

**Information Circular 8580**

# **Materials Handling Research: The Bucket-Wheel Excavator**

**By G. C. Price, Health and Safety Technical Support Center,  
Pittsburgh, Pa.**

**C. B. Manula and Rajaraman Venkataramani, Pennsylvania  
State University, University Park, Pa.**



**UNITED STATES DEPARTMENT OF THE INTERIOR  
Rogers C. B. Morton, Secretary**

**BUREAU OF MINES  
Elbert F. Osborn, Director**

This publication has been cataloged as follows:

Price, George C

Materials handling research: the bucket-wheel excavator, by  
G. C. Price, C. B. Manula, and Rajaraman Venkataramani.  
[Washington] U.S. Dept. of the Interior, Bureau of Mines [1973]

79 p. illus., tables. (U.S. Bureau of Mines. Information circular  
8580)

Includes bibliography.

1. Excavating machinery. 2. Materials handling research. I. Manula,  
Charles B., jr. auth. II. Venkataramani, Rajaraman, jr. auth. III.  
Title: Bucket-wheel excavator. (Series)

TN23.U71 no. 8580 622.06173

U.S. Dept. of the Int. Library

## CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	1
Acknowledgments.....	3
German and American excavators.....	3
Development and use of wheel excavators.....	6
American manufacturers of bucket-wheel excavators.....	9
Comparison with shovels or draglines.....	10
Design features of bucket-wheel excavators.....	11
Material classification.....	11
Bucket-wheel excavator output considerations.....	15
Power calculations of the wheel drive.....	16
Slewing motor considerations.....	18
Bucket-wheel design.....	19
Other considerations.....	19
Mining methods.....	20
Terracing cut.....	21
Lateral block cut.....	22
Drop cut.....	22
Deep cutting.....	22
Operations research.....	24
Sequence of bucket-wheel excavator operations.....	24
Simulation.....	25
Simulator.....	25
Power calculations.....	28
Required data.....	28
Computer program.....	29
Testing the model.....	30
Mining plan.....	30
Application selection.....	30
Data collection.....	31
Results.....	32
Conclusions.....	33
Bibliography.....	34
Appendix A.--Computer program.....	43
Appendix B.--Computer program input controls.....	65
Appendix C.--Data input.....	70
Appendix D.--Data output.....	72
Appendix E.--Glossary.....	78

## ILLUSTRATIONS

1. German-type bucket-wheel excavator.....	3
2. American Kolbe-type bucket-wheel excavator.....	4
3. Rail-mounted, bucket-wheel stacker/reclaimer, fully automated.....	5
4. Kolbe-type wheel excavators.....	7
5. Bucket wheel, showing chain-mat backing in buckets and rollers for transfer of material from wheel to belt.....	8
6. Terracing cut method with crowd.....	20

## ILLUSTRATIONS--Continued

	<u>Page</u>
7. Terracing cut method without crowd.....	21
8. Lateral block cut method.....	22
9. Drop cut method.....	23
10. Deep cut by terracing cut method.....	23
11. System flow diagram.....	25
12. Mining plan with computer terms.....	26
13. Plan view of the slice taken by the bucket wheel.....	27
14. Complete program flow diagram.....	29
15. Plat showing classification and thickness of strata.....	31

## TABLES

1. Bucket-wheel excavators in American coalfields.....	2
2. Availability factors.....	10
3. Comparison of different types of excavators.....	11
4. Specific cutting forces of virgin material for bucket-wheel excavator excavation.....	14
5. Specific cutting forces of materials suitable for bucket-wheel excavator loading operations.....	14
6. Material characteristics.....	32
7. Mining dimensions.....	32
8. Bucket-wheel excavator specifications.....	32
9. Model results.....	33

# MATERIALS HANDLING RESEARCH: THE BUCKET-WHEEL EXCAVATOR

by

G. C. Price,<sup>1</sup> C. B. Manula,<sup>2</sup> and Rajaraman Venkataramani<sup>3</sup>

---

---

## ABSTRACT

This study traces the development of the bucket-wheel excavator, points out the differences in the German- and American-type wheels, and gives the major design criteria and the advantages and disadvantages of bucket-wheel operations. A computer program, written in FORTRAN IV for use with an IBM 360 computer, simulates the operation of the digging components of a bucket-wheel excavator. By supplying certain mining dimensions, soil characteristics, and machine design specifications, this program will print out a time study of the various components of an operation, power calculations for the operation, and production data. This program, when combined with a truck, belt, or rail program, should be helpful in planning a complete mining system in material suitable for a bucket-wheel excavator operation.

## INTRODUCTION

Materials handling is an integral part of the mining system. The cost of this function ranges from 30 to 70 percent of the selling price of mined materials.

As the remaining domestic minerals and fuels are of a poorer quality and must be mined under increasingly deeper cover, higher volumes of waste and barren overburden must be mined and handled. The Bureau's materials handling research program has a primary goal--the development of safer and more efficient materials handling systems so that the Nation's mineral industry can meet the current and projected mineral and fuel demands.

The bucket wheel excavator (BWE) has received little attention in the United States mainly because domestic equipment manufacturers have opted to increase unit capacity by increasing the size of the more conventional shovels and dragline excavators. Shovels for stripping cover over coalbeds with dipper capacities of 200 cubic yards are currently in operation.

---

<sup>1</sup>Mining engineer.

<sup>2</sup>Assistant professor of mining, The Pennsylvania State University, University Park, Pa.

<sup>3</sup>Graduate assistant, The Pennsylvania State University, University Park, Pa.

High productivity, versatility, economy, continuous operation, and adaptability to most types of haulage systems make BWE's potentially attractive as prime excavators of low-grade ores, for stripping overburden, and for other earth moving operations. Because of its continuous operation and simplicity, the operation of the BWE can be mathematically modeled and simulated by a computer, thus providing estimates of its productivity for a given set of operating conditions.

This report traces the development of the BWE and points up its advantages, disadvantages, and limitations as a primary excavator of materials. A complete computer program has been developed which simulates the operation of the BWE and provides estimates of power consumption and productivity given the mining dimensions, soil characteristics, and machine specifications.

Wheel excavators have been the most commonly used machines in German lignite fields for over 30 years. More recently, their use has spread to the United States for coal strip-mining operations and for other large earthmoving operations such as the San Luis and Oroville Dam projects in California. In the American coalfields, they usually are used in conjunction with a large stripping shovel to increase the depth of overburden which may be economically removed; the wheel excavator mining the relatively soft upper portion while the shovel mines the harder material. A lighter version of the bucket-wheel also is becoming popular for stockpiling and reclaiming operations because of its high loading capacities, ease of automation, and its adaptability to various materials handling systems. Table 1 lists bucket wheel excavators used in American coalfields.

TABLE 1. - Bucket-wheel excavators in American coalfields

Type	Mine	Location	Company
Kolbe W-1.....	Little Sister.....	Saint David, Ill.	Truax-Traer Coal.
Kolbe W-2.....	Buckheart.....	Canton, Ill.....	United Electric Coal.
Kolbe W-3 <sup>1</sup> .....	Banner.....	Banner, Ill.....	Do.
Kolbe W-4.....	Cuba.....	Cuba, Ill.....	Do.
Kolbe W-5.....	Fidelity.....	DuQuoin, Ill.....	Do.
Bucyrus-Erie 1054WX...	Middle Grove.....	Farmington, Ill..	Peabody Coal.
Bucyrus-Erie 954WX...	Red Ember.....	Fiatt, Ill.....	Truax-Traer Coal.
Krupp 1500.....	Northern Illinois..	Wilmington, Ill..	Peabody Coal.
Lauchhammer <sup>2</sup> .....	Glenharold.....	Stanton, N. Dak..	Truax-Traer Coal.

<sup>1</sup>Not in operation.

<sup>2</sup>Operated in lignite fields; all others in bituminous coalfields.

Wheel excavators are being used in Australia, Guayana, Canada, Congo, Czechoslovakia, Great Britain, India, Indonesia, Japan, Morocco, Zambia, U.S.S.R., South Africa, the United States, and Yugoslavia for loading chalk, lignite, clay, sandstone, phosphate, broken iron ore, coal, clay, shale, oil sands, and loose, semiloose, and rock overburden.

### ACKNOWLEDGMENTS

The cooperation of the officials of Peabody Coal Co., Truax-Traer Coal Co., United Electric Coal Co., Dravo Corp., and McGraw-Hill Publishing Co. is hereby gratefully acknowledged. The computer model of the bucket-wheel excavator was developed by the Department of Mining of the Pennsylvania State University through a research grant from the Bureau of Mines.

### GERMAN AND AMERICAN EXCAVATORS

Bucket-wheel excavators for strip mining may be divided into two main types--German and American-Kolbe.<sup>4</sup> The wheel, or digging component, of both types consists of a relatively large diameter wheel with buckets arranged around its circumference and with an arrangement to transfer the mined material from these buckets to a conveyor system.

The German type was developed for use in their lignite fields. It usually is crawler mounted, with mountings arranged to give three-point support,

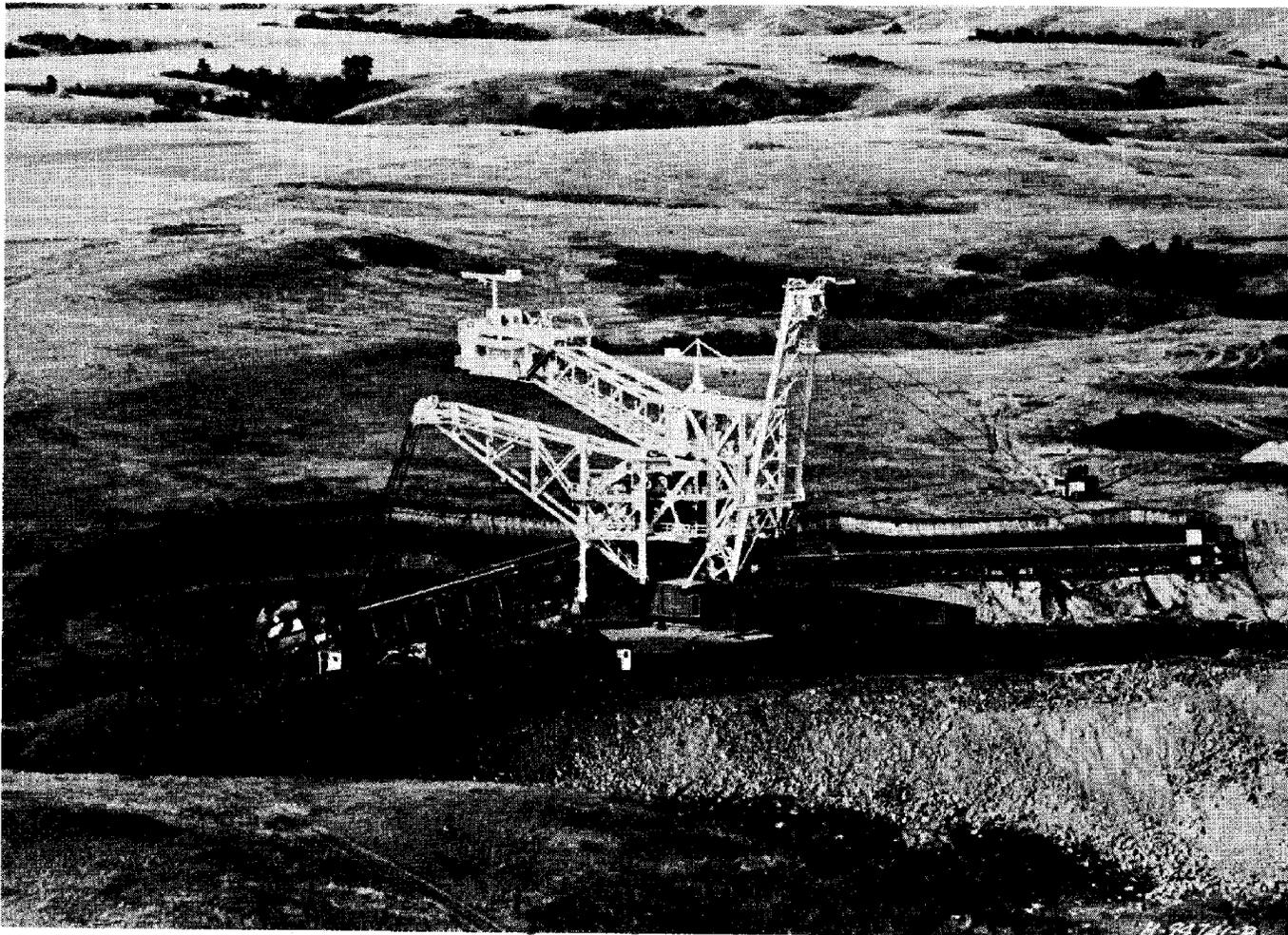


FIGURE 1. - German-Type Bucket-Wheel Excavator.

<sup>4</sup>Reference to specific models of equipment is made for identification only and does not imply endorsement by the Bureau of Mines.

and has a relatively low ground-bearing pressure (approximately 15 pounds per square inch). The ladder (loading) and stacker (discharge) booms swing independently of each other and therefore require counterbalances. Each boom is equipped with a conveyor belt and the transfer of material from the ladder boom to the stacker boom is accomplished through a somewhat complicated chute arrangement. Some vertical adjustment is possible in the stacker boom; but this is not as critical as in the American type, since the material is ordinarily transferred to an exterior haulage system such as a bridge or stacker conveyor, trucks, or rail cars. These machines may excavate overburden, lignite, or both overburden and lignite (fig. 1).

Early model German-type bucket-wheel excavators were equipped with both independent swing of the ladder and stacker booms and with "crowd," a feature whereby the ladder assembly is mounted on rollers and a track so that it may be advanced or retracted. As the size of excavators increased, it became uneconomical to retain both independent swing and crowd, so most late model German-type excavators do not have the crowd feature.

Most American-Kolbe-type machines are crawler-mounted with four-point support and have hydraulic cylinders for leveling. Ground-bearing pressures are high (approximately 45 pounds per square inch), as the machines were

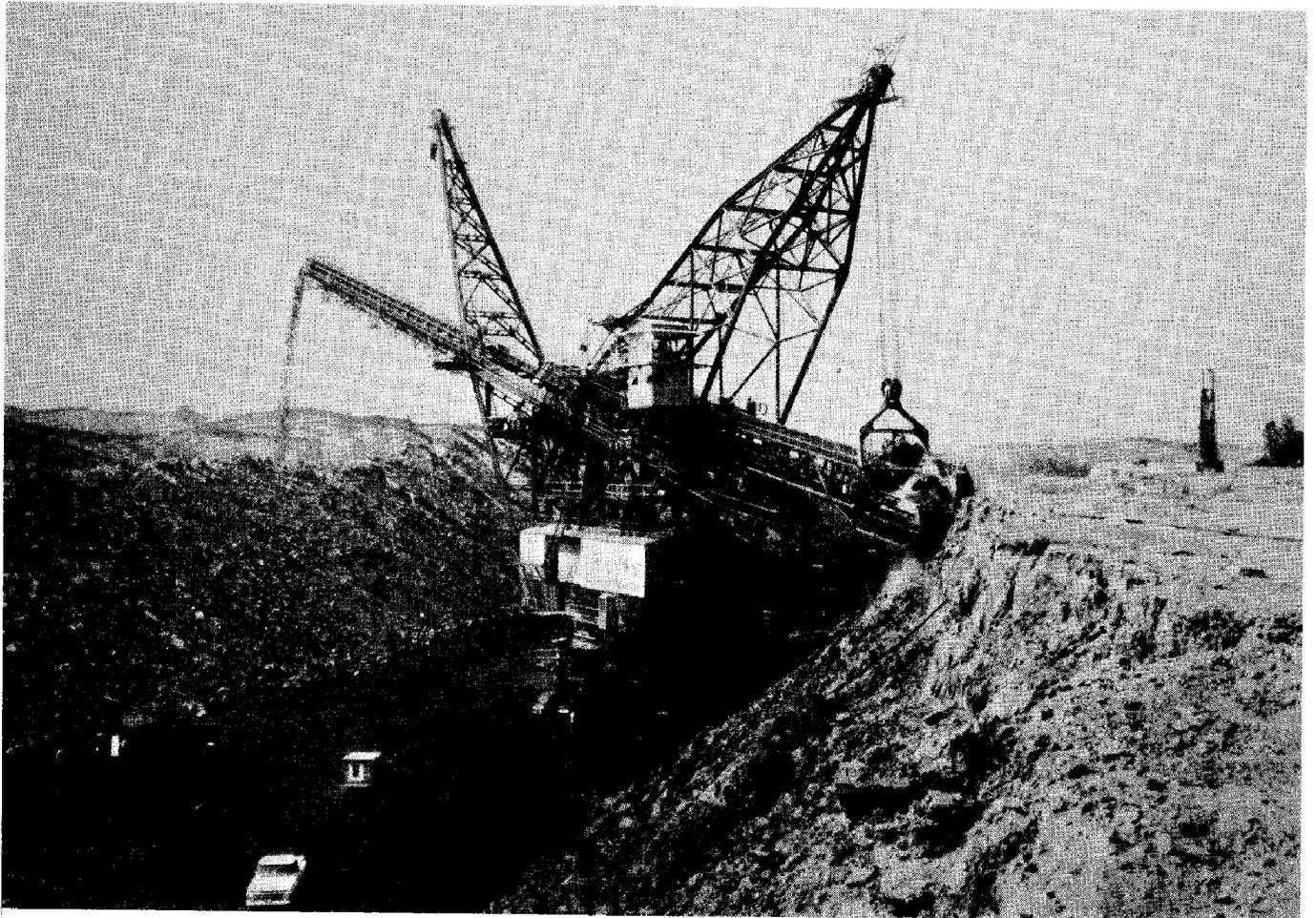


FIGURE 2. - American Kolbe-Type Bucket-Wheel Excavator.

designed to operate from the coal surface. The ladder and stacker booms do not have independent swing and are not as heavily counterweighted as the German-type machines; since their horizontal relationship does not change, each tends to counterbalance the other. Transfer of materials from the loading to the stacker boom conveyor is simple, since the direction of material flow does not change. These machines usually excavate overburden only, and may be used in conjunction with a stripping shovel. Overburden is usually spoiled but may be transferred to an external haulage system (fig. 2).

The Kolbe-type bucket-wheel excavators have crowd. Due to mechanical design restrictions, these excavators do not have independent swing of the stacker boom (fig. 2). Several other types of bucket-wheel excavators have been developed in the United States for special applications. These may be either crawler, rubber tire, or rail mounted and have a wide range of capacities.

Bucket-wheel reclaimers, which are of lighter construction than bucket-wheel excavators, are becoming increasingly popular for reclaiming and stacking/reclaiming operations. Higher capacity, higher availability, simplicity of operation, low degree of operator skill required, and the possibility of complete automation combine to make these machines more attractive than intermittent operating machines such as clamshells and draglines for reclaiming. The ability to use the reclaimer as a stacker by reversing the belts is a further advantage since it eliminates a separate stacker (fig. 3).



FIGURE 3. - Rail-Mounted, Bucket-Wheel Stacker/Reclaimer, Fully Automated.

## DEVELOPMENT AND USE OF WHEEL EXCAVATORS

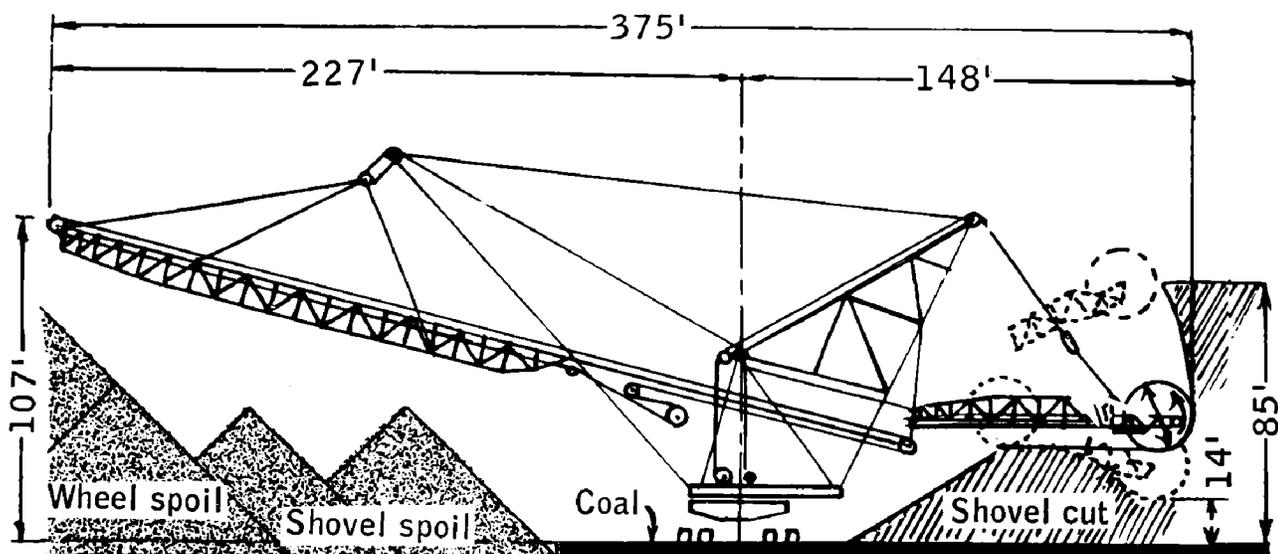
The bucket-wheel excavator was patented in 1913. Its first practical application was in an open pit lignite mine in Germany in 1920; however, because of technical problems rather than wheel design, this operation was not a success. By 1936 several bucket-wheel excavators, capable of handling 650 cubic yards of material per hour, were in operation in the German lignite fields.

During the war years, 1942 through 1945, the demand for coal in America increased substantially. Large reserves of coal were available in Illinois, provided mining machines could be found that would remove the overburden more efficiently than the draglines and/or shovels in use at the time. Mr. Frank Kolbe pioneered the development of the bucket-wheel excavator as a solution to this problem.

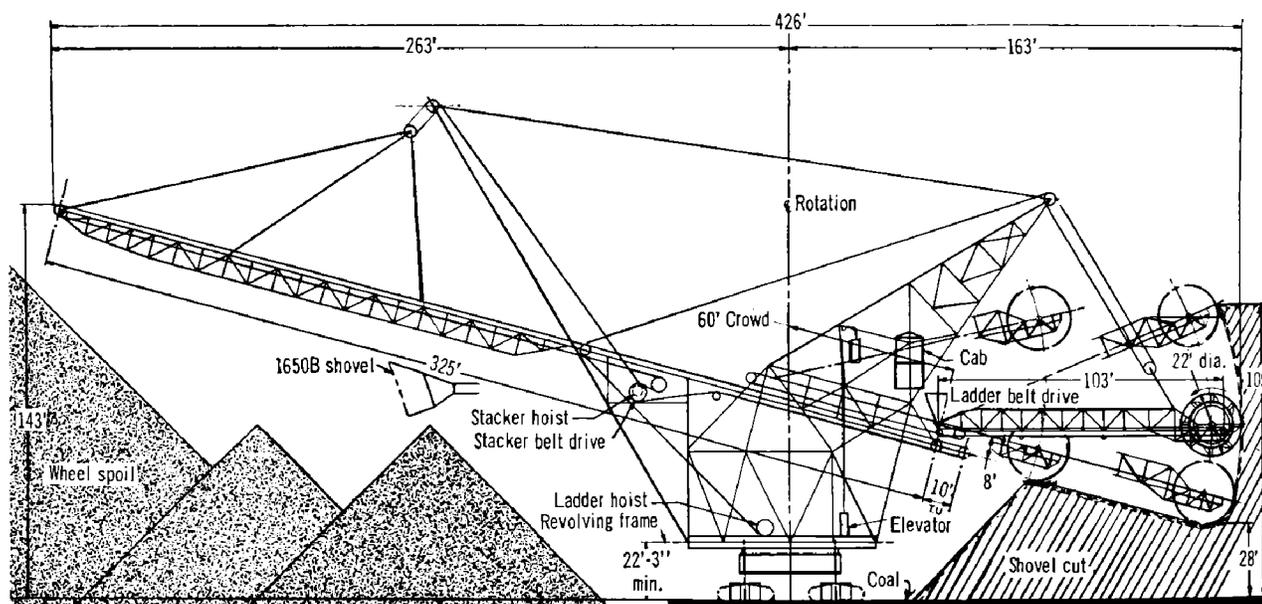
The board of directors of the United Electric Coal Co. approved a plan for fabricating an experimental wheel excavator in April 1943. This machine, Model A-307, was built by the Bucyrus-Erie Co. on a Marion 360 dragline frame. It had a 20-foot-diameter wheel with eight cast-steel buckets. As this was an experimental model, it had no stacker boom but discharged the material at the highwall. This machine was field tested at the Company's Cuba mine early in 1944; it performed so well that an order was placed with the Bucyrus-Erie Co. for two production machines. The first of these machines, Model A-309 (W-1), was placed in service at the Cuba mine during the summer of 1944. It was later sold to the Truax-Traer Coal Co. and is presently in service at their Little Sister mine. The second machine, Model A-310 (W-2), was placed in service at the Buckheart mine in August 1948. Delivery of the second machine was delayed by operational problems encountered with the earlier model, which required extensive modifications. In 1951 the company decided to order a third machine; this machine (W-3) was placed in service at the Fidelity mine near DeQuoin, Ill., in August 1955. It differed from earlier models in that the wheel rotated in the opposite direction, digging downward instead of upward into the overburden, and throwing the material back upon the ladder conveyor. This arrangement did not perform as well as expected, and in 1961 the machine was taken out of service and converted to a standard bucket wheel. It was placed back in service in January 1963 at the Banner mine. In 1957 a fourth machine (W-4) was ordered to replace the W-1 and was placed in service at the Cuba mine in January 1959.

The latest Kolbe-type wheel excavator (W-5) went into service August 1967 at the Fidelity mine. This excavator has an overall length of 426 feet, wheel diameter of 22 feet, and a practical capacity of 2,000 to 2,400 cubic yards per hour. The Kolbe-type wheels were designed to operate in conjunction with a stripping shovel; with the wheel excavator removing the upper layer of overburden and spoiling it on top of the harder material mined by the shovel (fig. 4).

Each machine underwent many modifications; as operational problems were encountered, changes were made to minimize them. The cup-type buckets on the original machine would clog whenever the moisture and clay content of the



Wheel Excavator No. 2



Wheel Excavator No. 5

FIGURE 4. - Kolbe-Type Wheel Excavators.

overburden was high. A bucket chain mat, invented in 1952 by Frank Kolbe, practically eliminated problems of clogging (fig. 5). Conveyor speeds were increased from about 400 to nearly 1,000 feet per minute. Impact rollers were redesigned to minimize belt damage from large boulders. A floating drive minimized the effect of shock on the wheel when boulders were encountered. During this period, the practical machine capacity rose from 1,000 to nearly 4,000 cubic yards per hour.

In 1954 the Truax-Traer Coal Co. placed a Bucyrus-Erie Model 954WX bucket-wheel excavator in service at their Fiatt mine, Fiatt, Ill. This machine operated in conjunction with a 35-cubic-yard shovel removing overburden.

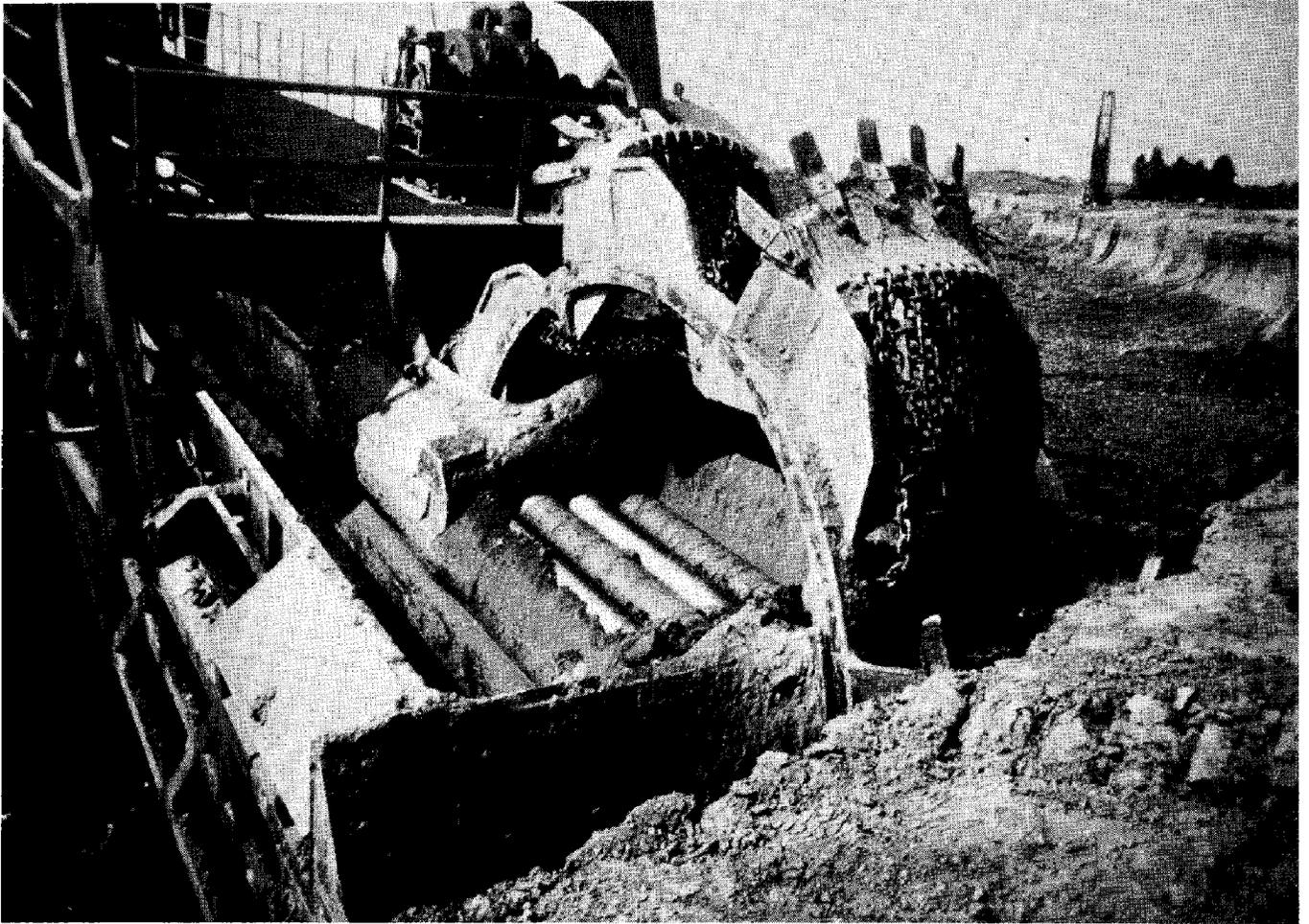


FIGURE 5. - Bucket Wheel, Showing Chain-Mat Backing in Buckets and Rollers for Transfer of Material From Wheel to Belt.

They also placed a Kolbe-type wheel excavator in service at their Little Sister mine, Saint David, Ill. This machine operated in conjunction with a 45-cubic-yard shovel removing overburden.

McDowell-Wellman Engineering Co., licensed by Demag-Lauchhammer, erected a wheel excavator for use at Truax-Traer's Glenharold lignite mine, Stanton, N. Dak., where they mined two lignite seams. The wheel excavator spoiled the overburden above the upper lignite seam and then mined this upper seam. The lignite was deposited on the base seam on which the machine operated, and the excavator then spoiled the overburden between the upper and lower lignite seams. A 12-cubic-yard shovel then loaded the lignite from both seams into trucks for transfer to a powerplant.

This wheel excavator had a 29-1/2-foot-diameter wheel, a total length of 425 feet, and a practical capacity of 1,800 cubic yards per hour.

The Peabody Coal Co. placed a Bucyrus-Erie Model 1054WX excavator in service at their River King mine, Freeburg, Ill., in 1960. This machine had a 25-foot-diameter wheel with nine 1-1/8-cubic-yard buckets, a practical

capacity of 1,750 cubic yards per hour, and could mine from 38 to 100 feet above the top of the coal seam. It operated in conjunction with a 70-cubic-yard shovel. The wheel excavator was later moved to their Middle Grove mine near Farmington, Ill.

The Peabody Coal Co. also operates a Krupp 1500 bucket-wheel excavator at their Northern Illinois mine near Wilmington, Ill. This machine has a 37-1/2-foot-diameter wheel with nine 2-1/2-cubic-yard buckets, a capacity of over 3,000 cubic yards per hour, a 239-foot stacker boom, and a 152-3/4-foot ladder boom, and will mine from 18 feet below to 100 feet above the coal seam. It operated in conjunction with a 30-cubic-yard walking dragline, which removed about 12 feet of blasted hard shale immediately above the coal seam.

In 1963 the United States Borax and Chemical Co. placed a Mechanical Excavators, Inc., Model 500 wheel excavator in service at their Boron mine, Boron, Calif. This machine was much smaller than the ones used in removing overburden from coal seams. It had a 12-foot 10-inch-diameter wheel with six 1/6-cubic-yard buckets, a total overall length of 60 feet, and a rated capacity of 500 cubic yards per hour.

A Bucyrus-Erie Model 684WX excavator was used to load fill for the San Luis Dam project near Los Banos, Calif. This machine had a 31-foot-diameter wheel with 10 buckets, each with a 2-1/2-cubic-yard capacity, a total length of 130 feet, and a rated capacity of 3,500 to 3,800 cubic yards per hour.

A McDowell-Wellman/Lauchhammer excavator was used to handle gravel tailings from an old gold mining operation for fill at the Oroville Dam project on the Feather River in California. The machine had a 30-foot-diameter wheel with eight 1.8-cubic-yard buckets and a rated capacity of 3,500 to 4,200 cubic yards per hour.

The original Mechanical Excavators, Inc., Model 2000 excavator was placed in service at the Abiquiu Dam project on the Rio Chama River in New Mexico. This machine had a 20.3-foot-diameter wheel with six 1.5-cubic-yard-buckets and a rated capacity of 2,000 cubic yards per hour. Mechanical Excavators, Inc., and Barber-Greene Co. have tested bucket-wheel excavators in coal seams.

#### American Manufacturers of Bucket-Wheel Excavators

Bucyrus-Erie has built Kolbe-type excavators for use in coal stripping operations and a special machine used at the San Luis Dam project. Each of these machines was designed for one specific project.

McDowell-Wellman Engineering Co. is licensed by Demag-Lauchhammer, Dusseldorf, West Germany, to produce their line of excavators. They have erected German-type excavators for use on the Oroville Dam project and the lignite operation in North Dakota.

Mechanical Excavators, Inc., built their original large wheel excavator for use at Abiquiu Dam, and a smaller unit used at the Boron mine in California.

They offer crawler-mounted units with 300- to 3,000-cubic-yard-per-hour capacities and rubber tire units with 300- and 500-cubic-yard-per-hour capacities.

Dravo Corp. builds rail-mounted bucket wheels expressly for stacker/reclaimer operations.

### Comparison With Shovels or Draglines

Mani (76 -77)<sup>5</sup> provides some idea of the availability for certain excavation equipment as shown in table 2.

TABLE 2. - Availability factors (76 -77)

	Power shovels, draglines, motorized scrapers	Bucket chain excavators and scraper loaders	Bucket-wheel excavators	Ideal excavating machines
Basic work content: Excavation of soil (A).....percent..	25	32	45	70
Excess work content:				
Transporting and shifting of the machine (B).....percent..	50	33	10	5
Downtime (C).....do....	25	35	45	25
Availability factor in percent:				
$\frac{(A+B)}{(A+B+C)} \times 100$ .....	75	65	55	75

Gartner (58) has devised an index which measures the machine weight in comparison to the cutting height and the theoretical output. This index, which can be termed as "economy efficiency," is expressed as:

$$\frac{\text{service weight}}{\text{theoretical capacity} \times \text{height of bank (cutting height)}}$$

The lower the number, the more efficient the machine compares weightwise. Table 3 gives a comparison of values for various excavation equipment and, as can be seen, the value is the smallest for bucket wheels.

Advantages of bucket-wheel excavators:

1. Lower instantaneous power demands.
2. Lower power consumption (60 to 70 percent of shovel).
3. Less shock loading.
4. Less weight for output capacity.
5. Adaptable to a wide range of haulage systems.
6. Long stacker boom aids spoiling.
7. Continuous operation.
8. Able to do selective mining.
9. Simple to operate.

<sup>5</sup>Numbers in parentheses refer to items in the bibliography preceding the appendixes.

## Disadvantages of bucket-wheel excavators:

1. Does not work well in hard material that must be blasted, thereby limiting its effectiveness for stripping operations in American coalfields.
2. Does not work well in loose material containing large boulders.
3. Capital investment is high.

TABLE 3. - Comparison of different types of excavators (74)

Excavator type	Bucket capacity, m <sup>3</sup>	Maximum output, m <sup>3</sup> per hr	Cutting height, m	Delivery weight mechanical and electrical units, metric tons	Gaertner's index
	A	B	C	D	$[D/(B \times C)] \times 1,000$
Power shovels.....	1.5	155	10.1	42.6	27.2
	2.3	215	12.1	63.6	24.5
	13.8	1,030	28.3	655.0	22.4
	30.6	1,530	32.4	1,220.0	24.6
	46.0	3,300	27.5	2,050.0	22.6
Dragline excavators.....	7.64	298	58.0	460.0	26.6
	15.30	900	58.0	1,380.0	26.4
	23.00	840	58.0	1,120.0	23.0
Bucket-chain excavators.	0.4	575	32.5	460.0	24.3
	.65	780	26.0	570.0	28.3
	.8	1,070	40.0	890.0	20.9
	1.4	1,720	36.0	1,430.0	23.0
Bucket-wheel excavators.	.1	330	10.5	68.3	19.4
	.15	840	19.0	240.0	14.7
	.25	1,150	12.6	180.0	12.5
	.85	3,180	29.5	1,290.0	13.8
	1.35	4,200	30.5	1,560.0	12.1
	1.50	4,300	33.0	1,820.0	12.8
	4.00	8,500	55.0	4,530.0	9.7

## DESIGN FEATURES OF BUCKET-WHEEL EXCAVATORS

Much research and trial-and-error experience have gone into the design of the modern wheel excavator. Each one is more or less job tailored to fit a particular application. Before starting to design a bucket-wheel excavator for a particular job, one must have a thorough knowledge of the type of material to be mined, desired output, and the pit layout.

Material Classification

The bucket-wheel excavator is an ideal machine for working in soft to medium hard strata; it is gradually being developed for use in harder strata. Specifically, the digging resistance of the soil is the most sensitive parameter affecting the bucket-wheel excavator operation. For excavation purposes, material can be classified as follows:

1. Material that can be excavated by a spade; for example, unconsolidated strata like sand, gravel, and silt.

2. Material that can be loosened by a pickax before excavation; for example, partly consolidated stratalike clay beds.

3. Material that can be loosened by blasting before excavation; for example, hard shales, sandstone, and so forth.

The above classification is broad and general and cannot be of specific assistance to the bucket-wheel excavator designer. Classification of material according to their diggability is vital; but, unfortunately, there is not any clear-cut, standard method for determining this factor. Some common methods of expressing the digging resistance are given:

1. Kilograms per centimeter, where the cutting resistance is calculated on the basis of load per unit length of the cutter in contact with the material.

2. Kilograms per square centimeter, where the load is related to the area of the cut slice.

3. Kilograms per cubic centimeter, where the digging resistance is calculated as a function of the excavated volume per bucket.

The theories that are being advanced and the discussions taking place on what is considered to be the most suitable measurement vary widely. So far, most design calculations have been based on the length of cutting edge or cross-sectional area of the slice cut (that is, methods 1 and 2), but it must be recognized that the volume of material excavated per bucket has no small influence on the digging resistance. At the 5th International Earthmoving Conference held in Prague in October 1963, Professor N. G. Dombrowsky (30) gave the following specific digging forces for various types of ground:

<u>Type of ground</u>	<u>Digging force,</u> <u>kg/cm<sup>2</sup></u>
Light.....	1.8 to 2.5
Medium.....	3.0 to 3.5
Heavy.....	7.0 to 18

While it is not uncommon in non-German technical literature to consider the resistance to digging in relation to the cross section of the slice, manufacturers of wheel excavators in Germany, because of the large number of test results available on various materials, generally are using the effective cutting edge length for determining the cutting forces. Based on 150 large-scale tests of bucket-wheel excavation operations, Himmel (61) has calculated the specific cutting forces required to dig the types of ground encountered in open-cut mines. On an average, these were found to be:

1. About 20 kg/cm for light ground, such as sand and gravel.

2. About 30 to 40 kg/cm for medium heavy ground, such as sandy loam, pure loam, loess, lean clay, and so forth.

3. About 50 to 60 kg/cm for heavy ground, such as heavy compact and plastic clays.

It is not possible to draw any conclusions on the above values because the cutting power depends on the type of material, cross-sectional area and shape of the slice cut, configuration and sharpness of cutting edge, shape of the teeth, and cutting speed. Hard types of ground require a higher specific cutting force, high cutting speeds, and additional cutting blades between the buckets. Reducing the output and rate of swing decreases the slice cross section and increases the specific cutting force for a given wheel drive rating. This is shown by the following formula (112).

$$N_G = \frac{K}{\eta \times C} \sqrt{Q_a \times S \times R}$$

where:

$N_G$  = power required for cutting in kilowatt,

$Q_a$  = actual digging capacity in bank cubic meters per hour,

$S$  = number of bucket discharges per minute,

$R$  = radius of the cutting wheel in meters,

$C$  = constant depending on the bench height/wheel diameter ratio.

For the cutting height = 2/3 wheel diameter, its value is 171,

$\eta$  = efficiency of the motor drive, and

$K$  = specific cutting force in kilograms per centimeter.

Shown in tables 4 and 5 are reference values for specific cutting forces applied to the more important bulk materials and virgin soils. The tables must be viewed with reservation as to the nonhomogeneity of the different material from one geographical location to the other.

Devising methods for measuring the cutting resistance is difficult because the results from such theoretical considerations vary with the size of the sample tested, angle of loading, rate of loading, and other such experimental procedures. Methods commonly employed for the determination of the cutting resistance are as follows:

1. Simulating equipment pulled through the material to be excavated for direct measurement of the force applied.
2. Laboratory tests with tooth and tooth impression measurements on the rock or soil samples.
3. Determination of the compactness by proctor needles.

In a method developed by LMG (Orenstein-Kappel and Lubecker Maschinenbau Aktiengesellschaft), a leading German manufacturer of bucket-wheel excavators,

the entry of an excavator tooth into the material is copied in the laboratory on a specimen (114). This gives some information with respect to the material split resistance. If numerous tests have been made with material on which the cutting effect of the bucket-wheel excavator has been studied and analyzed, a correlation can be drawn between the theoretical laboratory values and actual digging resistance. From observations so far, theoretical analysis can at best serve only as a guideline in the selection of the wheel, because of the vast complex of influences which exist in practice that cannot be considered theoretically. Practical tests on the site of employment will confirm the suitability of the machine selected for a particular job.

TABLE 4. - Specific cutting forces of virgin material for bucket-wheel excavator excavation (56)

Material type	Specific cutting forces, kg/cm	Material type	Specific cutting forces, kg/cm
Earth.....	10- 30	Sandstone (hard digging)....	160-280
Loess.....	20- 40	Gypsum.....	50-130
Sand (fine, coarse, wet, or dry).....	10- 40	Lime.....	30-120
Clayey sand.....	10- 50	Phosphate.....	80-200
Gravel, fine.....	20- 50	Marl.....	60-140
Gravel, coarse.....	20- 80	Limestone.....	100-180
Sandy loam and wet loam....	20- 60	Weathered granite.....	50-100
Dry loam.....	20- 80	Alluvial, light consolidation	30- 60
Clay, wet.....	30- 65	Alluvial, heavy consolidation	70-150
Clay, dry.....	50-120	Alluvial, medium consolidation.....	50- 80
Clay, schistose.....	35-120	Hard coal, normal.....	50-100
Sandy clay.....	20- 65	Hard coal, frozen.....	100-160
Clayey slate.....	50-160	Lignite.....	20- 70
Slate.....	70-200	Brown iron ore.....	190-210
Sandstone (easy digging)...	70-160		

TABLE 5. - Specific cutting forces of materials suitable for bucket-wheel excavator loading operations (56)

Material type	Size, mm	Specific cutting force, kg/cm
Sand.....	-	10-20
Gravel, fine.....	0-100	10-25
Gravel, coarse.....	100-400	20-35
Earth.....	-	10-15
Phosphate.....	-	10-20
Bauxite.....	-	10-20
Iron-Mn-Cr.....	0-150	20-40
Ores.....	150-300	20-50
	300-450	20-80
Loose hard coal.....	-	10-30
Solidified hard coal.....	-	10-40
Lignite.....	-	10-25
Coke.....	-	10-30
Pellets (ore, cement).....	-	10-25
Limestone.....	-	10-30
Slag.....	-	10-25

Tests conducted on glacial till, sandstone, and Devonian shale, confirmed that earth containing a high percentage of boulders is unsuitable for wheels (13). The capacity of any excavator operating in earth material with boulders will be affected adversely in proportion to the frequency of boulder occurrence. Two possible reasons can be attributed

to this poor performance. Some boulders, like basalt and granite, are too hard for economical cutting. On the other hand, boulders and rocks composed of materials which the machine could cut in the solid state, become loosened during excavation and cannot be rehandled.

### Bucket-Wheel Excavator Output Considerations

The theoretical output of a bucket-wheel excavator is based on the bucket size and number of bucket discharges per minute. If

I = nominal bucket capacity in cubic meters,

Z = number of buckets in the wheel,

$V_1$  = peripheral cutting speed of the wheel in meters per second, and

D = diameter of the wheel in meters,

then

$$S_s = \frac{V_1}{\pi D} \quad \text{and} \quad Q_t = I \times S \times 3,600,$$

where

$S_s$  = number of bucket discharges per second, and

$Q_t$  = theoretical capacity of the excavator in cubic meters per hour.

As can be seen from the above equations, the number of bucket discharges is dependent on the peripheral speed. The peripheral speed of a bucket wheel is limited by the ability of the wheel to discharge its bucket content on the chute against the counteracting centrifugal force. In theory, the maximum peripheral speed must be such that the bucket discharge will just be insured. Mathematically,

$$M \times g = M \times V_1^2 / R,$$

where

M = mass of material in the bucket in metric tons,

R = radius of the wheel in meters, and

g = acceleration due to gravity in meters per second,

which yields the following expression:

$$V_1 = \sqrt{g \times R} = V_{max}.$$

Practical values of speed for dumping lie between  $0.4 V_{max}$  to  $0.6 V_{max}$  and, for reasons of wear of the bucket's cutting knives or teeth, do not exceed 5 meters per second. The peripheral speed selected also will depend

greatly on the nature of material to be excavated. In principle, however, a higher peripheral speed will be decided upon if hard material is to be cut, in which case, maximum output may not be attained. Based on a constant output, the doubling of the peripheral speed will halve the amount of material excavated by each bucket; thus, cutting performance will be reduced.

Yet another factor that affects the output of a bucket-wheel excavator is the bucket-filling capacity. Experience has shown that in hard ground, bucket filling is around 30 to 40 percent of the nominal bucket capacity. The relationship between digging resistance and the hourly capacity of the bucket-wheel excavator is

$$Q_1/Q_2 = K_2^2/K_1^2,$$

where

$Q_1$  = bucket-wheel excavator hourly capacity in material with specific cutting resistance  $K_1$ , and

$Q_2$  = bucket-wheel excavator hourly capacity in material with specific cutting resistance  $K_2$ .

Thus, the actual capacity of the bucket-wheel excavator in any soil is given by

$$Q_a = I \times B_f \times S_s \times 3,600,$$

where

$B_f$  = bucket-filling capacity in the material expressed as a fraction of the nominal bucket capacity,

$S_s$  = number of bucket discharges per second, and

$Q_a$  = actual capacity of the bucket-wheel excavator in cubic meters per hour.

In material with high cutting resistance, higher cutting speeds with lower bucket filling will result in a very small  $Q_a$ , as compared to  $Q_t$ . The ratio may be as small as 0.2. One can visualize that in hard material the excavating operation of the bucket-wheel excavator has changed to a milling operation.

#### Power Calculations of the Wheel Drive

The drive power requirement of a bucket wheel is composed of the following individual power ratings:

- |                               |  |
|-------------------------------|--|
| 1. Digging power in kilowatts | $N_G = \frac{K \times \Sigma L \times V_1}{102}$ |
| 2. Lifting power in kilowatts | $N_H = \frac{T_t \times R}{367}$                 |

$$\text{Total power required in kilowatts} = \frac{1}{\eta} (N_G + N_H)$$

where

- K = specific digging resistance in kilograms per centimeter,  
 $\Sigma L$  = total length of the cutters in the material in centimeters,  
 $T_t$  = the bucket-wheel excavator capacity in metric tons per hour,  
 $V_1$  = peripheral cutting speed in meters per second,  
 $\eta$  = efficiency of the motor drive, and  
R = radius of the bucket wheel in meters.

In most bucket-wheel excavator calculations, the ratio of the bench height to the wheel excavator diameter is taken at two-thirds because the machine performance is near optimum at this ratio. With a lesser bench height, full advantage of the wheel capacity is not taken. Also, increases in bench height above this limit result in undercutting which may lead to excessive spillage to be rehandled; and, in soft materials, sliding of the burden over the wheel may result. The specific cutting resistance of the material can be calculated for a given digging power rating from the following formula,

$$K = \frac{N_G \times \eta \times C}{\sqrt{Q_a \times S \times R}}$$

where

- K = specific cutting resistance in kilograms per centimeter,  
S = number of bucket discharges per minute,  
 $Q_a$  = actual capacity in cubic meters per hour,  
R = radius of the bucket wheel in meters,  
 $N_G$  = digging power rating of the drive in kilowatts,  
 $\eta$  = efficiency of the motor drive, and  
C = constant depending on the bench height to wheel diameter ratio, is found to be increasing with decreasing bench height for a given wheel diameter.

The change in the value of C with a change in the height/diameter ratio can be observed in the following tabulation (121):

Height/diameter ratio.....	0.1	0.2	0.3	0.4	0.5	0.6	0.67	0.7
Value of C.....	295	248	222	203	189	178	171	168

The power calculations done so far have been based on theoretical considerations; but in actual practice, the most important factors are the condition of the teeth, their position on the bucket, and their lacing. Shape of the cutters, sharpness, and digging angle affect the power required to dig. Worn cutters require up to 30 percent or higher additional digging force compared with new ones.

### Slewing Motor Considerations

The bucket-wheel excavator excavates in two directions--while the buckets are cutting in a vertical direction, the cutting boom is slewed across the bench face such that new ground is continually exposed. For effective excavation, the cutting boom should slew through a length equal to the width of the bucket in the time the bucket travels through the height of the bench. The power to effect this slewing motion is calculated from the following considerations. The digging forces in the two planes bear the relation

$$\frac{M_d}{M_s} = \frac{V_1}{V_2} ,$$

where

$M_d$  = cutting force exerted by the wheel drive in kilograms,

$M_s$  = cutting force exerted by the slewing motor in kilograms,

$V_1$  = peripheral cutting speed of the wheel in meters per second,  
and

$V_2$  = slewing speed of the wheel boom in meters per second.

Besides the power for cutting, the slewing motor also supplies the necessary energy for rotating the superstructure. If

$W$  = weight of the superstructure in kilogram,

$\mu$  = frictional coefficient at the ball race on which the superstructure revolves,

$D_r$  = diameter of the ball race in meters,

$L_b$  = length of the cutting boom in meters, and

$\eta$  = efficiency of the motor drive;

then the force at the bucket wheel end, due to the rotation of the superstructure, will be

$$M_f = D_r W \mu / L_b .$$

$$\text{The slewing motor power in kilowatts} = \frac{(M_f + M_s) \times V_2}{\eta \times 102} .$$

Two other factors that need to be considered are (1) lifting power which arises in slewing with the machine at an angle to the vertical due to the movement of the center of gravity; and (2) swing counterforce due to wind resistance, which usually is taken at 25 kilograms per square meter (5.12 pounds per square foot). As a rule, operation of the wheel is stopped at higher wind velocities.

### Bucket-Wheel Design

At present, two types of bucket wheels are used--the celled and cell-less. In cell-less wheels, the buckets are free to dump their loads continuously into an inner annular ring. At high wheel speeds, the discharge capacity may be double that of celled wheels. In the celled wheels, each bucket has a separate chute for the transfer of material from the bucket to the belt conveyor. Transfer may take place only between the time the bucket reaches a vertical position and the time it reaches the chute plate above the conveyor. If the wheel is rotated at too great a speed or the material does not flow well, some of the material will not have time to slide down the chute and will not be unloaded. This will result in a buildup in the buckets and ultimately a decrease in capacity of the excavator.

The most important factor in bucket-wheel design is the diameter of the wheel. Much stress is placed on the correct sizing of the wheel since the service weight of the machine varies as the square of the diameter, cutting torque varies inversely as the diameter, and the cutting speed should never exceed  $\sqrt{0.2gD}$ ;

where

g = acceleration due to gravity in meters per second per second,  
and

D = wheel diameter in meters.

The diameter should be sufficient to accommodate the chute and/or roller bar and to transfer material from the buckets to the ladder-conveyor. Since the ladder-conveyor is taken beyond the axle of the wheel, it is a controlling factor in wheel design.

### Other Considerations

Wheel-boom and discharge-boom lengths have to be derived from operating conditions. The length of the wheel boom depends on the specified cutting height above and cutting depth below the grade and on the block width. The slope on the ladder-conveyor is an important factor which is governed by the type of material being handled. The length of the discharge boom depends on the height and distance of the discharge point. In an open cut mine, the length of the discharge boom should be such that "spoiling" is properly effected on the dump zone and not within the pit limits.

Limitations on the size of a modern-day, bucket-wheel excavator are imposed not by the design of the wheel, but by the conveying of material from

the bucket wheel to the discharge point on the stacker boom. Also, with the design of bucket-wheel excavators for high banks, a dependable steep angle conveyor is necessary. Belt speeds of 300 to 400 meters per minute and belt widths of 200 centimeters are not uncommon. In cases where the inclination angle of the ladder boom is excessive, sandwich belt conveyors have proved to be highly satisfactory.

#### MINING METHODS

Modern bucket-wheel excavators generally mine in blocks. There are several methods of attacking these blocks: (1) Terracing (or block) cut; (2) lateral block cut; (3) drop (or dropping) cut; and (4) deep cutting.

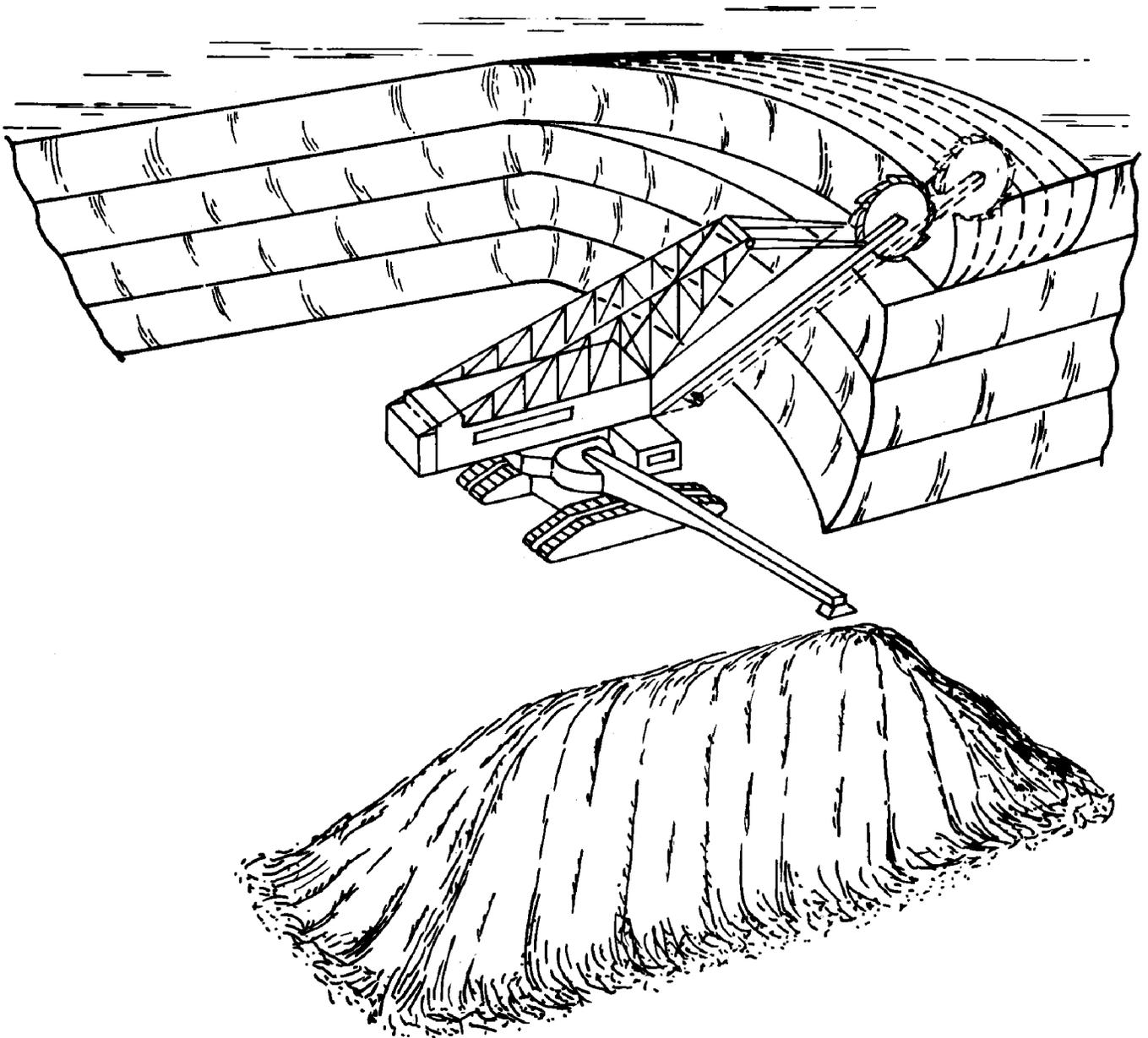


FIGURE 6. - Terracing Cut Method With Crowd.

### Terracing Cut

The machine crawlers are behind and parallel to the highwall and the block is excavated in a number of layers (benches), the height of each bench cut is 60 to 72 percent of the wheel diameter and the block width is determined by the length of the ladder boom and horizontal arc through which it swings. With a machine not having a crowd feature, the face is advanced, starting with the top layer. The machine is then trammed forward a distance sufficient to fill the buckets, and the ladder boom is swung through an arc to the desired width. The machine is again trammed forward, and the process is repeated until the crawlers reach the lower bench. Successive lower layers are mined in a like manner. Upon completion of the lowest layer, the machine is trammed forward to start a new block. A machine with crowd would mine essentially the same way, except that the crowd would have to be used instead of the crawlers (figs. 6 and 7).

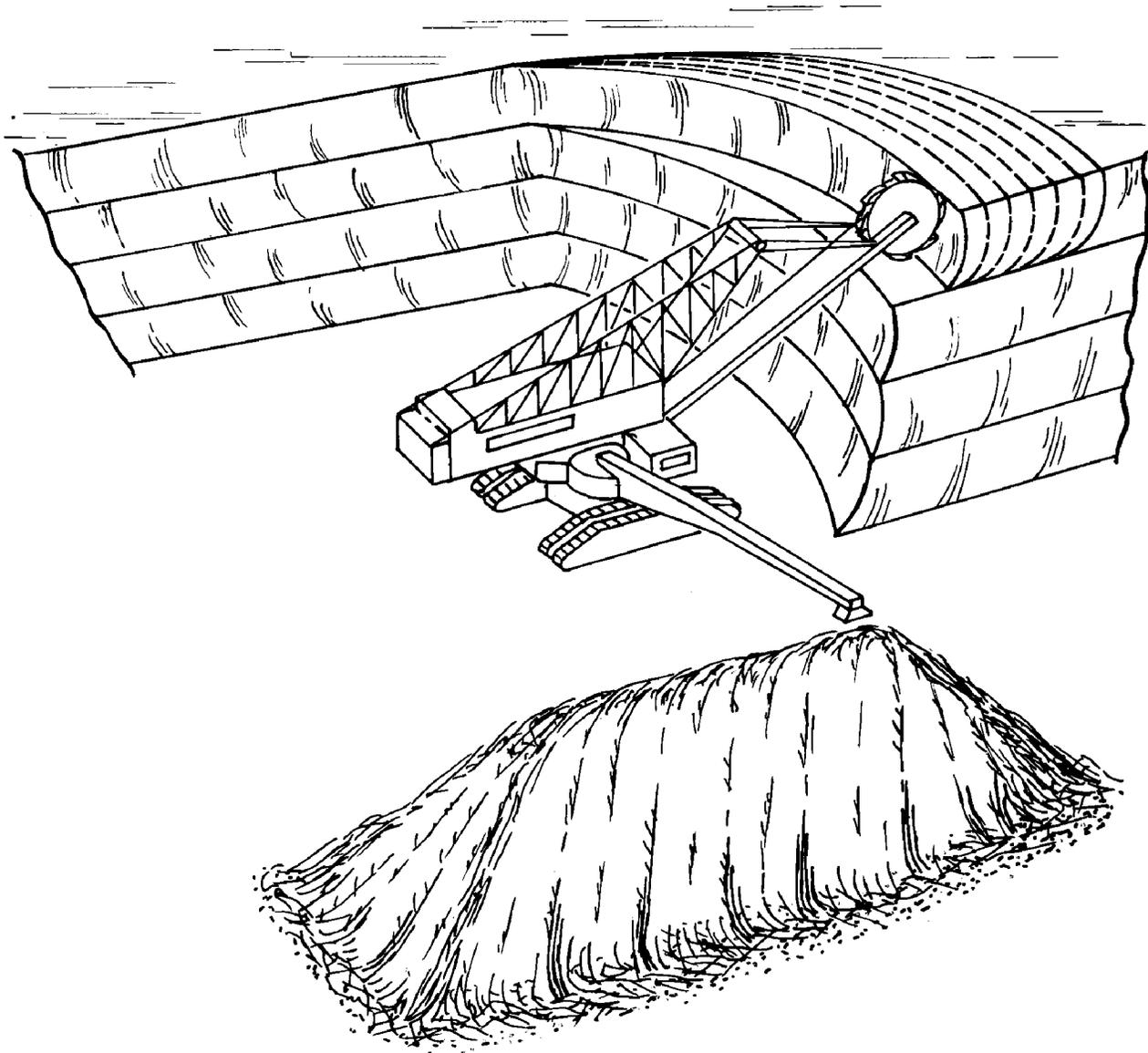


FIGURE 7. - Terracing Cut Method Without Crowd.

### Lateral Block Cut

The machine crawlers are placed parallel to the highwall, but to the side rather than behind it, and material is mined in layers and at right angles to the highwall. This method is often employed when selective mining is practiced as in multiple seam mining or where a wheel/shovel combination is employed. Mining sequence is the same as for the terracing cut method, except that the upper bench may be exposed for a relatively long distance before starting the next lower bench (fig. 8).

### Drop Cut

In certain situations, especially where mining tends to dislodge large lumps of material, this method may be employed. The top layer is mined by the bench cut method. The machine then is trammed back a short distance, the wheel lowered a distance sufficient to fill the buckets, and swung through an arc to achieve block width. The wheel is again lowered and swung back. This is repeated until the total height is achieved. Production rate by this method is approximately the same as by the terracing cut method, although power requirements are greater (fig. 9).

### Deep Cutting

Some bucket-wheel excavators are designed to operate below crawler elevation. These machines use essentially the same methods of attacking the face as the regular machines. Deep cutting poses problems of transporting the mined material up rather steep grades and, therefore, is not as widely accepted as high cutting (fig. 10).

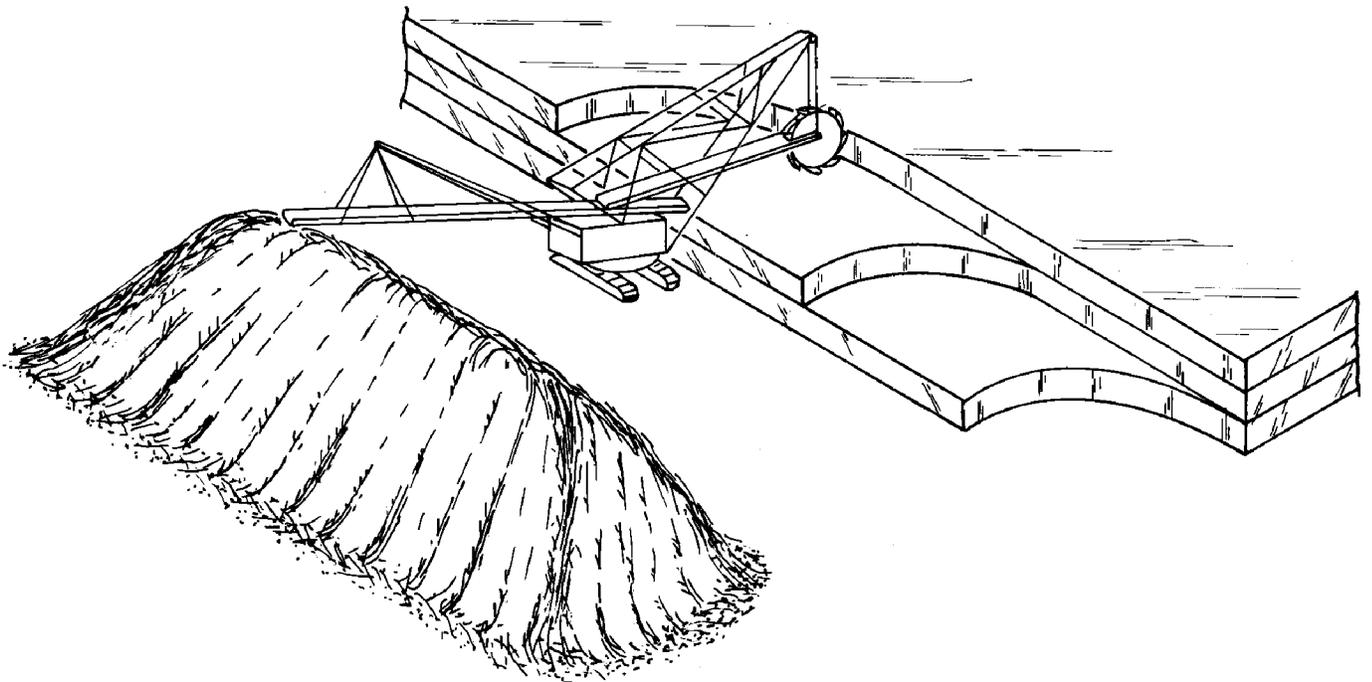


FIGURE 8. - Lateral Block Cut Method.

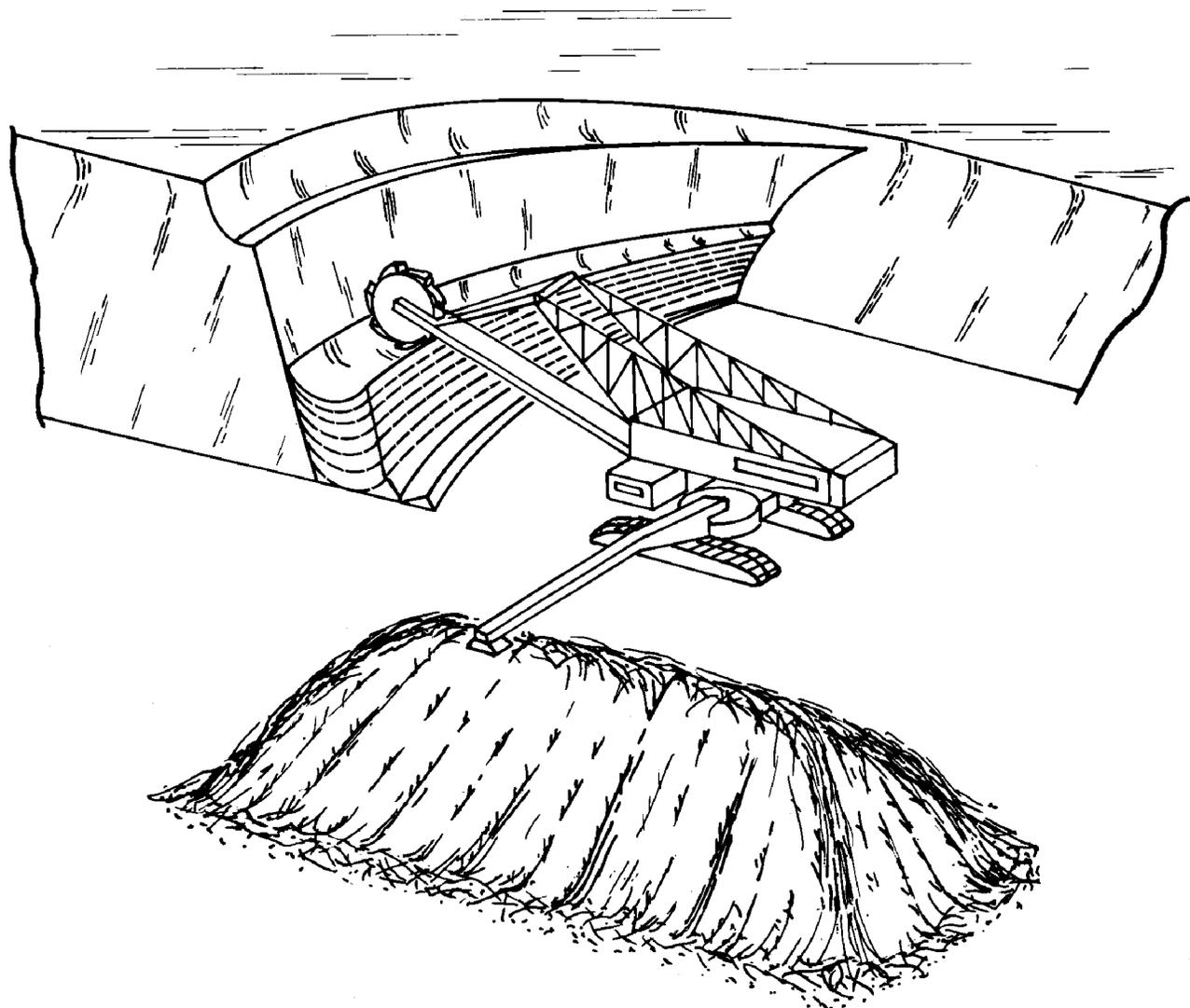


FIGURE 9. - Drop Cut Method.

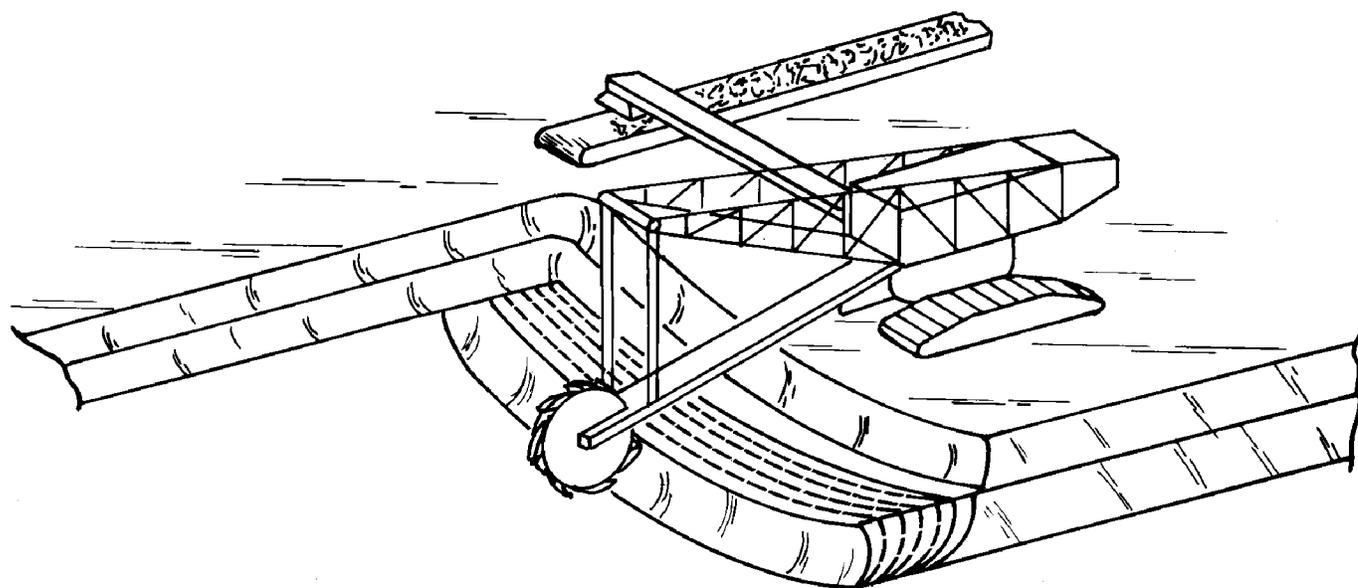


FIGURE 10. - Deep Cut by Terracing Cut Method.

## OPERATIONS RESEARCH

Where applicable, a bucket-wheel excavator will move large volumes of material at a low cost. The operating characteristics of mines vary widely from one another; therefore, it is difficult to generalize the results of many economic studies. In fact, the optimized method at one mine may be completely unworkable at another. Management, therefore, needs a method to generate adequate quantitative information to appraise all possible alternatives, before making a major decision. Operations research techniques are becoming widely used in the mining industry to supply management with this information.

The Pennsylvania State University, through a research grant from the Bureau of Mines, developed a mathematical model to simulate the digging component of a bucket-wheel excavator. To reflect the dynamic characteristics of a bucket-wheel excavator system, rate equations based on formulas from published literature are used to generate the goal-seeking, self-correcting interactions between the unit operations.

The computer program can simulate both the bench and drop cut method of mining. The bench cut routine was tested against an operation.

The simulator can provide answers to the following questions:

1. Can a bucket-wheel excavator be used in the deposit?
2. If so, which bucket-wheel excavator will operate most efficiently?
3. Which method of bucket-wheel excavator operation is most efficient?

The computer output consists of a timestudy, production study, and power consumption for mining a specified block of material.

### Sequence of Bucket-Wheel Excavator Operations

The interdependent nature of the unit operations of a bucket-wheel excavator was incorporated in the model. Rapid insight into the effects of changing any one or more parameters can be gained. The unit operations encompassed by a bucket-wheel excavator system are illustrated in figure 11. The main components are the continuous cutting head and the high-speed belt conveyors. The stacker conveyor may discharge onto a stockpile or load directly into trucks, railroad cars, or transfer the material to a main line belt.

The wheel excavator performs the dual function of digging and transporting material. In building the model, however, attention has been directed solely toward the digging component of the system. In fact, knowing the volume of material to be handled, the design of the transportation system can be determined by recognized design formulas.

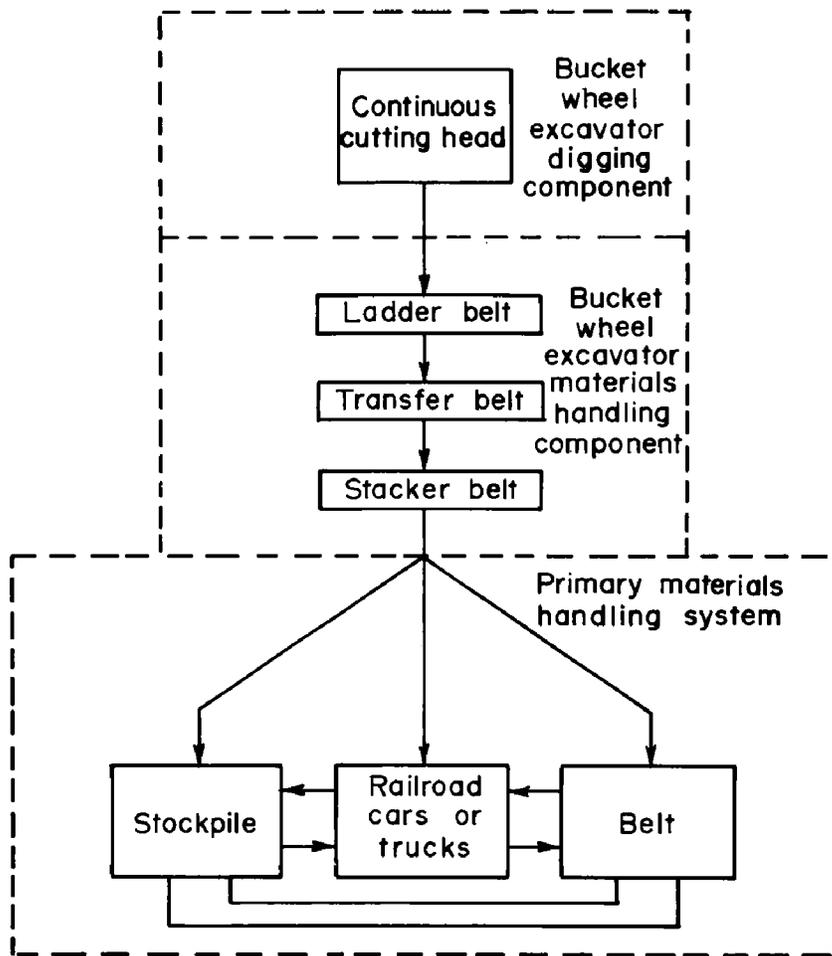


FIGURE 11. - System Flow Diagram.

different values of  $X_i$  form guidelines for management decision making.

The computer model is a special kind of mathematical model; namely, one which is not intended to be solved analytically but rather to be simulated by an electronic computer. The computer program traces numerically or graphically the time path of all variables generated by the model. Here, the cutting action of the wheel is simulated and a current journal of the mining advance, elapsed time, and power requirements is maintained. The model is programmed to simulate the bench and drop cuts. This simulation enables the wheel to perform according to its mechanical capabilities along the physical profile of the mining property. A probability function is used to determine whether any boulder was struck during the cutting operation.

#### Simulator

The passage of a bucket through the bench height, the slewing motion of the cutting boom, the crowding action of the crawlers, and the advance of the machine from bench to bench and after each cut are achieved in the model by simulation (fig. 12). This application adds considerable power and flexibility to the model by actually duplicating the machine performance. A deterministic approach was decided upon because the input parameters for

#### Simulation

The role of simulation, as used here, can be described by the following symbolic model.

Let  $E$  represent the measure of effectiveness to be used. Let  $X_i$  represent the aspects of the system (variables) which can be controlled by management, and let  $Y_j$  represent the uncontrollable aspects of the system. Then, in model construction, an attempt is made to formulate one or more equations of the form:

$$E = f(X_i, Y_j).$$

The extraction of a solution from such a model consists of determining those values of the control variables,  $X_i$ , for which the measure of effectiveness is maximized. In fact, the various solutions for

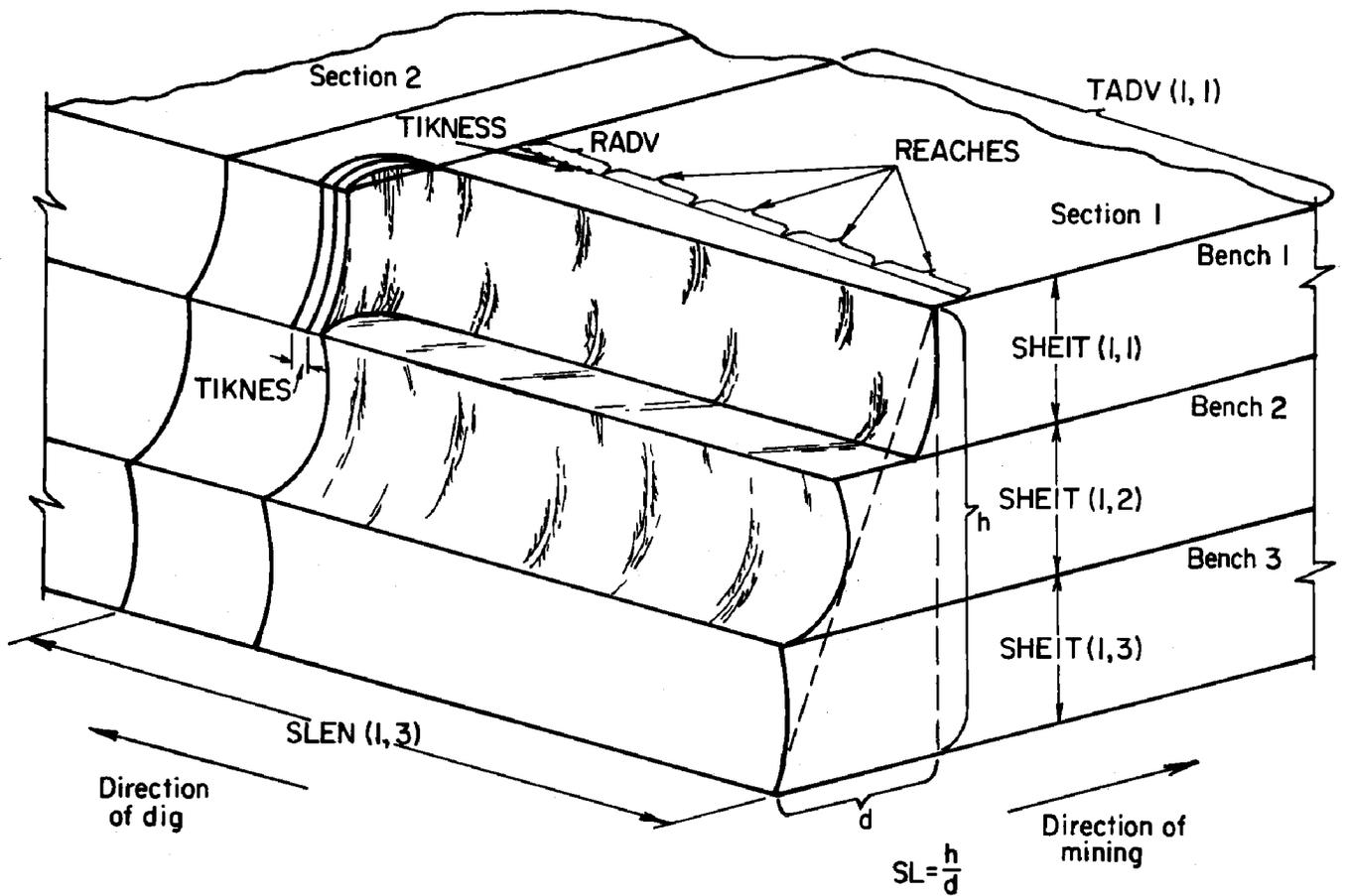


FIGURE 12. - Mining Plan With Computer Terms.

the machine are known with certainty, and the interrelationship between parameters, however complicated, can be determined by their functional relationships. Recalling the various formulas for the cutting action and referring to figure 13, the recurrent steps are established.

$$t = 0.133 \sqrt{Q/RXS},$$

$$t_p = t \left( \cos \theta + \frac{\sin^2 \theta}{2P_1} \right),$$

$$P_1 = \frac{S_r}{t}, \text{ and}$$

$$V_\theta = V / \cos \theta,$$

where

$t$  = thickness of slice in meters,

$t_p$  = thickness at the point  $p$  in meters,

$R$  = radius of the wheel in meters,

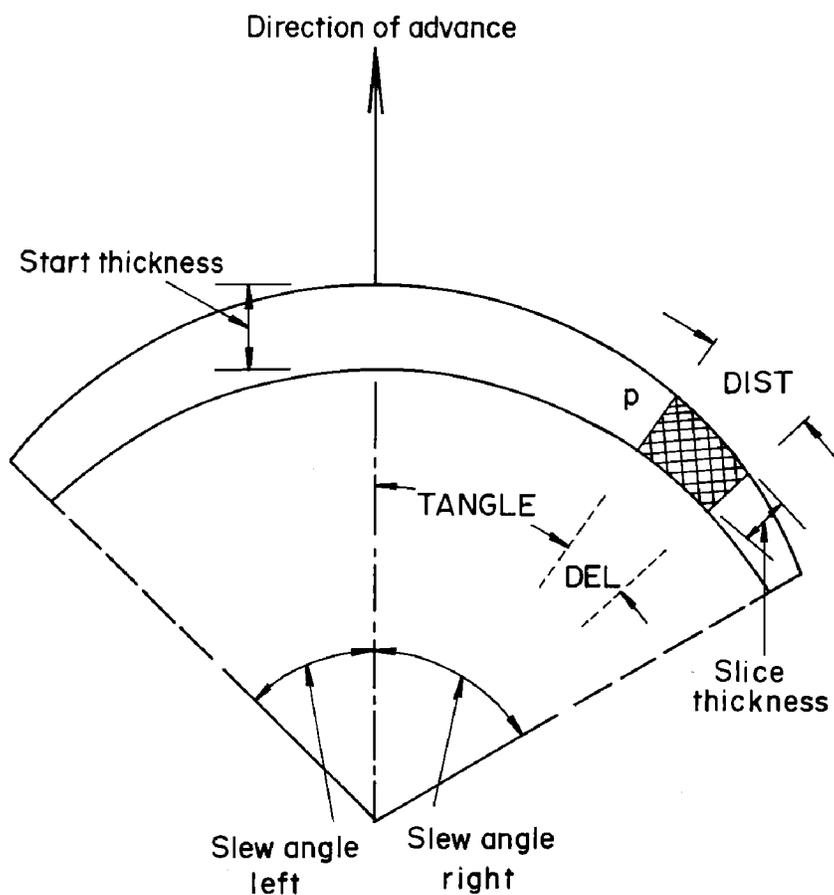


FIGURE 13. - Plan View of the Slice Taken by the Bucket Wheel.

$S$  = number of bucket discharges per minute,  
 $\theta$  = angle of slew from the direction of advance,  
 $V$  = starting slewing speed in meters per second,  
 $V_{\theta}$  = slewing speed at the point  $p$  in meters per second, and  
 $S_r$  = slewing radius in meters.

The repeating procedure used in the model is explained as follows:

- Step 1. Cut one bucket, cumulative material, power, and time.
- Step 2. Calculate width traversed by the boom to take one bucket of material.

$$\text{DIST} = \frac{\text{bucket capacity}}{\text{bench height} \times \text{slice thickness.}}$$

Step 3. Calculate angle made by "DIST" at the slew axis.

$$\text{DEL} = \text{arc sin} (\text{DIST}/\text{SLEW RADIUS})$$

Cumulate the angle

$$\text{TANGLE} = \text{TANGLE} + \text{DEL}$$

Step 4. Is TANGLE less than SLEW ANGLE?

If "NO," go to Step 5.

If "YES,"

$$\text{PET} = \text{SLEW RADIUS}/\text{Start thickness}$$

$$\text{Slice thickness} = \text{Start thickness}$$

$$\left( \text{COS}(\text{TANGLE}) + \frac{\text{SIN}^2(\text{TANGLE})}{2 \times \text{PET}} \right)$$

Go to Step 1.

Step 5. Advance machine on crawlers (or crowd in) by start thickness.  
Cumulate time, power and crowd distance.

Go to Step 1.

A block diagram showing the complete sequence of computer operations can be seen in figure 14.

### Power Calculations

If the material is homogeneous and the bench height constant, the power requirement on the wheel for each bucket through the material will be identical. In an actual mining situation, neither of these is true; therefore, the power demand on each bucket for digging and raising and, consequently, for slewing across, varies according to conditions at that instant of time. Referring to figure 3 and assuming a square cross section for the slice taken by the bucket, the length of cutters in contact with the material depends upon the position of the buckets on the cut slice. Although power requirements will normally be within narrow limits of variation, instantaneous peak demands will arise. The model is programed to detect such peak values.

The power calculations for crawlers assume a rolling resistance of 6 percent of the overall weight of the machine. It is impossible to give an exact rolling resistance for all types of ground conditions and all crawler tracks. However, the values provided below are reasonably accurate and may be used for estimation purposes (108):

Earth, compacted and well maintained.....percent..	3 to 4
Earth, poorly maintained and rutted.....do....	4 to 6
Earth, rutted, muddy, no maintenance.....do....	7 to 9
Loose sand and gravel.....do....	8 to 10
Earth, very muddy, rutted and soft.....do....	10 to 12

A factor that could not be accounted for in calculating the power rating of the slew motors is wind resistance. An adequate allowance has to be made in the final design of the slew motor to withstand a wind pressure of at least 25 kilograms per square meter.

### Required Data

To operate the simulator, the data input are divided into four categories:

1. Mining dimensions. These include (a) the length of the mining property, (b) the number of benches, and (c) the elevations of the benches.

2. Soil characteristics. The data required here are (a) various soil types, (b) their specific cutting resistance, (c) operating speed of the wheel in the soil types, (d) bucket filling capacity, and (e) swell factor. In soils with higher specific cutting resistances, the wheel is speeded up and the successive slices that are taken are thinner. This seriously affects

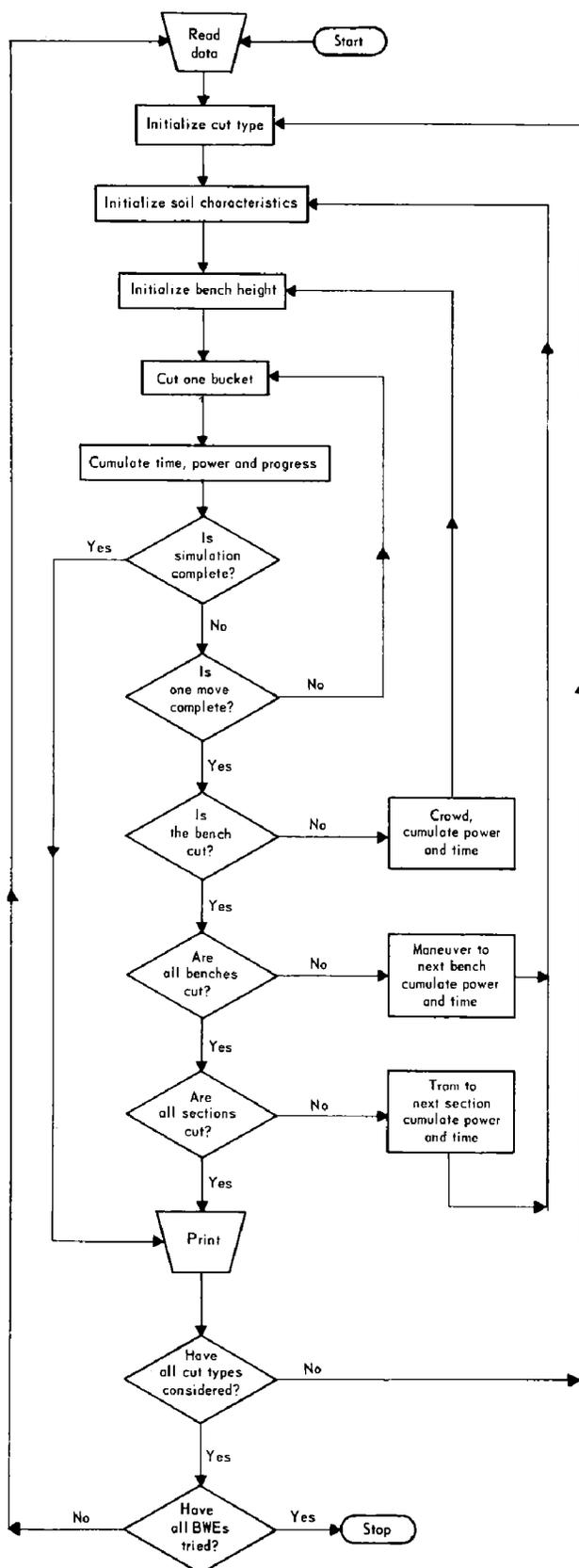


FIGURE 14. - Complete Program Flow Diagram.

bucket filling capacities and, in some cases, less than 25 percent of the theoretical output is mined. Swell factors for sand and similar loose, broken material is not very significant; whereas, a compacted material may increase in volume by 30 to 40 percent on fragmentation.

3. Wheel specifications. The data input here include (a) diameter of the wheel, (b) number of buckets in the wheel, (c) length of the slew axis, (d) overall weight of the machine, and (e) weight of the superstructure. Also, read in are (f) the ball race diameter, and (g) maximum slewing speed.

4. Miscellaneous. Realistic efficiency figures have been assumed for the mechanical and electrical components of the bucket-wheel excavator to arrive at proper power rating of the electrical motors. Allowances for setup time of the bucket-wheel excavator and downtime if a boulder is struck are also read in.

#### Computer Program

The simulation program consists of four program units--three subprograms and a main program. Subroutines Bencut and Falcut simulate the German bench cut and drop cut methods. Subroutine Randa generates uniformly distributed random variables. The main program is used primarily for performing the input-output functions.

The program can be terminated by either a time trigger device or after program completion. At the end of the simulation run, the statistics supplied by the computer are as follows:

1. A timestudy which is broken down into cutting, crowding, delay, maneuvering, tramming, and total time in a bench.

2. Power calculations for the above operations.

3. A production study which includes the volume excavated, the theoretical capacity, and actual capacity in each bench. Also printed out are the time spent and the power consumption in each cut by the machine.

The computer program is written in FORTRAN IV for use with the IBM 360 computer. A complete listing of the program can be found in appendix A. The input controls and variable names used in the program are listed in appendix B. Input data and simulation results are printed in appendix C and appendix D, respectively, and a glossary of symbols is shown in appendix E.

### Testing the Model

A scientific model is a representation of some subject of inquiry such as objects, events, processes, and systems. Therefore, testing the model is always an indispensable step in the procedure. In any event, if operations research is the study of executive type decisions, it must regard the procedures of model testing to be as critical as those of model building. Acceptance of the model by decisionmakers is much more likely to depend on its tested performance than on its underlying logic or the validity aspects of the model itself.

The ability of a simulation model to reproduce past operating data serves to evaluate its usefulness. This retrospective testing usually consists of a comparison of actual performance for which the recorded data are available with performance obtained from the model.

### Mining Plan

The simulator was tested in an actual case study of a bucket-wheel excavator application in the midwestern coalfields. The major components are the unit operations of stripping, coal reclamation, and materials handling.

The seam, which varies in thickness from 0.75 to 1.0 meter, is under 18 to 25 meters of cover. Trucks, which convey coal to an integral train facility, are used directly behind the loading shovel; while overburden is handled by a bucket-wheel excavator. The bucket-wheel excavator is used to excavate the top loose sand and underlying soft and medium shales. Boulders more than 1 cubic meter in size are embedded in the upper layer of sand. The abrasive nature of the strata is evident from the  $\text{SiO}_2$  content of the beds. Analysis has shown that streaks of sandstone in the beds contain 73.5 percent  $\text{SiO}_2$ , and the shales 34 percent  $\text{SiO}_2$ . A typical section of the stratification is shown in figure 15.

### Application Selection

This bucket-wheel excavator application was selected for testing the model for the following reasons:

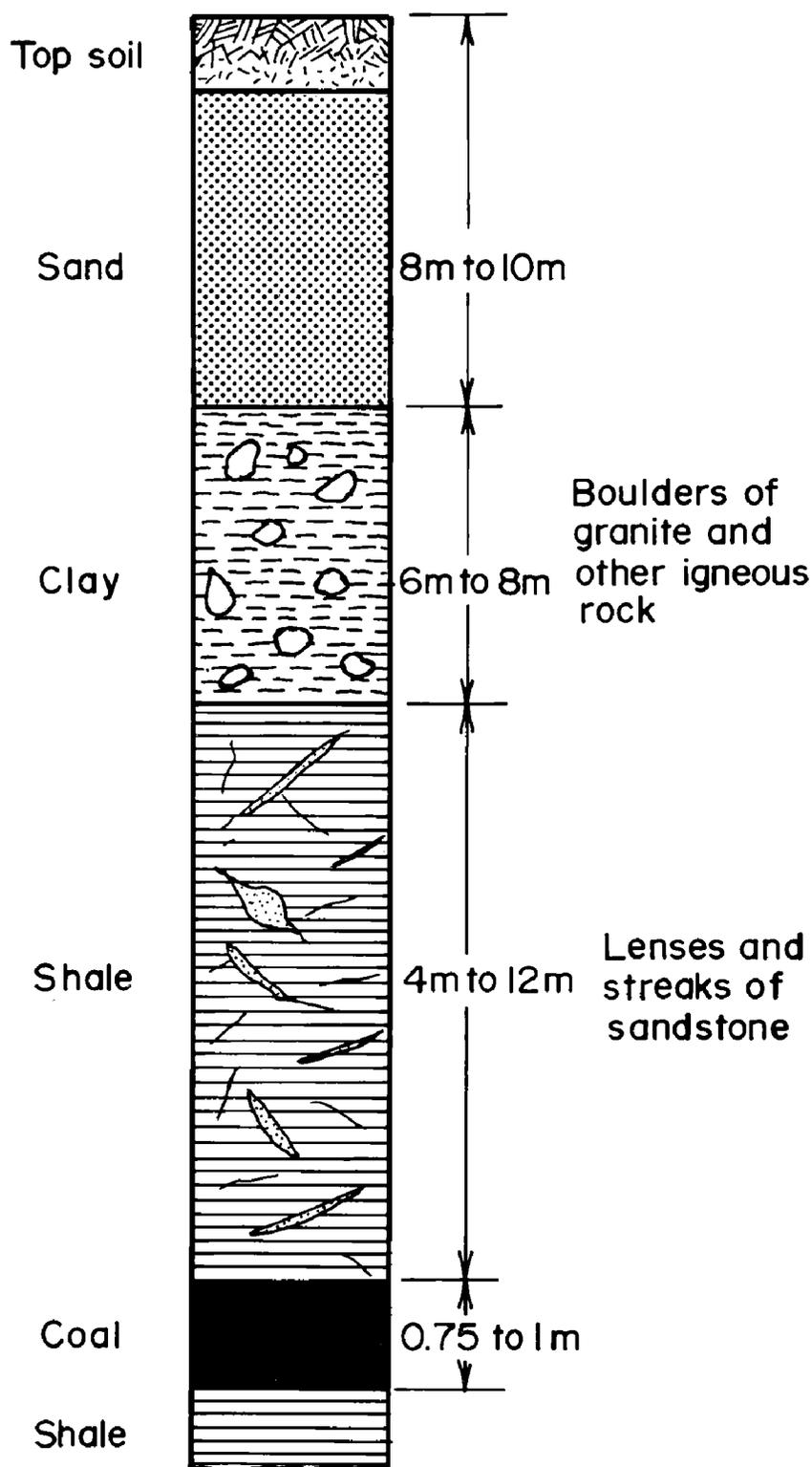


FIGURE 15. - Plat Showing Classification and Thickness of Strata.

result of this test run, are presented in tables 6, 7, and 8. The frictional coefficient at the ball race was estimated at 0.03 (76), and the mechanical and electrical efficiencies were taken at 80 and 90 percent, respectively.

1. The bucket-wheel excavator stripping plan uses the German bench cut method, a standard way of working with bucket-wheel excavators. The American frontal block may be advantageous in certain cases for strip mining coal; but bucket-wheel excavator application, in general, is for open-pit mining where the machines are linked together by a huge transportation complex.

2. A range of mining conditions were present for model testing. These included (a) easy to very hard digging conditions, and (b) boulder embedded beds.

3. The performance data were readily available.

#### Data Collection

Operating data for the test application were collected at the mine site. A journal of pit advance and shift production was maintained for the test run. The simulator was tested against a 2-day operating period, during which the performance of the wheel was set at 90 percent availability and a block, roughly 144 meters long, 50 meters wide, and nearly 24 meters high, was mined.

The required input data for model operation, as a

TABLE 6. - Material characteristics

Material type	Specific cutting resistance, kg/cm	Boulder occurrence frequencies	Wheel speed, percentage of maximum	Bucket-filling capacity, percentage theoretical	Swell factor ratio of volume, in situ to loose
Loose sand.....	Mean 45 Range 30- 60	0	0.4	0.90	1.0
Soft shale.....	Mean 75 Range 60- 90	.1	.4	.80	0.8
Medium shale.....	Mean 135 Range 120-150	0	.6	.40	0.7

TABLE 7. - Mining dimensions

(Slew angle, degrees: Left 50; right 20)

Section	Bench	Height, meters		Length, meters
		Initial	Final	
1	1	8.53	7.02	144.0
	2	7.92	7.92	144.0
	3	7.92	7.92	144.0

TABLE 8. - Bucket-wheel excavator specifications

Wheel diameter.....meters..	11.48
Number of buckets.....	14
Overall weight of machine.....kilograms..	3,267,000
Weight of superstructure.....do.....	2,500,000
Crawler speed.....meter per second..	0.15
Radius of ball race assembly.....meters..	5.9
Slewing radius.....do.....	44.24
Capacity of buckets.....cubic meters..	1.53
Maximum permissible slewing speed.....meter per second..	0.5

### Results

The results presented here represent the information obtained when the model was tested under the conditions listed above. The depth of block taken by the bucket-wheel excavator in one cut was 24 meters. This is based on the bucket-wheel reach, the batter angle, and the number and height of the benches.

Model results presented in table 9 are higher than in actual operations. This is to be expected, since the model assumes 100-percent bucket-wheel excavator availability. It will be necessary to modify model production towards reality by making allowances for the human and conditional work components which cause real work performance to be suboptimum. A subjective

estimate of the combined effects of these components may be set at 10 to 15 percent of model production.

TABLE 9. - Model results

Operating time.....hours..	47
Production.....cubic meters..	165,800
Average production capacity.....cubic meters per hour..	3,520
Power consumption.....kilowatt hours..	<sup>1</sup> 50,800
Service factor.....percent..	100
Digging motor rating.....kilowatts..	1,631
Slewing motor <sup>2</sup> .....do.....	95
Crawler motors.....do.....	670

<sup>1</sup>Does not reflect the power expended in belting. Power consumption here is estimated at 32,800 kilowatt-hours.

<sup>2</sup>Wind resistance not taken into consideration.

Economic justification of new mining units depends to a large extent not only on performance, but also on how well these units match with other units in the system. The poor performance of the bucket-wheel excavator in harder beds suggests that a smaller bucket-wheel excavator for soft beds, and a dragline or shovel for the harder beds, would be a proper choice.

#### CONCLUSIONS

The demand for minerals and fuels is steadily increasing. As high-grade deposits are depleted, lower grade deposits must be worked. This, coupled with rising labor and material costs, requires more and more efficiency in mining operations. Production capacity of mining equipment has increased rapidly in the last decade, requiring increasing capital expenditures for equipment.

Bucket-wheel excavators are highly specialized machines. Practically all in use today were built to specifications for a particular mining application; whereas, except for the very large sizes, standard models of shovels and draglines are available. Shovels and draglines remain the most popular machines for stripping operations; however, where the material to be mined is either medium hard or when easily mined material must be mined rapidly and transported some distance from the pit, the bucket-wheel excavator merits serious consideration.

Simulation studies offer a practical means of predicting the operating characteristics of equipment before actually going to the expense of installing the equipment in a mine. If properly used, these studies should supply valuable assistance in the selection of the proper equipment and pit layout for a mining operation.

BIBLIOGRAPHY<sup>e</sup>

1. Adams, K. L. Conditions Dictate Wheel Excavating Design. Coal Min. and Processing, v. 1, No. 10, October 1964, pp. 28-29.
2. Aiken, G. E. Bucket-Wheel Excavators--How To Choose the Right One for the Job. Min. Eng., v. 18, No. 1, January 1966, pp. 76-81.
3. Aiken, G. E., and Reinhard H. Wohlbier. Continuous Excavators (Bucket Wheel and Chain Diggers). Ch. 8.4 in Surface Mining (Seeley W. Mudd Series). American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 1968, pp. 478-502.
4. Bahr, J. The Dynamic Effects on a Bucket Wheel Dredger Digging in Heavy Soils. Bergbautechnik, v. 15, No. 5, May 1965, pp. 230-237.
5. Barber-Greene Company. Continuous Excavator Model XL-50. 22 pp.
6. Bhadada, R. Opencast Working of a Small Lignite Deposit at Depth. J. Mines, Met., and Fuels, v. 14, No. 1, January 1966, pp. 17-23.
7. Brealey, S. C. Open Cast Mining. Min. J. Ann. Rev., May 1966, pp. 145-151.
8. Bredthauer, R. O., and T. N. Williamson. Mechanization Potential in Oil Shale Mining. Quarterly Rept. Colorado Sch. of Mines, 3d Symp. on Oil Shale, v. 61, No. 3, July 1966, pp. 55-67.
9. Canadian Chemical Processing. Sun Begins Mining Oil at Athabasca. V. 51, No. 10, October 1967, pp. 49-54.
10. Caplan, Basil. Lumpy Materials on a Grand Scale--The Road to Automation. Mech. Handling, v. 54, No. 12, December 1967, pp. 533-539.
11. Carthew, Douglas J. Open Pit Planners Face Complex Problems When Designing the Total Mine Operation. Eng. and Min. J., v. 168, No. 9, September 1967, pp. 93-106.
12. Caseley, J. R. Materials Handling in Open-Cast Mining. Coll. Guard., v. 208, No. 5360, January 10, 1964, pp. 52-63.
13. Cheek, Edward E. Application of a Standard Wheel Excavator in Coal. Min. Cong. J., v. 52, No. 11, November 1966, pp. 33-35, 38-39.
14. Coal Age. High Capacity Dredges Strip Foreign Lignite. V. 56, No. 4, April 1951, pp. 124-125.
15. \_\_\_\_\_. World's Largest Excavator. V. 57, No. 10, October 1952, p. 93.

---

<sup>e</sup>Titles enclosed in parentheses are translations from the original language in which the article was published.

16. \_\_\_\_\_. Wheel Excavator Extends Stripping Range. V. 61, No. 7, July 1956, pp. 60-65.
17. \_\_\_\_\_. The Strip Mining Guide Book. V. 63, No. 7, July 1958, p. 116.
18. \_\_\_\_\_. Wheel Giant Shovel Pace New Production Records at River King. V. 68, No. 7, July 1963, pp. 84-89.
19. \_\_\_\_\_. Overburden Removal. V. 69, No. 7, July 1964, p. 214.
20. \_\_\_\_\_. Wide Range of Equipment Uncovers Coal at Consol Mines. V. 69, No. 10, October 1964, pp. 139-146.
21. Coal Mining and Processing. Bucket Wheel Machine is a U.S. First. V. 1, No. 7, July 1964, p. 8.
22. \_\_\_\_\_. What's Ahead for Surface Mining? V. 2, No. 7, July 1965, pp. 18-21.
23. \_\_\_\_\_. New Wheel in Southern Illinois. V. 4, No. 11, November 1967, p. 14.
24. Colliery Engineering. Large Paddle-Wheel Dredger. V. 27, No. 319, September 1950, pp. 386-387.
25. \_\_\_\_\_. Reclaiming and Excavating Machine. V. 42, No. 501, November 1965, pp. 496-497.
26. \_\_\_\_\_. Bucket-Wheel Excavator. V. 44, No. 524, October 1967, pp. 411-413.
27. Colliery Guardian. Bucket-Wheel Excavator. V. 215, No. 5552, Sept. 15, 1967, p. 309.
28. Dickey, R. M. Modern Trends in Deep Bituminous Coal Stripping. Proc. Illinois Min. Inst., 1947, pp. 85-92.
29. Diesel Equipment Superintendent. Diesel Powered Wheel. V. 41, October 1963, p. 31.
30. Dombrowsky, N. G. The New Bucket-Wheel Excavator and Its Construction Problems. Bergbautechnik, v. 14, 1944, p. 277.
31. Dravo Corporation Publications. A New Concept in Coal Handling. No. 252-1. January 1965, 4 pp.
32. \_\_\_\_\_. Rotary Bucket-Wheel Machines. Bull. 252. September 1962, 8 pp.
33. Earthmoving and Construction. Barber-Greene Announces Continuous Excavator. V. 45, No. 2, February 1968, p. 22.

34. The Engineer. Large Bucket Excavator for a German Lignite Mine. V. 201, No. 5, Jan. 6, 1956, pp. 24-29.
35. \_\_\_\_\_. Rotary Excavator. V. 204, Dec. 20, 1957, p. 916.
36. \_\_\_\_\_. Bucket-Wheel Reclaimer. V. 218, July 10, 1964, pp. 74-75.
37. \_\_\_\_\_. Earthmoving at Oroville Dam. V. 218, Sept. 11, 1964, p. 419.
38. Engineering and Mining Journal. Huge Machines Mine Continuously. V. 161, No. 6, June 1960, pp. 218-219.
39. \_\_\_\_\_. Bucket Wheel Is Versatile Excavator. V. 161, No. 10, October 1960, p. 3.
40. \_\_\_\_\_. Two-Wheeled Reclaimer Blends Kaiser Ore. V. 163, No. 12, December 1962, p. 83.
41. \_\_\_\_\_. Bucket Wheels, Nuclear Blasts, Proposed To Recover Oil Shale. V. 167, No. 5, May 1966, pp. 109-110.
42. \_\_\_\_\_. Bucket Wheel-Excavators Move Big Tonnage. V. 167, No. 6, June 1966, pp. 295-296.
43. \_\_\_\_\_. Stacker-Reclaimer Permits 12-Month Operation at Mine. V. 167, No. 7, July 1966, p. 101.
44. \_\_\_\_\_. Tar Sand Mining--Start of a New Era. V. 168, No. 12, December 1967, pp. 65-71.
45. \_\_\_\_\_. Continuous Excavator. V. 169, No. 1, January 1968, pp. 42-43.
46. Engineering News Record. Fifth Wheel Does the Digging. V. 171, No. 21, Nov. 21, 1963, p. 45.
47. \_\_\_\_\_. 3,500-Cubic-Yard-an-Hour Digging Wheel Makes Debut at San Luis. V. 172, No. 19, May 7, 1964, pp. 28-30.
48. \_\_\_\_\_. Big Wheel Replaces Dragline at Oroville. V. 172, No. 20, May 14, 1964, pp. 26-27.
49. \_\_\_\_\_. First Stock Wheel Excavator. V. 178, June 8, 1967, p. 15.
50. \_\_\_\_\_. Seawater Flushes Spoil Fast To Reclaim Harborland. V. 178, June 22, 1967, pp. 28-29.
51. Equipment Guide Book Report. Mechanical Mole Has Big Capacity. V. 3, No. 4, April 1968, p. 12.

52. Excavating Engineer. Wheel Excavator: Coal Stripping Tool With a Future. V. 49, No. 5, May 1955, pp. 21-31, 56.
53. \_\_\_\_\_. Wheel Excavator Cranks Up at San Luis Dam. V. 58, No. 9, September 1964, pp. 12-19.
54. Frenkel, M. I. Criteria for the Control Parameters of Bucket Excavators. Sov. Min. Sci. Nos. 9-10, September-October 1966, pp. 518-521.
55. Gaertner, Karl. Handling With the Bucket-Wheel Excavator. Min. Mag., v. 114, No. 2, February 1966, pp. 72-85.
56. \_\_\_\_\_. (Bucket-Wheel Excavator on Building Sites.) Forden und Heben, v. 3, No. 6, November 1965, p. 67.
57. \_\_\_\_\_. (Strip Mining Methods for Opening Up a Coal Deposit.) Braunkohle, Wärme und Energie, v. 18, No. 1, January 1966, pp. 1-6.
58. Gartner, E. (Trends of Development in Mining and Haulage Equipment of the Rhenish Brown Coal Open Cut Mines.) Braunkohle, Wärme und Energie, v. 7, No. 11/12, June 1955, pp. 226-241.
59. Gruschka, G. (Dimensioning the Length of the Boom on the Spreader in Dredger-Spreader Combinations for Direct Dumping.) Bergbautechnik, v. 15, No. 12, December 1965, pp. 629-635.
60. Hallingsworth, John A. History of the Development of Strip Mining Machines. Proc. Illinois Min. Inst., 1963, pp. 64-84.
61. Himmel, W. The Specific Digging Resistance in Dependency on the Shaving Area and Shaving Form in Different Soils. Frerberger. Forschungshf,e, A265, 1961, pp. 1-40.
62. Huey, J. J. Modern Development in Strip Mining Wheel Excavator, Cuba, Illinois. Proc. Illinois Min. Inst., 1949, pp. 62-66.
63. \_\_\_\_\_. Wheel Excavator for Overburden Removal. Min. Cong. J., v. 36, No. 8, August 1950, pp. 70-73.
64. \_\_\_\_\_. Development and History of Wheel Excavators in the U.S.A. Proc. Illinois Min. Inst., 1964, pp. 65-89.
65. Kendall, R. E. Germany's Answer to Low Cost Dirt Moving. Min. Cong. J., v. 46, No. 1, January 1960, pp. 26-29.
66. Kharakhash, I. M. Developments in Soviet Excavating Equipment. Part II. Min. Mag., v. 117, No. 1, July 1967, pp. 32-41.
67. Kolbe, Frank F. Developing the Wheel for American Coal Stripping. Coal Age, v. 60, No. 3, March 1955, pp. 58-65.

68. Kolbe, Frank F. The Fourth Kolbe Wheel--Two Million Yards per Month. *Coal Age*, v. 64, No. 8, August 1959, pp. 89-92, 193.
69. Krupp, Fred (staff of), and Lubecke Maschinenboea. Bucket-Wheel Excavators for Opencast Mines and Materials Handling. *South African Min. and Eng. J.*, v. 77, No. 3822, May 6, 1966, pp. 1026-1032.
70. Krysl, Ladislav. The Type K1000 Giant Bucket-Wheel Excavator. *Czech. Heavy Ind.*, September 1965, pp. 3-8.
71. Kuznetsov, K. K. Planning Large Opencast and Underground Coal Mines for High Productivity. *Min. Mag.*, v. 115, No. 6, December 1966, pp. 452-461.
72. Lamin, K. A. Australian Bucket-Wheel Excavator Coal Production. *Australian Min. Ind.*, No. 194, June 1960, pp. 268-273.
73. Lee, Arthur F. Stripping in Heavy Overburden. *Proc. Illinois Min. Inst.*, 1952, pp. 131-148.
74. Linden, Guenther. The Bucket-Wheel Excavator and the Versatility in Practice. *Krupp Tech. Pub.* 18 pp.
75. Mackintosh, Ian B. Wheel Excavator at Abiquiu Dam. *Water Power*, v. 15, December 1963, pp. 510-515.
76. Mani, M. S. Design Features of Bucket-Wheel Excavators. *J. Mines, Met., and Fuels*, v. 14, No. 3, March 1966, pp. 71-81.
77. \_\_\_\_\_. Some Features of Excavator Design. *Min. Mag.*, v. 114, No. 3, March 1966, pp. 152-163.
78. Manula, Charles B., and R. Venkataramani. Bucket Wheel Simulator. *BuMines OFR 13-68*, April 1968, 105 pp.
79. Mashkovich, O. N. The Choice of Optimal Parameters for a Two-Bench System, Regarded as a Problem in Material Programming. *Sov. Min. Sci.*, No. 2, March-April 1965, pp. 142-150.
80. \_\_\_\_\_. Improving the Efficiency of a Rotary Excavator. *Sov. Min. Sci.*, No. 1, January-February 1966, pp. 48-52.
81. *Materials Handling Engineering*. Stockpiling Keeps Bulk Materials Moving. V. 23, No. 3, March 1968, pp. 75-104.
82. Matthews, C. W. Buckets and Related Equipment Answer Many Reclaiming Problems. *Stockpiling of Materials*. *Rock Products*, Pt. 11-A, v. 69, No. 6, pp. 98-102; Pt. 11-B, No. 7, pp. 107-113.
83. McDowell, R. C., and R. E. Whikerhart. Moving 165 Million Tons for the World's Highest Compacted Fill--Oroville Dam. *Civ. Eng.*, v. 36, No. 4, April 1966, pp. 26-31.

84. McDowell-Wellman Engineering Company. Materials Handling Plan for Oroville Dam. 1964, 2 pp.
85. \_\_\_\_\_. Model 1000 Bucket-Wheel Excavator Mobile--Built To Dig. 1965, 4 pp.
86. Mechanical Excavators, Inc. Versatility and High Output Is Keynote to Wheel Excavator Success. Bull. 572-2, 1971, 3 pp.
87. Meyer, Dr. Ing. Herman. Questions About the Application Possibilities of the Bucket-Wheel Excavator in Special Coal Deposits. Braunkohle, Wärme und Energie, v. 10, No. 718, April 1958, pp. 148-153.
88. Millard, Lawrence O. German Brown-Coal Mining With Bucket-Wheel Excavators. Proc. Illinois Min. Inst., 1960, pp. 33-40.
89. The Mines Magazine. Australian Iron Ore Project. V. 57, October 1967, p. 19.
90. Mining Congress Journal. Wheel Excavator Speeds Stripping at Truax-Traer. V. 41, No. 6, June 1955, pp. 74-77.
91. \_\_\_\_\_. Oil Sands Project Dedicated. V. 53, No. 11, November 1967, pp. 52-55.
92. Mining Engineering. Bucket Wheels in Germany. V. 12, No. 9, September 1960, pp. 1013-1016.
93. \_\_\_\_\_. Bucket-Wheel Excavator Is of German Design. V. 20, No. 5, May 1968, p. 106.
94. Mining Journal Annual Review 1965. Opencast Mining, May 1965, pp. 135-143.
95. Mining Magazine. Annual Review-Loading. V. 116, No. 5, May 1967, pp. 151-161.
96. \_\_\_\_\_. Developments in Soviet Excavating Equipment--Part 3. V. 118, No. 1, January 1968, pp. 65-70.
97. Mining and Minerals Engineering. Bucket-Wheel Excavators. V. 1, No. 10, October 1965, pp. 556-557.
98. \_\_\_\_\_. New Excavator for Demba Bauxite Mine. V. 2, No. 3, March 1966, p. 117.
99. \_\_\_\_\_. Handling at Eagle Mountain. V. 2, No. 7, July 1966, pp. 265-270.
100. \_\_\_\_\_. Mavor E 10. Bucket-Wheel Excavator. V. 4, No. 1, January 1968, pp. 38-39.

101. Mining World. Bucket Wheel Stripping at Nchanga's Copper Pit. V. 21, No. 2, February 1959, pp. 40-41.
102. \_\_\_\_\_. New Rubber Tire Mounted Wheel Excavator Digs and Loads 500 Yards per Hour. V. 25, No. 9, September 1963, p. 35.
103. Monaghan, John O. New Developments in Earthmoving. Part 2: Wheel Excavators. Const. Mat. and Equipt., v. 47, No. 2, February 1965, pp. 1-11.
104. Morgan, B. V. Materials Handling in the Extractive Earthmoving Industries. Min. and Min. Eng., v. 3, No. 11, November 1967, pp. 410-421.
105. Naef, Ernest. Athabasca Tar Sands Yield at Last. Canadian Min. J., v. 88, No. 11, November 1967, pp. 49-50.
106. Nelson, A. Mining Brown Coal in Australia. Coll. Guard., v. 206, No. 5323, Apr. 25, 1963, pp. 502-508.
107. Nichols, Herbert L., Jr. Ch. 14 in Moving the Earth--The Workbook of Excavation. New Castle Books, Greenwich, Conn., January 1967, pp. 29-35.
108. Peurifoy, R. L. Construction, Planning, Equipment, and Methods. McGraw-Hill Book Co., Inc., New York, 1956, 534 pp.
109. Price, George C. Bucket-Wheel Excavator. A Literature Survey. BuMines Int. Rept. 20 pp. Available at the Bureau of Mines, 4800 Forbes Avenue, Pittsburgh, Pa.
110. Pundari, N. Let's Take a Look at Surface Mine Haulage Developments. Coal Min. and Processing, v. 4, No. 12, December 1967, pp. 26-29.
111. Rasper, Ludwig Von Dr. Ing. (The Development of Bucket-Wheel Excavators in Germany.) Braunkohle, Wärme und Energie, v. 7, No. 19/20, October 1955, pp. 429-441.
112. \_\_\_\_\_. (Present Stage of the Development of Bucket Wheel Excavators in the German Federal Republic.) Braunkohle, Wärme und Energie, v. 16, No. 11, November 1964, pp. 457-471.
113. \_\_\_\_\_. (First Daring Attempt To Work Oil Sands on the Athabasca River by the Great Canadian Oil Sands Limited.) Braunkohle, Wärme und Energie, v. 19, No. 6, June 1967, pp. 193-200.
114. Rasper, Ludwig Von Dr. Ing., and H. R. Ritter. Exploiting the Neyveli Lignite With Bucket-Wheel Excavators. Min. J., Pt. I, v. 258, No. 6618, June 22, 1962, pp. 644-647; Pt. II, v. 258, No. 6619, June 29, 1962, pp. 666-667; Pt. III, v. 259, No. 6620, July 6, 1962, pp. 10-11.

115. Rodgers, H. C. G. Excavation Equipment for Brown Coal. Proc. Australian Inst. Min. and Met., No. 194, June 1960, pp. 127-249.
116. Roman, George H. United Electric's New Wheel Moves 1,250,000 Cubic Yards per Month. Coal Age, v. 73, No. 3, March 1968, pp. 62-69.
117. Rumfelt, Henry. Application and Performance of Wheel Excavators. Min. Cong. J., v. 47, No. 7, July 1961, pp. 46-49.
118. Schellhern, H. W. Some Aspects of High Capacity Production With Bucket-Wheel Excavators. Pres. at 2d Athabasca Oil Sands Conf., Oct. 30-31, 1963, Edmonton, Alberta, Canada. K. A. Clark Volume. Research Council of Alberta, Edmonton, 1963, pp. 157-170.
119. Schuster, Eberhard. A Report on the Installation of a Split Copper Roller Bearing on a Bucket-Wheel Dredger. Bergbautechnik, v. 15, No. 11, November 1965, pp. 603-606.
120. Singhal, R. K. Some Recent Development Trends for Surface Mining. Min. and Min. Eng., v. 3, No. 3, March 1967, pp. 99-108.
121. Snouffer, Richard D. High Speed Loading and Unloading of Bulk Ores. Min. Eng., v. 15, No. 7, July 1963, pp. 86-90.
122. Surken Company. Surken Mechanical Mole. 4 pp.
123. Trofimov, V. K. Use of a Static Model To Study the Discharge of Rock From the Buckets of a Rotary Excavator. Sov. Min. Sci., No. 3, May-June, 1966, pp. 306-309.
124. U.S. Army Engineering District (Omaha, Nebr.). Estimating Manual--Large Earthwork Projects--Wheel Excavator. Prepared for Nuclear Cratering Groupe, Livermore, Calif., May 1966, pp. 66-110.
125. Utterbach, G. H. Deep Stripping in Future in Illinois. Proc. Illinois Min. Inst., 1959, pp. 68-76.
126. Venktaramani, R. Computer Simulation of Bucket-Wheel Excavators. Grad. Min. Seminar, The Pennsylvania State Univ., Dept. of Mining, Jan. 25, 1968. 104 pp.
127. Vladimirov, V. M. Choice of Relative Cutting Forces in Calculations of the Principal Drive Powers of Rotary Bucket-Wheel Excavators of Various Sizes. Sov. Min. Sci., No. 6, November-December 1966, pp. 584-590.
128. Vladimirov, V. M., V. P. Senchvrov, and R. S. Shmerkovich. Improving the Accuracy of Calculations of the Drive Power for a Rotary Excavator. Sov. Min. Sci., No. 2, March-April 1966, pp. 189-193.

129. Vladimirov, V. M., G. I. Sitkarev, and L. L. Khazanet. Determining the Design Characteristics of the Working Part of a Bucket-Wheel Excavator. Sov. Min. Sci., No. 3, May-June 1966, pp. 301-305.
130. Walter, Leo. Mechanization in Strip Mining of Coal in the U.S.A. Coll. Eng., v. 37, April 1960, pp. 138-145.
131. \_\_\_\_\_. Opencast Mining in Czechoslovakia. Coll. Guard., v. 210, June 27, 1963, pp. 770-774.
132. \_\_\_\_\_. German Lignite Industry Mechanizes Coal Min. and Processing, v. 1, No. 10, October 1964, pp. 24-27.
133. \_\_\_\_\_. What's New in European Mining Equipment--Part 2. Coal Min. and Processing, v. 3, No. 4, April 1966, pp. 38-42.
134. Weimer, W. A. Recent and Future Stripping Machines and Methods in Illinois. Proc. Illinois Min. Inst., 1956, pp. 37-50.

## APPENDIX A.--COMPUTER PROGRAM

## 80-80 LISTING

```

C      THE BUCKET WHEEL EXCAVATOR SIMULATOR                                MN000000
C                                                                 MN000010
C      THE SIMULATION PROGRAM CONSISTS OF THREE PROGRAM                   MN000020
C      UNITS - A MAIN PROGRAM AND TWO SUBROUTINES. SUBROUTINE           MN000030
C      BENCUT SIMULATES THE BENCH CUT AND THE SUBROUTINE                MN000040
C      FALCUT SIMULATES THE DROP CUT.                                    MN000050
C                                                                 MN000060
C      THE MAIN PROGRAM                                                  MN000070
C                                                                 MN000080
C*****                                                                    MN000090
C***** THE DIMENSION OF EACH ARRAY IN THE FOLLOWING BLOCK MUST BE OF   MN000100
C***** THE FORM (I,J), WHERE I IS AT LEAST N1+1 AND J IS AT LEAST     MN000110
C***** GREATER BY 1 THAN THE MAXIMUM NUMBER OF BENCHES IN A SECTION.  MN000120
C*****                                                                    MN000130
COMMON ACP(10,10),      CTIME(10,10),  DHEIT(10,10),  DLEN(10,10),  MN000140
1      HPKWH(10,10),    HPSMPD(10,10),  HPTPD(10,10),  HSKWH(10,10),  MN000150
2      HTKWH(10,10),    KWSMPD(10,10),  KWTPD(10,10),  MN000160
3      LTYPE(10,10),    MATL(10,10),    PGRADE(10,10),  PRUB(10,10),  MN000170
4      RTDIGP(10,10),   RTKWH(10,10),   SDHEIT(10,10),  SHEIT(10,10),  MN000180
5      SLEN(10,10),     SMISC(10,10),    SMPD(10,10),    STUCT(10,10),  MN000190
6      TADV(10,10),     TEM(10,10),     TIME(10,10),    TOTAL(10,10),  MN000200
7      TPU(10,10),     TPKWH(10,10),    TRAMP(10,10),   TRAMT(10,10),  MN000210
8      TRAVT(10,10),   TSKWH(10,10),    TSLEP(10,10),   TTIME(10,10),  MN000220
9      WIDTH(10,10)                                           MN000230
C                                                                 MN000240
C***** THE DIMENSION (N) OF EACH ARRAY IN THE FOLLOWING BLOCK MUST BE  MN000250
C***** AT LEAST THE NUMBER OF CUTS (MOUND) THAT THE EXCAVATOR WILL     MN000260
C***** MAKE. MOUND IS CALCULATED BY SUMMING (MSLEN(I)/REACH + 1),      MN000270
C***** WITH I INCREMENTALLY VARYING FROM 1 TO N1. MSLEN(I) IS THE     MN000280
C***** MAXIMUM SLEN(I,J) IN THE I*TH SECTION.                          MN000290
C*****                                                                    MN000300
COMMON RKPOT(500),      RTPOT(500)                                  MN000310
C                                                                 MN000320
C***** THE DIMENSION OF EACH ARRAY IN THE FOLLOWING BLOCK MUST BE AT   MN000330
C***** LEAST EQUAL TO N1.                                              MN000340
C*****                                                                    MN000350
COMMON GRADE(10),      HT(10),          NUM(10),          RJRI(10),    MN000360
1      VINC(10)                                               MN000370
C                                                                 MN000380
C***** THE DIMENSION OF EACH ARRAY IN THE FOLLOWING BLOCK MUST BE AT   MN000390
C***** LEAST EQUAL TO KS.                                              MN000400
C*****                                                                    MN000410
COMMON BUCFIL(50),     DIGMIN(50),     DIGMAX(50),     RPM(50)      MN000420
C*****                                                                    MN000430
C                                                                 MN000440
COMMON BWID,           KS,             KMAX,           N1,           CLB,           SMINL,    RANGLE,    MN000450
1LANGLE, USS,         SL,             DWM,           CS,           CUMTIM,   DTIME,    SETTIM,    MN000460
2CDNV,  SPGR,         GRAV,          DIA,          NUB,           CUB,      BID,      LUT,       MN000470
3WS,    RS,           FRS,          ALPHA,        RADV,        TBACK,    SETT,     ISECT,     MN000480
4ISET,  TANGLE,       KUUNT,        TTIK,        ETIK,        TADVAN,   Kb,       NDDA,     MN000490
5MATL,  TDIS,         TGTIM,        LEND,        REND,        VMAX,     FRIFOR,   TIKNES,   MN000500
6METHOD, REACH,       SLEKWM,      DIGKWM,      MOUND,      ANITA     MN000510

```

REAL NOB,LOT,MATL,LANGLE,LEND,KWTPQ,KWSMPQ	MN000520
INTEGER DIGMIN,DIGMAX	MN000530
LOGICAL*1 STYPE(10,10,10)	MN000540
DIMENSION MODEL(8)	MN000550
DIMENSION BWE(10)	MN000560
C	MN000570
C DATA IS BEING READ READ IN.	MN000580
C	MN000590
READ 10,N	MN000600
10 FORMAT (8I10)	MN000610
C	MN000620
C SIMULATE ALL THE WHEELS.	MN000630
C	MN000640
DO 255 KL=1,N	MN000650
READ 12,(MODEL(I),I=1,8)	MN000660
12 FORMAT(8I10)	MN000670
C	MN000680
C MINING DIMENSIONS	MN000690
C	MN000700
READ 15,N1,(NUM(I),GRADE(I),RORI(I),I=1,N1)	MN000710
15 FORMAT (I10/(3(I5,2F10.5)))	MN000720
SMINL=0.0	MN000730
DO 30 I=1,N1	MN000740
K=NUM(I)	MN000750
DO 30 J=1,K	MN000760
READ 20,PRUB(I,J),LTYPE(I,J)	MN000770
20 FORMAT (F10.2,I10)	MN000780
READ 25,(STYPE(I,J,L),L=1,10)	MN000790
25 FORMAT (80A1)	MN000800
30 CONTINUE	MN000810
N2=N1+1	MN000820
DO 45 I=1,N1	MN000830
K=NUM(I)	MN000840
READ 40,(SLEN(I,J),SHEIT(I,J),J=1,K)	MN000850
SMINL=SMINL+SLEN(I,K)	MN000860
IF (I-N1) 45,35,45	MN000870
35 READ 40,(SHEIT(N2,J),J=1,K)	MN000880
40 FORMAT (8F10.2)	MN000890
45 CONTINUE	MN000900
READ 95,ALPHA	MN000910
95 FORMAT(F10.2)	MN000920
C	MN000930
C SOIL CHARACTERISTICS	MN000940
C	MN000950
READ 50,KS,KMAX	MN000960
50 FORMAT (2I10)	MN000970
READ 70,(BUCFIL(I),RPM(I),VINC(I),DIGMIN(I),DIGMAX(I),I=1,KS)	MN000980
70 FORMAT(3F10.2,2I10)	MN000990
C	MN001000
C WHEEL SPECIFICATIONS	MN001010
C	MN001020
READ 55,(BWE(I),I=1,10)	MN001030
55 FORMAT (80A1)	MN001040
READ 60,CLB,REACH	MN001050
60 FORMAT (8F10.2)	MN001060

SREACH=REACH	MN001070
XREXN=REACH	MN001080
READ 65,RANGLE,LANGLE,USS,SL	MN001090
65 FORMAT (8F10.2)	MN001100
BWID=CLB*(SIN(RANGLE)+SIN(LANGLE))	MN001110
READ 75,UWM,CS	MN001120
75 FORMAT (8F10.2)	MN001130
READ 85,DIA,NUB,CUB	MN001140
85 FORMAT (8F10.2)	MN001150
READ 90,WS,RS,FRS	MN001160
90 FORMAT (8F10.2)	MN001170
C	MN001180
C OTHER INPUT DATA - CONVERSION FACTOR,EFFICIENCY ETC.	MN001190
C	MN001200
READ 80,CUMTIM,DTIME,SETTIM,CONV,SPGR,GRAV	MN001210
80 FORMAT (8F10.2)	MN001220
READ 100,EFFM,EFFE	MN001230
100 FORMAT (8F10.2)	MN001240
C	MN001250
C CALCULATE AVERAGE BENCH HEIGHT AND BENCH GRADES	MN001260
C	MN001270
DO 115 I=1,N1	MN001280
K=NUM(I)	MN001290
DO 115 J=1,K	MN001300
AVERHT=(SHEIT(I,J)+SHEIT(I+1,J))/2.	MN001310
WIDTH(I,J)=AVERHT/SL	MN001320
PGRADE(I,J) = (SHEIT(I,J) - SHEIT(I+1,J))/SLEN(I,J)	MN001330
0115 CONTINUE	MN001340
C	MN001350
C MAXIMUM LIMITS OF THE WHEEL	MN001360
C	MN001370
VMAX=SQRT(0.5*GRAV*DIA)	MN001380
XF1=(VMAX*60./(3.1416*DIA))*0.7	MN001390
THCP=COB*NUB*XF1*60.	MN001400
TONS=THCP*SPGR/1000.	MN001410
FRIFOR=FRS*WS*RS/CLB	MN001420
ANITA=(1./EFFM)*(1./EFFE)	MN001430
DO 254 MOD = 1,8	MN001440
IF (MODEL(MOD) .EQ. 0) GO TO 255	MN001450
REACH=SREACH	MN001460
XREXN=SREACH	MN001470
C	MN001480
C INITIALIZATION OF THE VARIABLES AND ARRAYS.	MN001490
C	MN001500
RADV=0.0	MN001510
TBACK=0.0	MN001520
SETT=0.0	MN001530
ISECT=1	MN001540
ISET=0	MN001550
TANGLE=0.0	MN001560
KOUNT=0	MN001570
TTIK=0.0	MN001580
ETIK=0.0	MN001590
TADVAN=0.0	MN001600
KB=0	MN001610

NODA=0	MN001620
SMAXI=0.0	MN001630
TMATL=0.0	MN001640
TDIS=0.0	MN001650
TUTIM=0.0	MN001660
DO 110 I=1,N1	MN001670
K=NUM(I)	MN001680
DO 110 J=1,K	MN001690
TIME(I,J)=0.0	MN001700
TADV(I,J)=0.0	MN001710
STUCT(I,J)=0.0	MN001720
CTIME(I,J)=0.0	MN001730
RTDIGP(I,J)=0.0	MN001740
MATL(I,J)=0.0	MN001750
TSLEP(I,J)=0.0	MN001760
TRAMP(I,J)=0.0	MN001770
TTIME(I,J)=0.0	MN001780
TRAVT(I,J)=0.0	MN001790
TPU(I,J)=0.0	MN001800
SMPU(I,J)=0.0	MN001810
TRAMT(I,J)=0.0	MN001820
TOTAL(I,J)=0.0	MN001830
SMISC(I,J)=0.0	MN001840
110 CONTINUE	MN001850
IMOD=MODEL(MOD)	MN001860
GO TO (101,102,103), IMOD	MN001870
101 CALL BENCUT	MN001880
PRINT 105	MN001890
GO TO 165	MN001900
102 METHOD = 1	MN001910
CALL FALCUT	MN001920
XREXN=REACH	MN001930
PRINT 106	MN001940
GO TO 165	MN001950
103 METHOD=0	MN001960
CALL FALCUT	MN001970
XREXN=REACH	MN001980
PRINT 107	MN001990
105 FORMAT('1',T47,'LATERAL CUT TECHNIQUE USED')	MN002000
106 FORMAT('1',T48,'DROP CUT TECHNIQUE USED')	MN002010
107 FORMAT('1',T41,'DROP CUT WITH INITIAL LATERAL CUT USED')	MN002020
165 TPMAX=0.0	MN002030
C	MN002040
C	MN002050
C	MN002060
DIGKWM=DIGKWM*ANITA	MN002070
SLEKWM=SLEKWM*ANITA	MN002080
DO 180 I=1,N1	MN002090
K=NUM(I)	MN002100
DO 180 J=1,K	MN002110
IF (TTIME(I,J).EQ.0.0)GO TO 181	MN002120
TIME(I,J)=TIME(I,J)/3600.	MN002130
TTIME(I,J)=TTIME(I,J)/3600.	MN002140
TRAVT(I,J)=TRAVT(I,J)/3600.	MN002150
STUCT(I,J)=STUCT(I,J)/3600.	MN002160

```

TRAMT(I,J)=TRAMT(I,J)/3600.
CTIME(I,J)=CTIME(I,J)/3600.
TOTAL(I,J)=CTIME(I,J)+TRAMT(I,J)+TRAVT(I,J)+TTIME(I,J)
SMISC(I,J)=TIME(I,J)-TOTAL(I,J)
RTDIGP(I,J)=RTDIGP(I,J)/CONV*ANITA
TSLEP(I,J)=TSLEP(I,J)/CONV*ANITA
TRAMP(I,J)=TRAMP(I,J)/CONV*ANITA
TPU(I,J)=TPU(I,J)/CONV*ANITA
SMPU(I,J)=SMPU(I,J)/CONV*ANITA
RTKWH(I,J)=RTDIGP(I,J)/CTIME(I,J)
HPKWH(I,J)=RTKWH(I,J)*1.34
TSKWH(I,J)=TSLEP(I,J)/CTIME(I,J)
HSKWH(I,J)=TSKWH(I,J)*1.34
TPKWH(I,J)=TRAMP(I,J)/TTIME(I,J)
HTKWH(I,J)=TPKWH(I,J)*1.34
IF (TRAVT(I,J)) 2,1,2
1 KWTPO(I,J) = 0
  GO TO 5
2 KWTPO(I,J)=TPU(I,J)/TRAVT(I,J)
5 IF (TPMAX-KWTPO(I,J)) 170,175,175
170 TPMAX = KWTPO(I,J)
175 HPTPO(I,J)=KWTPO(I,J)*1.34
  IF (TRAMT(I,J)) 4,3,4
3 KWSMPU(I,J) = 0
  GO TO 6
4 KWSMPU(I,J)=SMPU(I,J)/TRAMT(I,J)
6 HPSMPU(I,J)=KWSMPU(I,J)*1.34
130 CONTINUE
161 TIMM=TUTIM/3600.
C
C   SIMULATION IS COMPLETE AND RESULTS ARE PRINTED OUT.
C
  PRINT 120
120 FORMAT ('0',T45,'RESULTS OF THE BWE SIMULATION')
  PRINT 125,(BWE(I),I=1,10)
125 FORMAT ('0',T55,10A1)
  NXN=NUB
  PRINT 130,DIA,NXN,CUB,XREKN
130 FORMAT('0',T50,'WHEEL SPECIFICATIONS'//T20,'WHEEL DIA'
1      ,T60,F5.2,2X,'METERS'/T20,'NUMBER OF BUCKETS',T61
2,13/T20,'BUCKET CAPACITY',T60,F5.2,2X,'CU,MTS'/
3T20,'CUT LENGTH',T60,F5.2,2X,'METERS'//)
  PRINT 135
135 FORMAT('0',T50,'MINING PROFILE'//T20,'MATERIAL TYPE & #',
1T41,'SP.CUT.RESIS',T60,'START HEIGHT',T75,'FINISH HEI'
1'GHT',T100,'SECTION LENGTH',T120,'SLOPE'/T45,'RANGE'//)
  DO 140 I=1,N1
  K=NUM(I)
  L=1
  M1=I+1
  DO 140 J=1,K
  IA=LTYPE(I,J)
140 PRINT 145, I,J,(STYPE(I,J,LL),LL=1,10),IA,DIGMIN(IA),DIGMAX(IA),
1SHEIT(I,J),SHEIT(M1,J),SLEN(I,J),PGRADE(I,J)
145 FORMAT(' ',T5,'SEC',12,2X,'BENCH',12,T21,10A1,15,T41,14,

```

```

MN002170
MN002180
MN002190
MN002200
MN002210
MN002220
MN002230
MN002240
MN002250
MN002260
MN002270
MN002280
MN002290
MN002300
MN002310
MN002320
MN002330
MN002340
MN002350
MN002360
MN002370
MN002380
MN002390
MN002400
MN002410
MN002420
MN002430
MN002440
MN002450
MN002460
MN002470
MN002480
MN002490
MN002500
MN002510
MN002520
MN002530
MN002540
MN002550
MN002560
MN002570
MN002580
MN002590
MN002600
MN002610
MN002620
MN002630
MN002640
MN002650
MN002660
MN002670
MN002680
MN002690
MN002700
MN002710

```

```

12X,I4,T60,F9.2,T75,F9.2,T100,F8.2,T120,F6.2) MN002720
PRINT 150,BWID,SMINL MN002730
150 FORMAT('0',T20,'WIDTH OF THE BLOCK',T60,F6.0,4X,'METE' MN002740
2'RS'/T20,'PIT ADVANCE ',T60,F6.0,4X,'METERS'//) MN002750
136 FORMAT('1'/T55,'MATERIAL DESCRIPTION'//T25,'MATERIAL TYPE #',T45, MN002760
1'BUCKET',T55,'FRAC MAX',T65,'SWELL',T75,'CUTTING RESISTANCE'/
2T45,'FILL',T55,'CUT SP.',T65,'FACTOR',T75,'MIN',T85,'MAX'//) MN002770
PRINT 136 MN002780
137 FORMAT(T25,I10,4X,3F10.2,2I10) MN002790
PRINT 137, (I,BUCFIL(I),RPM(I),VINC(I),DIGMIN(I),DIGMAX(I),I=1,KS) MN002800
PRINT 400 MN002810
400 FORMAT ('1',T40,'POWER AND TIME STUDY FOR EACH CUT'//) MN002820
DO 761 KR=1,MOUND MN002830
PRINT 750,KR,RTPOT(KR),RKPUT(KR) MN002840
750 FORMAT(' ',T35,'CUT',2X,I3,5X,'TIME',2X,F5.1,2X, MN002850
1'HOURS',5X,'POWER',2X,F5.0,2X,'KWH') MN002860
761 CONTINUE MN002870
PRINT 185 MN002880
185 FORMAT('1',T50,'TIME STUDY'/T25,'MACHINE SOIL INTER' MN002890
1'FACE',T75,'MACHINE POSITIONING'/T29,'CUT',T40,'CROWD' MN002900
2,T52,'DELAY',T67,'MANEUVER',T85,'TRAM',T98,'TOTAL'//) MN002910
DO 190 I=1,N1 MN002920
K=NUM(I) MN002930
DO 190 J=1,K MN002940
190 PRINT 195,I,J,CTIME(I,J),TTIME(I,J),STUCT(I,J), MN002950
ITRAMT(I,J),TRAVT(I,J),TOTAL(I,J) MN002960
195 FORMAT(' ',T8,'SEC',I2,2X,'BENCH',I2,T25,F10.2,T36, MN002970
1F10.2,T47,F10.2,T64,F10.2,T79,F10.2,T93,F10.2) MN002980
PRINT 200,TIMM MN002990
200 FORMAT('0',T20,'TOTAL SIMULATION TIME',T45,F10.2,2X, MN003000
1'HOURS') MN003010
PRINT 205 MN003020
205 FORMAT('1',T50,'POWER CONSUMPTION'//T46,'CUTTING',T90, MN003030
1'POSITIONING'//T24,'CUT',T43,'CROWD',T63,'SLEW',T80, MN003040
2'MANEUVER',T101,'TRAM'/T24,'KWH',T44,'KWH',T64,'KWH', MN003050
3T83,'KWH',T105,'KWH'//) MN003060
DO 210 I=1,N1 MN003070
K=NUM(I) MN003080
DO 210 J=1,K MN003090
210 PRINT 215,I,J,RTDIGP(I,J),TRAMP(I,J),TSLEP(I,J), MN003100
1SMPD(I,J),TPD(I,J) MN003110
215 FORMAT(' ',T8,'SEC',I2,1X,'BENCH',I2,T23,F6.0,T43,F5.0, MN003120
1T63,F5.0,T83,F5.0,T103,F5.0) MN003130
PRINT 220,DIGKWM,SLEKWM,TPMAX MN003140
220 FORMAT('0',T20,'KW RATING OF THE DIGGING MOTOR',T60, MN003150
1F6.0/T20,'KW RATING OF THE SLEW MOTOR',T60,F6.0/T20, MN003160
2'KW RATING OF THE CRAWLER MOTORS',T60,F6.0//) MN003170
DO 225 I=1,N1 MN003180
K=NUM(I) MN003190
DO 225 J=1,K MN003200
TMATL=TMATL+MATL(I,J) MN003210
225 CONTINUE MN003220
AVER=TMATL/TIMM MN003230
PRINT 230,TMATL,NODA MN003240
230 FORMAT('1',T50,'PRODUCTION STUDY'//T20,'MATERIAL EXC' MN003250
MN003260

```

1'AVATED',T60,F10.0,2X,'CU.MTS'/T20,'NUMBER OF BUCKET'	MN003270
2' DISCHARGES',T54,I15)	MN003280
PRINT 235,THCP,AVER	MN003290
235 FORMAT('0',T20,'THEORETICAL CAPACITY IN CUBIC METERS'	MN003300
1' PER HOUR',F9.0/T20,'AVERAGE CAPACITY IN CUBIC'	MN003310
2' METERS PER HOUR',3X,F9.0)	MN003320
DO 250 I=1,N1	MN003330
K=NUM(I)	MN003340
DO 245 J=1,K	MN003350
PRINT 240,I,J,ACP(I,J)	MN003360
240 FORMAT(' ',T20,'SECTION',I3,2X,'BENCH',I3,T50,'ACTUAL'	MN003370
1' CAPACITY',F10.0)	MN003380
245 CONTINUE	MN003390
250 CONTINUE	MN003400
254 CONTINUE	MN003410
255 CONTINUE	MN003420
STOP	MN003430
END	MN003440

CARDS LISTED 345

## 80-80 LISTING

```

SUBROUTINE BENCUT
COMMON ACP(10,10),      CTIME(10,10),  DHEIT(10,10),  DLEN(10,10),  BEN00000
1   HPKWH(10,10),  HPSMPO(10,10),  HPTPO(10,10),  HSKWH(10,10),  BEN00010
2   HTKWH(10,10),  KWSMPO(10,10),  KWTPO(10,10),  BEN00020
3   LTYPE(10,10),  MATL(10,10),  PGRADE(10,10),  PROB(10,10),  BEN00030
4   RTDIGP(10,10),  RTKWH(10,10),  SDHEIT(10,10),  SHEIT(10,10),  BEN00040
5   SLEN(10,10),  SMISC(10,10),  SMPO(10,10),  STUCT(10,10),  BEN00050
6   TADV(10,10),  TEM(10,10),  TIME(10,10),  TOTAL(10,10),  BEN00060
7   TPO(10,10),  TPKWH(10,10),  TRAMP(10,10),  TRAMT(10,10),  BEN00070
8   TRAVT(10,10),  TSKWH(10,10),  TSLEP(10,10),  TTIME(10,10),  BEN00080
9   WIDTH(10,10)
COMMON RKPUT(500),      RTPOT(500)
COMMON GRADE(10),      HT(10),          NUM(10),          RORI(10),  BEN00090
1  VINC(10)
COMMON BUCFIL(50),      DIGMIN(50),      DIGMAX(50),      RPM(50)  BEN00100
COMMON BWID,  KS,      KMAX,  N1,      CLB,  SMINL,  RANGLE,  BEN00110
1L ANGLE,  USS,  SL,  OWM,  CS,  CUMTIM,  DTIME,  SETTIM,  BEN00120
2C UNV,  SPGR,  GRAV,  DIA,  NOB,  CUB,  BID,  LOT,  BEN00130
3WS,  RS,  FRS,  ALPHA,  RADV,  TBACK,  SETT,  ISECT,  BEN00140
4ISET,  TANGLE,  KOUNT,  TTIK,  ETIK,  TADVAN,  KB,  NQDA,  BEN00150
5TMATL,  TDIS,  TOTIM,  LEND,  REND,  VMAX,  FRIFOR,  TIKNES,  BEN00160
6METHOD,  REACH,  SLEKWM,  DIGKWM,  MOUND,  ANITA  BEN00170
REAL NOB,LOT,MATL,LANGLE,LEND,KWTPU,KWSMPO  BEN00180
INTEGER DIGMIN,DIGMAX  BEN00190
LOGICAL FNSHSN,TRMNTG  BEN00200
FNSHSN = .FALSE.  BEN00210
TRMNTG = .FALSE.  BEN00220
SLEKWM=0  BEN00230
DIGKWM=0.0  BEN00240
M1=1  BEN00250
KKR=0  BEN00260
WMINED=0.0  BEN00270
MOUND=0  BEN00280
RTIME=0.0  BEN00290
RPOWER=0.0  BEN00300
IXZ=19  BEN00310
IXZ1=17  BEN00320
IYZ=IXZ  BEN00330
IYZ1=IXZ1  BEN00340
C  BEN00350
C  SIMULATE ALL THE BENCHES IN ALL THE SECTIONS.  BEN00360
C  BEN00370
405 K=NUM(M1)  BEN00380
DO 765 J=1,K  BEN00390
BLOT=0.0  BEN00400
I = M1  BEN00410
407 HTINST=SHEIT(I,J)-PGRADE(I,J)*TADV(I,J)  BEN00420
C  BEN00430
C  CALCULATE TEMPORARY VALUES TO BE USED FOR TIME AND POWER  BEN00440
C  CALCULATIONS LATER.  BEN00450
C  BEN00460
TEMP3 = OWM*(RORI(I) + 0.02*GRADE(I))  BEN00470
BEN00480
BEN00490
BEN00500
BEN00510

```

```

TEMP4 = 2*(WIDTH(I,J) + WIDTH(I,J-1))
TEMP5 = TEMP4/CS
TEMP6 = TEMP5 + SETTIM
IA=LTYPE(I,J)
C
C THE SOIL CHARACTERISTICS ARE INITIALIZED.
C
410 BCOB=BUCFIL(IA)*COB*VINC(IA)
CSPEED=VMAX*RPM(IA)
XF=CSPEED*60./(3.1416*DIA)
420 ACP(I,J)=BCOB*NOB*XF*60.
TIKNES=0.133*SQRT(ACP(I,J)/((DIA/2)*XF*NOB))
IF(.NOT. TRMNTG) GO TO 421
IF (TIKNES .LE. SN) GO TO 421
TIKNES=SN
421 SN=TIKNES
TIKMIN=BCOB/(HTINST*CLB)
BETANG=(6.2832/NOB)
NNBID=1.5708/BETANG
C
C CALCULATION OF CUTTER LENGTH IN THE BENCH
C
DD 430 II=1,100
IF (NNBID-II) 435,425,425
425 BL0T=BL0T+2.*TIKNES*(COS(BETANG*II))
430 CONTINUE
435 PET=CLB/TIKNES
LEND=TIKNES*COS(LANGLE)
REND=TIKNES*COS(RANGLE)
BKTSPA=3.1416*DIA/NOB
BAT=BKTSPA/CSPEED
SBDTH=BCOB/(HTINST*TIKNES)
C
C PASSAGE OF A BUCKET THROUGH THE SOIL SIMULATED.
C
440 IXZ=IYZ
CALL RANDU(IXZ,IYZ,XE)
CUTRES=DIGMIN(IA) + (DIGMAX(IA)-DIGMIN(IA))*XE
C
C CHECK FOR BOULDERS AND CALC. DOWN TIME IF STRUCK
C
IXZ1=IYZ1
CALL RANDU(IXZ1,IYZ1,XX)
XX=XX*100.
IF (XX-PROB(I,J)) 445,445,450
445 TIME(I,J)=TIME(I,J)+DTIME
RTIME=RTIME+DTIME
KB=KB+1
STUCT(I,J)=STUCT(I,J)+DTIME
TOTIM=TOTIM+DTIME
C
C ACCUMULATE TIME AND NUMBER OF PASSAGES
C
450 TIME(I,J)=TIME(I,J)+BAT
RTIME=RTIME+BAT

```

```

BEN00520
BEN00530
BEN00540
BEN00550
BEN00560
BEN00570
BEN00580
BEN00590
BEN00600
BEN00610
BEN00620
BEN00630
BEN00640
BEN00650
BEN00660
BEN00670
BEN00680
BEN00690
BEN00700
BEN00710
BEN00720
BEN00730
BEN00740
BEN00750
BEN00760
BEN00770
BEN00780
BEN00790
BEN00800
BEN00810
BEN00820
BEN00830
BEN00840
BEN00850
BEN00860
BEN00870
BEN00880
BEN00890
BEN00900
BEN00910
BEN00920
BEN00930
BEN00940
BEN00950
BEN00960
BEN00970
BEN00980
BEN00990
BEN01000
BEN01010
BEN01020
BEN01030
BEN01040
BEN01050
BEN01060

```

```

NODA=NODA+1
CTIME(I,J)=CTIME(I,J)+BAT
TOTIM=TOTIM+BAT
TTTR=(1.5708+ATAN((HTINST-DIA/2.)/(DIA/2.)))
NBID=(TTTR/6.2832)*NOB+0.5
ALOT=2.*TIKNES*(NBID-NNBID)
LOT=(BLOT+ALOT)*100.
C
C ACCUMULATE POWER
C
DIGP=CUTRES*LOT*BKTSPA
RISP=BCOB*SPGR*DIA
RPOWER=RPOWER+RISP+DIGP
TOTPER=DIGP+RISP
DIGKW=(TOTPER/CONV)*(1./BAT)*3600.
IF (DIGKW-DIGKWM) 460,460,455
0455 DIGKWM = DIGKW
460 RTDIGP(I,J)=RTDIGP(I,J)+DIGP+RISP
MATL(I,J)=MATL(I,J)+BCOB
IF (TOTIM-CUMTIM) 465,770,770
C
C CALCULATE SLEWING POWER
C
465 DIST=SBDTH
SLP=DIST/BAT
IF (SLP-USS) 480,480,475
475 SLP=USS
480 IF (DIST .LE. CLB) GOTO 481
C
C CHECK FOR ROUND OFF DISCREPANCIES IN CALCULATION OF DIST
C
IF (DIST-CLB .LE. 0.001) GO TO 484
LABEL=480
482 PRINT 483,LABEL
CALL PDUMP(DLEN(1,1),DLEN(10,10),5,TADV(1,1),TADV(10,10),5,
IBWID,ANITA,5,BWID,ANITA,4, FNSHSN,TEMP1,5,FNSHSN,TEMP1,4)
RETURN
483 FORMAT(' BENCUT TERMINATED ABNORMALLY AT ',I5)
484 DIST=CLB
481 ANGLE=ARSIN(DIST/CLB)
DIST=SLP*BAT
TANGLE=TANGLE+ANGLE
SLEP=(CUTRES*LOT*SLP/CSPEED+FRIFOR)*DIST
RPOWER=RPOWER+SLEP
SLEKW=(SLEP/CONV)*(1./BAT)*3600.
IF (SLEKWM-SLEKW) 485,490,490
0485 SLEKWM=SLEKW
490 TSLEP(I,J)=TSLEP(I,J)+SLEP
C
C SELECT SLEWING DIRECTION
C CORRECT MATERIAL EXCAVATED FOR ANGLE
IF (ISET) 770,495,560
495 IF (ISECT) 770,520,500
500 IF (LANGLE-TANGLE) 510,515,505
C

```

```

BEN01070
BEN01080
BEN01090
BEN01100
BEN01110
BEN01120
BEN01130
BEN01140
BEN01150
BEN01160
BEN01170
BEN01180
BEN01190
BEN01200
BEN01210
BEN01220
BEN01230
BEN01240
BEN01250
BEN01260
BEN01270
BEN01280
BEN01290
BEN01300
BEN01310
BEN01320
BEN01330
BEN01340
BEN01350
BEN01360
BEN01370
BEN01380
BEN01390
BEN01400
BEN01410
BEN01420
BEN01430
BEN01440
BEN01450
BEN01460
BEN01470
BEN01480
BEN01490
BEN01500
BEN01510
BEN01520
BEN01530
BEN01540
BEN01550
BEN01560
BEN01570
BEN01580
BEN01590
BEN01600
BEN01610

```

C	WHEEL MOVING FROM LEFT TO RIGHT.	BEN01620
C		BEN01630
505	SNTIK=TIKNES*(COS(LANGLE-TANGLE)+((SIN(LANGLE-TANGLE) 1**2.)/(2.*PET)))	BEN01640
	SBDTH=BCOB/(HTINST*SNTIK)	BEN01650
	GO TO 440	BEN01660
C		BEN01670
510	D=TANGLE-LANGLE	BEN01680
	DIS=CLB*SIN(D)	BEN01690
	MATL(I,J)=MATL(I,J)-DIS*HTINST*SNTIK	BEN01700
515	TANGLE=0.0	BEN01710
	ISECT=0	BEN01720
	GO TO 440	BEN01730
C		BEN01740
520	IF (RANGLE-TANGLE) 530,535,525	BEN01750
525	SNTIK=TIKNES*(COS(TANGLE)+(SIN(TANGLE)**2.)/(2.*PET))	BEN01760
	SBDTH=BCOB/(HTINST*SNTIK)	BEN01770
	GO TO 440	BEN01780
C		BEN01790
530	D=TANGLE-RANGLE	BEN01800
	DIS=CLB*SIN(D)	BEN01810
	MATL(I,J)=MATL(I,J)-DIS*HTINST*SNTIK	BEN01820
535	SNTIK=REND	BEN01830
C		BEN01840
C	THE BWE IS CROWDED IN BY THICKNESS.	BEN01850
C		BEN01860
	ISET=1	BEN01870
	ISECT=1	BEN01880
536	TANGLE=0.0	BEN01890
	TADV(I,J)=TADV(I,J)+TIKNES	BEN01900
	RADV=RADV+TIKNES	BEN01910
	HTINST=SHEIT(I,J)-PGRADE(I,J)*TADV(I,J)	BEN01920
	IF (RADV-REACH) 540,650,537	BEN01930
C		BEN01940
C	CHECK IF REACH WAS EXCEEDED BY AN ACCEPTABLE AMOUNT	BEN01950
C		BEN01960
537	IF (TIKMIN+REACH .GE. RADV) GO TO 650	BEN01970
	LABEL = 537	BEN01980
	GOTO 482	BEN01990
540	IF (TADV(I,J) - SLEN(I,J)) 545,713,713	BEN02000
545	DIFF=REACH-RADV	BEN02010
	IF (DIFF-TIKNES) 550,555,555	BEN02020
550	SN=TIKNES	BEN02030
	IF (DIFF .LT. TIKMIN) DIFF=TIKMIN	BEN02040
	TIKNES=DIFF	BEN02050
555	TRAMP(I,J) = TRAMP(I,J) + TEMP3*TIKNES	BEN02060
	TIMINC= TIKNES/CS	BEN02070
	TTIME(I,J)= TIME(I,J) + TIMINC	BEN02080
	TIME(I,J) = TIME(I,J) + TIMINC	BEN02090
	TOTIM = TOTIM + TIMINC	BEN02100
	RTIME = RTIME + TIMINC	BEN02110
	RPOWER = RPOWER + TEMP3*TIKNES	BEN02120
	GO TO 440	BEN02130
C		BEN02140
C	WHEEL MOVING FROM RIGHT TO LEFT.	BEN02150
C		BEN02160

C		BEN02170
	560 IF (ISECT) 770,585,565	BEN02180
	565 IF (RANGLE-TANGLE) 575,580,570	BEN02190
	570 SNTIK=TIKNES*(COS(RANGLE-TANGLE)+((SIN(RANGLE-TANGLE)	BEN02200
	1**2.)/(2.*PET))	BEN02210
	SBDTH=BCOB/(HTINST*SNTIK)	BEN02220
C		BEN02230
	GO TO 440	BEN02240
	575 D=TANGLE-RANGLE	BEN02250
	DIS=CLB*SIN(D)	BEN02260
	MATL(I,J)=MATL(I,J)-DIS*HTINST*SNTIK	BEN02270
	580 TANGLE=0.0	BEN02280
	ISECT=0	BEN02290
	GO TO 440	BEN02300
	585 IF (LANGLE-TANGLE) 595,536,590	BEN02310
	590 SNTIK=TIKNES*(COS(TANGLE)+(SIN(TANGLE)**2.)/(2.*PET))	BEN02320
	SBDTH=BCOB/(HTINST*SNTIK)	BEN02330
	GO TO 440	BEN02340
	595 D=TANGLE-LANGLE	BEN02350
	DIS=CLB*SIN(D)	BEN02360
	MATL(I,J)=MATL(I,J)-DIS*HTINST*SNTIK	BEN02370
	SNTIK=LEND	BEN02380
	ISECT=0	BEN02390
	ISECT=1	BEN02400
	GO TO 536	BEN02410
C		BEN02420
C	A REACH HAS BEEN COMPLETED.	BEN02430
C		BEN02440
	0650 RADV=0.0	BEN02450
	TIKNES=SN	BEN02460
	IF (TADV(I,J)-SLEN(I,J)) 655,705,695	BEN02470
	655 IF (J-K) 710,675,770	BEN02480
	675 M1=I	BEN02490
	MOUND=MOUND+1	BEN02500
	RTPOT(MOUND)=RTIME/3600.	BEN02510
	RKPOT(MOUND)=RPOWER/CONV*ANITA	BEN02520
	RTIME=0.0	BEN02530
	RPOWER=0.0	BEN02540
	WMINED=WMINED+REACH	BEN02550
C		BEN02560
C	TEST FOR COMPLETING SIMULATION ALLOWS FOR ROUNDOFF ERROR	BEN02570
C		BEN02580
	IF (ABS(WMINED-SMINL) .LE. 0.001) RETURN	BEN02590
	IF (WMINED .GT. SMINL) GO TO 482	BEN02600
C		BEN02610
C	THE BWC MOVES FOR THE NEXT CUT.	BEN02620
C		BEN02630
	0755 TRAVT(I,J)=TRAVT(I,J)+TEMP5	BEN02640
	TIME(I,J) = TIME(I,J) + TEMP6	BEN02650
	TOTIME = TOTIME+ TEMP6	BEN02660
	TPU(I,J) = TPU(I,J) + TEMP3*TEMP4	BEN02670
	SETT=SETT+SETTIM	BEN02680
	IF (I-N1) 690,680,770	BEN02690
	0680 TEMP1 = SLEN(I,J) - TADV(I,J)	BEN02700
	IF (TEMP1 .GE. REACH) GO TO 405	BEN02710

0685	REACH = TEMP1	BEN02720
	IF (TIKNES .LE. REACH ) GO TO 405	BEN02730
	TRMNTG=.TRUE.	BEN02740
	IF (REACH-TIKMIN) 686,687,687	BEN02750
686	TIKNES=TIKMIN	BEN02760
	SN = TIKMIN	BEN02770
	REACH=TIKMIN	BEN02780
	GO TO 405	BEN02790
687	TIKNES=REACH	BEN02800
	SN=REACH	BEN02810
	GO TO 405	BEN02820
690	IF (.NOT. FNSHSN) GO TO 405	BEN02830
	FNSHSN=.FALSE.	BEN02840
	M1=I+1	BEN02850
	GO TO 405	BEN02860
0695	TADV(I+1,J) =TADV(I,J) - SLEN(I,J)	BEN02870
705	IF (J-K) 710,708,770	BEN02880
708	FNSHSN = .TRUE.	BEN02890
	GO TO 675	BEN02900
C		BEN02910
C	THE BWE MOVES TO NEXT BENCH.	BEN02920
C		BEN02930
0710	TEMP1 = (REACH + 2.*WIDTH(I,J))/CS	BEN02940
	TRAMT(I,J) = TRAMT(I,J) + TEMP1	BEN02950
	SETT = SETT + SETT1M	BEN02960
	TEMP1 = TEMP1 + SETT1M	BEN02970
	TIME(I,J) = TIME(I,J) + TEMP1	BEN02980
	TOTIME = TOTIM + TEMP1	BEN02990
	RTIME = RTIME + TEMP1	BEN03000
	TEMP1 = TEMP3*(REACH + 2.*WIDTH(I,J))	BEN03010
	SMPD(I,J) = SMPD(I,J) + TEMP1	BEN03020
	RPOWER = RPOWER + TEMP1	BEN03030
	GO TO 765	BEN03040
C		BEN03050
C	INTRUDED INTO THE NEXT SECTION	BEN03060
C		BEN03070
713	TADV(I+1,J) = TADV(I,J) - SLEN(I,J)	BEN03080
	DIFF = REACH-RADV	BEN03090
	IF (DIFF .GE. TIKNES) GOTO 715	BEN03100
	SN = TIKNES	BEN03110
	IF (DIFF .LT. TIKMIN) DIFF = TIKMIN	BEN03120
	TIKNES=DIFF	BEN03130
715	IF (I-N1) 725,720,770	BEN03140
720	IF (J-K) 710,765,770	BEN03150
0725	I = I + 1	BEN03160
	GO TO 407	BEN03170
765	CONTINUE	BEN03180
770	RETURN	BEN03190
	END	BEN03200

## 80-80 LISTING

```

SUBROUTINE FALCUT
COMMON ACP(10,10), CTIME(10,10), DHEIT(10,10), DLEN(10,10), FAL00000
1   HPKWH(10,10), HPSMPO(10,10), HPTPO(10,10), HSKWH(10,10), FAL00020
2   HTKWH(10,10), KWSMPO(10,10), KWTPD(10,10), FAL00030
3   LTYPE(10,10), MATL(10,10), PGRADE(10,10), PROB(10,10), FAL00040
4   RTDIGP(10,10), RTKWH(10,10), SDHEIT(10,10), SHEIT(10,10), FAL00050
5   SLEN(10,10), SMISC(10,10), SMPO(10,10), STUCT(10,10), FAL00060
6   TADV(10,10), TEM(10,10), TIME(10,10), TOTAL(10,10), FAL00070
7   TPD(10,10), TPKWH(10,10), TRAMP(10,10), TRAMT(10,10), FAL00080
8   TRAVT(10,10), TSKWH(10,10), TSLEP(10,10), TTIME(10,10), FAL00090
9   WIDTH(10,10) FAL00100
COMMON RKPOT(500), RTPOT(500) FAL00110
COMMON GRADE(10), HT(10), NUM(10), RORI(10), FAL00120
1  VINC(10) FAL00130
COMMON BUCFIL(50), DIGMIN(50), DIGMAX(50), RPM(50) FAL00140
COMMON BWID, KS, KMAX, NI, CLB, SMINL, RANGLE, FAL00150
1LANGLE, USS, SL, OWM, CS, CUMTIM, DTIME, SETTIM, FAL00160
2CONV, SPGR, GRAV, DIA, NOB, CUB, BID, LOT, FAL00170
3WS, RS, FRS, ALPHA, RADV, TBACK, SETT, ISECT, FAL00180
4ISET, TANGLE, KOUNT, TTIK, ETIK, TADVAN, KB, NDDA, FAL00190
5MATL, TDIS, TOTIM, LEND, REVD, VMAX, FRIFOR, TIKNES, FAL00200
6METHOD, REACH, SLEKWM, DIGKWM, MOUND, ANITA FAL00210
REAL NOB, LOT, MATL, LANGLE, LEND, KWTPD, KWSMPO FAL00220
INTEGER DIGMIN, DIGMAX FAL00230
SLEKWM=0 FAL00240
DIGKWM=0.0 FAL00250
RTIME=0.0 FAL00260
RPOWER=0.0 FAL00270
KADVA=0 FAL00280
SAV=0.0 FAL00290
IXZ=19 FAL00300
IXZ1=17 FAL00310
IYZ=IXZ FAL00320
IYZ1=IXZ1 FAL00330
C
C SIMULATE ALL THE BENCHES IN ALL THE SECTIONS. FAL00340
C FAL00350
DO 1135 I=1,NI FAL00370
STARAH=2./3.*DIA FAL00380
ADVAN=STARAH/SIN(ALPHA) FAL00390
REACH = ADVAN FAL00400
SADVAN=ADVAN FAL00410
KKK=0 FAL00420
VARAH=STARAH FAL00430
XCLB=CLB FAL00440
KOUNT=KOUNT+1 FAL00450
MOUNT=0 FAL00460
K=NUM(I) FAL00470
TEMP3 = OWM*(RORI(I)+0.02*GRADE(I)) FAL00480
610 DO 1130 J=1,K FAL00490
BL0T=0.0 FAL00500
C FAL00510

```

```

C     AVERAGE HEIGHT OF THE CUT TAKEN CALCULATED.
C
C     IF (KKK) 1140,615,635
615 SDHEIT(I,J)=SHEIT(I,J)-PGRADE(I,J)*TADVAN
625 SDHEIT(I+1,J)=SHEIT(I,J)-PGRADE(I,J)*(TADVAN+ADVAN)
630 DHEIT(I,J)=(SDHEIT(I,J)+SDHEIT(I+1,J))/2.
635 IF (J-K) 645,640,1140
640 KKK=0
645 MOUNT=MOUNT+1
     IA=LTYPE(I,J)
C
C     THE SOIL CHARACTERISTICS ARE INITIALIZED.
C
C     410 BCUB=BUCFIL(IA)*COB*VINC(IA)
     CSPEED=VMAX*RPM(IA)
     XF=CSPEED*60./(3.1416*DIA)
     ACP(I,J)=BCOB*NOB*XF*60.
     TIKNES=0.133*SQRT(ACP(I,J)/((DIA/2)*XF*NOB))
     LEND=TIKNES*COS(LANGLE)
     REND=TIKNES*COS(RANGLE)
660 SN=TIKNES
C
C     CALCULATION OF CUTTER LENGTH IN THE BENCH.
C
C     BETANG=(6.2832/NOB)
     NNBDID=1.5708/BETANG
     DO 670 II=1,100
     IF (NNBDID-II) 675,665,665
665 BLOT=BLOT+2.*TIKNES*(COS(BETANG*II))
670 CONTINUE
675 PET=CLB/ADVAN
     BKTSPA=3.1416*DIA/NOB
     BAT=BKTSPA/CSPEED
     VLEND=STARAH*(COS(LANGLE)+((SIN(LANGLE)**2.)/(2.*PET)))
     VREND=STARAH*(COS(RANGLE)+((SIN(RANGLE)**2.)/(2.*PET)))
     BDTH=BCOB/(DHEIT(I,J)*TIKNES)
     SBDTH=BDTH
     IF (METHOD-1) 680,685,680
680 IF (J-1) 1140,690,685
685 TTIK=DHEIT(I,J)/COS(1.5706-ALPHA)
     GU TO 895
690 TTIK=(DHEIT(I,J)-DIA/2.)/COS(1.5706-ALPHA)
C
C     TOP CUT TAKEN BY BENCH CUT.
C
C     LOT=BLOT*100.
     HEIT=DIA/2.
     IF (N1-1) 1140,725,700
700 IF (KOUNT-1) 1140,705,710
705 IF (MOUNT-1) 1140,720,725
710 IF (KOUNT-N1) 725,715,1140
715 IF (MOUNT-1) 1140,730,725
720 DCUTA=1.5*SADVAN
     GU TO 735
725 DCUTA=SADVAN

```

```

FAL00520
FAL00530
FAL00540
FAL00550
FAL00560
FAL00570
FAL00580
FAL00590
FAL00600
FAL00610
FAL00620
FAL00630
FAL00640
FAL00650
FAL00660
FAL00670
FAL00680
FAL00690
FAL00700
FAL00710
FAL00720
FAL00730
FAL00740
FAL00750
FAL00760
FAL00770
FAL00780
FAL00790
FAL00800
FAL00810
FAL00820
FAL00830
FAL00840
FAL00850
FAL00860
FAL00870
FAL00880
FAL00890
FAL00900
FAL00910
FAL00920
FAL00930
FAL00940
FAL00950
FAL00960
FAL00970
FAL00980
FAL00990
FAL01000
FAL01010
FAL01020
FAL01030
FAL01040
FAL01050
FAL01060

```

	GO TO 735	FAL01070
	730 DCUTA=0.5*SADVAN	FAL01080
C		FAL01090
C	CHECK FOR BOULDERS AND CALC. DOWN TIME IF STRUCK	FAL01100
C		FAL01110
	735 IXZ=IYZ	FAL01120
	CALL RANDU(IXZ,IYZ,XE)	FAL01130
	CUTRES=DIGMIN(IA) + (DIGMAX(IA)-DIGMIN(IA))*XE	FAL01140
	BAT=BKTSPA/CSPEED	FAL01150
	IXZ1=IYZ1	FAL01160
	CALL RANDU(IXZ1,IYZ1,XX)	FAL01170
	XX=XX*100.	FAL01180
	IF (XX-PROB(I,J)) 740,740,745	FAL01190
	740 TIME(I,J)=TIME(I,J)+DTIME	FAL01200
	RTIME=RTIME+DTIME	FAL01210
	TOTIM=TOTIM+DTIME	FAL01220
	STUCT(I,J)=STUCT(I,J)+DTIME	FAL01230
	KB=KB+1	FAL01240
C		FAL01250
C	ACCUMULATE TIME AND NUMBER OF PASSAGES	FAL01260
C		FAL01270
	745 TIME(I,J)=TIME(I,J)+BAT	FAL01280
	TOTIM=TOTIM+BAT	FAL01290
	RTIME=RTIME+BAT	FAL01300
	NODA=NODA+1	FAL01310
	CTIME(I,J)=CTIME(I,J)+BAT	FAL01320
C		FAL01330
C	ACCUMULATE POWER	FAL01340
C		FAL01350
	DIGP=CUTRES*LOT*BKTSPA	FAL01360
	RISP=BCOB*SPGR*DIA	FAL01370
	RPOWER=RPOWER+RISP+DIGP	FAL01380
	TOTPER=DIGP+RISP	FAL01390
	DIGKW=(TOTPER/CONV)*(1./BAT)*3600.	FAL01400
	IF (DIGKW-DIGKWM) 755,755,750	FAL01410
	750 DIGKWM=DIGKW	FAL01420
	755 RTDIGP(I,J)=RTDIGP(I,J)+DIGP+RISP	FAL01430
	MATL(I,J)=MATL(I,J)+BCOB	FAL01440
	IF (TOTIM-CUMTIM) 760,1140,1140	FAL01450
	760 DIST=SBPTH	FAL01460
	SLP=DIST/BAT	FAL01470
	IF (SLP-USS) 770,770,765	FAL01480
	765 SLP=USS	FAL01490
	770 ANGLE=ARSIN(DIST/CLB)	FAL01500
	TANGLE=TANGLE+ANGLE	FAL01510
	DIST=SLP*BAT	FAL01520
	SLEP=((CUTRES*LOT*SLP/CSPEED)+FRIFOR)*DIST	FAL01530
	TSLEP(I,J)=TSLEP(I,J)+SLEP	FAL01540
	RPOWER=RPOWER+SLEP	FAL01550
	SLEKW=(SLEP/CONV)*(1./BAT)*3600.	FAL01560
C		FAL01570
C	CALCULATE MATERIAL EXCAVATED	FAL01580
C		FAL01590
	IF (SLEKWM-SLEKW) 775,780,780	FAL01600
	775 SLEKWM=SLEKW	FAL01610

780 IF (ISET) 1140,785,835	FAL01620
785 IF (ISECT) 1140,810,790	FAL01630
790 IF (LANGLE-TANGLE) 800,805,795	FAL01640
795 SNTIK=LEND* $\cos(\text{LANGLE-TANGLE})/\cos(\text{LANGLE})$	FAL01650
SBDTH=BCOB/(HEIT*SNTIK)	FAL01660
GO TO 735	FAL01670
800 D=TANGLE-LANGLE	FAL01680
DIS=CLB*SIN(D)	FAL01690
MATL(I,J)=MATL(I,J)-DIS*HEIT*SNTIK	FAL01700
805 TANGLE=0.0	FAL01710
ISECT=0	FAL01720
GO TO 735	FAL01730
810 IF (RANGLE-TANGLE) 820,825,815	FAL01740
815 SNTIK=TIKNES* $\cos(\text{TANGLE})$	FAL01750
SBDTH=BCOB/(HEIT*SNTIK)	FAL01760
GO TO 735	FAL01770
820 D=TANGLE-RANGLE	FAL01780
DIS=CLB*SIN(D)	FAL01790
MATL(I,J)=MATL(I,J)-DIS*HEIT*SNTIK	FAL01800
825 SNTIK=REND	FAL01810
TANGLE=0.0	FAL01820
SAV=SAV+TIKNES	FAL01830
IF (SAV-DCUTA) 830,890,885	FAL01840
830 ISET=1	FAL01850
ISECT=1	FAL01860
TRAMP(I,J) = TRAMP(I,J) + TEMP3*TIKNES	FAL01870
TIMINC= TIKNES/CS	FAL01880
RTIME = RTIME + TIMINC	FAL01890
TTIME(I,J) = TIME(I,J) + TIMINC	FAL01900
TIME(I,J) = TIME(I,J) + TIMINC	FAL01910
TOTIM = TOTIM + TIMINC	FAL01920
RPOWER = RPOWER + TEMP3*TIKNES	FAL01930
GO TO 735	FAL01940
835 IF (ISECT) 1140,860,840	FAL01950
840 IF (RANGLE-TANGLE) 850,855,845	FAL01960
845 SNTIK=REND* $\cos(\text{RANGLE-TANGLE})/\cos(\text{RANGLE})$	FAL01970
SBDTH=BCOB/(HEIT*SNTIK)	FAL01980
GO TO 735	FAL01990
850 D=TANGLE-RANGLE	FAL02000
DIS=CLB*SIN(D)	FAL02010
MATL(I,J)=MATL(I,J)-DIS*HEIT*SNTIK	FAL02020
855 TANGLE=0.0	FAL02030
ISECT=0	FAL02040
GO TO 735	FAL02050
860 IF (LANGLE-TANGLE) 870,875,865	FAL02060
865 SNTIK=TIKNES* $\cos(\text{TANGLE})$	FAL02070
SBDTH=BCOB/(HEIT*SNTIK)	FAL02080
GO TO 735	FAL02090
870 D=TANGLE-LANGLE	FAL02100
DIS=CLB*SIN(D)	FAL02110
MATL(I,J)=MATL(I,J)-DIS*HEIT*SNTIK	FAL02120
875 TANGLE=0.0	FAL02130
SNTIK=LEND	FAL02140
SAV=SAV+TIKNES	FAL02150
IF (SAV-DCUTA) 880,890,885	FAL02160

880	ISET=0	FAL02170
	ISECT=1	FAL02180
	TRAMP(I,J) = TRAMP(I,J) + TEMP3*TIKNES	FAL02190
	RPOWER = RPOWER + TEMP3*TIKNES	FAL02200
	TIMINC= TIKNES/CS	FAL02210
	RTIME = RTIME + TIMINC	FAL02220
	TIME(I,J) = TIME(I,J) + TIMINC	FAL02230
	TTIME(I,J) =TTIME(I,J) + TIMINC	FAL02240
	TOTIM = TOTIM + TIMINC	FAL02250
	GO TO 735	FAL02260
885	DEF=SAV-DCUTA	FAL02270
	MATL(I,J)=MATL(I,J)-DEF*HEIT*BWID	FAL02280
890	SMPO(I,J) = SMPO(I,J)+TEMP3*DCUTA	FAL02290
	RPOWER=RPOWER+TEMP3*DCUTA	FAL02300
	TIMINC=DCUTA/CS	FAL02310
	TEMP5=TIMINC+SETTIM	FAL02320
	RTIME=RTIME+TEMPS	FAL02330
	TIME(I,J)=TIME(I,J)+TEMPS	FAL02340
	TOTIM=TOTIM+TEMPS	FAL02350
	TRAMT(I,J) =TRAMT(I,J) +TIMINC	FAL02360
	ISET=0	FAL02370
	ISECT=1	FAL02380
	SAV=0.0	FAL02390
	KRAM=0	FAL02400
	IF (TOTIM-CUMTIM) 895,1140,1140	FAL02410
C		FAL02420
C	DROP CUT STARTS HERE.	FAL02430
C	PASSAGE OF THE BUCKET THROUGH THE SOIL IS SIMULATED	FAL02440
C		FAL02450
895	IXZ=IYZ	FAL02460
	CALL RANDU(IXZ,IYZ,XE)	FAL02470
	CUTRES=DIGMIN(IA) + (DIGMAX(IA)-DIGMIN(IA))*XE	FAL02480
	TTTR=(1.5708+ATAN((VARAH-DIA/2.)/(DIA/2.)))	FAL02490
	NBID=(TTTR/6.2832)*NDB+0.5	FAL02500
	ALUT=2.*TIKNES*(NBID-NNBID)	FAL02510
	LUT=(BLUT+ALUT)*100.	FAL02520
	IXZ1=IYZ1	FAL02530
	CALL RANDU(IXZ1,IYZ1,XX)	FAL02540
	XX=XX*100.	FAL02550
	IF (XX-PROB(I,J)) 900,900,905	FAL02560
900	TIME(I,J)=TIME(I,J)+DTIME	FAL02570
	RTIME=RTIME+DTIME	FAL02580
	STUCT(I,J)=STUCT(I,J)+DTIME	FAL02590
	TOTIM=TOTIM+DTIME	FAL02600
	KB=KB+1	FAL02610
905	MATL(I,J)=MATL(I,J)+BCOB	FAL02620
C		FAL02630
C	ACCUMULATE TIME AND NUMBER OF PASSAGES	FAL02640
C		FAL02650
	NUDA=NUDA+1	FAL02660
	CTIME(I,J)=CTIME(I,J)+BAT	FAL02670
	TIME(I,J)=TIME(I,J)+BAT	FAL02680
	RTIME=RTIME+BAT	FAL02690
	TOTIM=TOTIM+BAT	FAL02700
C		FAL02710

```

C      ACCUMULATE POWER                                FAL02720
C
DIGP=CUTRES*LOT*BKTSPA                                FAL02730
RISP=BCOB*SPGR*DIA                                    FAL02740
RPOWER=RPOWER+RISP+DIGP                              FAL02750
TOTPER=DIGP+RISP                                      FAL02760
DIGKW=(TOTPER/CONV)*(1./BAT)*3600.                  FAL02780
IF (DIGKW-DIGKWM) 915,915,910                        FAL02790
910 DIGKWM=DIGKW                                       FAL02800
915 RTDIGP(I,J)=RTDIGP(I,J)+DIGP+RISP              FAL02810
IF (TOTIM-CUMTIM) 920,1140,1140                    FAL02820
920 DIST=BCOB/(VARAH*TIKNES)                         FAL02830
SLP=DIST/BAT                                         FAL02840
IF (SLP-USS) 930,930,925                            FAL02850
925 SLP=USS                                           FAL02860
C
C      DEBUG STATEMENTS & STOP CONDITIONS            FAL02870
C
930 IF (DIST .LE. XCLB) GO TO 932                   FAL02890
IF (DIST-XCLB .LE. 0.001) GO TO 931                 FAL02900
C      COMPARISON ALLOWS FOR ROUND OFF DISCREPANCIES FAL02910
CALL PDUMP(DHEIT(1,1),DHEIT(10,10),5,SDHEIT(1,1),SDHEIT(10,10),5, FAL02930
IRTIME,TEMHT1,5,RTIME,TEMHT1,4,BWID,ANITA,5,BWID,ANITA,4) FAL02940
RETURN                                              FAL02950
931 DIST=XCLB                                        FAL02960
932 ANGLE=ARSIN(DIST/XCLB)                          FAL02970
TANGLE=TANGLE+ANGLE                                FAL02980
DIST=SLP*BAT                                        FAL02990
SLEP=((CUTRES*LOT*SLP/CSPEED)+FRIFUR)*DIST         FAL03000
RPOWER=RPOWER+SLEP                                 FAL03010
SLEKW=(SLEP/CONV)*(1./BAT)*3600.                  FAL03020
IF (SLEKWM-SLEKW) 940,945,945                      FAL03030
940 SLEKWM=SLEKW                                    FAL03040
945 TSLEP(I,J)=TSLEP(I,J)+SLEP                    FAL03050
IF (ISET) 1140,950,1010                            FAL03060
950 IF (ISECT) 1140,975,955                        FAL03070
955 IF (LANGLE-TANGLE) 965,970,960                FAL03080
C
C      WHEEL MOVING FROM LEFT TO RIGHT.             FAL03090
C
960 VARAH=STARAH*(COS(LANGLE-TANGLE)+((SIN(LANGLE-TANGLE)**2)/ FAL03120
1(2.*PET)))                                       FAL03130
GO TO 895                                          FAL03140
965 D=TANGLE-LANGLE                                FAL03150
DIS=CLB*SIN(D)                                     FAL03160
MATL(I,J)=MATL(I,J)-DIS*TIKNES*VARAH             FAL03170
970 TANGLE=0.0                                     FAL03180
ISECT=0                                           FAL03190
GO TO 895                                          FAL03200
975 IF (RANGLE-TANGLE) 985,990,980                FAL03210
980 VARAH=STARAH*(COS(TANGLE)+((SIN(TANGLE)**2.)/(2.*PET))) FAL03220
GO TO 895                                          FAL03230
985 D=TANGLE-RANGLE                                FAL03240
DIS=CLB*SIN(D)                                     FAL03250
MATL(I,J)=MATL(I,J)-DIS*TIKNES*VARAH            FAL03260

```

```

990 TANGLE=0.0
ETIK=ETIK+TIKNES
IF (TTIK-ETIK) 1070,1075,995
995 DIFF=TTIK-ETIK
1005 ISET=1
ISECT=1
C
C CHECKING TO DETERMINE IF TIKNES IS SO SMALL THAT THE VALUE OF
C DIST WILL EXCEED THE SLEWING RADIUS (XCLB) CAUSING AN ARCSIN
C ERROR (AT 930). THEREFORE, TIKNES WILL BE RE-CALCULATED SO AS TO
C AVOID ARCSIN ERROR. ANY MATERIAL MINED IN EXCESS WILL BE
C ADJUSTED BY THE STATEMENTS AT 1070.
C
1000 IF(TIKNES .LE. DIFF) GO TO 1008
IF ( BCOB/(VARAH*DIFF) .GE. XCLB) GO TO 996
TIKNES=DIFF
GO TO 1008
996 TIKNES = BCOB/(VARAH*XCLB)
C
C
C CALCULATIONS FOR THE CROWD.
1008 TEMP1=TIKNES*COS(ALPHA)
TBACK=TBACK+ TEMP1
TRAMP(I,J) =TRAMP(I,J) + TEMP1*TEMP3
RPOWER = RPOWER + TEMP3*TEMP1
TIMINC=TEMP1/CS
RTIME =RTIME+TIMINC
TIME(I,J)=TIME(I,J) + TIMINC
TTIME(I,J) =TTIME(I,J) + TIMINC
TOTIM =TOTIM + TIMINC
GO TO 895
1010 IF (ISECT) 1140,1035,1015
1015 IF (RANGLE-TANGLE) 1025,1030,1020
C
C WHEEL MOVING FROM RIGHT TO LEFT.
C
1020 VARAH=STARAH*(COS(RANGLE-TANGLE)+((SIN(RANGLE-TANGLE))*
1*2.)/(2.*PET)))
GO TO 895
1025 D=TANGLE-RANGLE
DIS=CLB*SIN(D)
MATL(I,J)=MATL(I,J)-DIS*TIKNES*VARAH
1030 TANGLE=0.0
ISECT=0
GO TO 895
1035 IF (LANGLE-TANGLE) 1045,1050,1040
1040 VARAH=STARAH*(COS(TANGLE)+((SIN(TANGLE)**2.)/(2.*PET)))
GO TO 895
1045 D=TANGLE-LANGLE
DIS=CLB*SIN(D)
MATL(I,J)=MATL(I,J)-DIS*TIKNES*VARAH
1050 TANGLE=0.0
ETIK=ETIK+TIKNES
IF (TTIK-ETIK) 1070,1075,1055
1055 DIFF=TTIK-ETIK

```

```

FAL03270
FAL03280
FAL03290
FAL03300
FAL03310
FAL03320
FAL03330
FAL03340
FAL03350
FAL03360
FAL03370
FAL03380
FAL03390
FAL03400
FAL03410
FAL03420
FAL03430
FAL03440
FAL03450
FAL03460
FAL03470
FAL03480
FAL03490
FAL03500
FAL03510
FAL03520
FAL03530
FAL03540
FAL03550
FAL03560
FAL03570
FAL03580
FAL03590
FAL03600
FAL03610
FAL03620
FAL03630
FAL03640
FAL03650
FAL03660
FAL03670
FAL03680
FAL03690
FAL03700
FAL03710
FAL03720
FAL03730
FAL03740
FAL03750
FAL03760
FAL03770
FAL03780
FAL03790
FAL03800
FAL03810

```

ISET=0	FAL03820
ISECT=1	FAL03830
GO TO 1000	FAL03840
1070 DIFF=ETIK-TTIK	FAL03850
MATL(I,J)=MATL(I,J)-DIFF*BWID*STARAH	FAL03860
1075 IF (J-K) 1080,1085,1140	FAL03870
1080 TTIK=0.0	FAL03880
ETIK=0.0	FAL03890
GO TO 1130	FAL03900
C	FAL03910
C THE BWE MOVES FOR THE NEXT CUT.	FAL03920
C	FAL03930
1085 TADVAN=TADVAN+ADVAN	FAL03940
TEMP4=TBACK+ADVAN	FAL03950
TEMP5=TEMP4/CS	FAL03960
TEMP6 = TEMP5+SETTIM	FAL03970
TEMP7=TEMP4*TEMP3	FAL03980
TRAVT(I,J) =TRAVT(I,J) + TEMP5	FAL03990
TIME(I,J) = TIME(I,J) + TEMP6	FAL04000
RTIME=RTIME+TEMP5	FAL04010
TOTIM=TOTIM+ TEMP6	FAL04020
TPO(I,J) = TPO(I,J) + TEMP7	FAL04030
RPOWER = RPOWER+ TEMP7	FAL04040
TBACK=0.0	FAL04050
TTIK=0.0	FAL04060
ETIK=0.0	FAL04070
KADVA=KADVA+1	FAL04080
MOUND=KADVA	FAL04090
RTPOT(MOUND)=RTIME/3600.	FAL04100
RKPOT(MOUND)=RPOWER/CONV*ANITA	FAL04110
RTIME=0.0	FAL04120
RPOWER=0.0	FAL04130
IF (TADVAN-SLEN(I,J)) 1095,1125,1120	FAL04140
1095 DISTGO=SLEN(I,J)-TADVAN	FAL04150
IF (DISTGO-ADVAN) 1100,610,610	FAL04160
1100 IF (I-N1) 1110,1105,1140	FAL04170
1105 ADVAN=DISTGO	FAL04180
SADVAN=ADVAN	FAL04190
STARAH=ADVAN*SIN(ALPHA)	FAL04200
GO TO 610	FAL04210
1110 DIFFER=ADVAN-DISTGO	FAL04220
DO 1115 J=1,K	FAL04230
TEMHT1=(DHEIT(I,J)+SHEIT(I+1,J))/2.*DISTGO	FAL04240
TEMHT2=(SHEIT(I+1,J)+(SHEIT(I+1,J)-PGRADE(I+1,J)*	FAL04250
1DIFFER))/2.*DIFFER	FAL04260
1115 DHEIT(I,J)=(TEMHT1+TEMHT2)/ADVAN	FAL04270
KKK=1	FAL04280
GO TO 610	FAL04290
1120 TADVAN=DIFFER	FAL04300
DIFFER=0.0	FAL04310
GO TO 1135	FAL04320
1130 CONTINUE	FAL04330
1125 TADVAN=0.0	FAL04340
1135 CUNTINUE	FAL04350
1140 RETURN	FAL04360

END

FAL04370

CARDS LISTED 438

## 80-80 LISTING

	SUBROUTINE RANDU(IX,IY,YFL)	RANDU000
	IY=IX*65539	RANDU010
	IF(IY)5,6,6	RANDU020
5	IY=IY+2147483647+1	RANDU030
6	YFL=IY	RANDU040
	YFL=YFL*.4656613E-9	RANDU050
	RETURN	RANDU060
	END	RANDU070

CARDS LISTED 8

## APPENDIX B.--COMPUTER INPUT CONTROLS

## 80-80 LISTING

```

C***** DATA0000
C DATA0010
C INPUT SPECIFICATIONS * BWE SIMULATOR DATA0020
C ***** DATA0030
C DATA0040
C***** RUN CARD ***** DATA0050
C DATA0060
C VAR.NAME COLS. FORMAT DESCRIPTION DATA0070
C DATA0080
C N 1-10 (I10) NUMBER OF BUCKET-WHEELS AND/OR CUT- DATA0090
C TYPES TO BE SIMULATED. FOR EACH DATA0100
C BUCKET-WHEEL/CUT-TYPE COMBINATION, DATA0110
C ALL OF THE FOLLOWING CARDS ARE RQRD. DATA0120
C DATA0130
C DATA0140
C*****MINING TECHNIQUE CARD***** DATA0150
C DATA0160
C THE DATA ON THIS CARD DETERMINES THE MINING TECHNIQUE(S) TO BE DATA0170
C SIMULATED: DATA0180
C CODE MEANING DATA0190
C 1 LATERAL CUT TECHNIQUE USING BENCUT DATA0200
C 2 DROPCUT TECHNIQUE USING FALCUT DATA0210
C 3 DROPCUT TECHNIQUE USING AN INITIAL LATERAL CUT. DATA0220
C THE VARIOUS MINING TECHNIQUES AND THE ORDER IN WHICH THEY ARE DATA0230
C SIMULATED ARE DETERMINED BY THE CODES AND THEIR ORDER ON THIS CARD. DATA0240
C DATA0250
C VAR.NAME COLS. FORMAT DESCRIPTION DATA0260
C ** ** DATA0270
C MODEL(1) 1-10 * 8I10 * MINING TECHNIQUE CODE. DATA0280
C MODEL(2) 11-20 * * SAME DATA0290
C ETC. * * DATA0300
C ** ** DATA0310
C DATA0320
C DATA0330
C***** SECTION DESCRIPTION DECK ***** DATA0340
C DATA0350
C THE TOTAL NUMBER OF CARDS IN THIS DECK WILL BE 1+N1/3 DATA0360
C DATA0370
C VAR.NAME COLS. FORMAT DESCRIPTION DATA0380
C DATA0390
C N1 1-10 (I10) NUMBER OF SECTIONS TO BE MINED. DATA0400
C DATA0410
C ** ** DATA0420
C NUM(I) 1-5 * * NUMBER OF BENCHES IN THE I,TH SECTION DATA0430
C NUM(I+1) 26-30 * * DATA0440
C NUM(I+2) 51-55 * * DATA0450
C * * DATA0460
C GRADE(I) 6-15 * * GRADIENT OF THE I'TH SECTION (PRCNT). DATA0470
C GRADE(I+1) 31-40 *3(I5,2F10.5) DATA0480
C GRADE(I+2) 56-65 * * DATA0490
C * * DATA0500
C RORI(I) 16-25 * * ROLLING RESISTANCE OF THE I'TH DATA0510

```

```

C RURI(I+1)      41-50 *      * SECTION (DECIMAL FRACTION).      DATA0520
C RURI(I+2)      66-75 *      *      DATA0530
C                **      **      DATA0540
C                **      **      DATA0550
C                **      **      DATA0560
C                **      **      DATA0570
C***** BENCH DESCRIPTION DECK-1 *****      DATA0580
C                **      **      DATA0590
C THE TOTAL NUMBER OF CARDS IN THIS DECK WILL BE TWICE THE      DATA0600
C TOTAL NUMBER OF BENCHES. THE 2*NUM(I) CARDS DESCRIBING THE      DATA0610
C BENCHES IN THE I'TH SECTION ARE IMMEDIATELY FOLLOWED BY      DATA0620
C 2*NUM(I+1) CARDS DESCRIBING THE BENCHES IN THE (I+1)'TH SECTION.      DATA0630
C                **      **      DATA0640
C VAR.NAME      COLS.      FORMAT      DESCRIPTION      DATA0650
C                **      **      **      **      DATA0660
C PRUB(I,J)      1-10 *      * PROBABILITY OF STRIKING, ON A PARTI- DATA0670
C                *      * CULAR PASS OF A BUCKET, A      DATA0680
C                *      * BOULDER IN THE J'TH BENCH OF THE I'TH DATA0690
C                *      * SECTION. (PERCENT)      DATA0700
C                *(F10.2,I10)*      DATA0710
C LTYPE(I,J)     11-20 *      * AN INDEX SPECIFYING THE LOCATION IN DATA0720
C                *      * THE SOIL DESCRIPTION DECK OF THE SOIL DATA0730
C                *      * TYPE FOUND IN THE J'TH BENCH OF THE DATA0740
C                *      * I'TH SECTION.      DATA0750
C                **      **      DATA0760
C STYPE(I,J,*)   1-80      80A1      * AN ALPHA-NUMERIC DESCRIPTION OF THE DATA0770
C                *      * J'TH BENCH OF THE I'TH SECTION. ONLY DATA0780
C                *      * THE FIRST 10 COLUMNS ARE READ IN AND DATA0790
C                *      * PRINTED OUT.      DATA0800
C                **      **      DATA0810
C                **      **      DATA0820
C***** BENCH DESCRIPTION DECK-2 *****      DATA0830
C                **      **      DATA0840
C THE TOTAL NUMBER OF CARDS IN THIS DECK IS N1+NN+N3+NUM(N1)/8. N1 IS DATA0850
C THE NUMBER OF SECTIONS, NN IS THE NUMBER OF SECTIONS HAVING MORE DATA0860
C THAN 4 BENCHES, AND N3 IS THE NUMBER OF SECTIONS HAVING MORE THAN DATA0870
C 8 BENCHES. SLEN AND SHEIT ARE ENTERED FOR EACH BENCH, UP TO 4 DATA0880
C PER CARD, IN A SECTION. THE DATA FOR THE FIRST BENCH OF A SUBSEQUENT DATA0890
C SECTION ALWAYS BEGINS ON A NEW CARD.      DATA0900
C                **      **      DATA0910
C VAR.NAME      COLS.      FORMAT      DESCRIPTION      DATA0920
C                **      **      **      **      DATA0930
C SLEN(I,J)      1-10 *      * LENGTH OF THE J'TH BENCH IN THE I'TH DATA0940
C                *      * SECTION. (METERS)      DATA0950
C SLEN(I,J+1)    21-30 *      *      DATA0960
C SLEN(I,J+2)    41-50 *      *      DATA0970
C SLEN(I,J+3)    61-70 *      (8F10.2) *      DATA0980
C                *      *      DATA0990
C SHEIT(I,J)     11-20 *      * HEIGHT OF THE J'TH BENCH AT THE DATA1000
C                *      * BEGINNING OF THE I'TH SECTION. THE DATA1010
C SHEIT(I,J+1)   31-40 *      * HEIGHT OF THE J'TH BENCH AT THE END DATA1020
C SHEIT(I,J+2)   51-60 *      * OF THE I'TH SECTION IS ASSUMED TO BE DATA1030
C SHEIT(I,J+3)   71-80 *      * SHEIT(I+1,J). (METERS)      DATA1040
C                **      **      DATA1050
C                **      **      DATA1060
C SHEIT(N2,J)    1-10 *      * HEIGHT OF THE J'TH BENCH AT THE END DATA1060

```

```

C SHEIT(N2,J+1)11-20 * (8F10.2) * OF THE LAST (N2*TH) SECTION. (METERS)DATA1070
C SHEIT(N2,J+2)21-30 * * THIS DATA FILLS THE LAST NUM(N1)/8 DATA1080
C ETC. ETC. * * CARDS OF THE BENCH DESCRIPTION DECK-2DATA1090
C ** ** DATA1100
C DATA1110
C DATA1120
***** DROP CUT CONTRBATTER ANGLE CARD ***** DATA1130
C DATA1140
C THIS CARD IS NECESSARY WHETHER OR NOT A DROP CUT IS TO BE SIMULATED. DATA1150
C DATA1160
C VAR.NAME COLS. FORMAT DESCRIPTION DATA1170
C DATA1180
C ALPHA 11-20 F10.2 FRONTAL BATTER ANGLE.(RADIAN) DATA1190
C DATA1200
C DATA1210
C DATA1220
C***** SOIL TYPE CONTROL CARD ***** DATA1230
C DATA1240
C VAR.NAME COLS. FORMAT DESCRIPTION DATA1250
C DATA1260
C KS 1-10 I10 NUMBER OF SOIL TYPES. DATA1270
C * * DATA1280
C KMAX 11-20 I10 MAXIMUM DIGGING RESISTANCE OF THE DATA1290
C KS*TH SOIL TYPE. (KG/CM) DATA1300
C DATA1310
C DATA1320
C***** SOIL DESCRIPTION DECK ***** DATA1330
C DATA1340
C THE TOTAL NUMBER OF CARDS IN THIS DECK WILL BE KS. THE INFORMATIONDATA1350
C FOR TWO SOIL TYPES IS LISTED ON EACH CARD. THE I*TH SOIL TYPE LISTEDDATA1360
C IN THIS DECK IS REFERENCED IN THE BENCH DESCRIPTION DECK-1 BY SET- DATA1370
C TING A PARTICULAR LTYPE EQUAL TO I. DATA1380
C DATA1390
C VAR.NAME COLS. FORMAT DESCRIPTION DATA1400
C DATA1410
C ** *** DATA1420
C BUCFIL(I) 1-10 * * BUCKET-FILLING CAPACITY IN THE I*TH DATA1430
C * * SOIL TYPE. DECIMAL FRACTION OF CUB. DATA1440
C * * DATA1450
C RPM(I) 11-20 * * CUTTING SPEED OF THE WHEEL IN THE DATA1460
C * * I*TH SOIL TYPE, EXPRESSED AS A DECI- DATA1470
C * * MAL FRACTION OF THE MAXIMUM CUTTING DATA1480
C * * SPEED VMAX = SQRT(0.5*G*DIAM). DATA1490
C *2(3F10.2,I10) DATA1500
C VINC(I) 21-30 * * SWELL FACTOR OF THE I*TH SOIL TYPE DATA1510
C * * (DECIMAL FRACTION). DATA1520
C * * DATA1530
C DIGMIN(I) 31-40 * * MINIMUM DIGGING RESISTANCE THAT MIGHTDATA1540
C * * BE ENCOUNTERED IN THE I*TH SOIL TYPE. DATA1550
C DIGMAX(I) 41-50 * * MAXIMUM DIGGING RESISTANCE THAT MIGHTDATA1560
C ** * * BE ENCOUNTERED IN THE I*TH SOIL TYPE. DATA1570
C * * NOTICE THAT RPM AND DIG'S ARE DATA1580
C * * MACHINE-DEPENDENT. DATA1590
C *** DATA1600
C DATA1610

```



```

C          **          ***          DATA2170
C CUMTIM    1-10 *      * LIMIT ON SIMULATION-TIME. (SEC)    DATA2180
C          *          *          DATA2190
C DTIME    11-20 *     * DOWNTIME WHEN A BOULDER IS STRUCK.  DATA2200
C          *          * (SEC)          DATA2210
C SETTIM   21-30 *     * SETTING TIME OF THE EXCAVATOR. (SEC) DATA2220
C          *          *          DATA2230
C CONV     31-40 *     * CONVERSION FACTOR FOR CONVERTING    DATA2240
C          *          * MECHANICAL TO ELECTRICAL ENERGY.  DATA2250
C SPGR     41-50 *     * SPECIFIC GRAVITY OF THE MATERIALS    DATA2260
C          *          * 6F10.2 * BEING EXCAVATED. ALL SOIL TYPES  DATA2270
C          *          * REFERENCED BY THE BENCH DESCRIPTION DATA2280
C          *          * DECK-1 ARE ASSUMED TO HAVE THE SAME  DATA2290
C          *          * SPECIFIC GRAVITY.          DATA2300
C GRAV     51-60 *     * ACCELERATION DUE TO GRAVITY.    DATA2310
C          **          * (METERS/SEC**2)          DATA2320
C          *          ***          DATA2330
C          *          ***          DATA2340
C          **          ***          DATA2350
C EFFM     1-10 *     * EFFICIENCY OF THE MECHANICAL TRANS-  DATA2360
C          *          * 2F10.2 * MISSION. (DECIMAL FRACTION) DATA2370
C EFPE     11-20 *     * EFFICIENCY OF THE ELECTRICAL PARTS. DATA2380
C          **          * (DECIMAL FRACTION)          DATA2390
C          *          ***          DATA2400
C          *          ***          DATA2410
C          *          ***          DATA2420
C *****END OF INPUT SPECIFICATIONS*****DATA2430

```

CARDS LISTED 244

APPENDIX C.--DATA INPUT

SAMPLE DATA

	1	2	3						
	1								
	1								
	9								
	3	1.	.06	3	1.	.06	3	1.	.06
	3	1.	.06	3	1.	.06	3	1.	.06
	3	1.	.06	3	1.	.06	3	1.	.06
L- GRAV - B	.20	1							
C GRAV - B	.20	2							
B GRAV - B	.20	3							
L GRAV - B	.20	4							
C GRAV - B	.20	5							
B GRAV - B	.20	6							
L GRAV - B	.20	7							
C GRAV - B	.20	8							
B GRAV - B	.20	9							
L GRAV - B	.20	10							
C GRAV - B	.20	11							
B GRAV - B	.20	12							
L GRAV - B	.20	13							
C GRAV - B	.20	14							
B GRAV - B	.20	15							
L GRAV - B	.20	16							
C GRAV - B	.20	17							
B GRAV - B	.20	18							
L GRAV - B	.20	19							
C GRAV - B	.20	20							
B GRAV - B	.20	21							
L GRAV - B	.20	22							
C GRAV - B	.20	23							
B GRAV - B	.20	24							
L GRAV - B	.20	25							
C GRAV - B	.20	26							
B GRAV - B	.20	27							
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	8.167	1.98	8.167	1.98	8.167	1.98	8.167	1.98	8.167
	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98
	1.57								
	.27	240							
	.55	.28	.83	80	120				
	.55	.28	.83	120	180				
	.55	.28	.83	180	240				
	.55	.30	.83	80	120				
	.55	.30	.83	120	180				

.55	.30	.83	180	240
.55	.32	.83	80	120
.55	.32	.83	120	180
.55	.32	.83	180	240
.70	.28	.83	80	120
.70	.28	.83	120	180
.70	.28	.83	180	240
.70	.30	.83	80	120
.70	.30	.83	120	180
.70	.30	.83	180	240
.70	.32	.83	80	120
.70	.32	.83	120	180
.70	.32	.83	180	240
.85	.28	.83	80	120
.85	.28	.83	120	180
.85	.28	.83	180	240
.85	.30	.83	80	120
.85	.30	.83	120	180
.85	.30	.83	180	240
.85	.32	.83	80	120
.85	.32	.83	120	180
.85	.32	.83	180	240
MAVOR E10				
7.42	3.06			
1.22	1.22	0.50	77.00	
29972.00	0.46			
2.44	5.	0.10		
19982.00	1.64	0.03		
999900.00	30.00	60.00	367100.0	2017.00
0.80	0.90			9.81

APPENDIX D. -- DATA OUTPUT

LATERAL CUT TECHNIQUE USED

RESULTS OF THE BWE SIMULATION

MAVOR E10

WHEEL SPECIFICATIONS

WHEEL DIA 2.44 METERS  
 NUMBER OF BUCKETS 5  
 BUCKET CAPACITY 0.10 CU.MTS  
 CUT LENGTH 3.06 METERS

MINING PROFILE

SEC	MATERIAL	TYPE & #	SP.CUT.RANG	START HEIGHT	FINISH HEIGHT	SECTION LENGTH	SLOPE
SEC 1	BENCH 1	L-GRAV - B 1	80	1.98	1.98	8.17	0.0
SEC 1	BENCH 2	C GRAY - R 2	120	1.98	1.98	8.17	0.0
SEC 2	BENCH 3	B GRAY - R 3	180	1.98	1.98	8.17	0.0
SEC 2	BENCH 1	L GRAY - R 4	80	1.98	1.98	8.17	0.0
SEC 2	BENCH 2	C GRAY - B 5	120	1.98	1.98	8.17	0.0
SEC 2	BENCH 3	B GRAY - R 6	180	1.98	1.98	8.17	0.0
SEC 3	BENCH 1	L GRAY - R 7	80	1.98	1.98	8.17	0.0
SEC 3	BENCH 2	C GRAY - P 8	120	1.98	1.98	8.17	0.0
SEC 3	BENCH 3	B GRAY - P 9	180	1.98	1.98	8.17	0.0
SEC 4	BENCH 1	L GRAY - R 10	80	1.98	1.98	8.17	0.0
SEC 4	BENCH 2	C GRAY - R 11	120	1.98	1.98	8.17	0.0
SEC 4	BENCH 3	B GRAY - B 12	180	1.98	1.98	8.17	0.0
SEC 5	BENCH 1	L GRAY - R 13	80	1.98	1.98	8.17	0.0
SEC 5	BENCH 2	C GRAY - R 14	120	1.98	1.98	8.17	0.0
SEC 5	BENCH 3	B GRAY - B 15	180	1.98	1.98	8.17	0.0
SEC 6	BENCH 1	L GRAY - B 16	80	1.98	1.98	8.17	0.0
SEC 6	BENCH 2	C GRAY - R 17	120	1.98	1.98	8.17	0.0
SEC 6	BENCH 3	B GRAY - P 18	180	1.98	1.98	8.17	0.0
SEC 7	BENCH 1	L GRAY - P 19	80	1.98	1.98	8.17	0.0
SEC 7	BENCH 2	C GRAY - B 20	120	1.98	1.98	8.17	0.0
SEC 7	BENCH 3	B GRAY - B 21	180	1.98	1.98	8.17	0.0
SEC 8	BENCH 1	L GRAY - B 22	80	1.98	1.98	8.17	0.0
SEC 8	BENCH 2	C GRAY - B 23	120	1.98	1.98	8.17	0.0
SEC 8	BENCH 3	B GRAY - B 24	180	1.98	1.98	8.17	0.0
SEC 9	BENCH 1	L GRAY - B 25	80	1.98	1.98	8.17	0.0
SEC 9	BENCH 2	C GRAY - B 26	120	1.98	1.98	8.17	0.0
SEC 9	BENCH 3	B GRAY - B 27	180	1.98	1.98	8.17	0.0

WIDTH OF THE BLOCK  
 PIT ADVANCE

14. METERS  
 74. METERS

## MATERIAL DESCRIPTION

MATERIAL TYPE #	BUCKET FILL	FRAC MAX CUT	MAX SP.	SWELL FACTOR	CUTTING RESISTANCE MIN	RESISTANCE MAX
1	0.83	0.28		0.83	80	120
2	0.83	0.28		0.83	120	180
3	0.83	0.28		0.83	180	240
4	0.83	0.30		0.83	80	120
5	0.83	0.30		0.83	120	180
6	0.83	0.30		0.83	180	240
7	0.83	0.32		0.83	80	120
8	0.83	0.32		0.83	120	180
9	0.83	0.32		0.83	180	240
10	0.83	0.28		0.83	80	120
11	0.83	0.28		0.83	120	180
12	0.83	0.28		0.83	180	240
13	0.83	0.30		0.83	80	120
14	0.83	0.30		0.83	120	180
15	0.83	0.30		0.83	180	240
16	0.83	0.32		0.83	80	120
17	0.83	0.32		0.83	120	180
18	0.70	0.32		0.83	180	240
19	0.85	0.28		0.83	80	120
20	0.85	0.28		0.83	120	180
21	0.85	0.28		0.83	180	240
22	0.85	0.30		0.83	80	120
23	0.85	0.30		0.83	120	180
24	0.85	0.30		0.83	180	240
25	0.85	0.32		0.83	80	120
26	0.85	0.32		0.83	120	180
27	0.85	0.32		0.83	180	240

## POWER AND TIME STUDY FOR EACH CUT

CUT	1	TIME	1.8	HOURS	POWER	217.	KWH
CUT	2	TIME	1.8	HOURS	POWER	217.	KWH
CUT	3	TIME	1.7	HOURS	POWER	232.	KWH
CUT	4	TIME	1.6	HOURS	POWER	218.	KWH
CUT	5	TIME	1.6	HOURS	POWER	217.	KWH
CUT	6	TIME	1.6	HOURS	POWER	248.	KWH
CUT	7	TIME	1.5	HOURS	POWER	218.	KWH
CUT	8	TIME	1.5	HOURS	POWER	217.	KWH
CUT	9	TIME	1.7	HOURS	POWER	264.	KWH
CUT	10	TIME	1.8	HOURS	POWER	217.	KWH
CUT	11	TIME	1.7	HOURS	POWER	231.	KWH
CUT	12	TIME	1.7	HOURS	POWER	217.	KWH
CUT	13	TIME	1.6	HOURS	POWER	217.	KWH
CUT	14	TIME	1.6	HOURS	POWER	257.	KWH
CUT	15	TIME	1.6	HOURS	POWER	226.	KWH
CUT	16	TIME	1.6	HOURS	POWER	227.	KWH
CUT	17	TIME	1.7	HOURS	POWER	263.	KWH
CUT	18	TIME	1.7	HOURS	POWER	218.	KWH
CUT	19	TIME	1.7	HOURS	POWER	232.	KWH
CUT	20	TIME	1.6	HOURS	POWER	217.	KWH
CUT	21	TIME	1.6	HOURS	POWER	217.	KWH
CUT	22	TIME	1.6	HOURS	POWER	248.	KWH
CUT	23	TIME	1.5	HOURS	POWER	218.	KWH
CUT	24	TIME	1.5	HOURS	POWER	217.	KWH
CUT	25	TIME	0.1	HOURS	POWER	1.	KWH

		MACHINE SCIL INTERFACE		TIME STUDY		MACHINE POSITIONING		TOTAL
		CUT	CRCMD	DELAY	MANEUVER	TRAM		
SEC 1	BENCH 1	1.48	1.57	0.09	0.00	0.0	3.06	
SEC 1	BENCH 2	1.48	1.55	0.07	0.00	0.0	3.03	
SEC 1	BENCH 3	1.48	1.59	0.13	0.0	0.00	3.08	
SEC 2	BENCH 1	1.36	1.44	0.06	0.01	0.0	2.81	
SEC 2	BENCH 2	1.36	1.45	0.07	0.01	0.0	2.82	
SEC 2	BENCH 3	1.36	1.44	0.06	0.0	0.00	2.80	
SEC 3	BENCH 1	1.28	1.32	0.06	0.01	0.0	2.60	
SEC 3	BENCH 2	1.28	1.35	0.08	0.01	0.0	2.63	
SEC 3	BENCH 3	1.28	1.29	0.03	0.0	0.00	2.57	
SEC 4	BENCH 1	1.44	1.50	0.06	0.00	0.0	2.94	
SEC 4	BENCH 2	1.44	1.51	0.07	0.00	0.0	2.95	
SEC 4	BENCH 3	1.44	1.49	0.07	0.0	0.00	2.93	
SEC 5	BENCH 1	1.36	1.46	0.08	0.01	0.0	2.83	
SEC 5	BENCH 2	1.36	1.46	0.07	0.01	0.0	2.83	
SEC 5	BENCH 3	1.36	1.40	0.03	0.0	0.00	2.77	
SEC 6	BENCH 1	1.28	1.32	0.06	0.01	0.0	2.60	
SEC 6	BENCH 2	1.28	1.29	0.03	0.01	0.0	2.57	
SEC 6	BENCH 3	1.53	1.54	0.04	0.0	0.00	3.06	
SEC 7	BENCH 1	1.42	1.46	0.04	0.00	0.0	2.88	
SEC 7	BENCH 2	1.42	1.46	0.05	0.00	0.0	2.89	
SEC 7	BENCH 3	1.43	1.46	0.03	0.0	0.00	2.88	
SEC 8	BENCH 1	1.34	1.44	0.07	0.01	0.0	2.79	
SEC 8	BENCH 2	1.34	1.39	0.03	0.01	0.0	2.74	
SEC 8	BENCH 3	1.34	1.41	0.05	0.0	0.00	2.75	
SEC 9	BENCH 1	1.23	1.35	0.10	0.01	0.0	2.59	
SEC 9	BENCH 2	1.23	1.27	0.02	0.01	0.0	2.51	
SEC 9	BENCH 3	1.23	1.30	0.05	0.0	0.00	2.53	

38.30 HOURS

TOTAL SIMULATION TIME

	POWER CONSUMPTION			POSITIONING		
	CUT KWH	CUTTING CROWD KWH	SLEW KWH	MANEUVER KWH	TRAM KWH	
SEC 1 BENCH 1	128.	0.	2.	0.	0.	0.
SEC 1 BENCH 2	190.	0.	3.	0.	0.	0.
SEC 1 BENCH 3	265.	0.	5.	0.	0.	0.
SEC 2 BENCH 1	129.	0.	2.	0.	0.	0.
SEC 2 BENCH 2	192.	0.	3.	0.	0.	0.
SEC 2 BENCH 3	266.	0.	5.	0.	0.	0.
SEC 3 BENCH 1	132.	0.	2.	0.	0.	0.
SEC 3 BENCH 2	196.	0.	4.	0.	0.	0.
SEC 3 BENCH 3	273.	0.	5.	0.	0.	0.
SEC 4 BENCH 1	134.	0.	2.	0.	0.	0.
SEC 4 BENCH 2	199.	0.	4.	0.	0.	0.
SEC 4 BENCH 3	277.	0.	5.	0.	0.	0.
SEC 5 BENCH 1	129.	0.	2.	0.	0.	0.
SEC 5 BENCH 2	191.	0.	3.	0.	0.	0.
SEC 5 BENCH 3	265.	0.	5.	0.	0.	0.
SEC 6 BENCH 1	132.	0.	2.	0.	0.	0.
SEC 6 BENCH 2	196.	0.	4.	0.	0.	0.
SEC 6 BENCH 3	301.	0.	5.	0.	0.	0.
SEC 7 BENCH 1	134.	0.	3.	0.	0.	0.
SEC 7 BENCH 2	200.	0.	4.	0.	0.	0.
SEC 7 BENCH 3	277.	0.	5.	0.	0.	0.
SEC 8 BENCH 1	128.	0.	3.	0.	0.	0.
SEC 8 BENCH 2	191.	0.	4.	0.	0.	0.
SEC 8 BENCH 3	265.	0.	5.	0.	0.	0.
SEC 9 BENCH 1	128.	0.	3.	0.	0.	0.
SEC 9 BENCH 2	191.	0.	4.	0.	0.	0.
SEC 9 BENCH 3	265.	0.	5.	0.	0.	0.

KW RATING OF THE DIGGING MOTOR 293.  
 KW RATING OF THE SLEW MOTOR 44.  
 KW RATING OF THE CRAWLER MOTORS 15.

## PRODUCTION STUDY

MATERIAL EXCAVATED 6140. CU.MTS  
 NUMBER OF BUCKET DISCHARGES 89647

THEORETICAL CAPACITY IN CUBIC METERS PER HOUR				569.
AVERAGE CAPACITY IN CUBIC METERS PER HOUR				160.
SECTION	1	BENCH	1	ACTUAL CAPACITY 157.
SECTION	1	BENCH	2	ACTUAL CAPACITY 157.
SECTION	1	BENCH	3	ACTUAL CAPACITY 157.
SECTION	2	BENCH	1	ACTUAL CAPACITY 168.
SECTION	2	BENCH	2	ACTUAL CAPACITY 168.
SECTION	2	BENCH	3	ACTUAL CAPACITY 168.
SECTION	3	BENCH	1	ACTUAL CAPACITY 179.
SECTION	3	BENCH	2	ACTUAL CAPACITY 179.
SECTION	3	BENCH	3	ACTUAL CAPACITY 179.
SECTION	4	BENCH	1	ACTUAL CAPACITY 157.
SECTION	4	BENCH	2	ACTUAL CAPACITY 157.
SECTION	4	BENCH	3	ACTUAL CAPACITY 157.
SECTION	5	BENCH	1	ACTUAL CAPACITY 168.
SECTION	5	BENCH	2	ACTUAL CAPACITY 168.
SECTION	5	BENCH	3	ACTUAL CAPACITY 168.
SECTION	6	BENCH	1	ACTUAL CAPACITY 179.
SECTION	6	BENCH	2	ACTUAL CAPACITY 179.
SECTION	6	BENCH	3	ACTUAL CAPACITY 151.
SECTION	7	BENCH	1	ACTUAL CAPACITY 160.
SECTION	7	BENCH	2	ACTUAL CAPACITY 160.
SECTION	7	BENCH	3	ACTUAL CAPACITY 160.
SECTION	8	BENCH	1	ACTUAL CAPACITY 172.
SECTION	8	BENCH	2	ACTUAL CAPACITY 172.
SECTION	8	BENCH	3	ACTUAL CAPACITY 172.
SECTION	9	BENCH	1	ACTUAL CAPACITY 183.
SECTION	9	BENCH	2	ACTUAL CAPACITY 183.
SECTION	9	BENCH	3	ACTUAL CAPACITY 183.

## APPENDIX E.--GLOSSARY

Q	Digging capacities in cubic meters per hour.
$Q_t$	Theoretical digging capacity in cubic meters per hour.
$Q_a$	Actual digging capacity in cubic meters per hour.
$Q_1$	Hourly digging capacity in material with specific cutting resistance $k_1$ .
$Q_2$	Hourly digging capacity in material with specific cutting resistance $k_2$ .
M	Mass of material in the bucket in metric tons.
$S_s$	Number of bucket discharges per second.
S	Number of bucket discharges per minute.
C	Constant depending on the bench height/wheel diameter.
$D_r$	Diameter of the ball race in meters.
D	Diameter of the wheel in meters.
R	Radius of the wheel in meters.
Z	Number of buckets in the wheel.
I	Nominal bucket capacity in cubic meters.
$\Sigma L$	Total length of cutters in material in centimeters.
$L_b$	Length of cutting boom in meters.
g	Acceleration due to gravity in meters/sec <sup>2</sup> .
$B_f$	Bucket filling capacity in the material expressed as a fraction of the nominal bucket capacity.
$T_t$	BWE capacity in tons per hour.
t	Thickness of slice in meters.
K	Specific cutting resistance in kilograms per centimeter.
$M_d$	Cutting force exerted by the wheel in kilograms.
$M_s$	Cutting force exerted by the slewing motor in kilograms.
$M_f$	Force at the wheel end in kilograms.

- $N_G$  Power required for cutting in kilowatts.
- $\mu$  Frictional coefficient at the ball race on which the superstructure revolves.
- $N_H$  Lifting power in kilowatts.
- $W$  Weight of superstructure in kilograms.
- $K$  Specific cutting resistance in kilograms per centimeter.
- $V_1$  Cutting speed of wheel in meters per second.
- $V_2$  Slewing speed of wheel in meters per second.
- $S_r$  Slewing radius in meters.
- $\eta$  Efficiency if the motor drive.
- $t_p$  Thickness at the point  $p$  in meters.
- $\theta$  Angle of slew from the direction of advance.
- $V$  Starting slewing speed in meters per second.
- $V_\theta$  Slewing speed at the point  $p$  in meters per second.