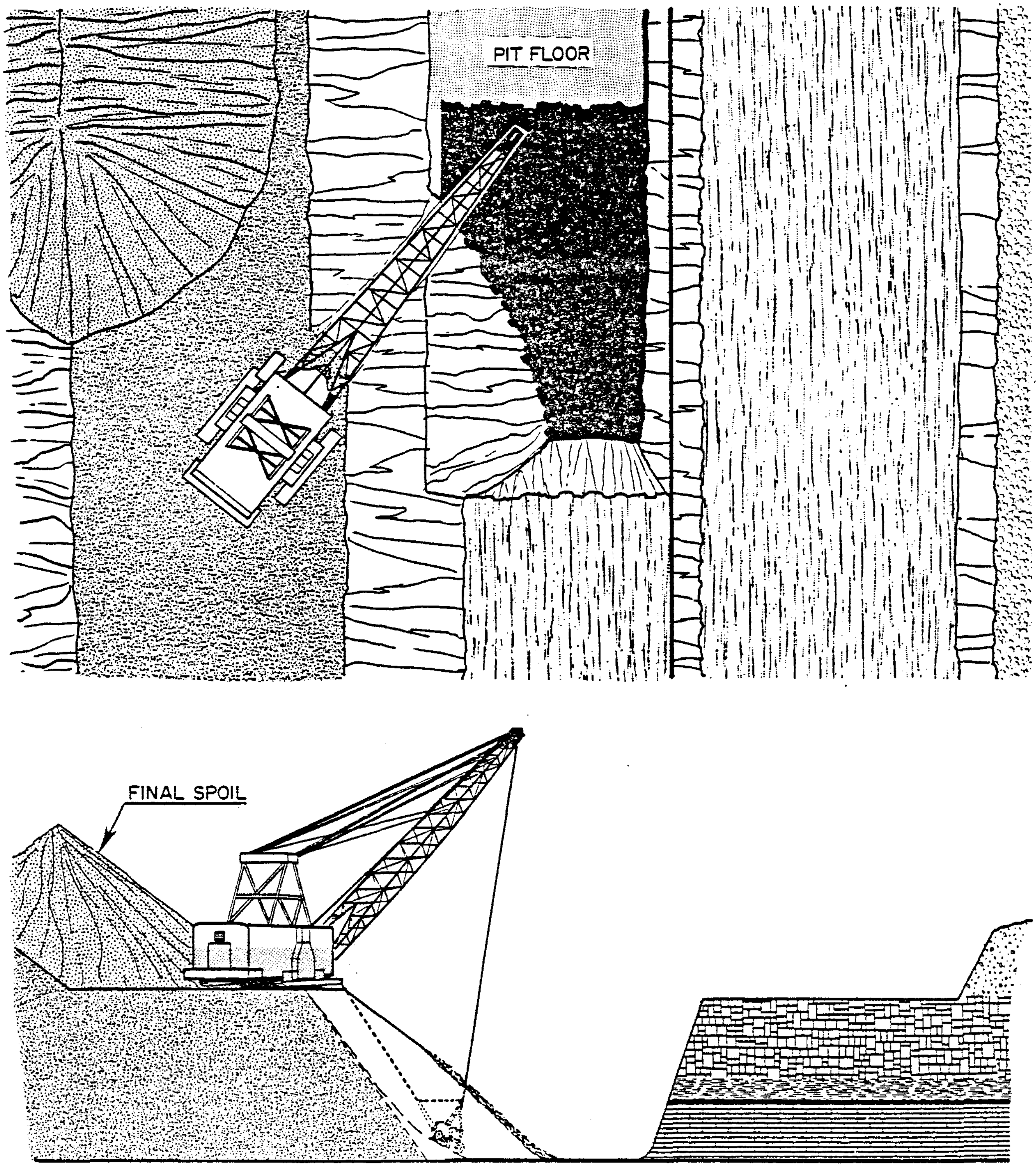


Figure 43. Digging Diagonally to Finish the Block

9.4 Characteristics of the Horseshoe Method

The horseshoe method just described had the following salient characteristics:

- Dragline performance on the overburden pass was better in two-seam mining than it would have been if only one seam was mined. This is because of the extra spoil storage room in the pit below the elevation of the upper coal seam. Ordinarily, in 69 feet of overburden with an 80-foot pit, the Marion 7400 dragline would have required an extended bench. Additionally, the average swing angle and spoil pile height would have been larger.

- When there is no extended bench on the overburden pass, all the rehandle is attributed to the interburden pass.

- There is always substantial rehandle on the interburden pass because the edge of the spoil bench must be dug two buckets wide (about 16 feet). In the case just described, the rehandle as a percentage of total bank (overburden and interburden) volume was 18 percent. But it was 73 percent of the interburden volume.

- After adjustment for digging depth, the digging time on the interburden pass was four seconds per cycle longer than that on the overburden pass. (Figure 44) This includes allowance for the fact that only one-third of the interburden dig cycles were chopping cycles.

- On the overburden pass, average swing angle was 71 degrees, and average spoil height was five feet. On the interburden pass, the average swing angle was 120 degrees and the average spoil height was 33 feet.

- Estimated average dragline production rate on the overburden pass was 635 bank cubic yards per operating hour. On the interburden pass, it was only 325 bank cubic yards per operating hour, or roughly 50 percent of the rate for the overburden removal pass.

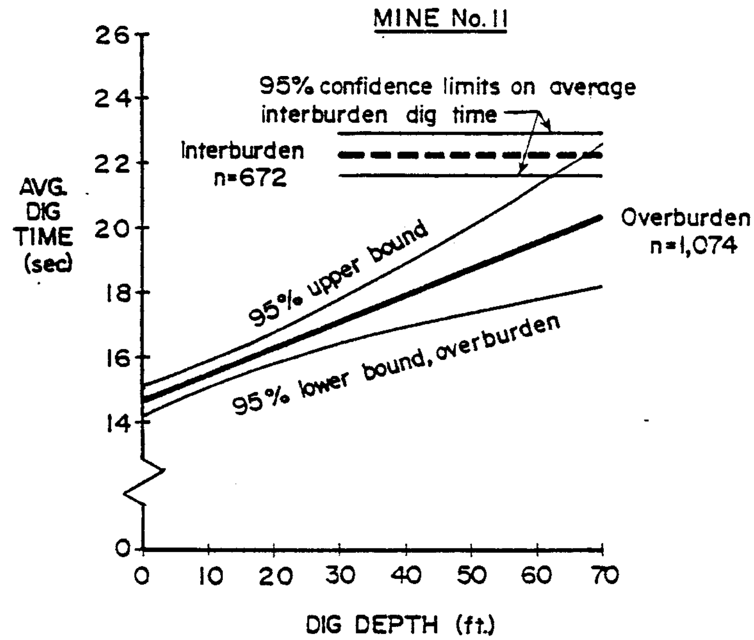


Figure 44. Comparison of Digging Times for Overburden and Interburden Passes

9.5 Components of Productivity Loss on Interburden Pass

The components of the 50-percent dragline production rate loss on the interburden pass are given below:

- Rehandle: 22 percent
- Chopping: 8 percent
- Swing angle: 12 percent
- Dump height: 3 percent
- Digging depth: 5 percent

10. THE EXTENDED BENCH METHOD OF TWO-SEAM STRIPPING

10.1 Background

In some two-seam stripping situations, the interburden thickness is equal to or greater than the overburden depth. The horseshoe method is not used in such cases because, on the second of two passes, the dragline can be positioned on top of the interburden, and its dump height will be adequate.

There is, however, an alternative to the two-pass method; it is a method in which both the upper and lower coal seams are uncovered in one pass. This one-pass method was observed in use at Mine 28, where it had been substituted for the two-pass method to improve productivity. The one-pass method is described in this chapter. An analysis of both methods is contained in Appendix K.

10.2 Mine Characteristics

Overburden consisted of an average of 50 feet of hard sandstone, whereas the interburden consisted of 45 feet of shale. The dragline was a Marion 7400 with a 14-yard bucket and a 150-foot dump radius.

For some time prior to the survey visit, the mine operators had used a two-pass stripping method. On the first pass, the dragline worked from a bench on overburden and uncovered the upper coal seam. At the end of the cut, a ramp was constructed down to the level of the interburden and the dragline was walked down to that level and dead-headed on top of the interburden to the opposite end of the cut to begin removing the interburden.

But, the operators had switched to the one-pass method because of the following disadvantages of the two-pass method:

- Ramping the dragline up and down between levels was time-consuming and costly.
- On the overburden pass, the dragline didn't have enough range to dump the spoil far enough out.
- They couldn't deadhead on the interburden until all of the upper coal had been loaded out. This caused delays.
- There was fireclay immediately beneath the upper coal seam. It was slippery when wet and caused deadheading delays.

In the one-pass method, the dragline was always positioned at the interburden level, or rather five feet above it on a shale "pad". Overburden was dug to the side and above the bench. Interburden was dug conventionally below the bench. The method is described in more detail on the following pages.

Digging the Interburden Keyway (Figure 45)

The first step on each block was to dig the interburden keyway and dump the spoil at 90 degrees to begin building the extended bench. The keyway spoil volume was not sufficient to extend the bench all the way across the pit.

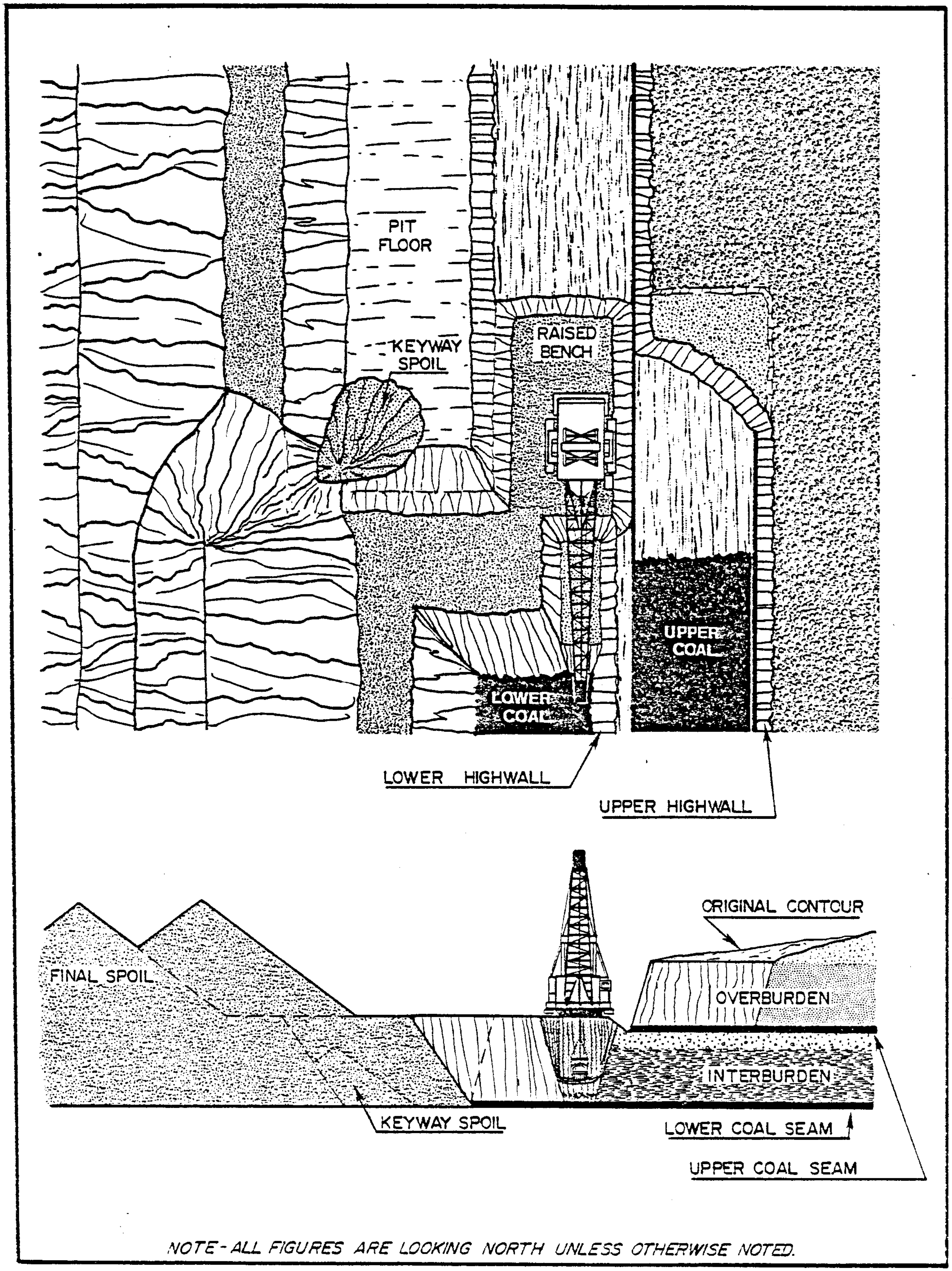


Figure 45. Digging Keyway and Building Part of Runway

Benching Overburden and Building Runway (Figure 46)

Next, with the dragline still in the keyway position, the operator turned the machine to dig the sandstone overburden above the bench and swung through an angle of about 130 degrees to dump and further extend the bench. Before completely digging all the overburden, the volume of spoil became large enough to extend the bench all the way across the pit.

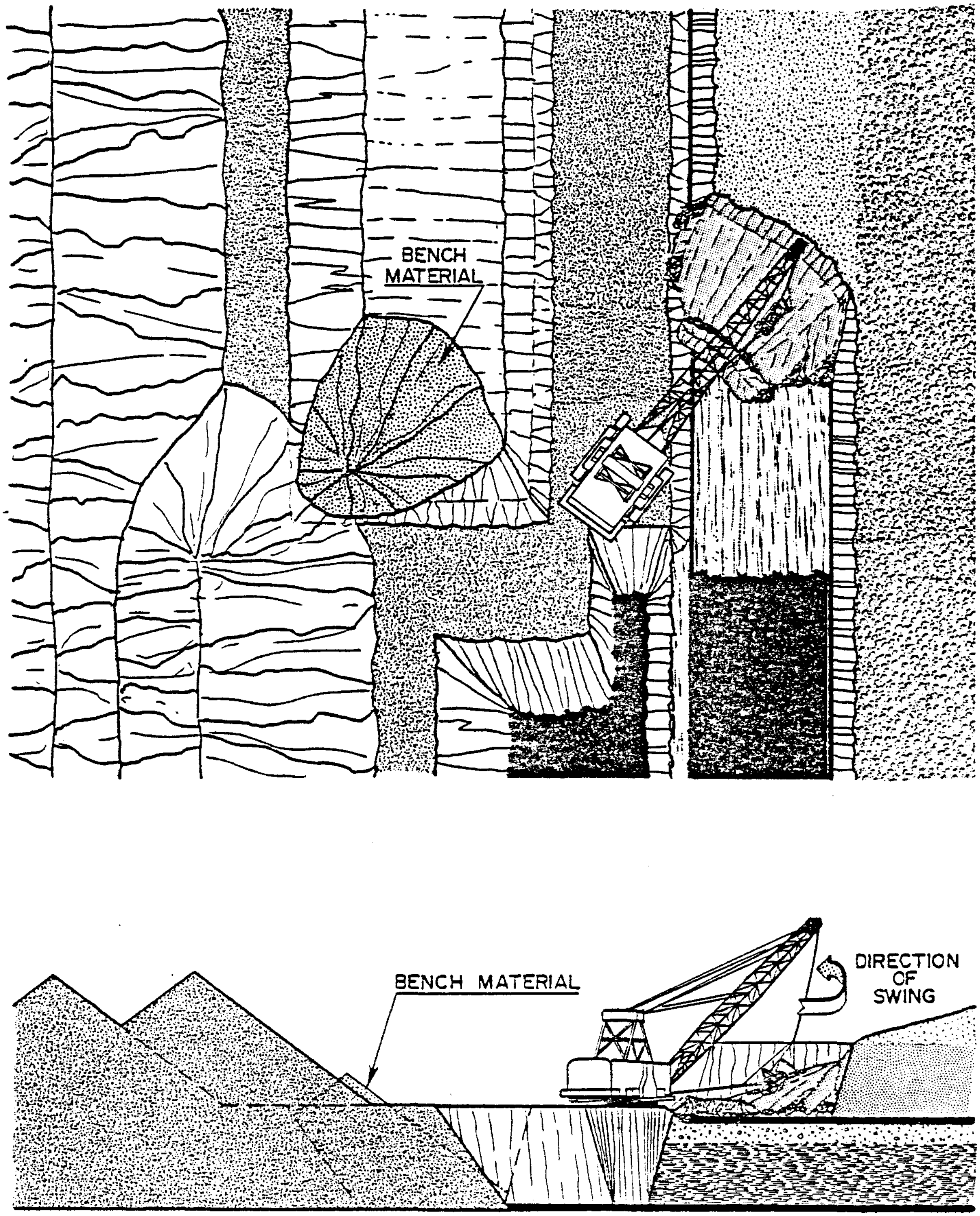


Figure 46. Benching Overburden and Building Runway

Mucking the Spoil Pile (Figure 47, note change of orientation)

Now the operator pulled back on the extended bench spoil to help level it. Later, leveling was completed by the dozer.

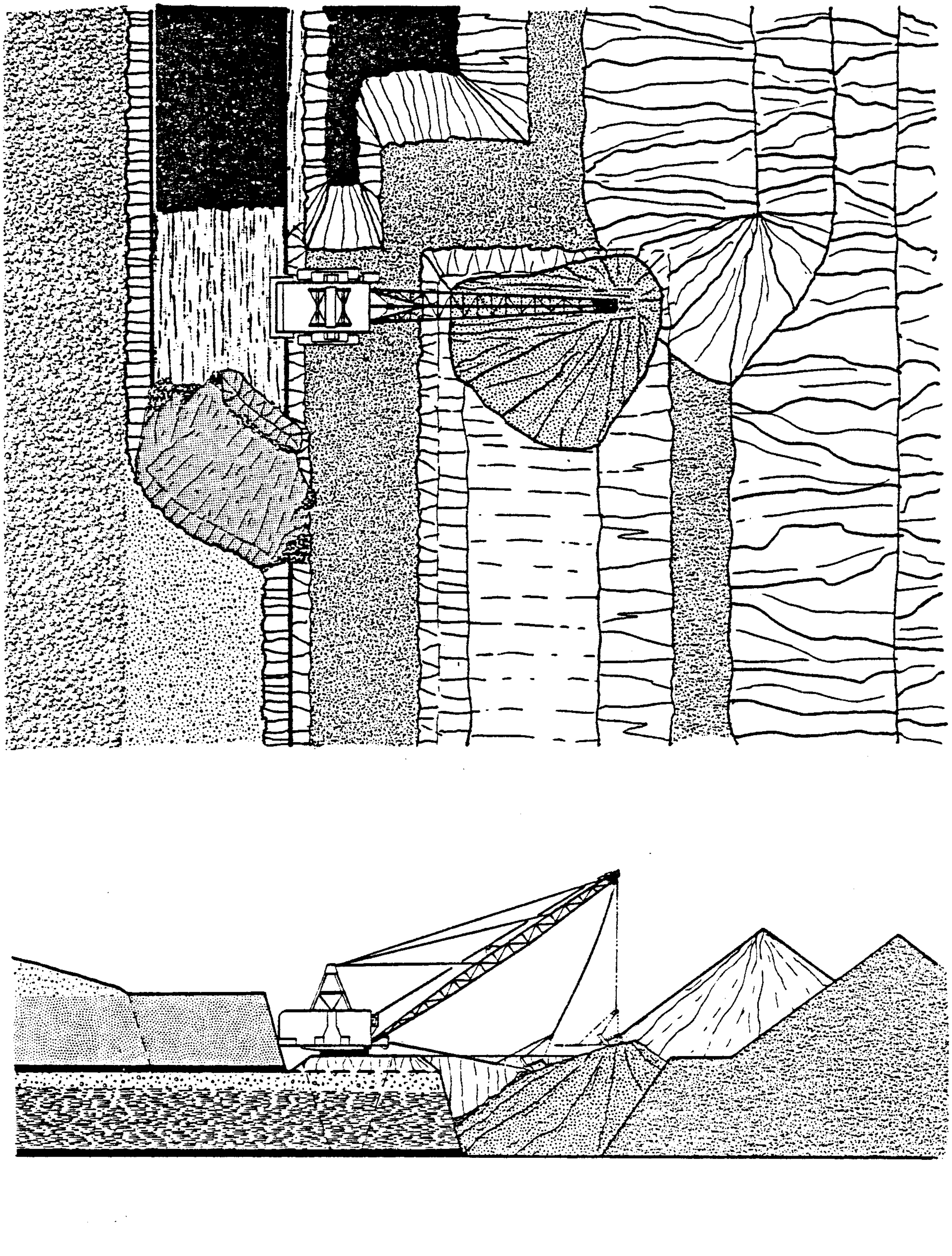


Figure 47. Pulling Back on Spoil Pile (Mucking)

Finishing the Overburden Benching (Figure 48)

The operator returned to digging the overburden above the bench. The question was where to dump the spoil. He didn't want to dump it on top of the extended bench because, later on, he'd have to move out there. So he dumped the remaining overburden temporarily in the open cut ahead of the current block. This spoil would eventually be rehandled.

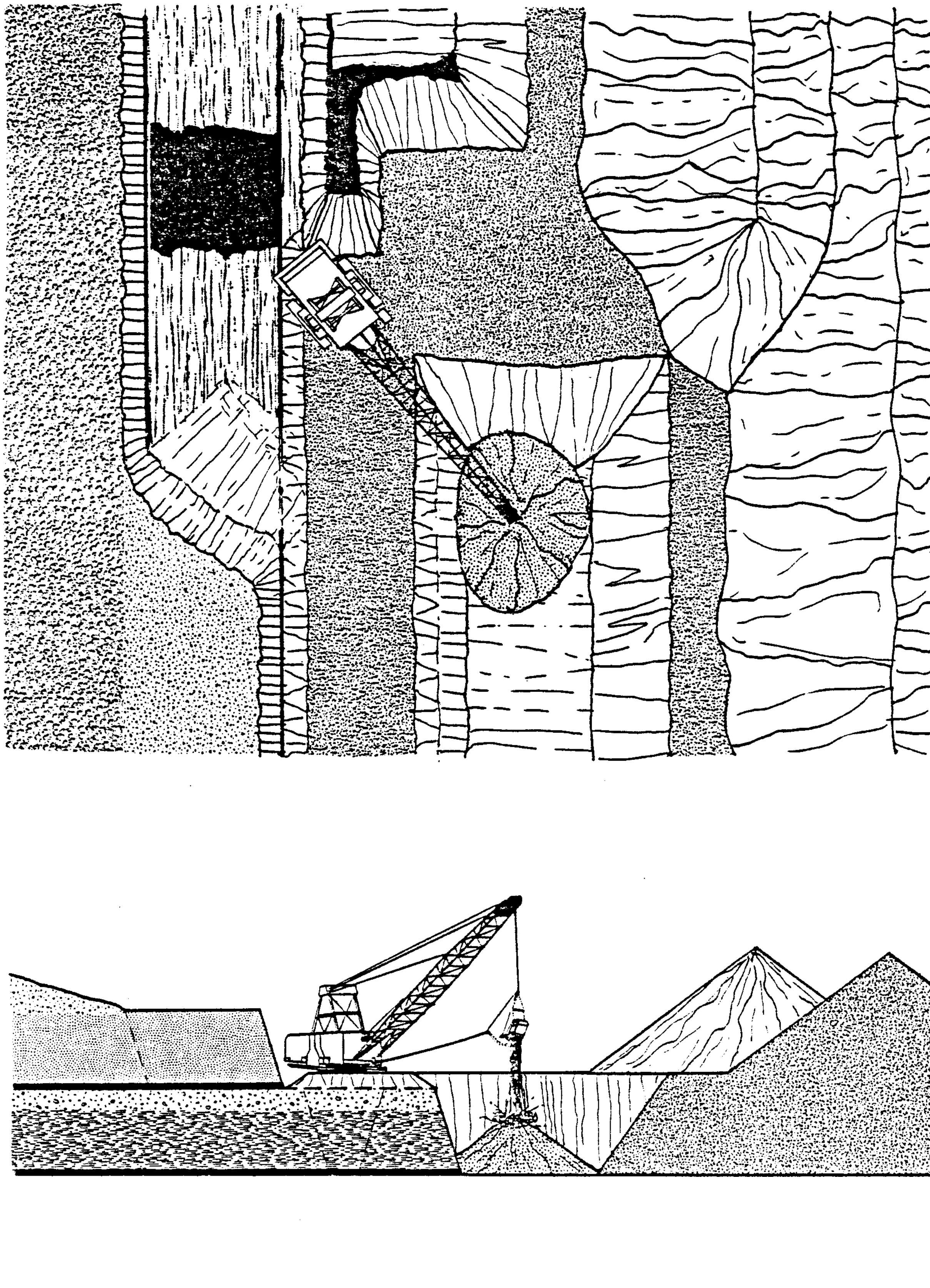


Figure 48. Finishing the Overburden Benching -- Spoiling Into Open Pit

Digging Interburden From Position On Runway (Figure 49)

The operator walked the machine way out onto the extended bench. He dug by facing the highwall and hooking the edge of the keyway. He dumped the spoil as far away as he could.

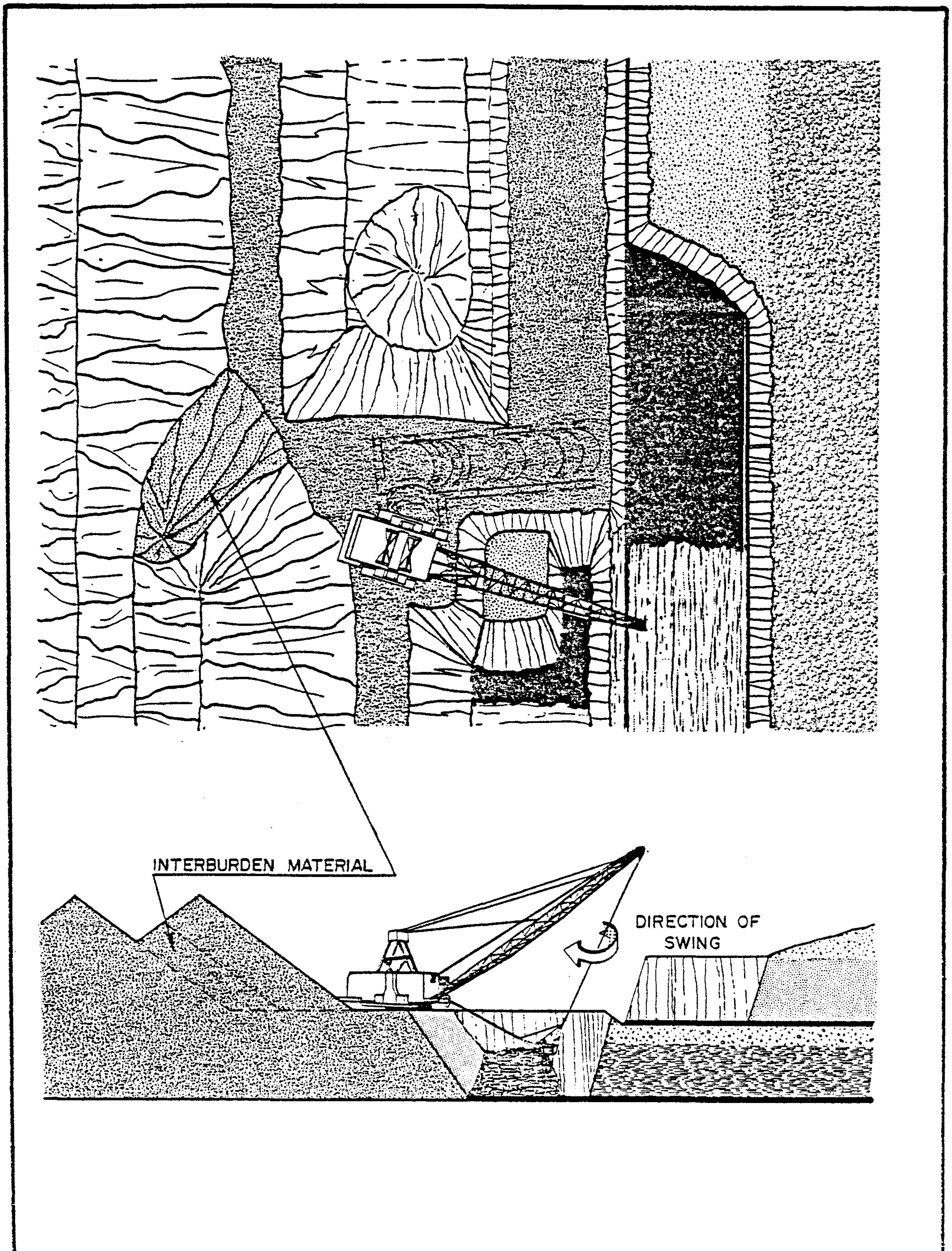


Figure 49. Digging Interburden From Position On Runway

Digging the Extended Bench Rehandle Section (Figure 50)

He walked the machine back in toward the pit to sit over the rehandle section and dig it. This finished the interburden digging.

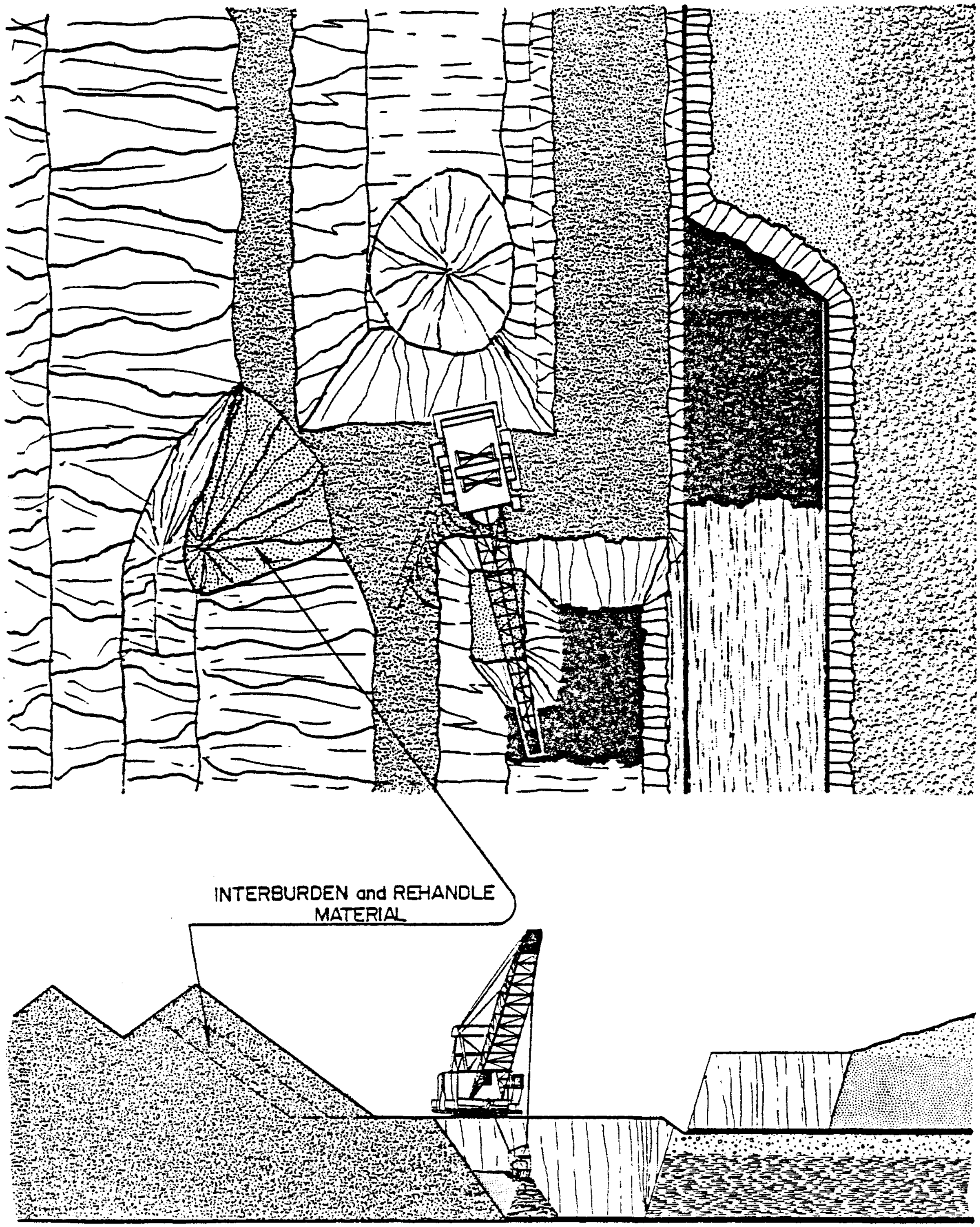


Figure 50. Finishing Digging the Rehandle and Interburden

Rehandling the Overburden Spoil (Figure 51)

The last component of the block was to face the other way and dig the overburden material that had been stored temporarily in the open cut. This was swung through an angle of about 90 degrees and dumped on the main spoil pile.

The operator couldn't have left that spoil in the open cut because there wouldn't have been room for the keyway spoil from the next block.

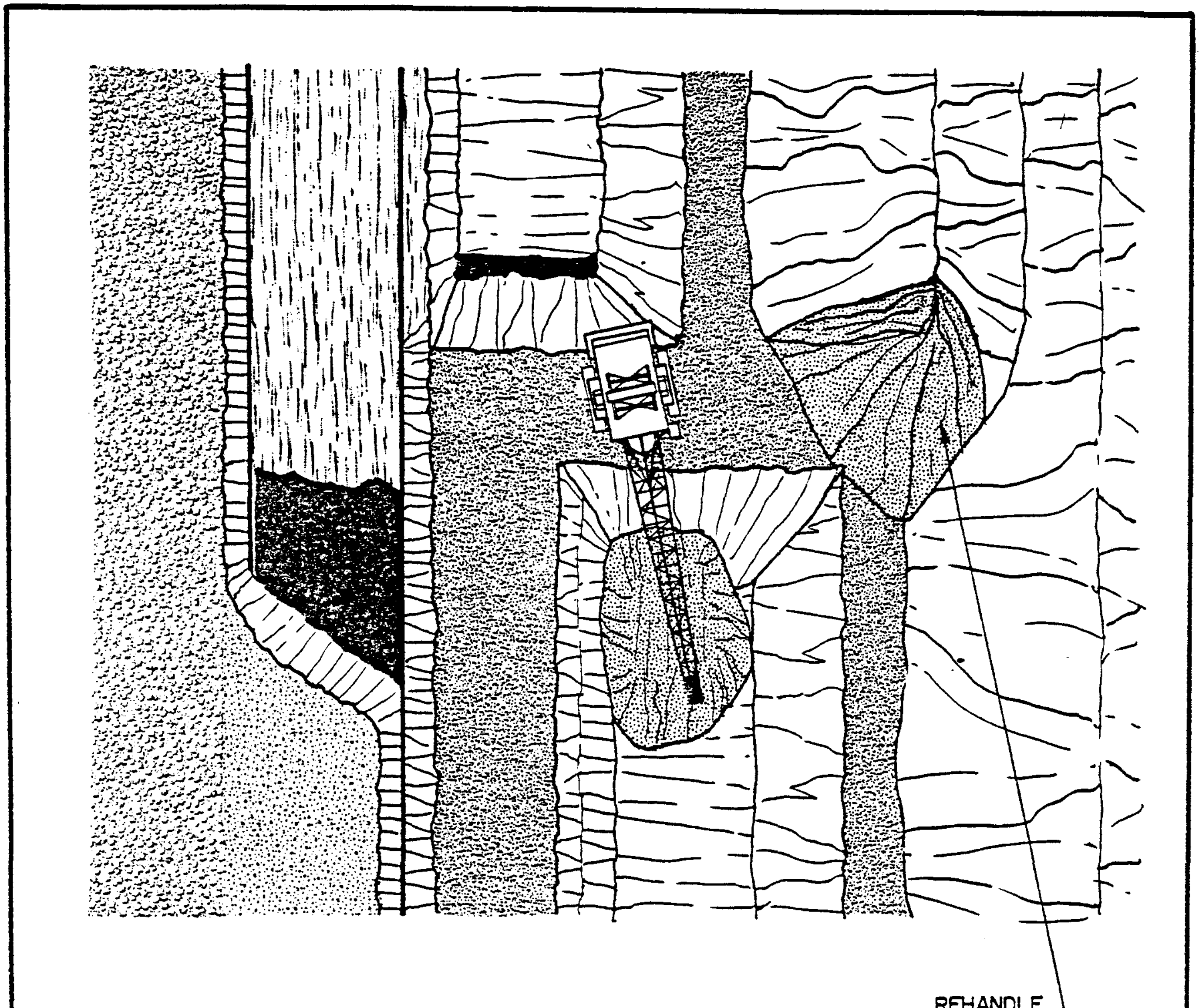


Figure 51. Rehandling

10.3 Comparison of the Methods

The principal disadvantages of the one-pass method, according to the operators, were the following:

- Longer digging time for above-bench digging. (Figure 52)
- Low bucket fill factor in above-bench digging. (Figure 53) It averaged only 75 percent as compared with 98 percent for below-bench digging.

The rehandle, 35 percent, was the same for the one- and two-pass methods. Overall, the bank cubic yards moved per operating hour were estimated to be 15 percent greater for the two-pass method than for the one-pass method. But the dragline walking time for the one-pass method was eight percent lower than that for the two-pass. Also, the utilization was higher.

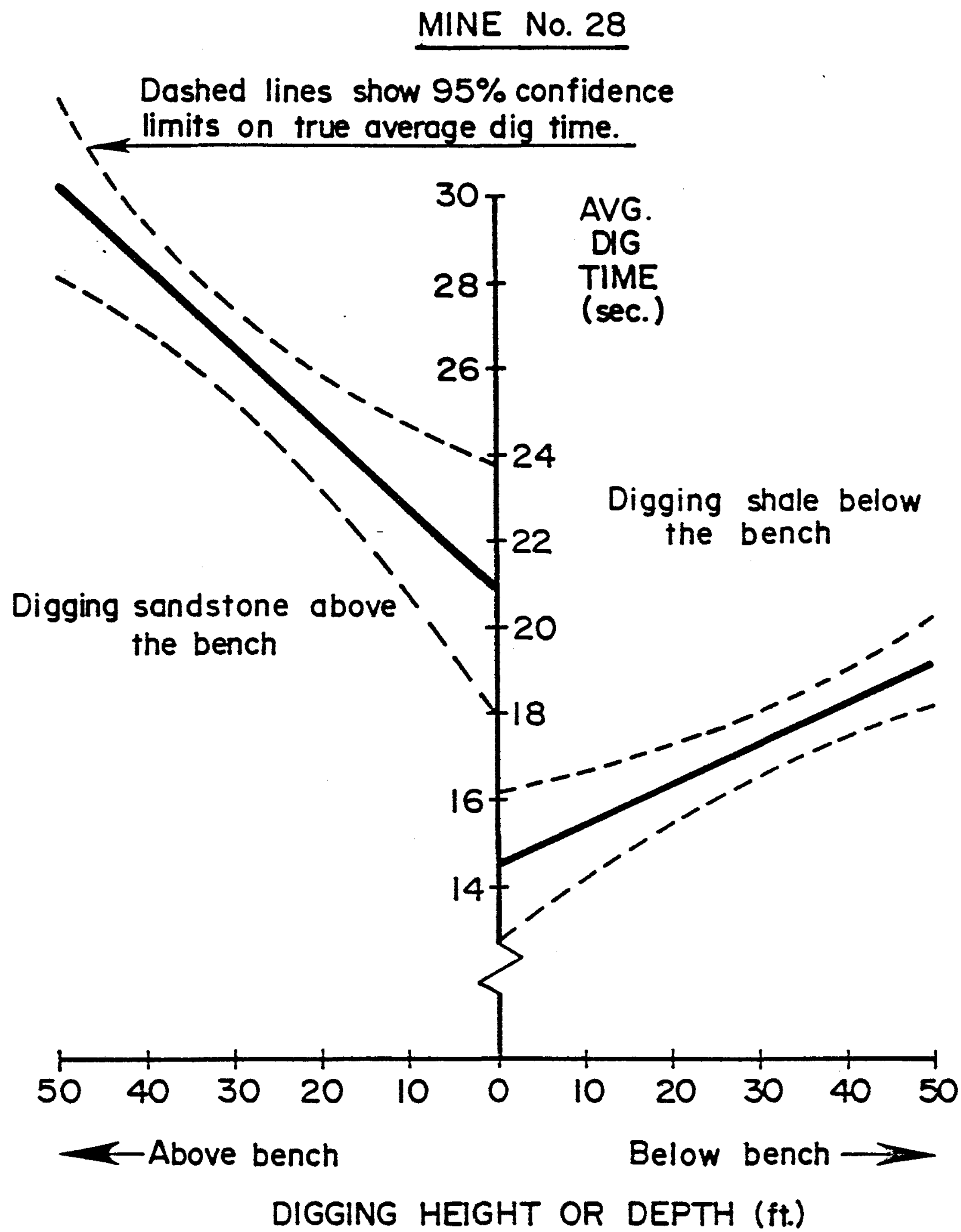


Figure 52. Comparison of Digging Times for Above- and Below-Bench Digging

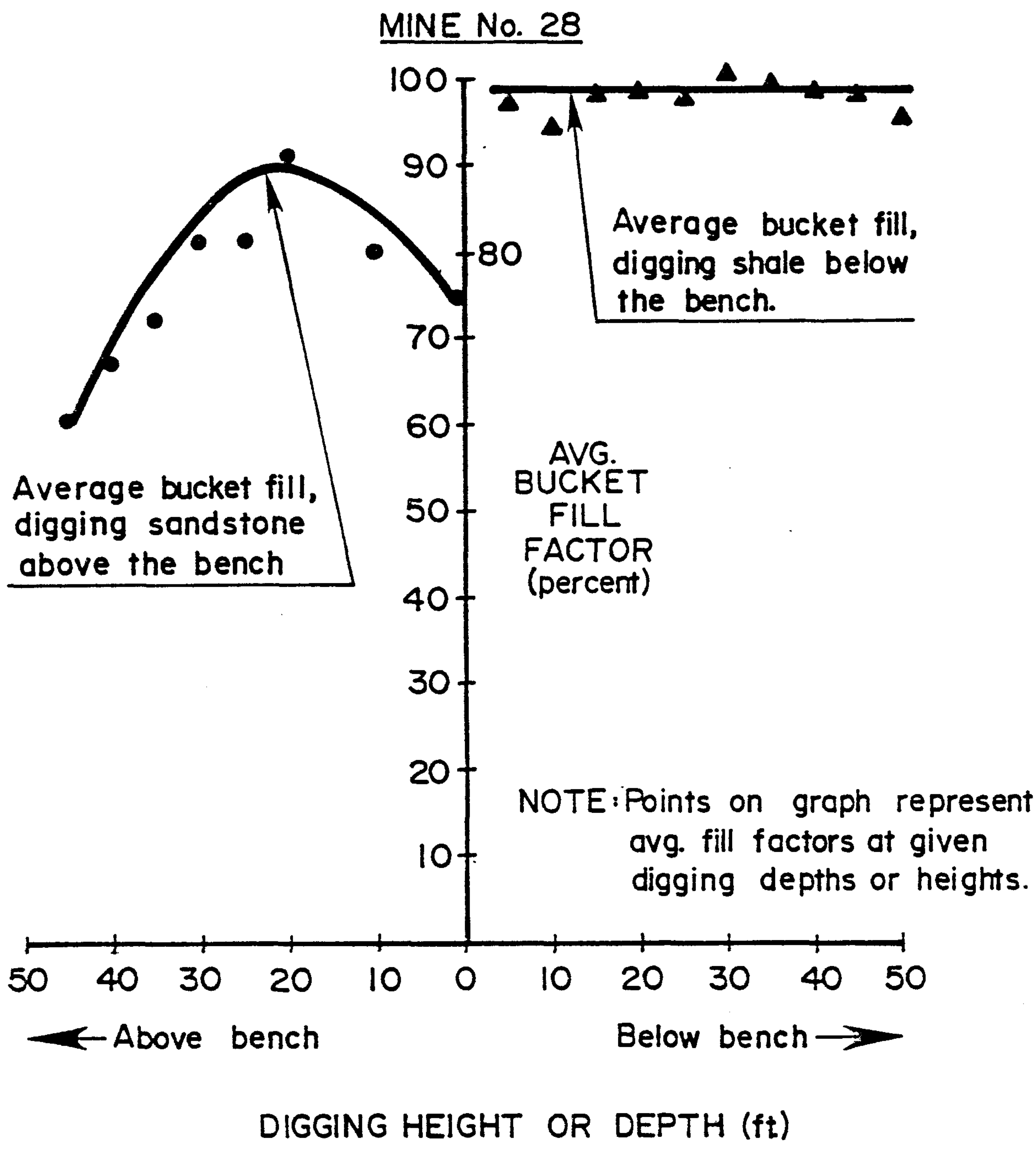


Figure 53. Comparison of Bucket Fill Factors for Above- and Below Bench Digging

GLOSSARY

ACID-PRODUCING MATERIAL: Overburden materials, usually shales or sandstones, that contain sulfur-bearing minerals such as pyrite which, when exposed to air and water, result in the formation of sulfuric acid.

ANFO: A mixture of ammonium nitrate (fertilizer) and fuel oil, widely used as an overburden blasting agent.

ANOVA: Analysis of Variance, a statistical technique used to test for the significance of differences among averages. For example, ANOVA might be used to determine if differences in average digging times for several draglines are statistically significant.

ARCHLESS BUCKET: A dragline bucket that does not have a stabilizing arch. These buckets were originally designed to have greater capacity than arched buckets, by substituting payload for the weight of the arch. Over time, however, the archless buckets had to be strengthened to prevent cracking of the side plates, so that the capacity advantage has largely been lost.

BUCKET WITH ARCH

ARCHLESS BUCKET

AVAILABILITY: Referring to a machine such as a dragline or dozer, availability is the proportion of scheduled operating hours that the machine is available for use.

$$\text{Availability} = \frac{\text{Scheduled operating hours - downtime hours}}{\text{Scheduled operating hours}}$$

BACKFILLING: Use of dozers to push spoil back into an open stripping cut, thereby wholly or partially filling the cut.

BAILING: Rehandling on the last move of a cut, necessitated by the practice of leading the spoil and filling the last open block of the open cut with spoil from the second-to-last move.

BANK CUBIC YARDS (BCY): A measure of the volume of overburden before blasting or excavation.

BEDDING PLANES: The planes separating overburden strata or beds. In eastern surface coal mining areas, bedding planes are usually horizontal.

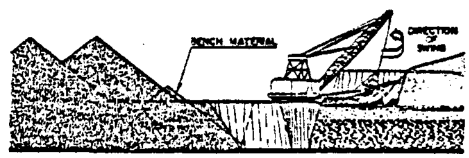
BENCH DIRT: Unconsolidated surface overburden material, usually clay, that is excavated by dozer or dragline to construct a level bench for a vertical overburden blasthole drill.

BENCH DOZER: A dozer assigned to work with a dragline for the purpose of constructing drill and dragline benches, in addition to grading spoil, constructing and maintaining haul roads, and cleaning coal.

BENCH HEIGHT: The height of the dragline bench, measured above the top of the coal seam being uncovered.

BENCHING: 1. For dozers, the process of constructing a drill or dragline bench by pushing surface overburden material into the adjacent open cut.

2. For draglines, the process of constructing a bench for a subsequent move by digging to the side and above the bench. When referring to draglines, the term "benching" always means above-bench digging.



Dragline Benching

BENCH WIDTH: The total width of the dragline bench. Ordinarily, the bench width is greater than the pit width, if only to allow tailroom for the dragline.

BLOCK: The block of overburden excavated by a dragline from one or more dragline positions characterized by a cycle of repetitive dragline positions or sets. Each cut consists of a series of blocks. Each block consists of one or more sets.

BLOCKING INTO THE HILL: Hillside stripping in which cuts are oriented perpendicular to the coal seam cropline. In a given cut, stripping begins at the coal cropline and proceeds back into the hill until the recovery line is reached. The blocking technique is used for three reclamation-related reasons: reduction of the area disturbed by placement of box cut spoil, reduction of the volume of spoil that must be moved to backfill the final cut, and maintenance of grading activities concurrent with mining.

BLOCK LENGTH: The length of a block measured horizontally in a direction parallel to the highwall.

BLOCKY: Overburden material that breaks into irregularly shaped blocks when blasted. This usually refers to sandstone, rather than shale, which breaks along bedding planes into slabs.

BOX CUT: The first cut made at a given mine.

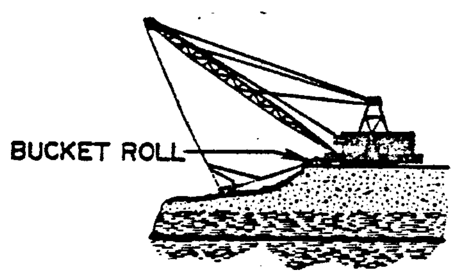
BUCKET STRUCK CAPACITY: The capacity of a dragline bucket, in loose cubic yards, when the bucket is filled level with the top of the sides of the bucket.

BUCKET FILL FACTOR: The amount that a dragline bucket is filled on a given dig cycle, expressed as a percentage of struck capacity.

BUCKET LIP: The portion of a dragline bucket to which the teeth are attached.

BUCKET POSITIONING: The process by which a dragline operator maneuvers the bucket into position to dig. Sometimes the bucket is positioned during the return swing but, more often, it is positioned after the return swing has been completed.

BUCKET ROLL: A pile of dirt that builds up on the dragline bench in front of the dragline, usually in shallow and above-bench digging. If the bucket roll gets too big, the dragline drag cable will drag in the roll, causing accelerated cable wear.

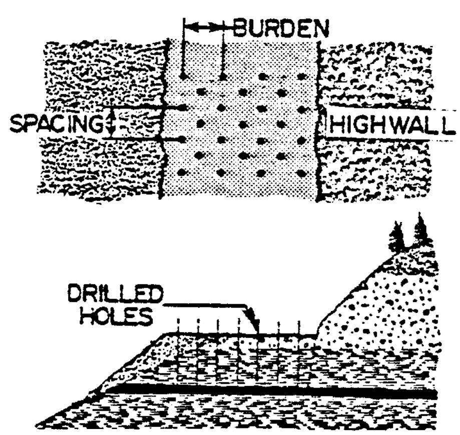


BUCKWALL: A spoil pile base constructed from competent overburden materials to minimize spoil pile instability. The buckwall is widely used at strip mines in the midwestern United States, but is used less frequently at eastern mines.

BUILD OUT: The process of extending the dragline bench.

BURDEN: The spacing between overburden blastholes, measured in a direction perpendicular to the highwall.

CABLE: Usually refers to the dump cable or drag cable on a dragline.



Blasthole Burden & Spacing

CASTING THE BUCKET: The process of using the force of gravity to cast the bucket far out for digging. In casting, the bucket is pulled all the way in to the fairlead during the return swing, and is held in using the drag brake until the return swing has been completed. Then the drag brake is released and the weight of the bucket carries it far out. Frequent casting is necessary for very long moves.

CATS: The crawlers on dozers, drills, or draglines.

CHOPPING: A dragline digging procedure in which the bucket is lowered vertically and dropped onto the surface to be dug. Chopping is a relatively inefficient digging procedure that is necessary in dragline benching and side-dipping.

COLLINEARITY: A statistical term referring to the association or correlation between two variables. For example, in dragline time study work, if deep digging occurred only when swing angles were large, then digging depth and swing angle would be said to be collinear. This is very undesirable if the resulting cycle time data are to be analyzed using regression analysis techniques.

COMPETENCE: A geological term, referring to the structural strength of (in this case) overburden materials. Incompetent materials are exemplified by topsoil, sand, sandy clays, and clays. Competent materials include most sandstones and limestones, and some shales.

CONFIDENCE INTERVAL: A statistical measure expressing the possible error in a measured quantity due to measurement of only a sample of values.

CONTOUR MINING: In hillside stripping, a method in which the box cut is made along the contour of the hill, following the coal seam cropline.

CORRELATION: Historical association between two variables. For example, dragline digging time is positively correlated with digging depth. This means that, historically, for a given dragline, digging time has increased when digging depth has increased.

CROP: See CROPLINE.

CROP COAL: Coal located at the coal seam cropline. This coal, sometimes called "blossom coal" is often inferior in quality because of its closeness to the surface of the ground.

CROPLINE: The imaginary line that marks the intersection of a coal seam with the ground surface.

CROW'S FOOT: A hitch used to join two or more cables, or to connect cables to a bucket or other device.

CUT: The trench or pit made to expose a coal seam.

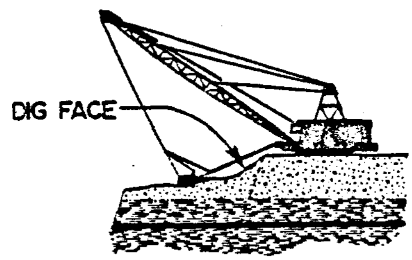
DEADHEADING: When referring to a dragline, the process of moving the dragline from the end of one cut to the beginning of the next. No productive work is done by the machine during deadheading.

DECKING: See DECK LOADING.

DECK LOADING: A special procedure for loading explosive into overburden blastholes, most often used when there are hard strata high in the overburden bank. It consists of placing explosive vertically adjacent to the hardest strata, with stemming in between.

DIGABILITY: A term expressing the ease or difficulty with which a material can be excavated. In this study, digability was expressed as easy, average, hard, or very hard.

DIG FACE: The inclined plane in front of the dragline, below the bench, at which digging stops. The angle of the dig face can be controlled to some extent by the dragline operator.

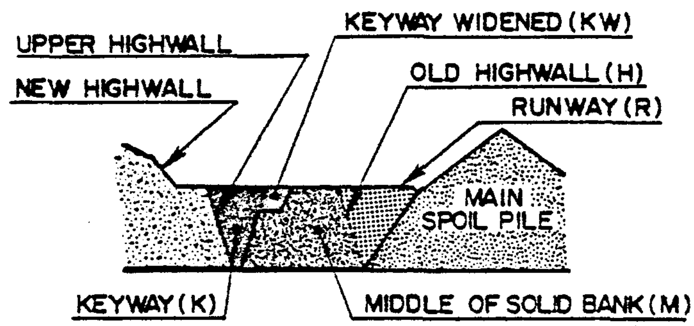


Dragline Dig Face

DIG DEPTH: The distance vertically below the dragline bench that the teeth of the dragline bucket penetrate to begin the dig.

DIG SECTION: A term defined for this study to identify the portion of the overburden or interburden that was dug on a given cycle. The dig sections were:

- K: keyway
- KW: widened keyway
- M: middle of solid bank
- H: portion of solid bank near old highwall
- R: runway (extended bench)
- S: side bench
- I: interburden
- SR: spoil rehandle dug from side-dipping position



Dragline Dig Sections

DIRT-BOUND: See SPOIL-BOUND.

DIRT ROOM: In dragline stripping, this refers to space to stack spoil by sidecasting. In very deep overburden, the operator may run out of places to stack spoil, a phenomenon termed "being out of dirt room" or "being spoil-bound".

DOUBLE BLOCKING: For draglines, this means hoisting the bucket to its maximum possible height for dumping. In such cases, the dump and point sheaves nearly touch.

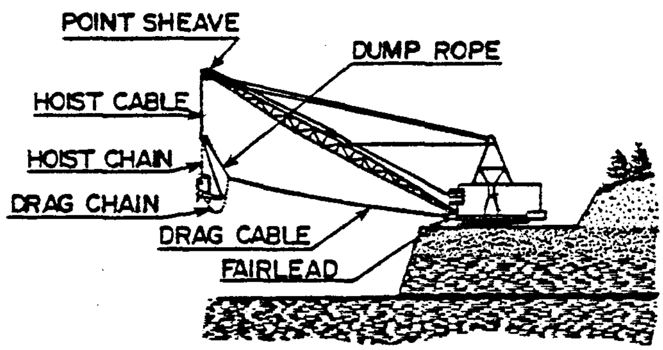
DRAG TIME: In this study, the elapsed time between initial penetration of the dragline bucket for digging and the moment at which the bucket is hoisted from the bank to begin the dump swing.

DRAG TIME AFTER FILL: The elapsed time between complete filling of the bucket and hoisting of the bucket from the bank.

DUMP HEIGHT: The vertical distance between the top of the dragline bench and the bucket teeth when the bucket has been tipped to dump.

DUMP RADIUS: The horizontal distance between the centerline of rotation of the dragline and the centerline of the point sheave.

DUMP ROPE: The wire rope connecting the dragline bucket to the hoist and drag cables. When the drag cable is taut, the dump rope holds the dump bucket upright, preventing it from dumping.



Some Dragline Components

EFFECTIVE SPOIL RADIUS (ESR): The horizontal distance from the outer edge of the dragline bench to the peak of the spoil pile created by swinging 90 degrees to dump.

EXTENDED BENCH METHOD: A method commonly used in dragline stripping of deep overburden, in which spoil is used to extend the dragline bench into the open cut, thereby increasing the effective spoil radius. Also called "building out".

FAIRLEAD: The point on the front of a dragline house at which the drag cable exists.

FERTILIZER: See ANFO.

FENDER: A narrow strip of coal left in place at the toe of spoil to prevent undercutting of the spoil toe or loading of dirty coal.

FILL: See SPOIL.

FINDING THE EDGE: A term used by dragline operators to describe the process of widening the pit on the spoil side to locate the edge of the coal seam being uncovered. A common practice.

F-VALUE: A statistical measure used to determine the significance of (in this study) differences among averages.

GRADING: Using dozers (usually) to shape spoil material and reestablish approximate original land contours.

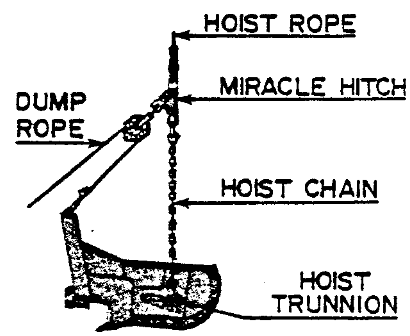
HARD DIGGING: Digging in which large drag forces are required to excavate material, resulting in slow drag speeds, skidding of the bucket across the top of the stratum, or stalling of the bucket.

HAUL ROAD: The road used by coal trucks and connecting the pit with public roads or coal loading facilities.

HIGH-LIFT: A front end loader.

HILLTOP REMOVAL: Removal of an entire hilltop, cut-by-cut, to expose a coal seam. There is no final highwall in hilltop removal.

HITCH PLATE: (Marketed under patents as the "Miracle Hitch".) A plate connecting the dragline hoist rope, dump rope, and hoist chain. Its purpose is to prevent the dragline bucket from tipping downward at the front when it is hoisted from the bank.



Dragline Bucket Connections

HOIST-LIMITED: A term referring to draglines with relatively slow hoist speeds, such that dump times are generally determined by dump heights rather than swing angles.

HORSESHOE METHOD: A common method of two-seam dragline stripping. The upper seam is uncovered conventionally. The lower seam is uncovered by the dragline positioned on a high bench in the spoil pile and using a procedure known as "side-dipping".

IN THE DIRT: Digging.

INCLINE: That portion of the coal haul road near the pit entrance.

INTERBURDEN: The non-coal strata separating two coal seams. If the interburden is less than five feet thick, it is termed a "parting" in this report, although most strip miners use the term parting for interburden of any thickness.

INTERLOCK: A device on Manitowoc draglines whereby the hoist and drag drums are interlocked, eliminating the need to hold the drag brake during the dump swing or the hoist brake during the return swing.

KEEPING THE CABLE OUT OF THE ROLL: The process of altering dragline position by moving up toward the dig face to keep the drag cable from dragging in the bucket roll -- described by some operators as one of the most important objectives in dragline operation.

KEYWAY: A relatively narrow trench excavated as the first operation on every dragline block to establish the new highwall.

LAGGING THE SPOIL: Swinging less than 90 degrees to dump spoil. Usually occurs on early moves in each cut.

LAYER LOADING: Digging so that the dragline bucket moves parallel to the overburden bedding planes. An efficient procedure, where possible, especially in shale.

LEADING THE SPOIL: Swinging more than 90 degrees to dump spoil ahead of, rather than adjacent to, the current move. May be used to build buckwall or extended bench, or because there is insufficient dirt room at a 90 degree swing.

LEAD SPOIL: Spoil that is dumped ahead of, rather than adjacent to, the current move.

LHD: A load-haul-dump machine, used without trucks to excavate, haul, and place material. Although not specifically designed for this mode of operation, front end loaders are sometimes used this way.

LIFT: A vertical section of overburden that is removed separate from other sections. For example, removal of overburden by a dozer and a dragline in tandem is a two-lift operation consisting of the dozer lift and the dragline lift.

LIP: See BUCKET LIP.

LOADING TIGHT: Loading of all coal exposed by the dragline, right up to the edge of the dig. Also known as "hogging the coal", this is a practice that annoys dragline operators because it increases the chances that they will accidentally hook into the coal and dig it.

LOOSE CUBIC YARDS (LCY): A measure of overburden volume after it has swelled due to blasting or excavation.

MINE LAYOUT: The pattern of stripping cuts and haul roads at a mine.

MUCKING: A process by which the dragline operator pulls back spoil, previously cast in the pit, to help level an extended bench.

MULTICOLLINEARITY: See COLLINEARITY.

MULTIPASS DIG: A dig on which the dragline operator lets the bucket out and drags it in several times without swinging. Common in hard digging where the bucket fill might be as low as 30 percent after the first dig pass on a given cycle.

NATURAL ANGLE OF REPOSE: The angle that spoil cast and allowed to "repose" naturally makes with the horizontal.

NEW HIGHWALL: The highwall that is established on a given block.

OLD HIGHWALL: The existing highwall adjacent to the open cut that is being filled.

OUTCROP: See CROPLINE.

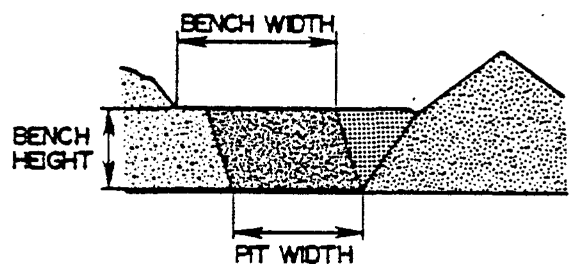
PAN: Scraper.

PARTING: See INTERBURDEN.

PASS: Movement of a stripping machine from one end of the cut to the other, excavating overburden in the process. The horseshoe method, for example, involves two dragline passes per cut.

PIT WIDTH: The width of the pit measured at its bottom, from the highwall toe to the spoil toe.

POINT SHEAVE: The sheave at the tip or point of the dragline boom. The hoist cable runs over the point sheave.



Some Pit Geometry

POOR SHOT: An overburden or interburden blast that does not adequately fragment the material, resulting in large fragments (especially in sandstone or limestone) or strata that are not fragmented at all.

PRODUCTION RATE: For stripping machines, the rate of overburden removal, usually expressed in bank cubic yards per month.

PRODUCTIVITY: For stripping machines, the bank cubic yards of overburden excavated per operating hour.

PULLING KEY: Digging the keyway.

R^2 (R-SQUARED): A statistical term used in regression analysis to measure the amount of variability in parameter values that is explained by the regression.

RANGE DIAGRAM: A scaled cross-sectional drawing of a dragline pit, used to depict the dragline dumping radius and spoil geometry, and, therefrom, to set pit widths and estimate spoil rehandle volumes.

REGRESSION ANALYSIS: Basically a statistical curve-fitting technique.

REHANDLE: Overburden or spoil material that is handled more than once.

RETURN SWING: The process of swinging a dragline boom from the dump position back into a digging position.

RIDER: A coal seam, usually relatively thin, that is associated with and "rides" above a thicker coal seam. Riders are not always mined; they are sometimes treated as spoil.

RIDER SEAM: See RIDER.

RIPPING: A process in which a large tooth-like device on the back of a dozer is used to penetrate and tear or "rip" consolidated materials.

ROAD: See EXTENDED BENCH.

ROLL: See BUCKET ROLL.

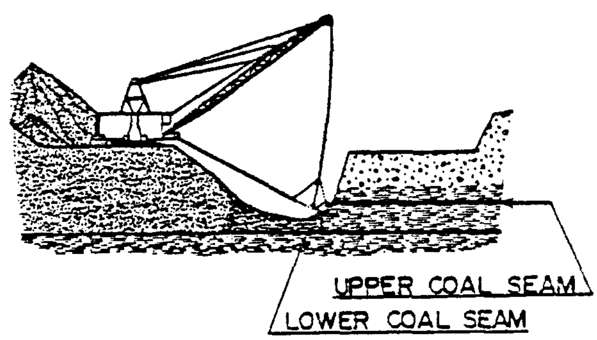
RUNWAY: See EXTENDED BENCH.

SCALING: Smoothing the new highwall, usually by pulling the dragline bucket along the highwall to knock off jagged rocks.

SCRATCHING IT DOWN: In dragline digging high above the bench, the process of pulling overburden down to form a large bucket roll on the bench, thereby forming a "backstop" to help fill the bucket on subsequent above-bench digs.

SET: The block of overburden excavated by a dragline from a single position.

SIDE-DIPPING: A dragline procedure commonly used to remove interburden in two-seam stripping. In side-dipping, the dragline is positioned on a high bench in spoil, facing the highwall, and the interburden is "chopped out".



Dragline Side-Dipping

SIDE PLATES: The plates on the sides of a dragline bucket to which the drag chains are attached. Also called "pull plates".

SLATE: A colloquialism for very hard shale, usually lying immediately above a coal seam.

SLOPING THE SPOIL: Digging of spoil (rehandle) material so that the spoil stands at an angle greater than the natural angle of repose.

STEEPENING THE SPOIL: See SLOPING THE SPOIL.

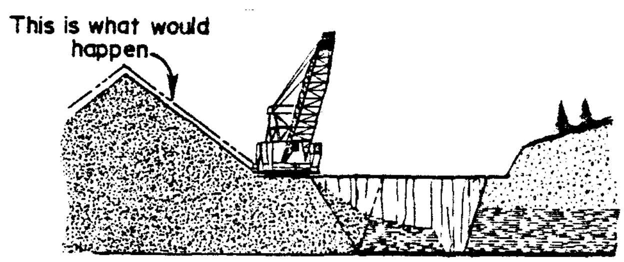
SLOUGHING: The gradual slippage of surface materials on a spoil pile.

SOLID BENCH: A machine-supporting bench constructed on material that has not yet been excavated.

SPACING: The spacing of overburden blastholes as measured in a direction parallel to the highwall.

SPOIL: Waste material -- overburden, interburden, or rider coal -- that has been excavated and moved to expose a coal seam or seams.

SPOIL-BOUND: A situation in which there is no more room for side-casting of spoil. In this situation, any attempt to side cast spoil would result in the spoil toe riding up the dragline.



A Spoil-Bound Dragline

SPOIL SWELL: The increase in material volume due to blasting or excavation.

SPREADER BAR: A bar used to separate the hoist chains that are attached to either side of a dragline bucket.

STEMMING: Material used to fill part of a blast hole in order to control the energy of the blast; usually fine rock created in the drilling of the hole.

STEP: The unit of movement for a walking dragline, usually about six feet long for a small dragline.

STRIPPING RATIO: The ratio of overburden removed to coal recovered, expressed as cubic yards of overburden per ton of coal, or feet of overburden per foot of coal. There are many different ratios for a given mine. The "virgin" ratio is based on bank overburden yardage, and therefore excludes rehandle. The "overall" ratio includes both bank and rehandle yardage. The denominator of the ratio may be expressed either as coal loaded or coal sold, the latter excluding washing losses.

SWING ANGLE: The angle between dragline boom centerlines in the digging and dumping positions.

SWING-LIMITED: A term referring to draglines with relatively fast hoist speeds, such that dump times are generally determined by swing angles rather than dump heights.

SWING TIME: For purposes of this study, for a given dragline cycle, this is the sum of the return swing, bucket positioning, and dump times.

TAILROOM: The horizontal distance between the centerline of a dragline on a bench in the keyway position and the upper highwall. The tailroom is needed so that the counterweight on the back of the dragline house does not hit the upper highwall during the swing to cast keyway spoil.

THREE-POINT HITCH: See HITCH PLATE.

TIGHT: 1. A stratum that is hard to dig.

2. An operating situation in which there is little dirt room.

TOE: The bottom corner of a highwall or spoil pile.

TOPSOIL: Unconsolidated surface material capable of supporting plant growth.

t-VALUE: A statistical measure used to determine the significance of differences between averages.

UNCONSOLIDATED: Non-rock overburden strata such as clay.

UTILIZATION: Referring to a machine such as a dragline or dozer, utilization is the proportion of available operating hours that the machine is used for productive work.

$$\text{Utilization} = \frac{\text{Available operating hours - actual operating hours}}{\text{Available operating hours}}$$

UPPER HIGHWALL: The highwall above the dragline bench.

WALKING: Movement of a walking dragline from one position to another.

WIDENING THE KEYWAY: A dragline digging procedure in which the keyway is widened, usually only at the top.