1947

The effect of rope speed and moisture on mine scrapers

Ronald L. Carmichael

THE EFFECT OF ROPE SPEED AND MOISTURE ON MINE SCRAPERS

BY

RONALD L. CARMICHAEL

****

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

DEGREE OF

MASTER OF SCIENCE

IN

MINING ENGINEERING

Rolla, Missouri

May 1947

****

Approved by J. D. Forrester
Professor of Mining Engineering

ACKNOWLEDGEMENTS

This study of the efficiency of mine scrapers was conducted during the tenure of an appointment as Research Fellow in Mining Engineering with the State Mining Experiment Station, School of Mines and Metallurgy, University of Missouri. Grateful acknowledgement of the aid thus provided is made.

The author wishes to express his appreciation for the council and guiding interest of Dr. J. D. Forrester, Chairman, Department of Mining Engineering, Missouri School of Mines and Metallurgy. Thanks are also due to Professors D. R. Schooler and L. E. Shaffer, of the same department, for their helpful suggestions and assistance during the course of this study.

The help of Dr. Aaron J. Miles, Professor of Mechanical Engineering, and his staff was of great assistance in construction and repair of the model equipment.

Much useful information was provided by various operating companies and scraper manufacturers.

PREFACE

This thesis is submitted to the Faculty of the School of Mines and Metallurgy of the University of Missouri in partial fulfillment of the work required for the degree of Master of Science in Mining Engineering.

The results included herein were obtained by efficiency studies of mine scrapers on model scale. Tests were run on four scraper types commonly used in underground mines. These include two hoe types, a box type, and a crescent type.

The tests were conducted during the first half of 1947 in the mining laboratory of the Missouri School of Mines.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

During recent years the use of power drawn scrapers, sometimes called "slushing", for the transfer of ore and waste rock has become standard practice in many mining operations. Scraper types have been developed to meet various operating conditions by trial and error methods and by practical research. The study of scraper efficiency has been confined in the past mainly to power consumption.

A detailed study of the effect of rope speed and moisture content of the material being moved on scraping efficiency, under controlled conditions, has not been noted in a review of the literature. The author feels that such a study would be of practical value in its application to scraping practice. Therefore, the following thesis problem was set up:

Purpose of Problem

For testing purposes the thesis problem was divided into two parts: rope speed studies and moisture studies.

The principal purpose of the rope speed studies was to determine the effect on scraping efficiency of various rope speeds as applied to common scraper types moving both sized and mixed-size rock.

The moisture studies were made to determine the effect of varying moisture content in mixed-size rock on scraper efficiency.

It is hoped that the results of these tests will furnish information to improve present scraping practice.

Problem Procedure

The scrapers ordinarily used at operating mines are modifications of three basic types: the hoe, the box, and the crescent. Models of two hoe types, one box type, and one crescent type, all constructed on a scale of one to six, were available in the mining laboratory. The laboratory also contained a small electrically driven hoist for pulling the models and a table on which the tests were run. The equipment was overhauled and modified for the purpose of the tests. A spring scale was used to measure the rope tension applied in drawing the scrapers.

With the above linear ratio the volumetric ratio between the full size and model scrapers was 1 to 216. The scrapers were tested on a horizontal plane and also, in the case of moisture tests, on a slight inclination below the horizontal.

The weight and moisture content of material moved per a given number of scraper passes was determined. Identical tests were applied to each scraper type. The data thus collected is tabulated and summarized.

REVIEW OF LITERATURE

History of Scraping

The first use of power scrapers 1/ in the moving of mine material is

1/ Van Barneweld, Charles, E., Mechanical underground loading in metal mines, Missouri School of Mines and Metallurgy Technical Bulletin, No. 3, Vol. 7, 1924, pp. 210-212.

believed to have taken place at Kellog, Idaho in 1898. At that time the Bunker Hill and Sullivan Mining Company used a small single drum air hoist to power a slip scraper. The scraper was guided and pulled back to the muck pile by hand. During the same year 2/ filling was distributed in square-

2/ Jackson, Charles F., Underground scraping practice in metal mines, U.S. Bureau of Mines Manuscript Report No. 1, March 1933, pp. 8-9.

set stopes at the Badger mine, Wisconsin by means of a slip scraper powered by a small air hoist. Slip scrapers were considered practical for mining operations until as late as 1921.

Early scraping practice, employing slip scrapers and single drum hoists, was tiring to the man who dragged the scraper and, therefore, expensive. The development of two-drum hoists and bottomless scrapers shortly before World War I contributed to greater scraper efficiency.

Probably the greatest application of scraping has been in the Lake Superior iron and copper country. Scraper loading did not come into full acceptance in the Tri-State[3/] lead-zinc district until about 1936. In this

3/ Clarke, S. S., Engineering and Mining Journal, Vol. 144, November 1943, p. 80.

district three-drum slushers are mounted on portable caterpillar loading ramps.

Pierce and Bryon[4/] summarize the reasons for present acceptance of

4/ Pierce, R. V., and Bryon, R. N., The Mining Journal, (London), Vol.218, No. 5581, August 8, 1942, pp. 375-6.

scraper loading as follows:

1. Scraping eliminates hand moving or loading of ore and rock.
2. Scrapers move chunks too large for hand loading.
3. War production required speed and more metal per man shift.
4. Comparatively inexperienced men can run a scraper.
5. Scraper loading has eliminated part of block holing.
6. Scrapers speed production so that ground need be kept open only a short time, thus saving timber and other supplies.
7. Workers are safer by less exposure to falling rock.
8. Scraper set-ups are flexible.
9. Ore is loaded directly into cars, skips, or elevators.

Operation Data on Scrapers

Scraper hoists may be powered by either electricity or air. In general air hoists are used for small, portable or temporary, set-ups while the electric hoists are used at permanent scraping stations or on large portable ramps. It is reported[5] that power costs may be 4 to 7 times greater

5/ Jackson, Charles F., op. cit., p.45.

for air than for electric hoists.

Hoists range in size from 3.5 to 100 horsepower and have "pull rope" speeds up to 400 feet per minute and "tail rope" speeds up to 550 feet per minute.

Table 1, modified from Jackson, gives comparative data on recent (1933) scraping practice. The present tendency in industry is towards faster rope speeds and longer hauling distances.

The wide variety of scrapers and scraper hoists permits choosing the best type of equipment for any particular set of conditions. In narrow working places, two-drum hoists are used. The pull rope is fastened to one drum and the tail rope to the other drum. The scraper operates along a straight line between the muck pile and the discharge point. In wide stopes where lateral movement of the scraper is desirable, three-drum hoists are used. Tail ropes occupy two of the drums and the rope sheaves are anchored at the most effective points in the stope walls. The operator is then able to move the scraper to almost any spot in the stope. Remote control operation is a recent development that enables the operator to observe the loading action more closely. Some set-ups allow the scraper to be moved around a 90 degree corner.

Using multiple sheave arrangements, almost an infinite variety of scraper set-ups is available. Sullivan Machinery Company, Ingersoll-Rand Company, and Gardner Denver Company publish illustrated catalogs showing many of these arrangements.

Table 1
Data on typical scraper installations

Type of Ore	Hoist Hp.	Hoist Rope Speed f.p.m.	Type	Size inches	Approximate load cubic feet	Scraping distance feet
1. Soft iron ore	6½	125	Box	40	12	50, max.
2. Do.	15	180	Box	42-48	13-18	75, max.
3. Soft & hard iron ore	15	180	Hoe	48	13	75, max.
4. Soft iron ore	15	225	Box	34	10	100, max.
5. Do.	15	200	Box	42-48	13-18	75, max.
6. Soft & hard iron ore	15	200	Hoe	48	13	80, max.
7. Soft iron ore	15	240-280	Hoe	48	13	75, max.
8. Do.	15	240	Semihoe	42	14	75, max.
9. Do.	15-25	240-280	Box	48	18	60 to 150
10. Hard & soft iron ore; some chunks	15	240-280	Hoe	42	9	125, max.
11. Soft iron ore	15	200	Box	42	13	75, max.
11-a Do.	25	230	Box	48	18	150, max.
12. Large blocks lard iron ore	25	230	Hoe	48	14	50 to 100
13. Hard chunky rock or soft iron ore	25	230	Semihoe	54	18	50 to 100

Table 1 (continued)

Type of Ore	Hoist Hp.	Hoist Rope Speed f.p.m.	Type	Size inches	Approximate load cubic feet	Scraping distance feet
13-a Soft iron ore	15	200	Semihoe	30	7	75, max.
13-b Do	10	200	Semihoe	30	7	75, max.
14. Large blocks zinc ore, dolomite gangue	25	200 h.s.	Arc-back hoe	72	2000 lb.	400, max. 175, ave.
15. Medium coarse zinc ore in dolomite gangue	10	200	Box	40	12	300, max. 75, ave.
16. Coarse copper amygdaloid	15	200-240	Semihoe	48	13	200, max.
17. Coarse and fine; copper bearing conglomerate	35 (air)	----	Hoe	48	13	150, max.
18. Copper amygdaloid; coarse and fine muck	25	230	Hoe	48	13	120, max.
19. Friable, altered porphyry	25	230	Hoe	48	18	100
20. Very hard ore breaks in large, angular blocks; sp.gr. 4.6	60	----	Hoe, arc-back	80	10,000 lbs.	150, max.
21. Hard, siliceous ore; fine, sticky gangue	15	240	Semihoe	40	700 lbs.	200, max.

Table 1 (continued)

Type of Ore	Hoist Hp.	Hoist Rope Speed f.p.m.	Type	Size inches	Approximate load cubic feet	Scraping distance feet
22. Hard, siliceous ore flat slabs, chunks and fines	15	230	Semihoe	40	700 lbs.	100, max.
22-a Do.	15	230	Semihoe	40	700 lbs.	75, max.
22-b Sand	15	230	Semihoe	40	400 lbs.	75, max.
23. Iron ore breaking in large slabs	55	130-150	Box, with teeth	48	6500 lbs.	200, max.
24. Hard, blocky magnetic iron ore	25	200	Hoe	48	2240 lbs.	330-max. 180, ave.
25. Large, heavy angular blocks	150	170 pull 190 return	Hoe	84	7600 lbs. actual ore load	100, max. 75, ave.

Design of Scrapers

All bottomless scrapers are modifications of the hoe. Three main types of scrapers in the hoe class are now commonly used, namely: the hoe, the box, and the crescent.

There are three component parts to the hoe scraper: the blade or back plate, the bail, and the baffle plate. The blade may be a plane or curved surface, the lower edge of which is known as the cutting edge. The bail is an arm or pair of arms extending out in front of and above the blade. The pull rope is attached to the bail and the tail ropes to the back of the blade. Bails may be straight or may curve downward (slope bail), lowering the line of pull. The baffle plate is fastened to the upper edge of the blade and is inclined forward. The blade and the baffle plate are sometimes incorporated as one unit in which case the upper portion of the blade is curved forward to act as a baffle.

The addition of a fourth part, side plates, changes a hoe scraper into a box scraper, combining side plates and blade into one curved unit forms a crescent scraper.

The angle made by the blade of the scraper with the surface of the muck pile when the pull rope is under maximum tension is known as the digging angle. The angle at which the bail is fastened to the blade determines the digging angle with respect to a surface parallel to the line of pull.

Van Barneveld[6/] states that the theoretical maximum digging effect should occur when the plane of the scraper blade lies along the resultant of the rope pull and the force of gravity. This would result, under ordinary conditions, in digging angles of approximately 30 degrees.

6/ Van Barneveld, Charles E., op. cit., p.

Actual experience[7] has shown, however, that the best digging action

[7] Modern methods for scraper mucking and loading, p. 6, Ingersoll-Rand Company, New York, 1939.

takes place when the blade is at a greater angle to the line of pull.

According to scraper manufacturers[8] the length of the bail should be

[8] See footnote 7, pp. 8-32

equal to or greater than the width of the scraper. The height of the scraper at the cutting edge should be about one-half the width and never more than two-thirds the width. The balance of the scraper should be such that the bail slightly over balances the blade and rests on the floor when not in motion.

Scrapers vary greatly in size, capacity, and shape. They range in size from "junior" models weighing 200 lbs. with a ¼ cubic yard capacity to "mammoth" types weighing 11,000 lbs. and having 15 cubic yard capacities. These larger sizes are used in surface pits.

The size of a scraper, however, is commonly expressed as inches of width, which may range from 26 to 139 inches. The 48 inch scraper is a common size used in underground mining operations.

Principles of Scraper Operations

Many of the basic principles of scraper operation were discovered through trial and error methods. Most of the research done on scraping efficiency has been concerned with power consumption and cost relationships.

The work of Clayton[9] is the only record found in the literature in

[9] Clayton, Austin B., A study of mine scraper buckets and their efficiency, Missouri School of Mines and Metallurgy, Rolla, 1946, 77 pp.

which the comparative efficiencies of the various scraper types were studied under identical conditions. This study was made on model scrapers.

According to Clayton[10] fine material flows before the scraper blade by

10/ Clayton, Austin B., ibid., pp. 35-55.

a process of each individual particle being lifted and falling forward. With larger pieces of rock, the particles tend to remain in their original position with respect to the load and move by rolling. This makes the blade tend to move over the particles and, therefore, additional weight must be added to the scraper to get digging action. Large boulders imbedded in fine muck are easier to move than when the muck consists of all large pieces of one size. Fine material wedges the boulders in place and prevents rolling action. The fine material also acts as a lubricant. The boulders, wedged in place, act as teeth to dig up more fine material.

The shape of the rock scraped has an effect on efficiency. Flat, splintery, or platy pieces of rock are harder to scrape than rounded particles. As the size of particles increases, weight must be added to the scraper.

A digging angle of 45 degrees is most efficient for the hoe type scrapers. The hoe scrapers lose material from the sides during transit. This material builds up into ridges along the scraper path. After a few passes with the scraper, the ridges are built up to the extent that they confine the scraper load and greatly increase the scraping efficiency.

With all types of hoes the bail weight must slightly over balance the hoe weight. A minimum scraper weight for structural durability is most efficient for scraping fine material. The weight must be increased for larger rock but beyond a certain weight the efficiency drops. The volumetric capacity increases with added scraper weight but the ratio of ore weight to scraper weight decreases. The hoe shows a wider range of applicability, with respect to various rock sizes, than either the box or the crescent.

The box scraper works best on relatively fine material. The best digging angle for the box scraper is 30 degrees. Maximum efficiency of the box at the same scraper weight and for the same muck is less than for the crescent or hoe. When the material scraped is large enough to roll, the box vibrates and loses part of its load. If the front end of the box scraper is too heavy the back is inclined to lift up losing part of the load. If the back end is too heavy the scraper tips back, riding on the blade, and material is lost out the sides.

The crescent exhibits the best ability of any type scraper to move fine material. This scraper loses very little of its load in transit. The crescent picks up material by a crowding and scooping action due to the curvature of the blade. The sides push the muck to the center and the rear angle lifts it to fill the scraper. The balance is affected by counterweights similar to the action described for the box scraper.

Like the hoe types, the volumetric capacity of the crescent increases by adding scraper weight but the ratio of rock weight carried to unit scraper weight decreases. However, the overall result of adding scraper weight is an increase in efficiency.

Clayton[11/] sums up the basic principles of scraper operations as

11/ Clayton, Austin B., ibid., p. 55

follows:

1. The pull required to draw a loaded scraper depends directly on the scraper weight plus its load and upon the digging angle of the scraper blade.

2. The efficiency of a scraper is at a maximum at a definite weight of scraper for any one type and size of material.

3. Scrapers must be properly balanced to give maximum efficiency.

4. For moving fine material the scrapers rank in the following order: crescent, slope bail hoe, straight bail hoe, and box.

5. For intermediate sizes of rock the scrapers rank as follows: slope bail hoe, straight bail hoe, crescent, and box.

6. For very coarse rock, the straight bail hoe is the only scraper applicable.

7. A baffle plate at the top of the scraper blade helps prevent the scraper from continuing to dig in after it has a full load.

PREPARATION OF APPARATUS FOR TESTS

Equipment Used in the Tests

The model scrapers available were eight inches in width. For testing purposes the linear ratio between the model equipment and comparable full size scrapers was established as one to six. Since the average mine scraper (See Table 1) is about 48 inches wide, the above ratio was considered suitable. Four types of scrapers (See Figs. 1, 2, 3, and 4) were used in the tests.

A three-drum hoist with double faced friction clutches was used to operate the scrapers. (See Fig. 5). The aluminum drums were mounted on a three-quarter inch line shaft set in ball bearing pillow blocks.

A quarter horsepower, split phase, electric motor using 60 cycle AC, 115 volt current furnished the motive power for the hoist. The drive from the 1750 RPM motor was belted to a 12 inch pulley on a jack shaft. A three step cone pulley on the other end of the jack shaft was belted to a similar pulley on the hoist shaft.

From this combination of pulleys and belts theoretical RPM of 155, 211, 233, 317, 429, 475, and 646 were available at the hoist drums. (see Appendix E, Part II). The diameter of the centers of the first lap of

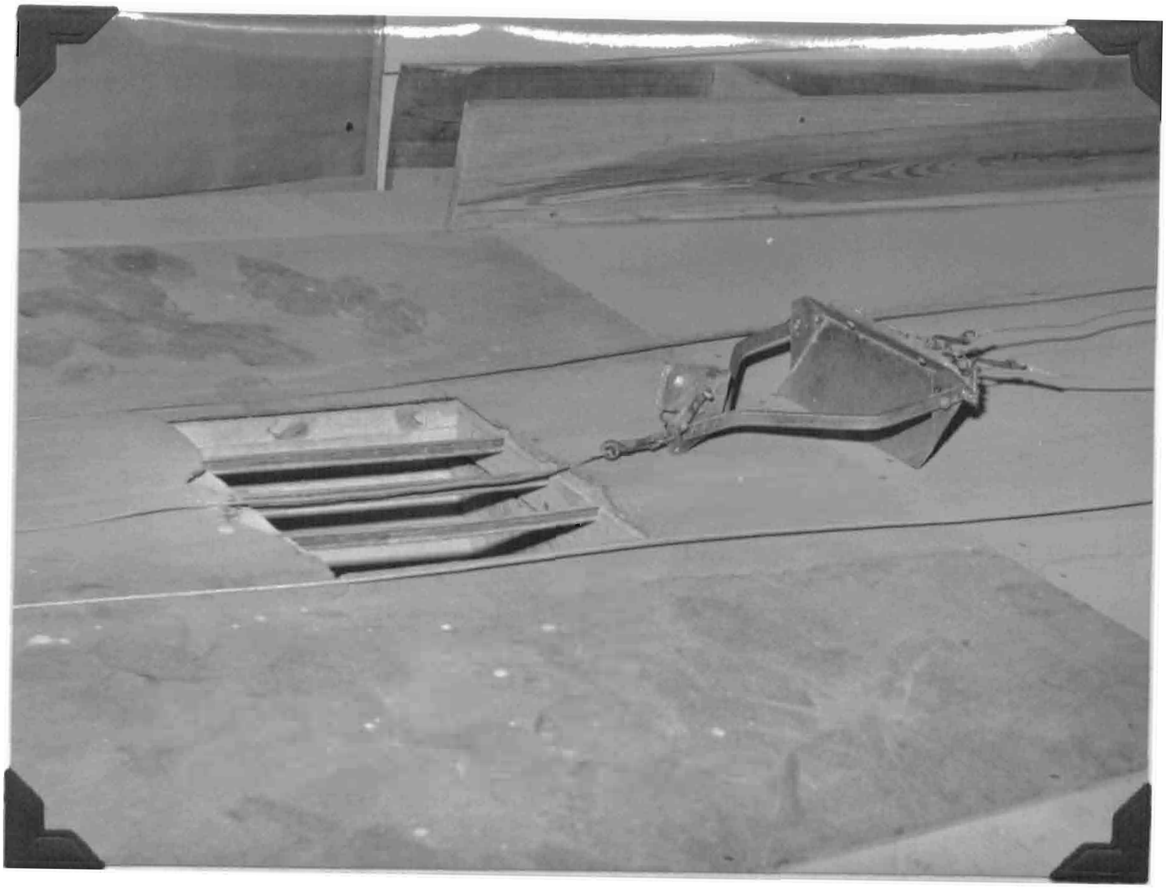

Figure 1. Photograph of Straight Bail Hoe Type Scraper with the blade bolted at a 45 degree angle to the line of pull. Note counterweights on bail and baffle plate.

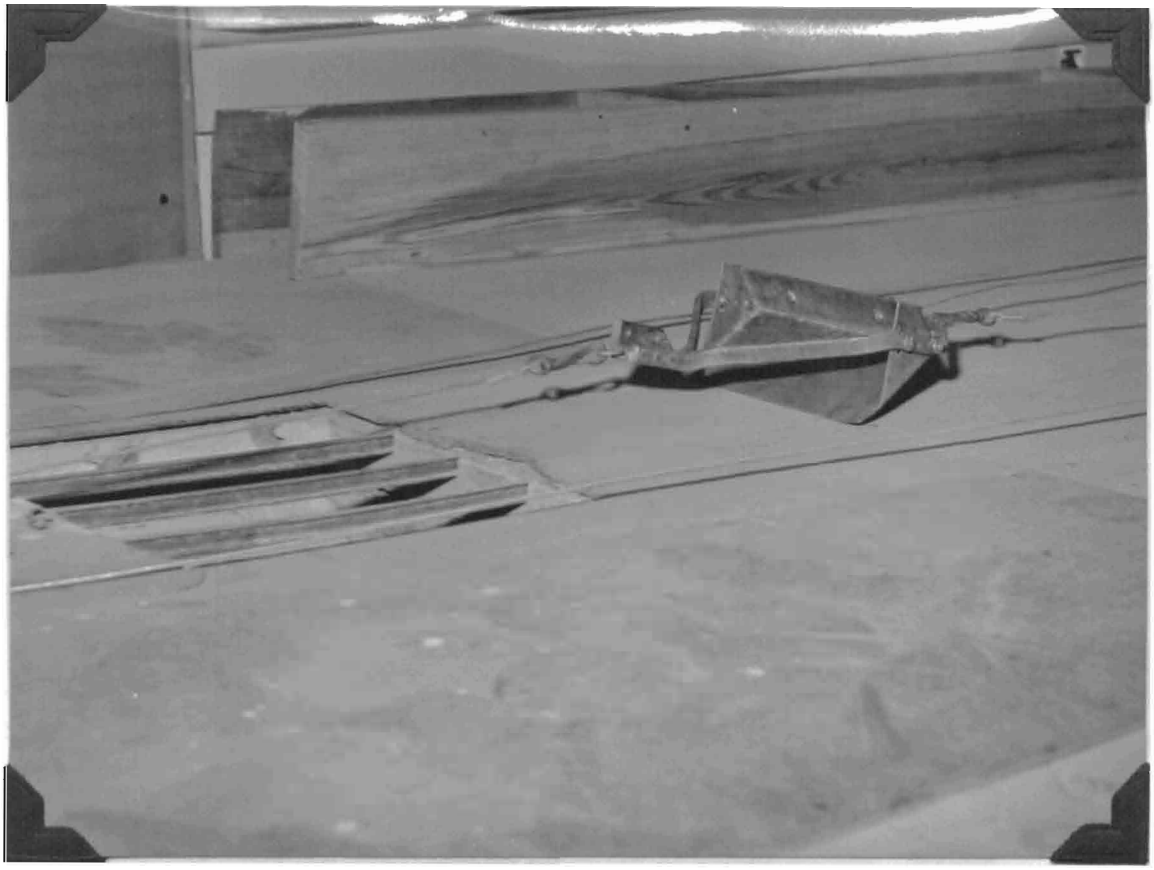

Figure 2. Photograph of Slope Bail Hoe Type Scraper with the blade bolted at a 45 degree angle to the line of pull.

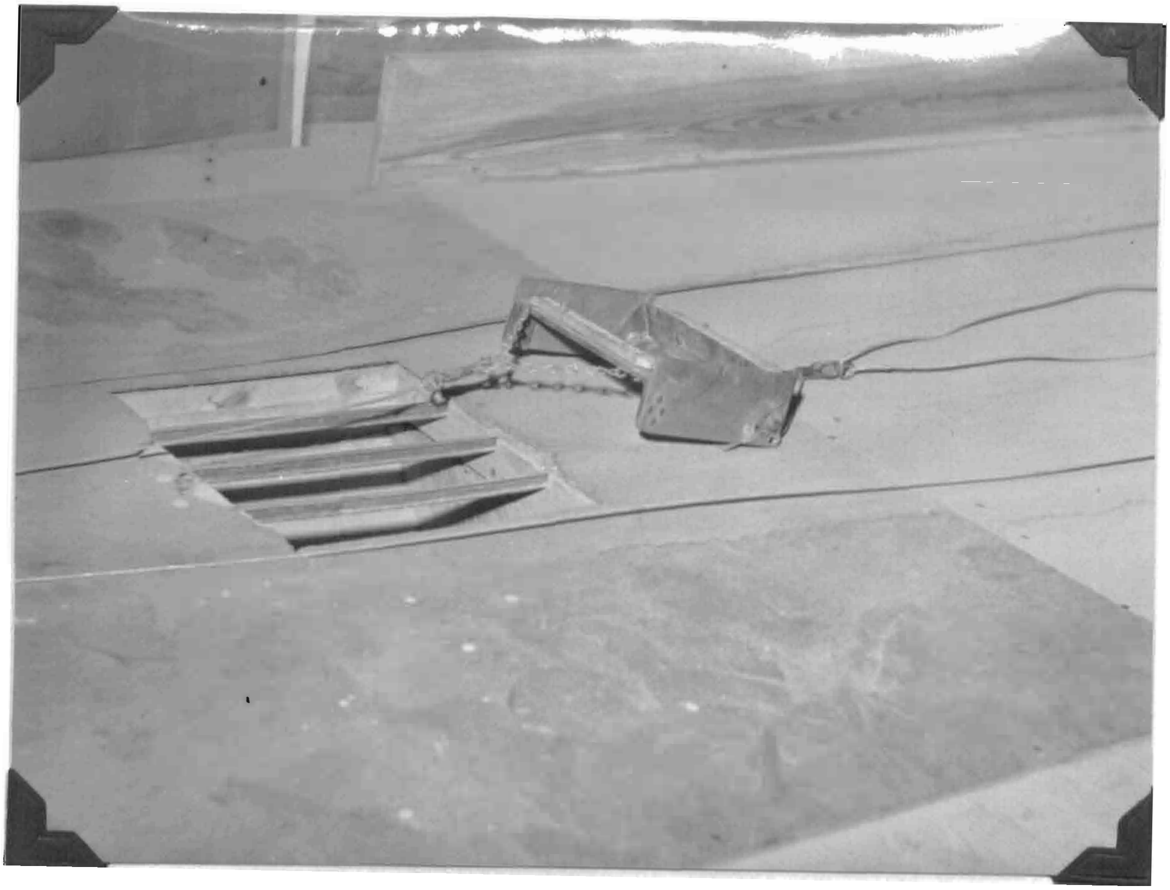

Figure 3. Photograph of Box Type Scraper with the blade bolted at a 30 degree angle to the line of pull.

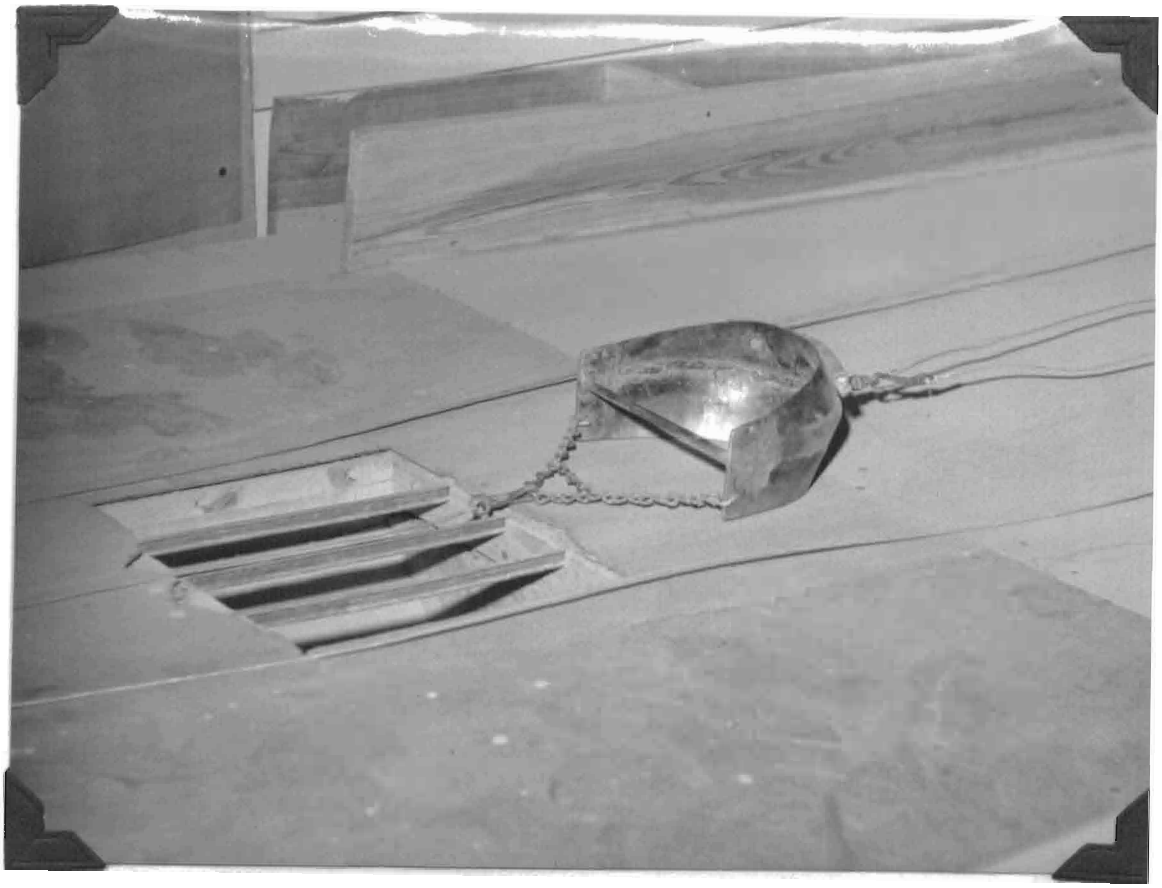

Figure 4. Photograph of a Crescent Type Scraper. This model has a digging angle of 60 degrees.

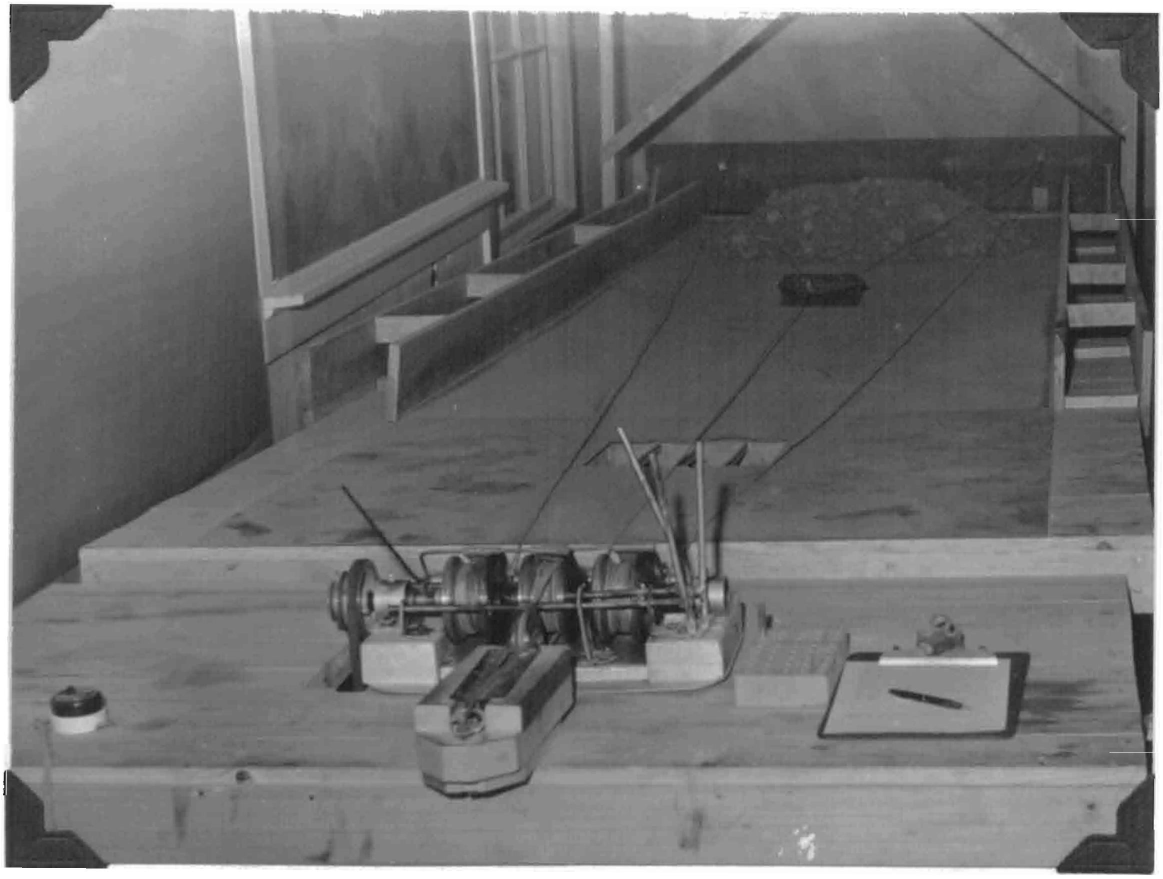

Figure 5. Photograph showing electric hoist assembly and table.

1/8th inch cable on the drum is 3 1/16 inches. The theoretical rope speeds available, therefore, on the first lap of the drum are 125, 169, 187, 254, 344, 381, and 518 feet per minute. Clutch and belt slippage reduced these speeds to some extent. Actual rope speeds were determined by using a tachometer to measure RPM of the hoist shaft. For the purpose of rope speed tests, pulley combinations were used giving actual speeds of 105, 220, and 315 feet per minute. All moisture tests were run at 105 feet per minute.

A wire cable one eighth of an inch in diameter and made up of six strands of seven wires each and a cotton cord center was used to draw the scraper. A half inch cable is commonly used on four foot mine scrapers.

The rope tension required to pull the scrapers was measured by a spring scale fitted with a ball bearing pulley three inches in diameter. It was fastened (See Fig. 5) by a swivel bolt behind the hoist so that the craw cable passes from the hoist drum around the pulley and back underneath the drum to the scraper bail. The pull registered by the scale was twice the actual pull on the scraper because of the two cables acting on the pulley. A 50 pound scale was used.

The table upon which the scraper tests were run was surfaced with rough Masonite fiber board. The table is arranged so that the end away from the hoist may be raised or lowered if necessary.

The table is 15 feet long and five feet wide. Additional side boards were fastened on the table to make the effective width four feet. An opening one foot square and equipped with a three inch grizzly of brass rails is located two feet from the hoist end of the table. Below the grizzly is an inclined chute to direct the scraped material into receiving pans. Sheave wheel supports are mounted at the opposite end of the table from the hoist. Side and back boards make the table water proof. However, the back end must be lowered slightly to keep water from flowing through the grizzly.

Material Tested

The rock used for all the scraper tests was fresh, unaltered granite. When crushed it was splintery to blocky in shape and abrasive.

The rock was screened and classified into six size ranges as follows: minus 3/16 inch, plus 3/16 minus 1/2 inch, plus 1/2 inch minus 1 inch, plus 1 minus 1 1/2 inch, plus 1 1/2 minus 2 inch, and plus 2 minus 6 inch. These sizes on model scale represent sizes six times greater in diameter for full scale scraping.

The specific gravity of the granite was determined by weighing a number of two inch pieces dry and then immersing them in water in a graduate cylinder to find their combined volume. The specific gravity of the granite was found to be 2.71.

The average density of the crushed rock was found to be 1.60 grams per cc. for the minus 3/16 inch size, 1.36 grams per cc. for each of the other sizes, and 1.71 grams per cc. for mixed-size rock in weighed proportions as described in Table 2.

Method of Collecting Data

During the course of the tests the scrapers, counterweights, and rock were weighed in grams and measured in cubic centimeters.

The theoretical volumetric capacity of each scraper was established by filling the scraper with minus 3/16 inch sand and then dragging it three feet along the level table top to dump through the grizzly. The sand was then measured with a 500 cc. graduated cylinder. This process was repeated three times and the average taken. (See Appendix E, Part I).

Two galvanized sheet-iron pans, 9 by 53 by 53 centimeters to a side, were used to measure the weight and volume of the rock scraped through the grizzly. The average depth of material in the pan was measured by first leveling off the top of the pile in the pan then taking eight measurements down from the top of the pan around the sides. The average of the eight measurements was subtracted from nine and the result multiplied by the area of the pan bottom. The pans and contained rock were weighed with an Ohaus 20 kilogram balance scale. Contained moisture in the scraped rock was determined by weighing the rock wet then drying the material and weighing again.

The desired moisture content of the rock to be scraped was established by placing a known weight of dry rock on the table and adding a previously determined amount of water. Moisture content was recorded as percent moisture by weight.

Application of the Principle of Similitude

The principle of similitude has been stated by Tolman [12/] as follows:

12/ Tolman, R. C., The principle of similitude: Physical Review, vol. 4, ser. 2, p. 244, 1914.

"The fundamental entities out of which the physical universe is constructed are of such a nature that from them a miniature universe could be constructed exactly similar in every respect to the present universe".

The above principle can be used for the derivation of the physical relations existing between a model and its prototype. If the testing conditions exactly simulate actual conditions then by applying transformation equations specific data as to the operation of the prototype scraper may be obtained. However, if it is impossible to exactly simulate actual conditions, then relative data concerning the variables such as rock sizes or rope speeds introduced into the tests may be obtained if the various factors influencing the tests are all recognized and carefully evaluated.

Since no two mining operations have identical characteristics it was not considered necessary nor practical to obtain specific data. The conclusions reached as a result of these tests are relative and as such may be applied to actual operations.

If the linear ratio between the model and its prototype is arbitrarily established as 1 to x, then the other scale-reduction ratios as determined by Tolman[13] and Carlson[14] would be as follows:

Lengths	---------------- $1:x_3$
Volumes	---------------- $1:x_2$
Forces	---------------- 1:x
Velocities	---------------- 1:1
Densities	---------------- x:1

13/ Tolman, R. C., The principle of similitude and the principle of dimensional homogeneity: Physical Review, Vol. 6, Ser. 2, p. 226, 1915.
14/ Carlson, R. W., General structural similitude: University of California Publications in Engineering, Vol. 3, No. 2, pp. 141-142, Nov. 8, 1933.

Since the scale chosen for the tests was 1 to 6, then x would equal six. Substituting this value in the above ratios, the scale-reduction factors, expressed as ratios of model value to prototype value, would be as follows:

Lengths	---------------- 1:6
Volumes	---------------- 1:216
Forces	---------------- 1:36
Velocities	---------------- 1:1
Densities	---------------- 6:1

From the velocity ratio above it may be seen that rope speeds are the same for the prototype as for the model.

It may also be seen that if specific data as to weight of rock scraped were to be obtained, then the rock tested on the model should have a density six times that of rock actually encountered in mining operations. It would be impractical if not impossible to obtain suitable material answering this qualification. It is cheifly because of the density relationship that the data presented in this paper is considered relative instead of specific.

DESCRIPTION OF MODEL SCRAPER TESTS

Although two series of tests, rope speed and moisture content of rock, were run, the procedure was similar in both series. Crushed granite of known size and specific gravity was used. Rope speed tests were run on a level floor but it was found necessary to lower the back end of the table to a two degree slope to contain the water for the moisture tests.

The scraper was pulled back over the muck pile and then forward to the grizzly. The trips or passes were counted by a peg board. (See Fig.5). Twenty passes were considered sufficient for one test. After 20 passes the material scraped was measured for volume and weight. On some tests the pans were filled before the test was finished and it was necessary to stop and weigh the material before continuing. The average weight and volume scraped per pass was averaged for each 20 trip test and these averages were used for all calculations and graphs.

Three rop operation was used throughout the course of the tests. An attempt was made to keep maneuvering of the scraper at a minimum. In other words, the operator spotted the scraper in a position considered best for picking up a maximum load and then pulled it forward to the grizzly. If a light load was inadvertently picked up due to deflection by a boulder or for some other reason, no attempt was made to go back and refill the scraper on that pass. Occasional light loads would be picked up in actual practice and it was believed that 20 passes were sufficient to give reasonably accurate average data for one pass.

Sixty-nine rope speed and 20 moisture tests were run. In any case in which the slightest question existed that the test results might be erroneous, additional tests were run until results that checked were obtained. Twenty-three check tests in all were run.

In the course of the tests the majority of the conclusions reached by Clayton[15] were corroborated.

15/ Clayton, Austin B., ibid., p. 55.

There seems to be some difference in the relative efficiency of the various scraper types with three rope operation as compared with two rope operation.

The chief difference was the increased efficiency of the box scraper under three rope operation. This scraper with the blade set a 30 degrees has the best digging action of any scraper type. Three rope operation enables the operator to take full advantage of that action.

The flow pattern of the muck during scraping can contribute greatly to efficiency of the hoe type scrapers. The hoes lose most of their load during the first few passes of the scraper. This lost material builds up into ridges on each side of the scraper path. (See Fig. 6). The ridges confine the scraper load and prevent further loss on later passes. When confined in such a trough the scraper often pushes quantities of rock on ahead of its full load. Best advantage of the ridge effect can be taken by the operator as follows: pick up the loads from the center of the muck pile while the ridges are being built. The scraper should be pulled back to the pile in a straight line so as not to disturb the ridges. With the

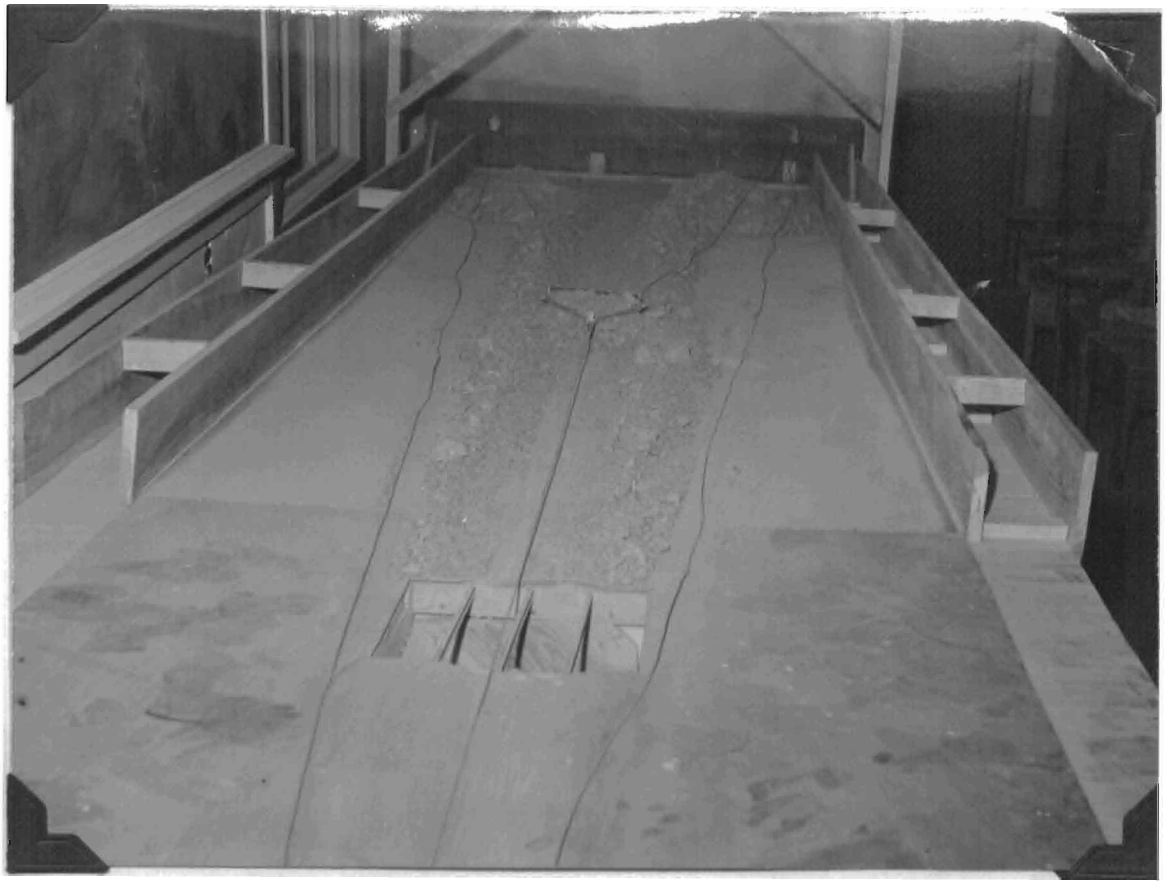

Figure 6. Photograph of Slope Bail Hoe Type Scraper moving mixed-size rock. Note ridges built up along path of scraper.

center of the pile cut out, two corner piles and trough between the ridges are left. The scraper can then be spotted behind either pile. Regardless of the direction of the line of pull when loading, the corner piles will swing the scraper around into the trough. The scraper bites its load off the side of the pile as it swings around into the trough.

The ridge effect is noticeable to a slight extent with the box and crescent scrapers but contributes little or nothing to their action.

By running identical tests at different rope speeds it was learned that there was a definite speed at which scraper efficiency was at a maximum for any particular size of rock.

The hoe type scrapers are less affected by variations in speed than either the box or the crescent scrapers. There was also little difference in efficiency of the hoes with regard to rock size, indicating a wide range of applicability for this type scraper.

With all types of scrapers the decline in efficiency beyond the optimum speed was gradual. This being the case, it might be practical to operate scrapers at a speed higher than the optimum. Up to a certain point the saving in time with higher speeds would overbalance the small drop in capacity. The rope speed at which such operation would be most practical would depend on the length of haul and the rate of decline in efficiency. The skill of the operator would be a human variable which should, of necessity, be taken into account.

The recapitulation table No. 2 showing maximum efficiencies obtained in laboratory tests for any combination of rope speed, rock size, and scraper type will serve to illustrate the above statements.

The moisture tests were run on mixed-size granite in weighed proportions as follows: -3/16", 55%; + 3/16"-½", 25%; +1/2 -1", 10%; +1-1 1/2", 5%, + 1 1/2" - 2", 3%; + 2 - 6", 2%. For moving mixed-size rock the

Table 2
RECAPITULATION OF ROPE SPEED TESTS

Figures given represent percent of theoretical capacity carried by scraper each trip, averaged from 20 trips.

		Scraper Types			
Rock size	Rope speed	Hoe Straight bail	Hoe, Slope bail	Box	Crescent
-3/16"	105 fpm	36.5	82.6	141.9	82.2
-3/16"	220	50.7	96.4	153.4	96.1
-3/16"	315	51.0	94.9	150.8	93.0
3/16"-1/2"	105	43.9	100.1	138.0	73.5
3/16"-1/2"	220	49.1	97.9	145.5	69.6
3/16"-1/2"	3.5	60.8	113.9	122.2	65.8
1/2"-1"	105	66.3	102.6	83.6	52.9
1/2"-1"	220	68.8	91.1	108.9	39.3
1/2"-1"	315	63.7	81.5	113.1	32.1
1"-2"	105	44.8	40.1	33.9	22.2
1"-2"	220	48.0	43.5	35.5	13.9
1"-2"	315	44.8	43.0	48.4	17.3
2"-6"	105	22.4*	none		
2"-6"	220	47.1*	none		
2"-6"	315	42.3*	none		

Mixed-size rock in weighed proportions as follows:

-3/16" : 55%, + 3/16"-1/2" : 25%, + 1/2"-1" : 10%, + 1"-1 1/2" : 5%,

+ 1 1/2"-2" : 3%, + 2"-6" : 2%.

Rope Speed	Hoe, Straight bail	Hoe, straight bail	Box	Crescent
105 fpm	48.5	100.0	114.0	74.3
220	50.1	98.4	126.4	62.7
315	60.4	91.6	116.5	59.8

---

* Average per trip for three tests of 20 trips each.

scrapers tested ranked in the following order: Box, slope bail hoe, crescent, and straight bail hoe.

The amount of moisture in the rock after scraping was less than that in the rock before scraping. This was caused by moisture in the scraper load draining out on to the table during scraping. As the original moisture content of the rock was increased the difference between it and the final moisture content was increasingly greater.

Recapitulation table No. 3 shows the difference in moisture content and also indicates the relative efficiencies of the different scrapers for various amounts of moisture.

Table 3

RECAPITULATION OF MOISTURE TESTS

Figures given represent percent of theoretical capacity and equivalent dry weight of rock in grams per unit of scraper weight carried by scraper in one trip, averaged from 20 trips.

Percent Moisture by weight		Scraper Types							
Before Scraping	After Scraping	Hoe, st. bail		Hoe, sl. bail					
		% cap.	Gm Rock dry/gm scraper	% cap.	Gm rock dry/gm scraper	% cap.	Gm Rock dry per grm scr	% cap.	Gm Rock dry scr. gm. scr.
0	0	48.5	1.23	99.9	1.53	114.0	1.61	74.3	1.86
4.76	4.73	52.7	1.24	122.1	1.48	122.4	1.81	78.2	1.73
9.09	5.61	57.3	1.25	116.5	1.52	135.2	1.72	68.3	1.63
15.00	6.65	58.8	1.33	118.7	1.61	133.8	1.69	61.2	1.36
20.00	8.20	56.5	1.27	117.0	1.58	130.5	1.63	58.3	1.29

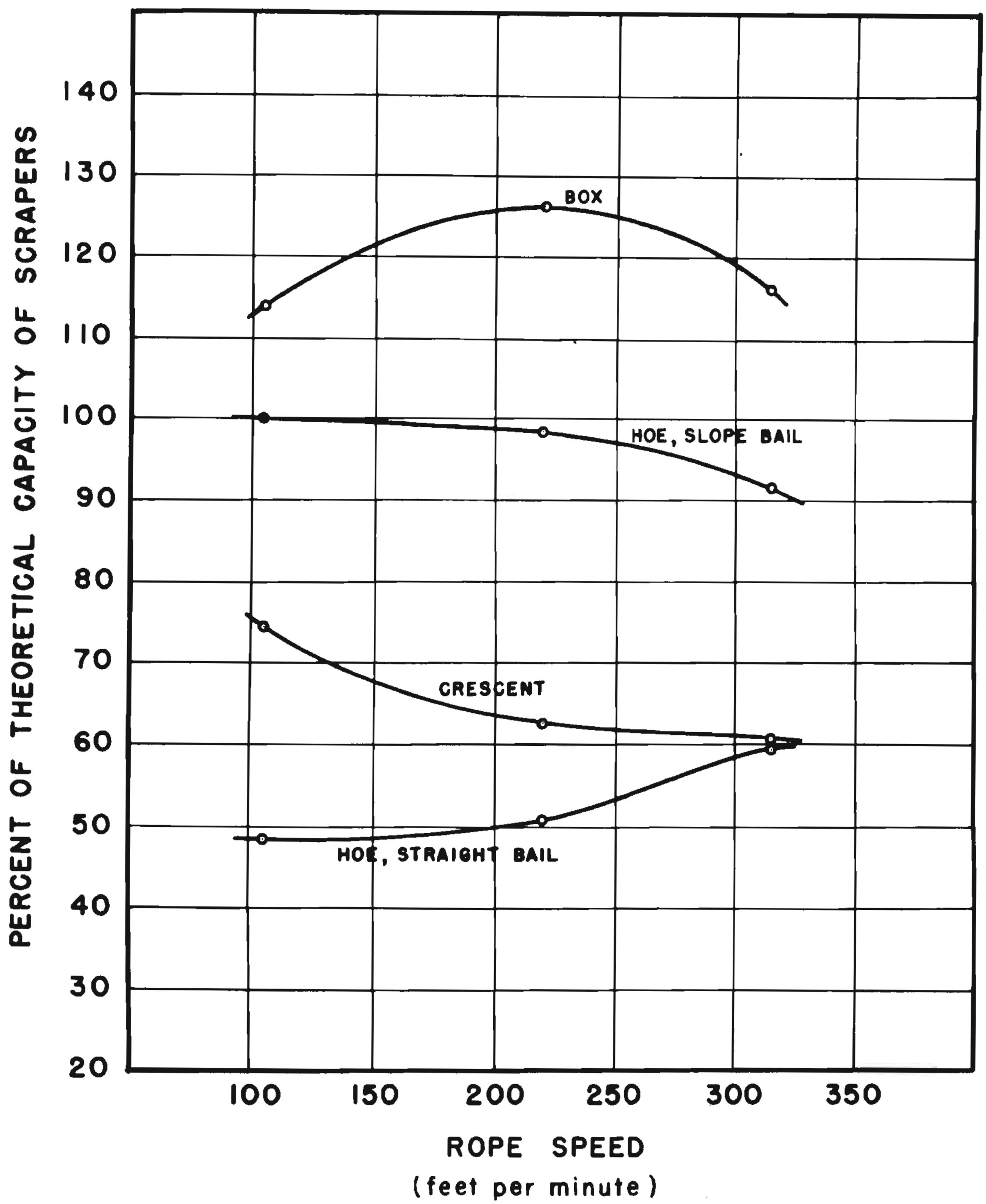

Figure 7. Relationship between scraper capacity and rope speed with mixed-size rock.

With the exception of the crescent scraper, the addition of moisture to the muck pile increased scraping efficiency. Since the mine operator is interested in the amount of ore moved and not in the water moved, the dry weight of the rock scraped was determined. Figure 12 illustrates the relationship between volumetric capacity and moisture for the various scraper types; Figure 13 illustrates the relationship between the dry weight of the rock moved and moisture content for the various scrapers.

The addition of five percent moisture to the dry rock made the material more cohesive. This had the effect of increasing capacity since there was less loss of material from the scrapers in transit. Addition of amounts of moisture over five percent had the effect of compacting the muck. There was also some standing water on the table.

The compacted muck made digging more difficult for the scrapers. This was the reason for the sharp decline in efficiency of the crescent scraper, which has poor digging action.

Hoe Type Scraper Tests

The slope bail and straight bail hoe scrapers both have blades adjustable to 30, 45, or 60 degrees to the line of pull. All tests were made with the blade at the 45 degree angle which is most suitable for hoe scrapers.

Figure 8 and 9 show graphically that in general the optimum rope speed for sized rock is about 250 feet per minute. For both hoes the optimum speed for the + 3/16" - 1/2" was 320 feet per minute or higher. The rock particles of this size were rounded and both scrapers exhibited excellent digging action on it.

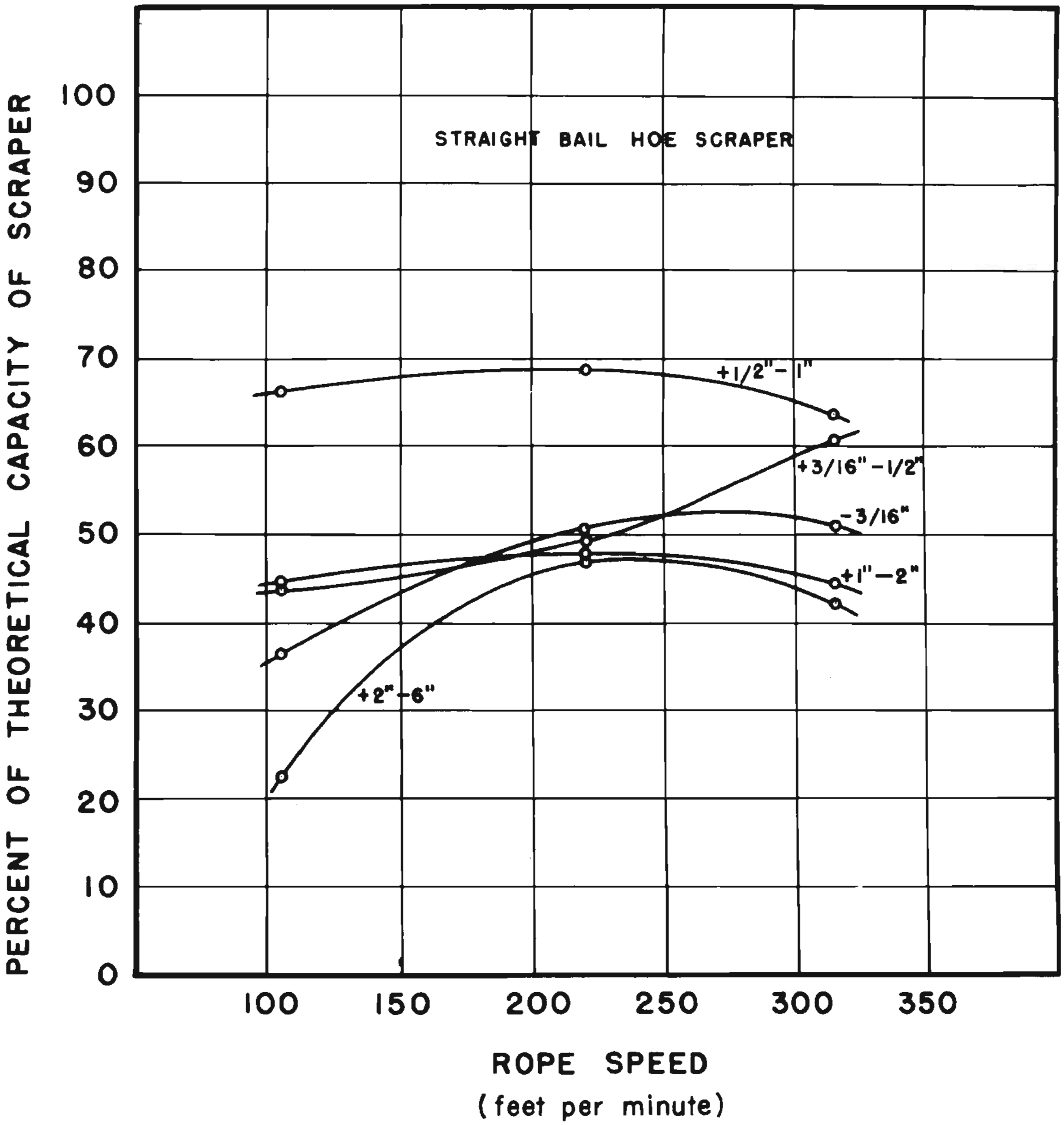

Figure 8 .Relationship between straight bail hoe scraper capacity and rope speed with sized rock.

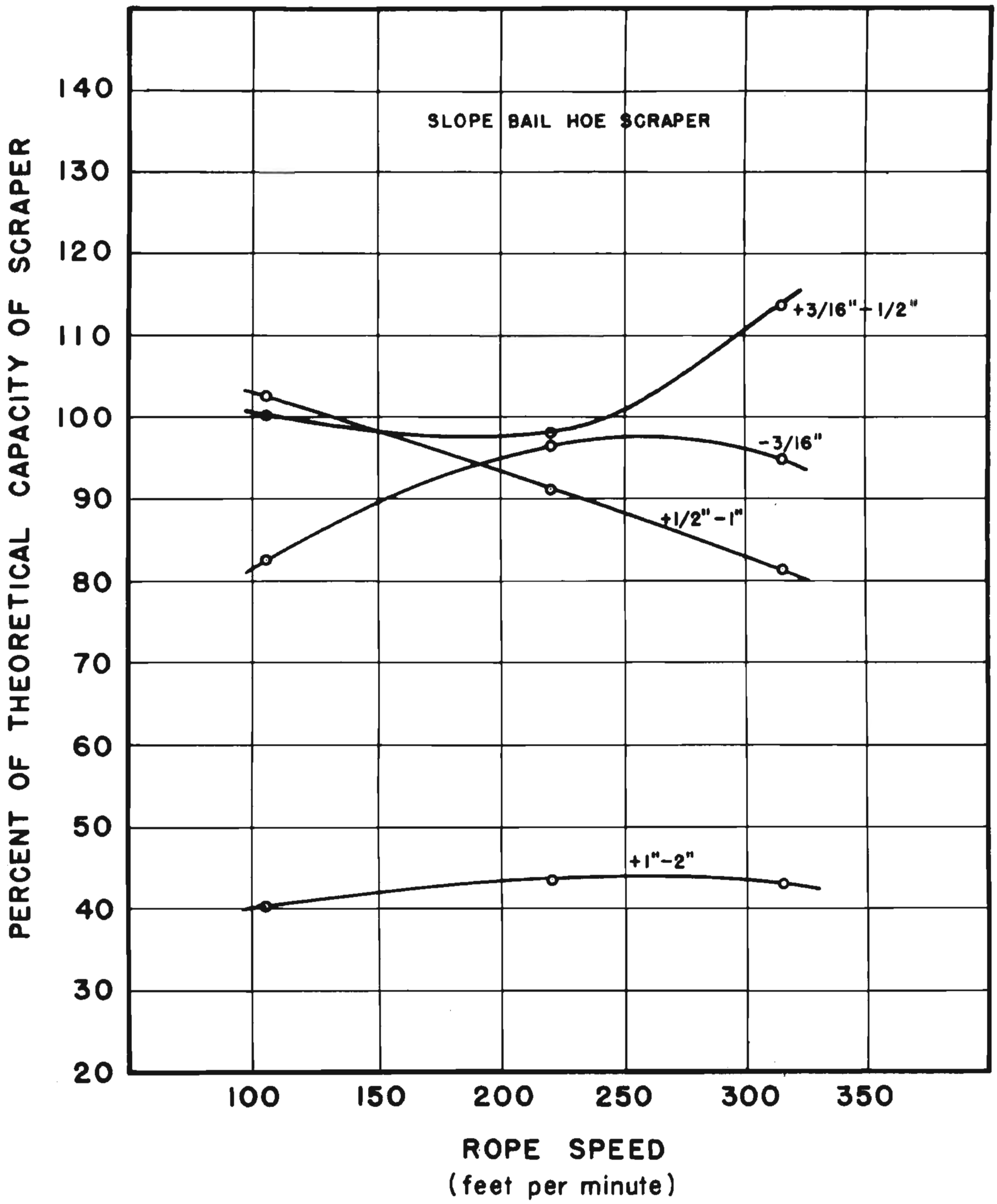

Figure 9. Relationship between slope bail hoe scraper capacity and rope speed with sized rock.

It will be noted that there was a sharp drop in efficiency for the slope bail hoe in scraping particles over 1" in diameter. This was because the front of the bail was bent down closer to the floor and acted as a "bumper" to push the large pieces out of the way.

The straight bail hoe showed a marked increase in efficiency on the + 2" sizes at higher speeds. The shock effect of the scraper hitting the pile at the higher speeds scattered the boulders and threw some of them into the path of the blade. At lower speeds the scraper was often deflected around large pieces of rock.

Both scrapers showed increased ability to carry boulders when embedded in a mixed-size rock.

The action of the hoe scrapers on muck containing various amounts of moisture was similar although the slope bail hoe was the more efficient of the two. Volumetric capacity and dry weight of rock carried were both at a maximum for the scrapers when the original moisture content of the muck was fifteen percent. Both hoes had good digging action in the compacted muck.

<u>Box Type Scraper Tests</u>

The box scraper was tested with a blade angle of 30 degrees. At this angle the scraper works with a scooping action. The box works best on fine material and fairly well on intermediate materials. It is the most stable scraper in operation of all types tested. It cleans up the table exceptionally well, leaving less ridge than any other scraper.

For the box a rope speed of 200 to 250 feet per minute is most efficient with mixed-size rock and sized rock up to $\frac{1}{2}$" in diameter. (See Figures 7 and 10). With + $\frac{1}{2}$" - 1" rock the best speed is from 250 to 300 feet per minute. Three hundred feet per minute or higher is the best speed

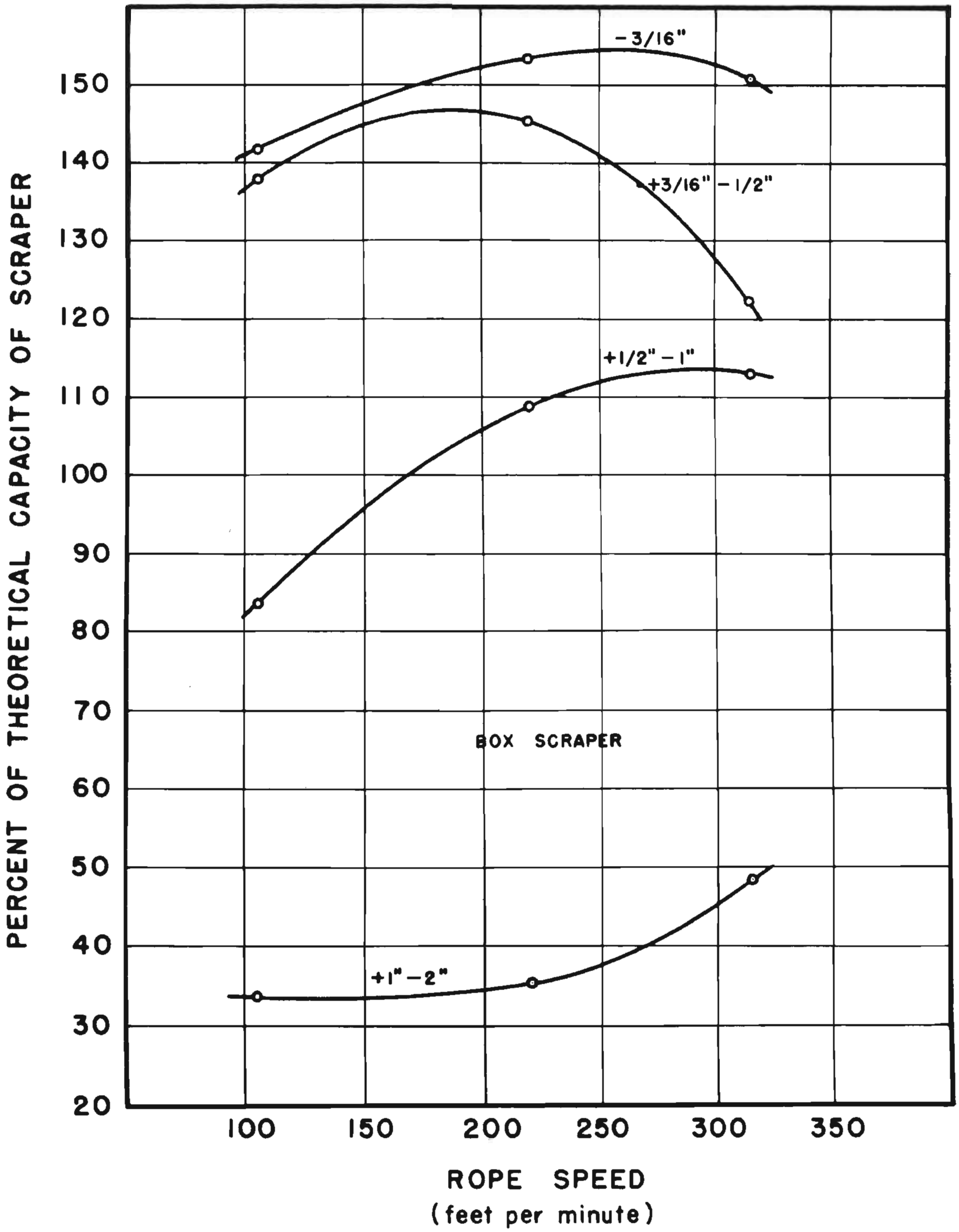

Figure 10. Relationship between box scraper capacity and rope speed with sized rock.

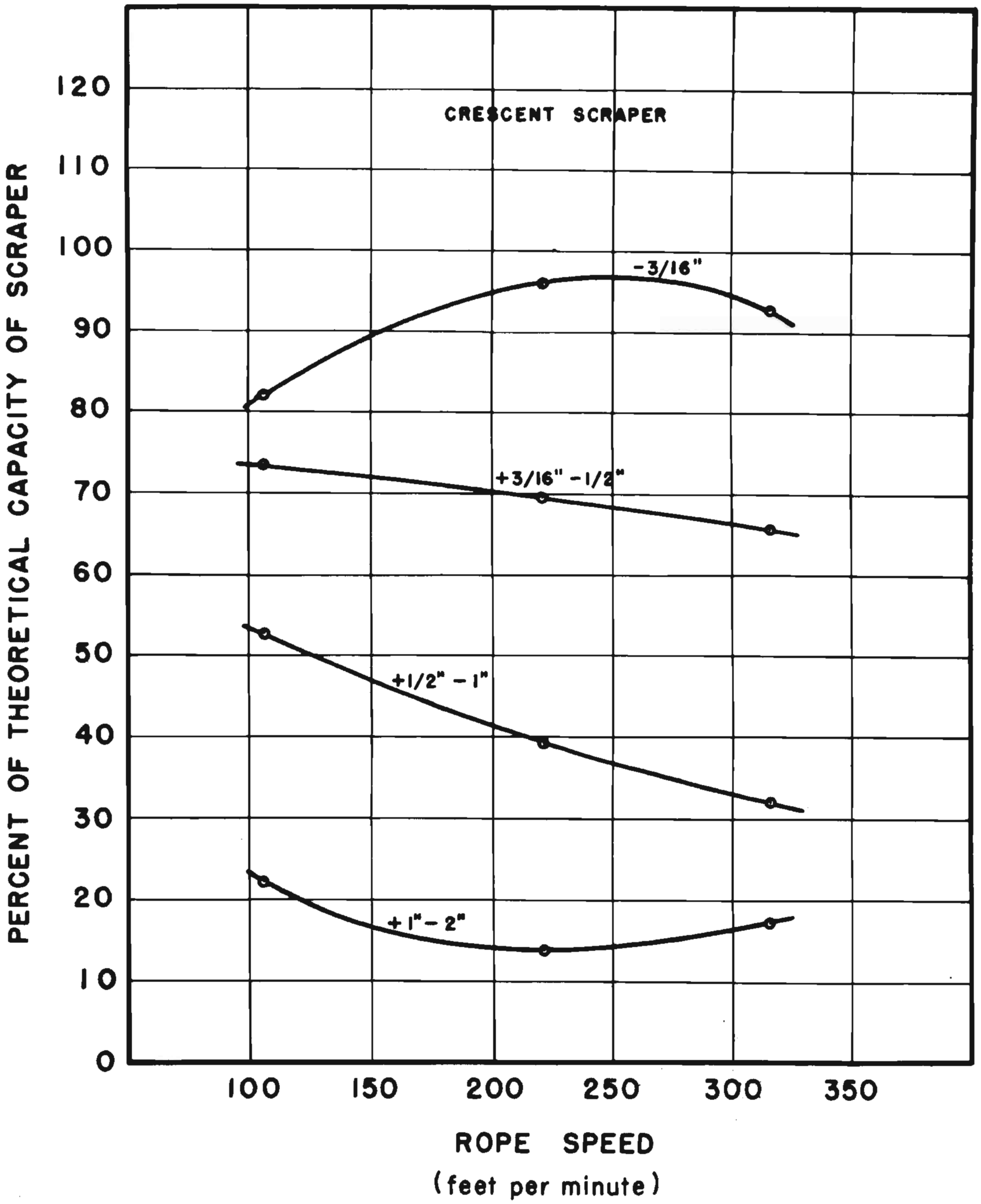

Figure 11. Relationship between crescent scraper capacity and rope speed with sized rock.

for rock over 1" in diameter. The increase in rope speed for greater efficiency with the larger rock sizes is probably due to the shock effect of the scraper scattering the boulders, similar to the action of the hoe scrapers.

As moisture content of the muck is increased the efficiency of the box scraper increases up to a certain point and then decreases. As illustrated in Figures 12 and 13, the volumetric capacity of the box was at a maximum when the original moisture content of the rock was 11 percent but greatest weight of dry rock was moved when the moisture content was five percent. The box scraper did not exhibit quite as good digging action on the compacted muck as the hoe type scrapers.

Crescent Type Scraper Tests

The crescent scraper blade was fixed by construction at 60 degrees to the line of pull. At this angle the digging action was poor. The scraper picks up its best load when the muck pile is spread out rather than gathered into a steep pile. It picks up a load slowly and consequently needs a greater area of muck to work on. The high angle of the blade also makes it difficult to pull the empty scraper back over the muck pile.

On the - 3/16" rock the most efficient speed of the scraper was about 250 feet per minute. The most efficient rope speed for all other sized and mixed-size rock was about 100 feet per minute.

Increased speed seems to make the crescent more unstable. If one of the crescent points rides up on a large rock particle there is a tendency for the scraper to roll on the curvature of the blade and turn over.

There is a small increase in volumetric capacity of the crescent when five percent moisture is added to the dry muck. About five percent moisture there is a sharp decline in scraper capacity.

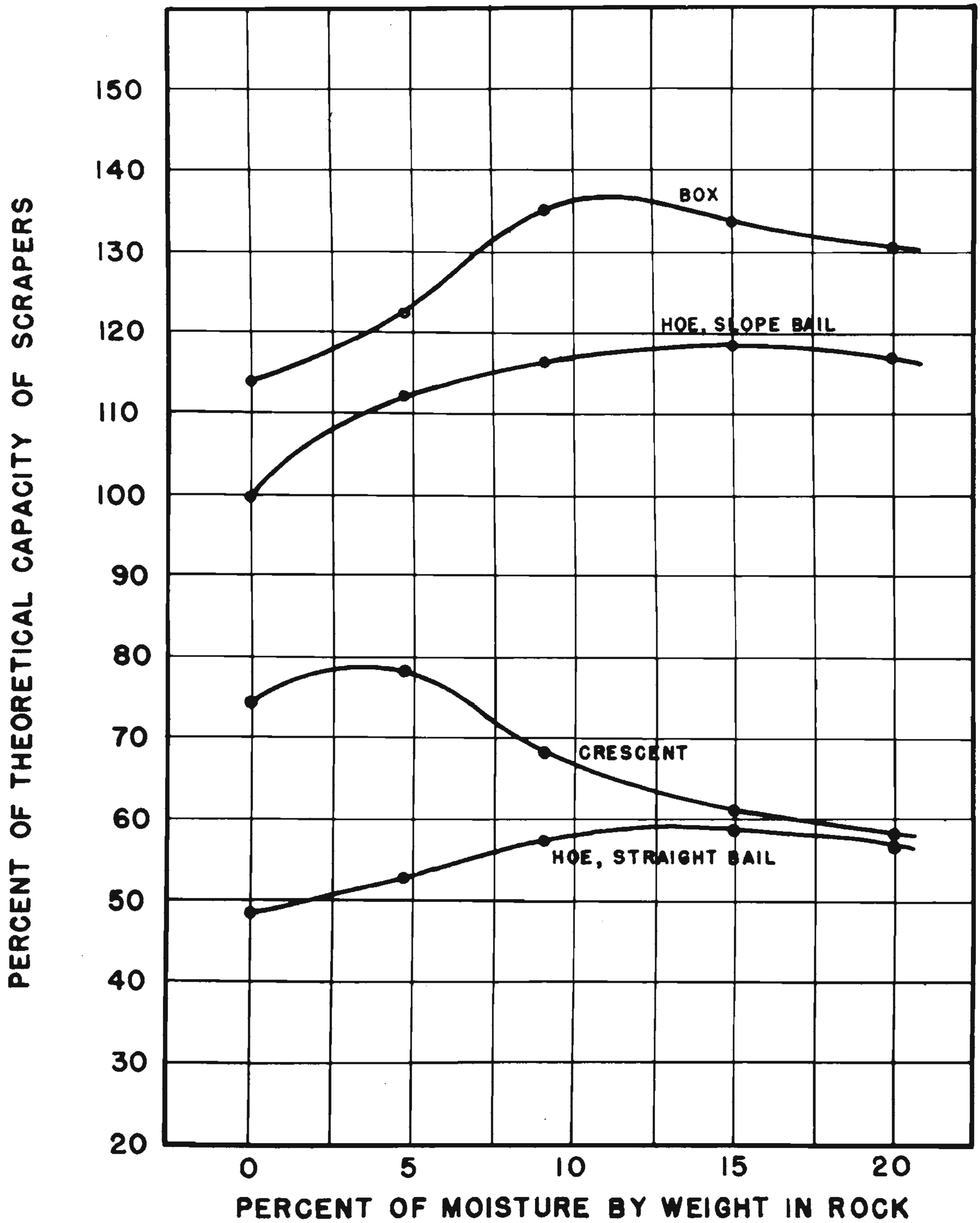

Figure 12. Relationship between scraper capacity and moisture content of rock.

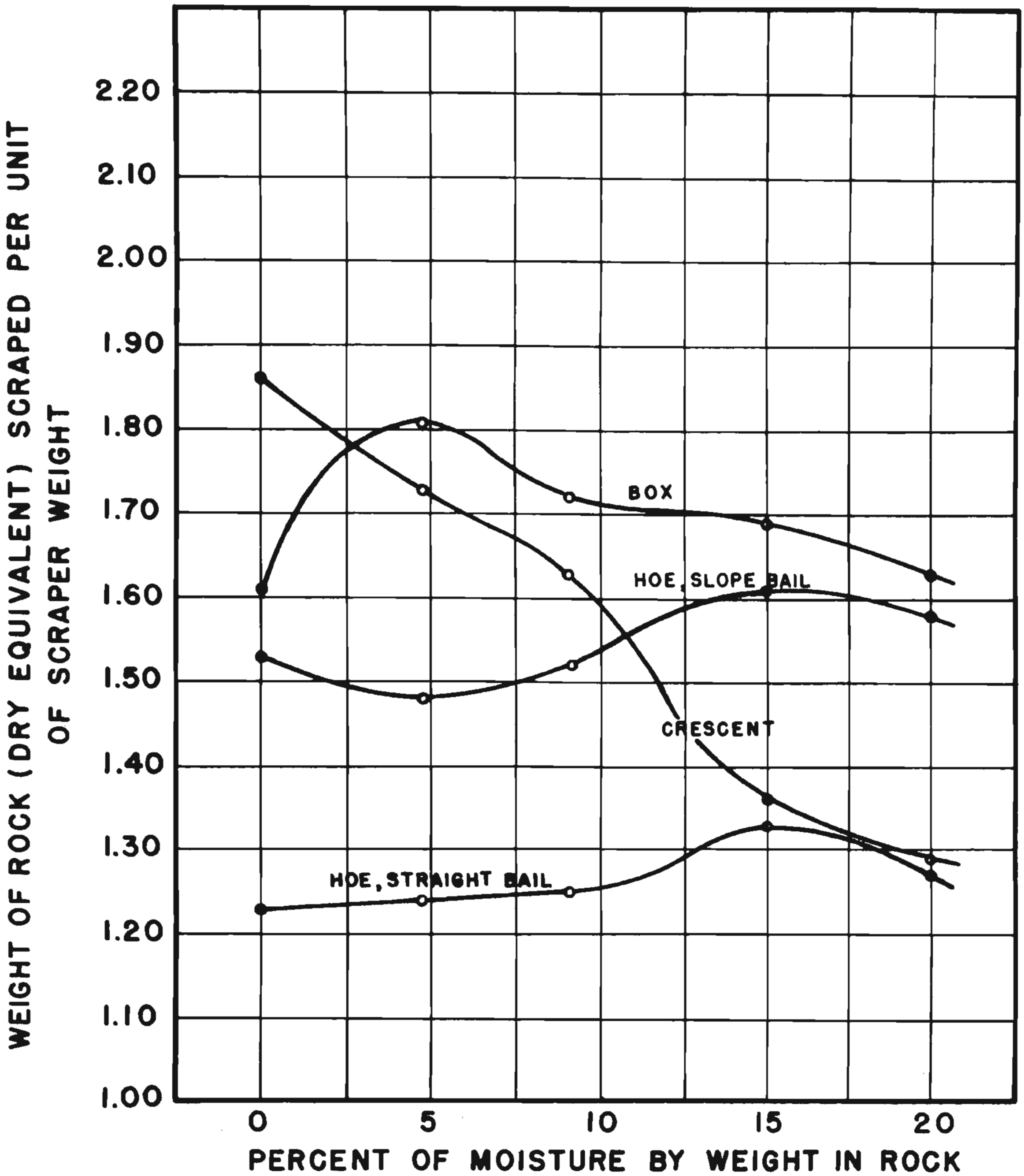

Figure 13. Relationship between equivalent dry weight of rock scraped and original moisture content of rock.

The dry weight of rock scraped shows a very sharp decline if any moisture at all is added to the muck. (See Figures 12 and 13). As previously mentioned this poor action is due to the compaction of the wet muck. The addition of teeth to the scraper blade might help the scraper action on this type of muck.

Conclusions Drawn from Model Scraper Tests

1. The flow of the muck pile during operation of the hoe scrapers can be utilized as a contributing factor to scraper efficiency.

2. The efficiency of a given scraper is at a maximum at a definite rope speed for any one size of material.

3. The hoe type scrapers are less affected by variations in rope speed than either the box or crescent scrapers.

4. The decline in scraper efficiency beyond the optimum speed is so gradual that the saving in time might outweigh the loss in efficiency at higher speeds.

5. The efficiency of a given scraper is at a maximum at a definite moisture content of any particular type of muck.

SUMMARY OF SCRAPER TESTS

Models of four bottomless type mine scrapers were tested to determine the effect of rope speed and moisture content of the muck on their efficiency in moving muck from a pile to a chute. The model scale was one to six and all four scrapers had a width of eight inches. The scraper types included a straight bail hoe, a slope bail hoe, a box, and a crescent.

The rock used in the tests was granite, crushed and sized to six different diameters, ranging from 3/16 inch to 6 inches. The rope speeds tested were 105, 220, and 315 feet per minute. Muck containing moisture ranging from zero to twenty percent by weight was also tested. Three rope operation was used throughout. Sixty-nine rope speed tests and 20 moisture tests were run. In addition 23 check tests were run.

It was determined that there is a definite rope speed and moisture content for any particular size and type of rock at which scraping efficiency is at a maximum. It is also believed that scrapers may be economically operated at speed beyond the optimum for carrying efficiency.

The hoe type scrapers are least affected by variations in rope speed or moisture content. The flow of the muck during scraping may be utilized to advantage with hoe scrapers.

It is believed that the present study of model scrapers has shown that much more useful information may be obtained by continued research with models.

Appendix A

ROPE SPEED TESTS AT 105 FPM

Three rope operation - dry granite on level floor - 10 ft. distance

Wt. Scraper	Type Scraper	Particle (inches Diameter) Sizes -3/16	+3/16-1/2	+1/2-1	+1-1 1/2	+1 1/2-2	+2-6	% Theor. Capacity	Gms. Rock per Gr. Scraper	Gms. Rock per CC.
1104	Hoe, St.*	100%						36.52	1.23	1.60
1414	" "		100%					43.89	0.98	1.36
2726	" "			100%				66.31	0.78	1.38
2821	" "				50%	50%		44.76	0.50	1.36
2821	" "				25%	25	50%	39.40	0.44	1.36
2821	" "						100	21.3	0.24	1.36
2821	" "						100	13.6	0.15	1.36
2821	" "						100	32.3	0.36	1.36
1571	" "	55	25	10	5	3	2	48.49	1.23	1.71
747	Hoe, Sl.**	100						82.56	1.81	1.60
1139	" "		100					100.05	1.28	1.45
2195	" "			100				102.61	0.65	1.36
2509	" "				50	50		40.08	0.22	1.36
2509	" "						100	0	0	----
1149	" "	55	25	10	5	3	2	99.96	1.53	1.70
1856	Box	100						141.87	2.08	1.60
1856	"		100					137.97	1.72	1.36
2969	"			100				83.64	0.84	1.42
2965	"				50	50		33.91	0.26	1.36
2065	"	55	25	10	5	3	2	114.01	1.61	1.71
1560	Crescent	100						82.15	2.19	1.60
1560	"		100					73.46	1.75	1.43
2466	"			100				52.92	0.70	1.26
2466	"				50	50		22.23	0.32	1.36
1780	"	55	25	10	5	3	2	74.32	1.86	1.71

* St. - Straight bail
** Sl. - Slope bail

Appendix B

ROPE SPEED TESTS AT 220 FPM

Three rope operation - dry granite on level floor - 10 ft. distance

Wt. Scraper	Type Scraper	Particle (inches Diameter) Sizes -3/16	+3/16-1/2	+1/2-1	+1-1 1/2	+1 1/2-2	+2-6	% Theor. Capacity	Gms. Rock per Gr. Scraper	Gms. Rock per CC.
1104	Hoe, St.*	100%						50.7	1.71	1.60
1414	" "		100%					49.1	1.10	1.36
2724	" "			100%				68.8	0.77	1.31
2821	" "				50%	50%		48.0	0.54	1.36
2821	" "						100%	41.8	0.47	1.36
2821	" "						100	51.9	9.58	1.36
2821	" "						100	47.6	0.53	1.36
1571	" "	55	25	10	5	3	2	50.1	1.17	1.71
747	Hoe, Sl.**	100						96.4	2.12	1.60
1139	" "		100					97.9	1.20	1.36
2195	" "			100				91.1	0.58	1.36
2509	" "				50	50		43.5	0.24	1.36
1149	" "	55	25	10	5	3	2	98.4	1.50	1.71
1856	Box	100						153.4	2.25	1.60
1856	"		100					145.5	1.82	1.36
2969	"			100				108.9	0.87	1.40
2965	"				50	50		35.5	0.28	1.36
2065	"	55	25	10	5	3	2	126.4	1.78	1.71
1560	Crescent	100						96.1	2.56	1.60
1560	"		100					69.6	1.62	1.39
2466	"			100				39.3	0.56	1.36
2466	"				50	50		13.9	0.20	1.36
1780	"	55	25	10	5	3	2	62.7	1.57	1.71

* St. - Straight bail
** Sl. - Slope bail

Appendix C

ROPE SPEED TESTS AT 315 FPM

Three rope operation - dry granite on level floor - 10 ft. distance

Wt. Scraper	Type Scraper	Particle (inches Diameter) Sizes -3/16	+3/16-1/2	+1/2-1	+1-1 1/2	+1 1/2-2	+2-6	% Theor. Capacity	Gms. Rock per Gr. Scraper	Gms. Rock per CC.
1104	Hoe, St.*	100%						51.0	1.72	1.60
1414	" "		100%					60.8	1.36	1.36
2724	" "			100%				63.7	0.74	1.36
2821	" "				50%	50%		44.8	0.50	1.36
2821	" "						100%	51.5	0.58	1.36
2821	" "						100	38.3	0.43	1.36
2821	" "						100	37.0	0.42	1.36
1571	" "	55	25	10	5	3	2	60.4	1.53	1.71
747	Hoe, Sl.**	100						94.9	2.08	1.60
1139	" "		100					113.9	1.40	1.36
2195	" "			100				81.5	0.52	1.36
2509	" "				50	50		43.0	0.24	1.36
1149	" "	55	25	10	5	3	2	91.6	1.40	1.71
1852	Box	100						150.8	2.21	1.60
1852	"		100					122.2	1.53	1.36
2969	"			100				113.1	0.88	1.36
2969	"				50	50		48.4	0.38	1.36
2065	"	55	25	10	5	3	2	116.5	1.64	1.71
1560	Crescent	100						93.0	2.48	1.60
1560	"		100					65.8	1.49	1.36
2466	"			100				32.1	0.46	1.36
2466	"				50	50		17.3	0.25	1.36
1780	"	55	25	10	5	3	2	59.8	1.50	1.71

* St. - Straight bail

** Sl. - Slope bail

Appendix D

MOISTURE TESTS

Three rop operation at 105 fpm, 10 ft. distance, scraping a weighed proportion of mixed-size granite

Wt. Scraper	Type Scraper	% Moisture by weight	% Theor. Capacity	Gm. Rock (wet) per Gm. Scraper	Gm. Rock (dry) per gm. Scraper	Gm. Rock (wet) per CC.	% Moisture after Scraping
1571	Hoe, St*	0	48.5	1.23	1.23	1.71	0
1149	Hoe, Sl**	0	99.9	1.53	1.53	1.70	0
2065	Box	0	114.0	1.61	1.61	1.71	0
1780	Crescent	0	74.3	1.86	1.86	1.71	0
1571	Hoe, St.	4.76	52.7	1.30	1.24	1.66	4.73
1149	Hoe, Sl.	4.76	112.1	1.55	1.48	1.55	4.73
2065	Box	4.76	122.4	1.90	1.81	1.55	4.73
1780	Crescent	4.76	78.2	1.82	1.73	1.59	4.73
1571	Hoe, St.	9.09	57.3	1.32	1.25	1.56	5.61
1149	Hoe, Sl.	9.09	116.5	1.61	1.52	1.55	5.61
2065	Box	9.09	135.2	1.82	1.72	1.64	5.61
1780	Crescent	9.09	68.3	1.73	1.63	1.73	5.61
1571	Hoe, St.	15.00	58.8	1.42	1.33	1.62	6.65
1149	Hoe, Sl.	15.00	118.7	1.73	1.61	1.63	6.65
2065	Box	15.00	133.8	1.81	1.69	1.65	6.65
1780	Crescent	15.00	61.2	1.46	1.36	1.64	6.65
1571	Hoe, St.	20.00	56.5	1.38	1.27	1.65	8.20
1149	Hoe, Sl.	20.00	117.0	1.72	1.58	1.65	8.20
2065	Box	20.00	130.5	1.78	1.63	1.66	8.20
1780	Crescent	20.00	58.3	1.41	1.29	1.65	8.20

* St. - Straight bail

**Sl. - Slope bail

Appendix E Part I
SCRAPER DATA SHEET

Maximum Capacity of Scrapers (Measured with -3/16" sand)

Hoe, Straight Bail Type 8 inches wide	Blade angle 30° - 1700 cc. Blade angle 45° - 2330 cc. Blade angle 60° - 2000 cc.
Hoe, Slope Bail Type 8 inches wide	Blade angle 30° - 1000 cc. Blade angle 45° - 1025 cc. Blade angle 60° - 1200 cc.
Box type 8 inches wide	Blade angle 30° - 1700 cc. Blade angle 45° - 1650 cc.
Crescent Type 8 inches wide	Blade angle 60° - 2600 cc.

Weight of Scrapers

Hoe Type (with chain)	- 809 grams (straight bail)
Hoe Type (with chain)	- 747 grams (slope bail)
Box Type (with chain)	- 934 grams
Crescent Type (with chain)	- 714 grams

Counterweights

Bail weight for hoe types	20	grams (with screws)
" " "	70	"
" " "	110	"
" " "	270	"
Back weight for hoe or box	222	grams (with screws)
"	229	"
"	695	"
"	910	"

(Above back weights also fron t weights for crescent)
Front counterweight cross brace for crescent 545 grams (With screws)
Back counterweight for crescent 295 grams

Pans For Rock Measurement (Galvanized Pans)

Pan #1 Weight 3745 grams - 53 x 53 x 9 cm. (vol. 25, 281 cc.)
area bottom 2809 sq. cm.
Pan #2 Weight 3690 grams - dimensions same as #1

Appendix E Part II

CALCULATION OF ROPE SPEEDS FROM PULLEY RATIOS

(Motor speed 1750 RPM)

D_1 = 2.125 inches Pulley #1 (on motor)

D_2 = 11.75 inches Pulley #2 (on jack shaft)

D_3 = 3.75, 2.8125, and 1.875 Pulley #3 (on jack shaft)

D_4 = 3.8125, 2.8125, and 1.875 Pulley #4 (on hoist axel)

Velocity ratios from formula $VR = \frac{D_2 \times D_4}{D_1 \times D_3}$

$VR_1 = \frac{11.75 \times 3.815}{2.125 \times 1.875} = 11.25 \quad \frac{1750}{11.25} = 155.5$ RPM

$VR_2 = \frac{11.75 \times 3.815}{2.125 \times 1.875} = 8.29 \quad \frac{1750}{8.29} = 211.1$ RPM

$VR_3 = \frac{11.75 \times 3.815}{2.125 \times 2.8125} = 7.50 \quad \frac{1750}{7.50} = 233.3$ RPM

$VR_4 = \frac{11.75 \times 2.8125}{2.125 \times 2.8125} = 5.52 \quad \frac{1750}{5.52} = 317.0$ RPM

$VR_5 = \frac{11.75 \times 2.8125}{2.125 \times 3.815} = 4.08 \quad \frac{1750}{4.08} = 428.9$ RPM

$VR_6 = \frac{11.75 \times 1.875}{2.125 \times 2.8125} = 3.68 \quad \frac{1750}{3.68} = 475.5$ RPM

$VR_7 = \frac{11.75 \times 1.875}{2.125 \times 3.815} = 2.71 \quad \frac{1750}{2.71} = 645.7$ RPM

Winding drum 3 1/16 inches in diameter is 0.8017 ft. in circ.

Combination #1 is 0.8017 x 155.5 = 124.0 ft. per minute rope speed

Combination #2 " " x 211.1 = 169 " " " " "

Combination #3 " " x 233.3 = 187 " " " " "

Combination #4 " " x 317.0 = 254 " " " " "

Combination #5 " " x 428.9 = 344 " " " " "

Combination #6 " " x 475.5 = 381 " " " " "

Combination #7 " " x 645.7 = 518 " " " " "

BIBLIOGRAPHY

1. Books

a. Given, Ivan A., Mechanical Loading of Coal Underground, 1st Ed., N.Y., McGraw-Hill, 1943, pp. 247-263.

b. Peele, Robert, and Church, John A., Mining Engineer's Handbook, 3rd Ed., N.Y., Wiley, 1941, Sec. 27, pp. 11-12.

2. Periodicals

a. Carlson, R. W., General Structural Similitude: University of California Publications in Engineering, Vol. 3, No. 2, Nov. 8, 1933, pp. 141-142.

b. Clarke, S. S., Mining Methods of the Tri-State: Engineering and Mining Journal, No. 11, Vol. 144, Nov. 1943, pp. 80-86.

c. Eaton, Lucien, Mechanical Loading in Metal Mines in 1929: Mining Congress Journal, No. 7, Vol. 15, July 1929, p. 536.

d. Eaton, Lucien, The Use of Scrapers in Metal Mines: Compressed Air Magazine, Vol. 26, May 26, 1921, pp. 10065-10075.

e. Fuller, Julian A., Slushing adapted to Bauxite Mining: Mining Congress Journal, January 1945, pp. 38-39.

f. Pierce, R.V., and Bryon, R. N., Scraping and Loading in Mines: Compressed Air Magazine, Vol. 47, No. 6, June 1942, pp. 6750-4. Also: Mining Journal (London), Vol. 218, No. 5581, August 8, 1942, pp. 375-6.

g. Tolman, R. C., The Principle of Similitude: Physical Review, Vol. 4, Ser. 2, 1914, pp. 244-255.

h. Tolman, R. C., The Principle of Similitude and the Principle of Dimensional Homogeneity: Physical Review, Vol. 6, Ser. 2, 1915, pp. 219-233.

3. U.S. Government Publications

   a. Anderson, Carl N., Mining Methods and Costs at the Interstate Zinc and Lead Company's Hartley-Mine, Tri-State Zinc and Lead District, United States Bureau of Mines Information Circular No. 6656, p.8., Sept. 1932.

   b. Crane, W. R., Mining Methods and Practice in the Michigan Copper Mines, United States Bureau of Mines Bulletin No. 306, 1929, pp. 93-94, 154-156.

   c. Jackson, Charles F., Underground Scraping Practice in Metal Mines, United States Bureau of Mines Manuscript Report No. 1, (Printed by Sullivan Machinery Company), 1933, pp. 1-88.

4. State Publications

   a. Matson, Robert C., Scraping Practice in the Michigan Iron Mines of the Lake Superior District, Michigan College of Mining and Technology, Bulletin 1928-1929, Vol. 2, No. 4, pp. 1-75.

   b. Van Barneveld, Charles E., Mechanical Loading in Metal Mines, Missouri School of Mines and Metallurgy Technical Bulletin No. 3, Vol. 7, 1924, pp. 210-225.

5. Catalogs from Manufacturers

   a. Gardner Denver Company, Airslushers. Bulletin AS1, 1945.

   b. Holcomb, M.D., The Original Holcomb "Westeeco" Scrapers. Catalog No. 3, (Twin City Iron Works) 1941.

   c. Ingersoll Rand Company. Modern Methods for Scraper Mucking and Loading. 1939, pp. 3-32.

   d. Sauerman Brothers, Incorporated. Crescent Scraper Buckets. Catalog 19, Section J., p. 1.

e. Sauerman Brothers, Incorporated. Power Drag Scrapers. Catalog 19, Section A.

6. Unpublished Material

a. Clayton, Austin B., A Study of Mine Scraper Buckets and Their Efficiency, Thesis, Missouri School of Mines and Metallurgy, Rolla, Missouri, 1946.

VITA

The author, Ronald Lad Carmichael, was born September 29, 1921 at Independence, Missouri. His elementary schooling was completed at Independence and he was graduated from William Chrisman High School in 1939. After finishing two years at Graceland Junior College, Lamoni, Iowa, he entered the Missouri School of Mines and Metallurgy from which he was graduated in 1944 with the degree of Bachelor of Science in Mining Engineering.

After graduating, Carmichael was employed for a year and a half by the U. S. Bureau of Mines in Arkansas. He left the Bureau of Mines to join the staff of the Rock Island Coal Company, Rock Island, Oklahoma. In July 1946 he was released to accept an appointment as Research Fellow at the Missouri School of Mines.

Carmichael is a junior member of the American Institute of Mining and Metallurgical Engineers.