ROCK DRILLING

WITH PARTICULAR REFERENCE TO

OPEN CUT EXCAVATION

AND

SUBMARINE ROCK REMOVAL

BY
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INTRODUCTORY

THE rock drill, perhaps more than any other instrument, except the engineer's transit, is the tool that accompanies the vanguard of civilization, and its contribution to the general economy of construction, its effect upon the cost of rock work, and its influence on standard engineering methods, have been enormous. In principle it is unique as a machine, and in practice it offers a class of problems which have long deserved special study and a special treatise.

It is a machine of many parts, sizes and shapes, and there are many ways of using it, some of which are better than others, and one of which, for the particular purpose in view, is the best of all. To establish the fundamental facts for determining this " best " way for any given conditions, and to place these facts at the disposal of engineers and contractors, the Ingersoll-Rand Company have instituted an investigation into the economics of drilling work, the results of which are herewith presented in the hope that this book will mark a step forward in the effort to place the study of rock drilling upon a scientific basis. While much still remains to be done, it is believed that the present work contains the cream of the available information on the subject, most of which has never before appeared in print. Most of the data was gathered by the Construction Service Company, Consulting Engineers, of New York, and some of it by Mr. Gilbert H. Gilbert, Consulting Engineer; and the whole was worked into its present form by the Chief Engineer of the Construction Service Company, in collaboration with Mr. W. L. Saunders, President of the Ingersoll-Rand Company.

No one in the Construction Service Company has any interest, direct or indirect, in any make of steam drills, or in the results of the work, except to see that it correctly represents the economic facts, and no effort has been spared to make the book entirely trustworthy as to these facts. Although it has been carefully checked for errors, it is, of course, possible that mistakes may have escaped notice. If any such should be noted by the reader, a memorandum to that effect, mentioning page number and line, addressed to Construction Service Company, 15 William Street, New York City, would be much appreciated.

RICHARD T. DANA.

NEW YORK, July, 1911.

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ROCK DRILLING

CHAPTER I

BLASTING AND EXPLOSIVES

THE breaking of rock by drilling and blasting as it is pursued to-day dates practically from Nobel's invention of dynamite. The blasting of rock by the use of gunpowder is of course as old as the general use of this agent; but blasting, considered as an economic art to-day, is in an entirely different category from that in which it was before the discovery of nitroglycerin.

The operation of blasting is conducted through the explosive force of gases generated either by explosion or by detonation. For clearness in the treatment of what follows it is advisable here to define these terms.

An explosion is the result of combustion instituted and propagated by high temperature. Gunpowder, which is an explosive mixture, is composed of saltpetre, charcoal and sulphur. Upon being raised to the temperature of combustion, or explosion, these materials combine chemically, and in so doing produce a gas. It is the sudden and powerful expansion of this gas which furnishes the force derived from the explosion. The chlorate powders are another example of explosives proper. It should be be noted that the chemical combination must take place progressively, from grain to grain as it were, and is not likely to be caused by a jar or shock unless such shock should be sufficiently violent to generate a spark in the mass. The explosives are comparatively bulky considering the amount of gas that they can liberate, and therefore they require a large hole in the rock in order to introduce a sufficient amount of explosive to break it. The black powders, even when glazed, are decidedly sensitive to moisture, a small amount of which is likely to destroy their efficacy, unless they are charged in waterproof canisters or packages.

A detonation may be defined as a disruption caused by synchronous vibrations of a wave-like character, but the causes of detonation have not as yet been satisfactorily determined. There are a great many detonating compounds, including the nitric derivatives, such as guncotton, nitroglycerin and dynamite, and the nitro-substitution compounds, such as joveite, masurite, lyddite, bellite, securite, and a host of others. These compounds are definite chemical substances, as distinct from mixtures of several different substances, which are in such condition that a wave-like shock will cause their decomposition into gas. The speed of the wave that can produce this combustion is so great as to make the detonation of large amounts of these substances practically simultaneous, thereby causing a very much more sudden and quick shock than in the case of the explosives proper. Some of these detonating compounds in addition to a shock require a high temperature to set them off, and they then come within the classification of the so-called "safety explosives."

Provided that no decided shock be administered, many of the detonating compounds can be entirely burned up without causing a detonation, in contrast to the capacity that gunpowder has of submitting to severe shocks without explosion. On the other hand, dynamite, nitroglycerin, nitrogelatin, and others, are liable to be detonated as a result of a rapid change of temperature, even if that change covers a comparatively small range. When frozen, the dynamites are generally very much more difficult to detonate than under normal conditions, but it often happens that frozen dynamite will be detonated by the breaking of the frozen stick or by a shock which would ordinarily not cause the detonation of the warm material. At the thawing point it is generally considered to be in a super-sensitive condition. Dynamite to-day has for its main constituent nitroglycerin with an absorbent, such as wood meal, sawdust, kieselguhr, wood pulp, or wood fibre, or even charcoal, and frequently one or more of the ingredients of the explosive mixtures such as sodium nitrate, sulphur or potassium chlorate. A peculiar property of these compounds is that a powder composed of nitroglycerin with an explosive "base" will have more explosive power than the sum of the explosive powers of the ingredients if fired separately. The composition of a considerable number of the powders in common use to-day is given in the following table from Gillette's "Rock Excavation," an inspection of which in conjunction with the text of this chapter will be of assistance in determining the economic grade of powder for a given purpose:

ATLAS POWDER (75 per cent)

Nitroglycerin	75 parts
Wood fibre	21 “
Sodium nitrate	2 “
Magnesium carbonate	2 “

RENDROCK (40 per cent)

Nitroglycerin	40 parts
Potassium nitrate	40 “
Wood pulp	13 “
Pitch	7 “

GIANT POWDER, NO. 2 (40 per cent)

Nitroglycerin	40 parts
Sodium nitrate	40 “
Sulphur	6 “
Resin	6 “
Kieselguhr	8 “

STONITE (68 per cent)

Nitroglycerin	68 parts
Kieselguhr	20 “
Wood meal	4 “
Potassium nitrate	8 “.

DUALIN (40 per cent)

Nitroglycerin	40 parts
Sawdust	30 “
Potassium nitrate	30 “

CARBONITE (25 per cent)

Nitroglycerin	25 parts
Woodmeal	40½ “
Sodium nitrate	34 “
Sodium carbonate	½ “

HERCULES (40 per cent)

Nitroglycerin	40 parts
Potassium nitrate	31 “
Potassium chlorate	3⅓ “
Magnesium carbonate	10 “
Sugar	15⅔ “

Vigorite (30 per cent)

Nitroglycerin	30 parts
Potassium chlorate	49 "
Potassium nitrate	7 "
Wood pulp	9 "
Magnesium carbonate	5 "

Horsley Powder (72 per cent)

Nitroglycerin	72 parts
Potassium chlorate	6 "
Nuttgalls	1 "
Charcoal	21 "

Gelignite (62½ per cent)

65 per cent of blasting gelatin, containing	Nitroglycerin, 96 per cent Collodion cotton, 4 per cent
35 per cent of absorbent, containing	Sodium nitrate, 75 per cent Sodium carbonate, 1 per cent Wood pulp, 24 per cent

Forcite (49 per cent)

50 per cent of blasting gelatin, containing	Nitroglycerin, 98 per cent Collodion cotton, 2 per cent
50 per cent of absorbent, containing	Sodium nitrate, 76 per cent Sulphur, 3 per cent Wood tar, 20 per cent Wood pulp, 1 per cent

Judson Giant Powder, No. 2 (40 per cent)

Nitroglycerin	40 parts
Sodium nitrate	40 "
Resin	6 "
Sulphur	6 "
Kieselguhr	8 "

Vulcanite (30 per cent)

Nitroglycerin	30 parts
Sodium nitrate	52½ "
Sulphur	7 "
Charcoal	10½ "

The dynamites are graded according to the percentage of nitroglycerin that they contain. Thus a "40% powder" would be one in which the sticks, weighing one-half pound each, would include one-fifth of a pound of pure nitroglycerin. Dynamite is usually packed in paper cartridges weighing about one-half pound each which will vary in diameter. When ordering, it is customary to specify a size of cartridge that will as nearly as possible fill the drill hole, the commonest size being 1¼″ in diameter by 8″ in length. It is nearly always shipped in 50-lb. boxes, which have a volumetric capacity of ¾ cu.ft.

The principal features of the high explosives, which vary with the different products, and which are economically important, are as follows, from Trans. Am. Soc. C. E., Vol. 50, p. 388:

1. Power.
2. Cost, initial price.
3. Rapidity of action.
4. Facility and cost of detonation.
5. Applicability to various conditions of work.
6. Temperature of detonation.
7. Freezing phenomena.
8. Ease of transportation and cost.
9. Ease of storage and cost.
10. Flame from explosion.
11. Fumes and effects from handling.
12. Specific gravity.
13. Risks; divided into (*a*) risks from proper handling; and (*b*) risks from improper handling.
14. Wet hole work.

Power. There is no satisfactory way of comparing the power of different explosives from the viewpoint of efficiency in the rock, except by actual tests under working conditions. The effect depends upon three factors: the rapidity of detonation, the volume of gases generated, and the temperature of the gases. When an explosive is inserted into a hole in the rock and the hole sealed up above it the gases generated are necessarily contained in the chamber that originally contained the explosive. The higher the temperature, other things being equal, the greater will be the pressure in any given gas; likewise the greater the natural volume under atmospheric pressure the greater the pressure when this volume of gas is liberated in a confined chamber. If there be fissures in the rock through which some of the gas can escape before the rock itself yields, or if the tamping which is intended to seal up the hole yields before the full pressure of the gases is developed, the escape of part of the gases will necessarily reduce the amount of useful work correspondingly. For these reasons the theoretical number of cubic feet of gas at atmospheric pressure, and at normal temperature, that would be liberated by the explosion, or detonation, of one cubic foot of explosive is not a useful criterion for measuring the economic value of the material. In certain kinds of seamy rock the gases can be dissipated so rapidly through the fissures as to make the slow black powders almost useless. Under such circumstances a quick powder will have an opportunity to shatter the rock before the gases have become dissipated.[1] The proper grade of dynamite for such cases is as slow a powder as can be found to do the work without an appreciable waste of gas. In practice to find this substance is not easy, and there seems to be no better way than to experiment with different grades of powder in holes that have been carefully measured and located under as nearly uniform conditions as possible. Most rock excavation is some distance from the base of supplies, and therefore it is expedient to order several kinds of explosives until it has been definitely settled by experiment which grade of powder is the most economic. Where the rock is faulty and variable in structure, as in many of the shales, schists, and granites, the rocky conditions surrounding one hole may be so different from those surrounding another one near by as to lead to a very confusing set of observations. The only way known to us that has proved successful in such a case is to keep careful and constant records during the whole progress of the work. Each blast will then contribute its share of information and the information will be of more and more value as the work progresses. After a day or two of experiment the approximate cost per cubic yard of rock loosened can be obtained.

Rapidity of Action. The slowest acting explosives are the regular black powders, the speed of action increasing through Judson powder, 25% dynamite, etc., up to pure nitroglycerin. This variation of speed in action can be made use of economically

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[1] Where the word "powder" is used in this text, it should be understood to comprise any of the explosives or detonants. It is the field term for all of them.

in the following ways: Where the rock does not break properly near the bottom of the holes a higher explosive or detonant can be placed at the bottom of the hole than at the top, and by placing the firing primer at or near the top of the hole the pressure of the gases can be made much greater at the bottom than elsewhere, thus producing a greater rupture. In this connection it must be thoroughly understood that the pressure of the liberated gases is equal in all directions, and that pressure will produce the most destructive results where it meets with most resistance. When the high explosive is placed at the bottom of the hole, if the primer also be placed at the bottom, the explosion is likely to be so quick as to blow some of the charge out of the hole before the explosive at the top has an opportunity to do its work; if, however, one grade of dynamite be used throughout the depth of the hole the detonation of the whole mass is likely to be so nearly simultaneous as not to affect the result.

Following this same idea, it is apparent that the holes which contain a low explosive, like black powder, should be more solidly tamped than those loaded with the high dynamites. It is fashionable on most contract work to use a minimum of tamping when loading dynamite, and the tamping that is used is generally selected at random in a haphazard way. It should be selected with great care from as dense material as can readily be obtained, and it should not be of such material as loose gravel or sand containing a large amount of voids. A mixture of loam or clay with sand makes a good tamping, and where the rock is soft, requiring the use of the low explosives, and the explosive nearly fills the hole, it is frequently economical to use a tamping mixture of three parts of sand to one part of plaster of Paris. The plaster of Paris sets up in a very short time, thus sealing the hole very firmly, and giving an admirable opportunity for the powder to do its work before blowing out. One bag of plaster of Paris of slight cost and six cubic feet of sand will provide sufficient tamping for 90 holes. By the use of this expedient it will often be found possible to use a lower grade of dynamite than otherwise at a considerable saving in the cost of powder.

Facility and Cost of Detonation. The higher grade dynamites are much easier to set off than the lower grades; thus it is possible to use a low strength primer with the higher explosives.

Applicability to Various Conditions of Work. The general applicability of a particular grade of explosive is a feature which recommends itself to a great many consumers who are purchasing it in large quantities. By far the commonest grade of dynamite in general use is the 40%, and this is the strength of most general applicability. Like the problem of the weight of a pick or shovel or the size of a locomotive, there is always one best grade to use for any given purpose, and no one grade is economic for general use. In short, as suggested above, in a great deal of work it is highly advisable to use two or more different kinds of powder in the same hole. The 40% dynamite, by virtue of the comparatively small amount of nitroglycerin and the large amount of absorbent or "buffer," is comparatively insensitive to shock, difficult to detonate, and safe to transport and store. It can be banged along a country road in a springless wagon and it can be hurled in individual sticks down a rock cliff with only occasional accidents from such treatment. It can be used for mud capping, block holing, or for breaking shaley rock and, with indifferent economy, the heavy traps and granites. It can be used to "spring' holes, and for the main charge after the holes have been sprung.

In very cold weather the 40% powder is sometimes difficult to detonate without double strength caps. Under these conditions it is advisable to use a higher powder, or to insert the primer in a cartridge of high powder at the top of the hole.

Freezing Phenomena. All users of dynamite appreciate that nitroglycerin will freeze, but few of them realize that the temperature of freezing is several degrees higher than that of melting snow. It is a common occurrence to hear one of the old-fashioned powder men, of vast experience and a considerable disdain for new-fangled ideas, observe that if the holes are full of water the dynamite cannot possibly freeze in them until the water turns to ice. After standing for an hour or two in water at a temperature of 35° F. the dynamite is likely to either not detonate at all or to do so with much less than its normal strength. The first warning of this condition generally comes when a number of holes "miss" while the others detonate. When this condition obtains it is fairly certain that the holes that did not misfire did not get the benefit of the full strength of the powder. When the holes are being loaded just before the powder is placed in the hole, it is frequently customary to blow all the water and small particles of stone out of the hole by means of a steam jet. This steam jet warms up the hole so that the powder can remain therein for some little time before congealing. The precise length of time depends upon the degree to which the hole has been heated, the conductivity of the rock, and the amount of cold water that is flowing into the hole or through the seams of the rock; and also on the length of time that cold weather has obtained before the time of loading. Where the holes are quite deep it takes considerable time for the cold to penetrate the rock. The dry powders, such as black powders, Judson, and many of the nitro-substitution class, will not freeze, and investigation regarding their use in freezing weather is highly recommended. The use of many of the latter for industrial purposes is still in the experimental stage.

Flame from Explosion. In mining work where fire damp is to be anticipated the flaming powders are an element of grave danger and therefore of high cost. Some of the so-called safety explosives are claimed to be flameless, and if the claim be true, are a valuable discovery in this line. We have, however, as yet not seen convincing proof that the perfectly flameless explosive has ever been developed. It is undoubtedly true, nevertheless, that some powders give a very much hotter flame than others.

Fumes. Nitroglycerin, besides being a high explosive, is a powerful heart stimulant, and when the fumes from its composition are inhaled the resultant effects are usually a severe and sometimes prolonged headache. The same effects will be produced by handling the dynamite cartridges with bare hands in hot weather or whenever the oily nitroglycerin penetrates the paper of the cartridge. This can be guarded against by wearing leather gloves, but the fumes can hardly be avoided except by the men keeping away from the vicinity of the blast until the fumes have been dissipated. In confined places, such as mines and ill-ventilated tunnels, this necessary time for clearing the air is often a half hour or more, adding an element of cost the amount of which can readily be estimated.

To avoid this element of cost the work may sometimes be so laid out that the men, after firing a blast, can be kept busy on some other work for the necessary period. Another method is by means of copious ventilation. One of the reasons why the Simplon Tunnel was driven at record breaking speed was because it was run in two parallel headings, through one of which a tremendous amount of air under pressure entered, finding its way out by the other through a system of cross drifts, all but the last one of which were sealed as the work progressed. This method insured a minimum of lost time on account of dynamite fumes and was highly economical.

Specific Gravity. The larger the amount of energy stored in a cubic inch of powder the smaller may be the diameter of the drill hole, or the farther the holes may be apart; therefore, other things being equal, the denser powders, as compared with the lighter ones, will often admit of a considerable saving in the collateral operation of drilling. The weight of dynamite per inch of stick is about as follows, and all the grades weigh about the same per stick:

Diameter of Stick in Inches.	Weight in Pounds per Inch of Stick.	Diameter of Stick in Inches.	Weight in Pounds per Inch of Stick.
1	0.042	1¾	0.128
1¼	0.065	2	0.168
1½	0.094	2¼	0.212

Risks. Accidents are always costly, and as an element of false economy the risk from any method of handling powder should be taken into account. The following list of some of the dangers arising from the use of dynamite points a moral which need not be elaborated. The list includes only actual causes that have been known to produce accidental detonations.

(*a*) Dangers inevitable, even with reasonable care:

1. Spontaneous explosion in storage.
2. Lightning.

3. Part of charge failing to go off and remaining undiscovered until exploded either by the sun's rays or by being struck by a tool.
4. Train wreck.
5. Drilling near missed hole.
6. Flame; fire damp.

(*b*) Dangers incidental to the handling of dynamite as practiced every day:

1. Dropping stick or box.
2. Hole too small for cartridge; ramming down cartridge.
3. Ramming too hard, or ramming with metal bar.
4. Deepening missed hole.
5. Returning to relight fuse.
6. Testing the end of a hole with an iron bar after a blast to see if any of the charge remains.
7. Forcing primer into cartridge.
8. Ramming in the first ball of tamping clay.
9. Breaking a cartridge when near the freezing point.
10. Stepping upon particles of explosive.
11. Thawing in front of kitchen fire.
12. Thawing in tin over fire.
13. Thawing in men's boots or shirts.
14. Thawing in an oven.
15. Hot water containing dynamite placed on a blacksmith's fire.
16. Thawing with candle.
17. Reheating water which has been used in thawer.
18. Throwing on ground water which contains nitroglycerin from thawing cartridges.
19. Rubbing cartridge in hands to complete thawing.
20. Cartridge left in pocket of garment hung before fire to dry.
21. Having cartridge and primer near each other when not in use.
22. Destroying material not considered desirable.

Suitability for Wet Hole Work. When immersed in water nitroglycerin will leave a stick of dynamite and its place will be taken by the water, owing to the greater affinity that the water has for the mechanical dope, so that in wet holes the nitroglycerin powders are not entirely suitable, and although usually they will detonate, they do so with reduced efficiency.

This objection does not apply to nitrogelatin. Theoretically, a waterproof cartridge can be made of paraffin paper, but as a matter of practical economics this expedient has not made its way into general use. A waterproof slow-burning powder of low explosive force and great cheapness would be of great value in blasting the softer rocks where water cannot be avoided.

Springing Holes. The usefulness of different grades of dynamite in the same holes has been pointed out above. A further development of the same idea can frequently be taken advantage of by springing the holes, an operation consisting of detonating a few sticks of high percentage dynamite in the bottom of the hole, thus producing an enlarged and approximately pear-shaped chamber, which then can be filled with an explosive powder to any desired amount. As in the general choice of an explosive, the kind and amount of powder necessary to chamber a hole must be determined by experiment for each particular case. In soft shale, where the lamination plane was inclined to the horizontal at an angle of about 50°, two sticks of 40% dynamite were sufficient to form a chamber about the size of a man's head in the bottom of a 10 foot hole. A tamping rod placed in the hole after springing with two sticks would usually descend from 4 to 6 inches lower than before the springing, and it was feasible to get the greater part of a charge of 18 sticks in the chamber. With the hard rocks, where large chambers are desired, it is necessary sometimes to make two or three shots. Thus in Eastern Ohio, Mr. W. M. Douglas[1] in sandstone work fired first 15 sticks, then 40 and then 80, and finally 130 sticks of 40% dynamite per hole. The chambers were then large enough to hold 45 kegs of black powder. We have sprung 20-foot holes in sandstone,

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[1] "Rock Work," p. 149.

using for the first shot 2 sticks, for the second 5 sticks, and for the third 20 sticks of 40% powder.

In charging sprung holes with black powder it is economical to use a so-called charging tube, which prevents the free running powder from sticking to the sides of the hole on the way down, or from becoming dissipated in fissures.

Advantages of Springing. The cost of springing holes is the cost of supplies, their handling and storage, and the time of the men employed. This work can be done by the regular blasting gang with almost no interruptions to the regular loading, since it is safe to stand within 10 or 15 feet of a hole that is being sprung with light charges. It seems hardly necessary to add that a large number of holes can be sprung at the same time. Each should be lightly tamped with one or two handfuls of clay. If this causes too much of a "shake-down" use less powder but not less tamping. Since the effect of blasting depends upon the explosive power of the generated gases, which press equally in all directions, if the explosive be concentrated at the bottom of the hole, the result will be to more thoroughly shatter the rock in the immediate vicinity of the charge than elsewhere. Where rock is to be excavated with a steam shovel, and particularly where the plane of lamination is at an angle to the horizontal, holes in which the charge is not concentrated at the bottom will frequently leave ridges that prevent the progress of a steam shovel until they have been cleared away by mud-capping or by drilling in front of the shovel while the shovel stands idle. To see thirty men with a steam shovel and two or three trains of cars wait while a drill or two "get busy" in front of the shovel, is one of the most demoralizing things in construction work. Delays to steam shovels from this cause often run as high as 50 to 60% of the working day, and perhaps no other cause is more conducive to loss of money in this kind of operation. It can usually be eliminated to a large extent by the proper springing of the holes, the rock being almost pulverized for a considerable distance from the centre of each charge.

The direct economic result from springing lies in the fact that the holes can be placed a much greater distance apart than otherwise, and a low and cheap grade of powder can be used for the rock. A peculiar collateral advantage from this fact should be mentioned. It has been observed that stone used for ashlar masonry is subject to the development of fine cracks when the very high explosives have been used in the quarrying operation. This is particularly true of the marbles. It would seem that the heavy blows of the high explosives cause fine initial cracks which do not appear while the stone is being quarried, and only come to light after it has been for some time in use. For this reason it is essential whenever quarrying dimension stone to utilize the very lowest grade of explosive possible, and to economically use the low explosives springing is necessary.

A further advantage from the use of the springing method lies in the fact that a very small drill hole can be used. As will be shown later, a hole with a diameter of 2 inches costs a good deal less money to drill than one of 3 inches, and therefore when springing makes a hole with a diameter of $1\frac{3}{4}''$ at the bottom adequately large, it is likely to greatly reduce the drilling cost.

Theoretical Disadvantages of Springing. When it is not desired to break up the stone, but to quarry it in large rectangular pieces with as small waste as possible, the holes must be comparatively small, close together and loaded throughout almost their entire length. Under these circumstances chambering is not feasible.

The "practical man" will often urge against springing the theory that the shaking from the springing shots may cause *débris* to fall into the hole if the rock be soft. We have investigated some cases of such objections, certified to by contractors with great vigor, but have never yet found them justified by the facts. Wherever the chambering method is feasible we have found it to be highly economic.

The Cushioning Effect of Air and Water. When the cartridge does not completely fill the hole there is an air space which acts as a cushion to the expanding gases and lessens the sharpness of the blow which these strike at the rock. This condition should be carefully avoided by having the cartridge of a size to fill the hole, or by carefully slitting the cartridges before loading, except where the powder at hand is of too high a grade for the rock. The grade of powder can be artificially lowered by purposely having such a cushion in the hole, but it should be emphasized that the correct grade of explosive is less expensive than this kind of cushion. A somewhat different effect is produced by a cushion of water. When the hole is full of water the most economic results are obtained with the powder thoroughly compressed into the hole in the rock. The overlying water then forms a sort of imperfect tamping. When the powder is not thoroughly packed and is surrounded by water, the cushioning effect is very considerable.

Simultaneous Explosions. Most blasting is done nowadays by electric firing, the holes being detonated together. This simultaneous firing, according to Eissler, is 25% more effective in breaking the rock than when holes are fired consecutively. A corollary to this is that the maximum effectiveness can be obtained when the largest number of holes possible is fired together; a second corollary is that it is not economic to buy a low powered blasting machine, or to neglect to have those on hand kept in good repair.

Blasting Machines. These are simply hand-operated dynamos; they do not require recharging, but with ordinary use should be overhauled once every two or three months. Leaving the blasting machine two or three nights in a damp place will tend to induce short circuiting in the coils, and has frequently been the cause of great expense through partial blasts. These machines should give a current of two or three amperes with an intensity of one volt for each fuse. Where an electric light main of suitable potential is at hand the blasting machine proper can be dispensed with, but an actual experiment should be made before depending upon this method, firing the actual number of fuses to be used in blasts.

Spacing of Blast Holes. No absolute rule can be given for the spacing of the holes. The cost of powder per cubic yard of rock may be a little greater if the holes are spaced far apart than otherwise, but not much greater, whereas the cost per cubic yard of rock excavated for drilling and blasting will vary inversely as the square root of the distance between the holes. Thus, if the holes are spaced 6′ apart and are 10′ deep there will be 13.3 cubic yards excavated per hole. If the distance between the holes is half of this or 3′, there will be excavated 3⅓ yards per hole, or one-quarter the performance in the former case. In practice, a common rule is to make the distance of a hole back from the face equal to its depth; another rule is to make this distance three-quarters of its depth. In stratified rock the holes can sometimes be placed a distance apart considerably greater than their depth, and, when the rock is laminated with a heavy dip, the distance between the holes parallel to the direction of the strike, can be considerably different from the distance in the other direction. Which distance is to be the greater will depend upon

(*a*) The grade of explosive.

(*b*) The friability of the rock in the different directions.

CUBIC YARDS OF MATERIAL LOOSENED PER FOOT

Spacing in feet and inches										
10′ 0″	0.370	0.741	1.11	1.48	1.85	2.22	2.59	2.96	3.33	3.70
9 6	0.352	0.704	1.06	1.41	1.76	2.11	2.46	2.82	3.17	3.52
9 0	0.333	0.667	1.00	1.33	1.67	2.00	2.33	2.67	3.00	3.33
8 6	0.315	0.630	0.944	1.26	1.57	1.89	2.20	2.52	2.83	3.15
8 0	0.296	0.593	0.889	1.19	1.48	1.78	2.07	2.37	2.67	2.96
7 6	0.278	0.556	0.833	1.11	1.39	1.67	1.94	2.22	2.50	2.78
7 0	0.259	0.519	0.778	1.04	1.30	1.56	1.82	2.07	2.33	2.59
6 6	0.241	0.481	0.722	0.963	1.20	1.44	1.69	1.93	2.17	2.41
6 0	0.222	0.444	0.667	0.889	1.11	1.33	1.56	1.78	2.00	2.22
5 6	0.204	0.407	0.611	0.815	1.02	1.22	1.42	1.63	1.83	2.04
5 0	0.185	0.370	0.556	0.741	0.926	1.11	1.30	1.48	1.67	1.85
4 6	0.167	0.333	0.500	0.667	0.833	1.00	1.17	1.33	1.50	1.67
4 0	0.148	0.296	0.444	0.593	0.741	0.889	1.04	1.19	1.33	1.48
3 6	0.130	0.259	0.389	0.519	0.648	0.778	0.907	1.04	1.17	1.30
3 0	0.111	0.222	0.333	0.444	0.556	0.667	0.778	0.889	1.00	1.11
2 6	0.093	0.185	0.278	0.370	0.463	0.556	0.648	0.741	0.833	0.926
2 0	0.074	0.148	0.222	0.296	0.370	0.444	0.519	0.593	0.667	0.741
1 6	0.056	0.111	0.167	0.222	0.278	0.333	0.389	0.444	0.500	0.556
1 0	0.037	0.074	0.111	0.148	0.185	0.222	0.259	0.296	0.333	0.370
0 6	0.019	0.037	0.056	0.074	0.093	0.111	0.130	0.148	0.167	0.185
0′ 0″	1	2	3	4	5	6	7	8	9	10

Spacing in feet.

(*c*) The amount and size of fissures.

(*d*) The character of the loading, whether throughout the hole or in chambers.

As stated above, no hard and fast rule can be laid down.

The accompanying table gives the yardage of rock loosened per lineal foot of hole when the holes are arranged in regular rows.

In some large blast firing in France 11.7 cubic yards of rock were loosened with one pound of powder. The rules in this practice were as follows:

1. Distance between powder chambers should equal the thickness of the rock above them.
2. The face left after a blast should be as nearly vertical as possible.
3. With one powder chamber only, the distance from its center to the face of the quarry and to the top of the mass should be equal.

OF DRILL HOLE WITH VARIOUS SPACINGS OF HOLES.

										Spacing in feet and inches
4.07	4.44	4.82	5.19	5.56	5.93	6.30	6.67	7.04	7.41	10′0″
3.87	4.22	4.57	4.93	5.28	5.63	5.98	6.33	6.69	7.04	9 6
3.67	4.00	4.33	4.67	5.00	5.33	5.67	6.00	6.33	6.67	9 0
3.46	3.78	4.09	4.41	4.72	5.04	5.35	5.67	5.98	6.30	8 6
3.26	3.56	3.85	4.15	4.44	4.74	5.04	5.33	5.63	5.93	8 0
3.06	3.33	3.61	3.89	4.17	4.44	4.72	5.00	5.28	5.56	7 6
2.85	3.11	3.37	3.63	3.89	4.15	4.41	4.67	4.93	5.19	7 0
2.65	2.89	3.13	3.37	3.61	3.85	4.09	4.33	4.57	4.82	6 6
2.44	2.67	2.89	3.11	3.33	3.56	3.78	4.00	4.22	4.44	6 0
2.24	2.44	2.65	2.85	3.06	3.26	3.46	3.67	3.87	4.07	5 6
2.04	2.22	2.41	2.59	2.78	2.96	3.15	3.33	3.52	3.70	5 0
1.83	2.00	2.17	2.33	2.50	2.67	2.83	3.00	3.17	3.33	4 6
1.63	1.78	1.93	2.07	2.22	2.37	2.52	2.67	2.82	2.96	4 0
1.42	1.56	1.69	1.82	1.94	2.07	2.20	2.33	2.46	2.59	3 6
1.22	1.33	1.44	1.56	1.67	1.78	1.89	2.00	2.11	2.22	3 0
1.02	1.11	1.20	1.30	1.39	1.48	1.57	1.67	1.76	1.85	2 6
0.815	0.889	0.963	1.04	1.11	1.19	1.26	1.33	1.41	1.48	2 0
0.611	0.667	0.722	0.778	0.833	0.889	0.944	1.00	1.06	1.11	1 6
0.407	0.444	0.481	0.519	0.556	0.593	0.630	0.667	0.704	0.741	1 0
0.204	0.222	0.241	0.259	0.278	0.296	0.315	0.333	0.352	0.370	0 6
11	12	13	14	15	16	17	18	19	20	0′0″

Spacing in feet.

One of the most satisfactory rules in blasting is to avoid so loading the holes as to throw much rock into the air. If a dense brown smoke with pieces of rock be thrown high in the air with each blast, the holes are too heavily loaded, or the bulk of the charge was not placed low enough in the hole.

CHAPTER II

DRILLING ON LAND

THE problem of drilling is closely related to that of blasting, since primarily the object of the drill holes is to enable the process of blasting to take place. Any method that decreases the number of the holes per cubic yard blasted through increasing the area covered by each hole, will also decrease the cost of drilling nearly in direct proportion to the decrease in the number of feet of hole per cubic yard of rock excavated.

Power Drilling. To the casual observer a steam drill hammering away indefatigably and with a tremendous racket seems an instrument peculiarly well adapted for its work and hardly admissable to criticism as to its performance; but to the expert after careful study and patient investigation the power drill appeals as presenting one of the *most difficult economic problems to master*, one of the most *perverse machines to handle*, and one of the most *complex tools ever invented.* To improve on it, however, is another story.

In the first place, the economic conditions which govern the drilling problem include the following:

1. Hardness of the rock.
2. The sludging characteristics of the rock.
3. Irregularities in the rock.
4. Whether steam or air is used.
5. Pressure in the boiler or air chamber.
6. Diameter of the pipe connection.
7. Length of the pipe connection.
8. The number of drills working at the same time and drawing pressure from the same reservoir.
9. The diameter of the drill cylinder.
10. The stroke of the piston.

11. The type of the drill.
12. The weight of the moving parts.
13. The cut-off in the steam chest.
14. The convenience of the arrangement for changing bits on each machine.
15. The weight of the drill and the kind of mounting.
16. Depth of hole.
17. Diameter of hole.
18. The rate of decrease in the diameter of successive bits.
19. The shape of the bit.
20. The nature of the drill steel.
21. The skill of the blacksmith.
22. The kind of coal at the blacksmith's disposal.
23. The direction of the hole.
24. The use of water for pouring into the hole.
25. The use of a powerful water jet in the hole.
26. The use of a hollow bit with a water or air jet.
27. The wages of the driller and helper.
28. The amount of mucking necessary.
29. The cost of power, including the cost of fuel.

In addition to these are the following, which may be classed as general causes having a peculiar effect upon drilling work:

1. Steam leakage in the neighborhood of the drills and condensing steam around the men.
2. Wind, in combination with cold weather.
3. Elevation above sea level, or barometric pressure.

It is at once apparent that any economic rule for taking into consideration all of these specific factors, with a number of general ones in addition, is enormously difficult to compose. The general effect of each of the above conditions, however, can be predicated with some accuracy, and thus the best procedure for any given case can be determined.

Hardness of the Rock. From the diagrams on pp. 60–63, under the caption "Time Study," it is apparent that in the hard rocks and the very soft rocks the actual time of cutting is a very great factor in the total expense, whereas in the medium soft rocks and the very soft rocks under favorable conditions, the cutting speed is so great as to make actual cutting take up a comparatively small percentage of the total time.

The hard rocks require a heavy blow with a sharp tool in order to break them up, and if other conditions are equal, the amount of work necessary to excavate a hole will be proportional to the hardness of the rock.

Sludging Characteristics of the Rock. When the very soft rocks are reached in the application of this rule the cutting is so fast that the amount of pulverized material or sludge formed is so great as to make a cushion for the bit on the downward stroke and a clog to the bit on the upward stroke. The shales will often form a sludge containing such proportions of large and small particles as to cake on the bit and make it difficult, if not impossible, to draw the bit out of the hole. Two kinds of delays to the action of the drill result. The first, or cushioning effect, prevents the drill from cutting rapidly in the latter part of the run of each bit; the other is that caused by the sticking of the bit. The sludge above the bit settles in the hole about 6 inches above the bottom and not only cakes on the bit but also on the side of the hole, and after a few strokes the bit jams. Under these conditions drilling is one of the most painful processes in the world. The efforts of the driller to loosen the drill by striking it on the steel just above the top of the hole are destructive of tool, equipment, temper, and time. After the drill has become stuck one or more of the following remedies should be applied:

(*a*) Run a powerful water jet through a pipe down to the bottom of the hole and work up and down. This is very effective in loosening up the bit and will also enable a new bit to descend promptly to the bottom of the hole so that the shank will pass over the head of the bit without the necessity of the helper dismounting and raising one of the legs of the tripod.

(*b*) Strike the drill steel as low as possible with the dolly bar or wrench.

(*c*) Put the dolly bar on the steel and pull as hard as possible while the helper attempts to crank up.

(*d*) If the material varies much in hardness drop a handful of pieces of cast iron the size of hazel-nuts into the hole.

(*e*) Shut off the pressure, crank up, turn the pressure on again and try to work the bit down into the hole while striking slowly. This must be done with great caution, else the piston will break the cylinder-head casting.

(*f*) With the dolly bar revolve the steel in the hole while the helper is cranking up and, if necessary, help with a little steam or air.

(*g*) While the drill is working churn up and down in the hole with a thin strip of hickory.

(*h*) Ascertain whether the drill is correctly set up in alignment with the axis of the hole; if not, correct the position of the drill.

It is a peculiarity of the rock-drilling process that the sludge which is formed in the drill hole contains fine and large grains in such proportion that when mixed with a little water the mass is pasty, and in this condition it retards the cutting process very much. When water is poured into the hole in small quantities it loosens up the sludge and tends to prevent the bit from sticking; but if poured into the hole in comparatively large quantities, say, a quart in granite or 6 quarts in shale, there is a decided tendency for the finer particles of the sludge to rise, while the larger pieces ranging in diameter from about $\frac{1}{40}''$ to nearly $\frac{1}{4}''$ (in the case of shale) settle to the bottom, get under the bit and are themselves again pulverized into still finer material, meanwhile greatly obstructing the progress of the drilling.

To remove this sludge as fast as it forms is theoretically and practically the best method of hastening the speed of drilling. In the softer shales the amount of sludge formed is so great that water poured into the hole only serves to make a paste that nearly fills the hole itself. When the sludge is very thick, as happens in the shales, the hole must be pumped out once for every foot of progress.

One very effective way of overcoming the necessity of pumping twice for each bit is to keep churning up and down in the hole with a hickory wand of the same size as a barrel hoop. The material for these can be bought in small bales in the principal cities. These wooden sticks, worked up and down by the drill runner, have the effect of keeping the sludge stirred up and away from the bit at the bottom of the hole, which results in a great increase in the number of blows per minute, and, consequently, in faster cutting. Just how much material they remove from under the bit itself is somewhat problematical, but the general effect in the soft shales is to approximately double the cutting speed. The method is of special advantage in very cold weather when it is not easy to use water jets and when the men like violent exercise to enable them to keep warm. In warm weather, the physical exertion necessary to work a wand in a 10-foot hole is so great as to make it hard to keep the men at it vigorously; and if not vigorously used the wands are of little use.

Jets. A jet of water introduced into the hole through a hollow bit or a small pipe is the most effective means of clearing away the sludge. The water keeps the material away from the bottom of the hole and allows the drill to cut about three times as fast in the soft rocks as before. It is necessary to have the jet sufficient in pressure and also in volume. If insufficient in pressure the speed of the moving water will not be enough to move the larger particles of stone, while if not in sufficient quantity the water will move the sludge from the point of the bit only to let it settle and cake higher up on the bit. It will then be difficult to get the bit out of the hole at all, and the entire method will be dubbed useless by the "practical men."

Aitken states that in trap rock the use of water reduces the time of drilling by 30%, and this is borne out by the remarkable results shown in the diagram on p. 62. These observations apply more particularly to holes with a downward dip. When driving holes that point upward the dry powder has a tendency to run out of the hole. With a rapidly moving drill this is productive of a cloud of dust which is distressing to the men and obstructive to the work. A jet of air played upon the mouth of the hole is the remedy for this trouble.

When the holes are nearly horizontal a jet of air into the hole, rather than the water jet, should greatly economize the process. Always the rule is to get the cut rock away from under the working bit as cleanly and as rapidly as possible.

Mr. H. P. Stow [1] reports an experiment in which the same miner drilled three equal shifts of similar holes with the following performance, using a 2¼″ drill:

Without water,	32 ft., using 38 bits.
Bailing,	41¾ ft., using 33 bits.
With jet of water,	52 ft., using 37 bits,

This is a gain of 30% for bailing, and 62½% with the jet over the dry holes per unit of total working time.

Theory of the Action of the Water Jet. According to the experiments of Rittinger, as described in *Engineering Contracting*, Vol. XXIX, p. 84, after a fall of short distance, grains of sand or rock will descend through water at a fixed and constant speed. Up to about 0.4″ in diameter the formula for this speed is as follows:

$$v = 15.4\sqrt{d(G-1)},$$

where v = speed of fall in inches per second;

d = diameter of falling grain in inches;

G = specific gravity of grain.

This formula relates to "average grains" and gives their velocity when falling through still water after they have attained a constant velocity. Rounded grains have a velocity about 10% greater, and flat grains have a velocity of about 20% less than "average grains."

In 1894 Prof. Robert H. Richards [2] made public the results of a large number of experiments on grains falling through water. The grains were all very small, none being larger than 0.08″. They were allowed to fall through 8 feet of water. Richards found that for quartz grains the velocity was

$$v = 30\sqrt{d}.$$

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[1] Mining and Scientific Press.

[2] Trans. Am. Inst. Min. Eng., Vol. XXIV, p. 409.

According to Rittinger, with quartz having a specific gravity of 2.64, the velocity would be

$$v=20\sqrt{d}.$$

Since civil engineers and contractors rarely have to excavate rock much heavier than quartz, it will be safe to use Richards' formula,

$$v=30\sqrt{d}.$$

In order to lift grains of rock vertically by means of an upward rising current of water, the vertical velocity of the water must exceed the velocity that those grains would attain when falling through still water. This is clearly the fundamental principle to be used in calculating the quantity of water required to keep a drill hole free of sludge by means of a water jet. Let A be the area in square inches of the drill hole not occupied by the steel at its mouth, then,

$$A=\frac{\pi D^2}{4}-\frac{\pi l^2}{4}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

when l=diameter of drill steel, D being the diameter of the hole in inches.

Let Q be the number of gallons of water per minute rising through the drill hole, as delivered by the water jet; then

$$Q=60\frac{vA}{231}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

v being the velocity of the rising current of water in inches per second. There are 231 cu.ins. per gallon, hence the 231 in the denominator. The 60 in the numerator is introduced to reduce a velocity (v) of inches per second to inches per minute.

Substituting for A its value given in Eq. (1) we have

$$Q=\frac{60v}{231}\times\frac{\pi(D^2-l^2)}{4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now, according to Richards' formula for the velocity of grains falling through still water, we have

$$v=30\sqrt{d}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

If the v in Eq. (3) is equal to the v in Eq. (4), we shall have barely enough water rising through the drill hole to elevate grains of sludge having a diameter d. Hence, combining Eqs. (3) and (4), we have

$$Q=\frac{60}{231}\times 30\sqrt{d}\frac{\pi(D^2-l^2)}{4}=\frac{450}{231}\pi(D^2-l^2)\sqrt{d}. \quad . \quad . \quad . \qquad (5)$$

Substituting for π its value 3.14, we have

$$Q=6.1(D^2-l^2)\sqrt{d}. \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

In order to provide a small factor of safety that will insure the delivery of the grains of sludge at the mouth of the drill hole, let us substitute 7 for the 6.1 in Eq. (6). Then we have

$$Q=7(D^2-l^2)\sqrt{d}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

where Q = gallons of water per minute;
D = diameter of mouth of drill hole in inches;
d = diameter of largest grain of sludge in inches;
l = diameter of drill steel in inches.

In very tough rock the grains of sludge are often exceedingly small. Assuming that the largest grains to be elevated by the water jet are one-hundredth of an inch in diameter, that the hole is 2½″ in diameter, and the steel ⅞″ in diameter, and applying Eq. (7), we have

$$Q=7\times\frac{(2.5^2-0.875^2)}{10}=3.84 \text{ gallons per minute.}$$

Should the specific gravity of the rock be greater than 2.6, our formula, Eq. (7), must be modified in accordance with Rittinger's formula for grains falling in water, above given.

Now that an accurate method of forecasting the amount of water for removing sludge and rock chips is available, there should be a much more frequent use of the water jet in the future than in the past.

By drying the sludge and screening it the diameter of the largest grain to be lifted by the current of water is readily ascertained. It will be found, however, that upon the introduction of a water jet grains of larger size than were previously found in the sludge will be removed. This in itself is one of the strongest reasons why the water jet increases the efficiency of a drill, for the drill bit is relieved of the work of pulverizing every chip of rock that it loosens.

We have plotted these formulas in the accompanying diagram (p. 28) entitled "Chart showing the quantity of water in gallons per minute required to remove particles of sludge from drill holes." To use this chart, obtain the squares of the diameters of the hole of the drill steel and of the grains of sludge. Thus if the diameter of the hole at the top is 3", that of the drill steel $\frac{3}{4}$" and of the sludge $\frac{1}{20}$", the expression

$$D^2 - l^2 = 9 \text{ sq.ins.} - 0.56 \text{ sq.in.} = 8.44 \text{ sq.ins.}$$

This is so nearly 9 sq.ins. that on the diagram we can use the line representing 9 sq.ins. which cuts the vertical line for a diameter of grain equivalent to a $\frac{1}{20}$" at the point corresponding to 14.1 gallons per minute. The theoretical amount of water necessary, then, is a little less than 14 gallons per minute.

In practice, when working in the hole the portion of the bit at the point of the drill is in a very much more confined space than that above. In addition to this the drill is churning the water at the bottom of the hole tremendously, so that large particles will be caused to float in the hole above the bottom but will not be lifted out by the upward current of water. It thus happens that upon stopping the drill to change bits it is advisable to put an extra jet into the hole while the helper is cranking up, in order to wash out as many of the large particles as possible. At the best, with an ordinary jet there will be a considerable number of grains, varying from $\frac{1}{8}$" up in the very soft rocks, which settle down into the holes after the bit has been withdrawn, to a depth of one or two inches. These cannot easily be removed by the pump. When the following bit is dropped into the hole, if it does not descend sufficiently to admit of the drill chuck passing over the shank, it can be immediately caused to settle down by pushing one of the jet pipes into the hole. As soon as the jet is within a few inches of the bottom it stirs up the small particles of broken

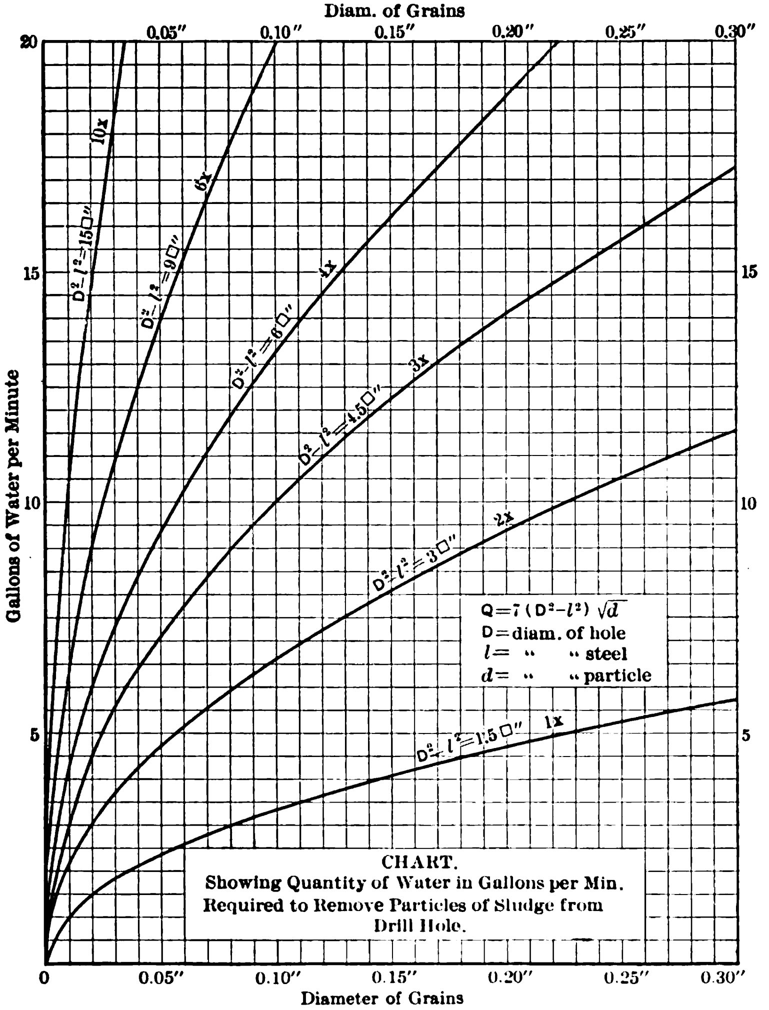

FIG. 1.

stone and the bit then descends by its own weight. It takes about one minute to teach the ordinary drill runner this trick, but usually they will discover it themselves in the first few minutes of work if they have not been instructed.

The first thing that the fresh bit does after getting to work is to break up these pieces which the jet will then take out of the hole. It should be noted that when operated in this manner there is practically no pumping to be done, and thus the time of changing bits can be materially reduced.

Attention has been called to the use of hollow drill steel and a special arrangement for jetting water into the hole through the bit; if this equipment be not at hand, we have found that the best arrangement is to use a half-inch hose as long as may be necessary, with a 30″ length of ⅜″ iron pipe inserted about 3″ in the end of the hose. When a small hole is drilled it is sometimes advisable to have the blacksmith taper the ⅜″ pipe slightly, but when the smallest bit has a diameter of 2¾″ this is not necessary.

To fasten the pipe into the hose it is only necessary to pull the rubber over the end of the pipe for about 3″. When in the drill hole, if the pipe is pulled, the rubber contracts around the end of the pipe, thus holding it very firmly. The weight of the pipe keeps the hose down in the hole and by reducing the diameter of the stream gives an extra speed to the water where speed will do the most good. The working of the bit, when the X bit is used, as it should be, keeps the end of the pipe from descending lower than about 6″ above the bottom of the hole.

It is often difficult to get sufficient head of water to work such a jet to the best advantage, excepting in hard rocks, unless a force pump be used. We have used a small Deane Duplex pump with 2¾×4″ cylinders, running at 90 revolutions per minute and operating six jets. At this speed each jet threw about 6 gallons per minute with pressure of about 100 lbs. per sq.in. through a 50-foot length of the half-inch hose, which was coupled to a "manifold," taking water from a 1″ discharge pipe from the pump. When the pump was operated at a higher speed than this it was found that the hose had a tendency to twist and squirm, so that with this arrangement 6 gallons of water per minute is about the limit for one jet. For grains of rock with a diameter of $\frac{1}{10}''$ reference to the diagram shows that the expression D^2-l^2 must be about 3 sq.ins. for one jet or about 6 sq.ins. for two jets. The use of this arrangement is not practical in holes of so small an area, consequently the larger grains will never entirely be removed from the hole by the jet, according to our experience in practice. Where a 3″ bit and two jets are used, the largest average diameter of a piece that will come out of the top of the hole is about $\frac{1}{20}$.″

The facts above enumerated explain why the use of a water jet has been condemned in the soft rocks by many so-called "practical men." They have from time to time experimented, in a half-hearted sort of way and with an insufficient head of water, and therefore the amount of the large grains that would not come out has often been enough to clog the bit. For the benefit of future experimenters we wish to say that we have always known the jet to work admirably even in the very softest rocks, when as much as 6 gallons per minute was forced through each jet pipe. In very cold weather these small pipes are likely to freeze, and it takes at least half the time of one man to care for the pump and keep a half-dozen jets going. In moderate weather a small pump of this type can be placed upon the boiler that furnishes the drills with steam and when oiled twice a day will run almost without attention. It should be noted that 6 gallons per minute for each six jets amounts to over 2000 gallons of water per hour, which in dry weather might be a heavy strain on the water supply. This, however, will carry away about 10% of its volume of sludge. Where it is desirable to pump the hole out clean, it is well to stop the bit in the soft rocks when the drill has about 5″ more to cut; thus, there will be sufficient thick sludge in the hole to make pumping feasible. One of the standard sets of instructions for this work is here given:

Rules for Drill Jets. "In shaley rock of rather soft quality in which under the jet a 3¼″ drill will drive a 3″ bit 12″ per minute.

"These rules apply to the use of a jet in which the nozzle has a diameter of ⅜″ and the water pressure is 100 lbs. per sq.in.

"As soon as the drill is set up and the first bit placed, get ready with the jet, start the drill and direct the jet into the hole under the bit as soon as it has cut about 1″. From this time on keep the jet in the hole with the nozzle of the pipe as near as possible to the working end of the bit.

"Let the nozzle follow the bit down into the hole until you see by the drill stem that the drill has about 5″ more to go before finishing the cut. Then immediately withdraw the jet and allow the bit to finish this cut. You will have plenty of time after taking out the jet to handle the throttle and wrench. By taking out the jet before the cut is finished there is left enough sludge in the hole to make it very easy to pump the hole clean.

"When the hole has been cleaned, which should be done thoroughly, put in the next bit and start the drill slowly. As soon as the drill has made about five strokes, put the jet in again and keep it there until you are within 5″ of the finish of that cut, and continue in the same way with the succeeding bits. See to it that the jet follows the bit down into the hole and once or twice for every cut raise it about 2′ and push it down again."

The cost of operating jets is approximately as follows:

	CENTS.
1 pump at $40.00, interest, depreciation, and repairs, say, 50%	13.33
300′ half-inch hose, at 10 cts, interest, depreciation, and repairs, say, 200%	40.00
Fittings, etc.	5.00
Coal	17.50
Pipe fitter ¼ day, 38½ cts	38.50
Incidentals	10.00
Total per working day for 6 drills	124.00

Under normal conditions these jets will increase the output from 30 to 100%, to say nothing of the collateral advantages gained by the use of a smaller main plant. The use of such a method as this, which we have here described at some length, sometimes makes the difference between a handsome profit and a sickening loss on a contract.

Irregularities in the Rock. The greatest trouble from variable rock occurs in the faulty shales and in schists, such as those on Manhattan Island. For the medium soft rocks a rather thin edge to the drill bit is preferable; while in the very hard rocks in which this thin edge would be broken the point of the bit must be at an obtuse angle. It follows therefore that points suitable for soft rock are not suitable for hard material, and when a bit that has been working for a long time in a soft rock strikes a layer of quartz or exceedingly indurated shale, so hard as to be practically a trap, the point will either be broken or so blunted as to go out of business. It is a familiar fact of practice that a blacksmith who can make either of the two kinds of bits almost perfectly, deteriorates in his work as soon as he has to make both kinds in one day. As soon as he has to change his temper he commences to vary it. This is one reason why the cost of drilling in a mixed quality of rock is generally rather higher than the cost of drilling in any one kind alone.

Where the rock is pitched, there is always a tendency for the bit to work out of line in the hole and then stick. This should be carefully watched. Little pieces of cast iron will frequently help the bit past a bad spot of this kind without "drifting."

The Use of Steam or Air. Aside from the cost of fuel the arrangement of the drills, whether by steam or air, has a good deal to do with the economy of operation. In mine work, of course, steam is not practicable, so that the following refers to open cut operations. In the first place, the ordinary hose will last a good deal longer with air than when steam is used; then again, the steam from all leaking joints and from the drills themselves obscures the drills and makes it difficult for the men to work and for the foreman to direct them. A compensating advantage in the use of steam is that every leak is at once noticeable. The heat from the steam is so great as to cause expansion in the drill cylinder, and this often results in broken castings. When turning on the steam at first, a jet of hot water comes out of the exhaust, which keeps the men dodging a good deal in confined work. Air at 60 lbs. pressure will pass through the ports with less friction than the same amount of steam, and becuase of this fact at least one authority has been in the habit of estimating that at the same pressure about 10% less in actual cubic feet of steam than air will be consumed by the same drill. Conversely, in order to get the standard number of strokes per minute it requires about 10% more pressure on a steam line than where air power is used.

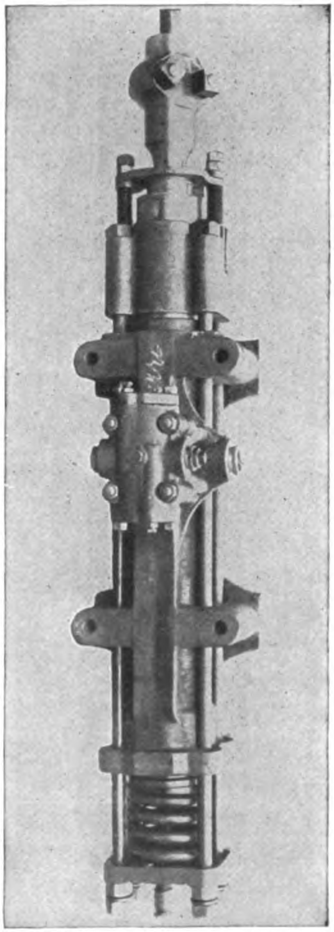

FIG. 2.—Ingersoll-Rand "H-64" Submarine Drill.

There is a rapid radiation of heat, and a corresponding amount of condensation in a steam line, amounting to about 750 pound-degrees per sq.ft. of pipe surface per hour in still air, and about 30% more than this in a strong wind. With an air line there is no such loss as this, and for long transmissions a steam line is at a great disadvantage unless it is heavily lagged. Inasmuch as the radiation of heat is proportional to the area of the pipe surface and the carrying capacity of the pipe is proportional to the area of the pipe section, the larger the diameter of the steam pipe line the less will be the proportionate amount of lost energy from this cause.

When compressed air is used there is frequently a choice as to what kind of power may be used to compress the air, whether a steam engine, a gas engine, or an electric motor.

Electric power is economical in a number of instances. It has the following advantages over steam and gasoline:

1. Cleanliness, which is more of a luxury than an economic advantage.
2. Convenience for operating purposes, in that no skilled labor is required to turn the switches on or off.
3. No large amount of housing is necessary.
4. No cost at all for transportation of fuel and supplies, and a very small cost for transportation of plant.

Among the disadvantages are the following:

a. Susceptibility to interruption from storms.
b. The motors must be wound to suit the current available.
c. Transmission line must be provided.
d. A spark or lightning arrester must be provided.
e. In case of the burning out of an armature, getting another machine on the ground is a slow business.
f. Where much exposed to the elements the deterioration of the motor is considerable.
h. It requires an electrician to operate and care for the plant.

Pressure in the Boiler or Air Chamber. In a paper entitled "Stope Drills," which we have elsewhere quoted, in the case of eight drills the depth of drilling per minute of actual running at 50 lbs. per sq.in. pressure varied from .93″ as a minimum to 1.83″ as a maximum, with an average of 1.343″, while with 60 lbs. pressure the same drills drilled per minute of actual running time from 1.06″ as a minimum to 2.22″ as a maximum, with an average of 1.733″. The increase of pressure from 50 to 60 lbs. is 20%. The increase in performance due to this increase in pressure is over 20%. This solitary fact should be enough to convince any one of the tremendous economic advantage of having all drills work at the highest practical pressure, and further, that is it absolutely essential to have the transmission lines so arranged that the available pressure will be freely supplied to the drill.

The Diameter of the Pipe Connection. The main fact to be borne in mind is that the area, and approximate carrying capacity, varies as the square of the diameter. Therefore a 3-inch main supply pipe will furnish all the steam that eight or nine 1-inch distributing pipes can take.

Length of the Pipe Connection. From Kent's "Handbook" it appears that the loss in efficiency at 80 lbs. pressure for pipe lines varying from 1″ to 14″ in diameter, and up to a length of 5000 ft., carrying air, is seldom more than 10%; so that for air transmission this is an almost negligible factor. With steam lines the loss, as has been stated above, is approximately 750 pound-degrees per sq.ft. of pipe surface per hour. This was figured upon an assumed difference of temperature between the steam and the outside air of 250° F., and the outside surface of the pipe is the one to be taken in the calculations.

The following table gives the number of square feet of external area for 100 lineal feet of pipe:

Nominal Inside Diameter, Inches.	Square Feet of Outside Surface of 100 Lineal Feet of Pipe.	Nominal Inside Diameter, Inches.	Square Feet of Outside Surface of 100 Lineal Feet of Pipe.	Nominal Inside Diameter, Inches.	Square Feet of Outside Surface of 100 Lineal Feet of Pipe.
½	22.2	2½	75.2	6	173.3
¾	27.5	3	91.7	7	198.0
1	34.4	3½	104.7	8	225.2
1¼	43.5	4	117.8	9	250.0
1½	49.8	4½	130.7	10	281.7
2	62.1	5	159.0	..	.....

At 60 lbs. pressure one pound of steam contains about 1175 pound-degrees of energy when evaporated from water at 22° F.

Number of Drills going at once and Drawing Pressure from Same Reservoir. The amount of power that it takes to run a battery of drills is not directly proportional to the number of drills operated. The boiler or air reservoir supplying pressure to a single drill must be able to furnish as much power as a drill would take if it were operating continuously, and therefore there will be a large excess of power, some of which must be wasted when the drill is quiescent. As the number of drills in the battery increases, the drills which are operating tend to balance the discrepancies in power due to the interruptions, and therefore the available margin of power may be less. The quantitative expression of this rule, obtained largely from the data in manufacturers' catalogues, is to be found in the diagram which accompanies the section of chapter III, entitled *Cost of Power.*

Diameter of the Drill Cylinder. With the same length of cylinder the force of the blow struck by the drill will vary approximately as the square of the diameter of the cylinder, and the selection of the economic size of drill depends upon the character of the rock that it is expected to work in. A 3¼" drill, which is the size in most general use in South Africa, will deal a sufficiently powerful blow to satisfactorily attack the harder rocks up to and including the granites. For the toughest trap a 3½" drill, which with tripod weighs nearly 175 pounds more than the next smaller size, may be preferable. In the soft rocks, such as the shales, the heavy drills are at a great disadvantage, since the force of the blow which is struck is so great as to drive the bit a comparatively long distance into the rock with each stroke, loosening very large pieces that have to be pulverized by subsequent blows at a great waste of power. For this reason, if for no other, even where comparatively large holes have to be drilled, the light drills from the 2¾" size down are most suitable for the soft rocks.

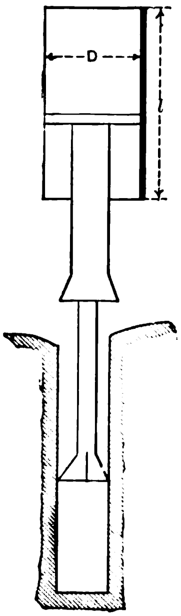

Fig. 3.

Stroke of the Piston. Every manufacturer has a standard length of stroke for each diameter of cylinder and each type of machine. This general fact is to be considered, viz., that, other conditions being equal, the longer the stroke the harder the blow.

The following equations explain how the length of drill stroke affects the economy of drilling in the rocks of various degrees of hardness and toughness, and the effect on the drill steel.

The illustration (Fig. 3) indicates the drill cylinder and bit.

Let P = steam or air pressure in lbs. per sq.in. free at drill;
A = net area of piston in sq.ins.;
l = length of stroke in ins.;
m = mass of all moving parts;
n = number of strokes per minute;
v = velocity of moving parts at any given time;
t = commencement of stroke.

Assume free passage of steam or air through parts, and assume cut off at 80% of stroke. The resultant decrease in effective pressure is negligible, when the drill is working vertically.

f = acceleration of the moving parts due to pressure;
g = acceleration of the moving parts due to gravity;
$= 32$ ft/sec.^{2}

$$E = \text{total energy of moving parts} = \tfrac{1}{2}mv^2. \quad . \quad . \quad . \qquad (1)$$

$$v^2 = 2l(f+g). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

by the familiar formula for motion in a straight line.

Also, total pressure = impelling force = 32 AP (since P was in pounds) = mf.

$$f = \frac{32AP}{m}$$

$$v^2 = 2l\left(\frac{32AP}{m} + g\right) \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

and
$$E = l(32AP + mg) \quad . \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

From these Eqs. (3) and (4) it appears that the velocity of impact is proportional to the square root of the length of the stroke, and the energy of impact is directly proportional to the stroke.

When the drill is working in a horizontal hole, the acceleration of gravity disappears, and we have

$$v^2 = 2l\frac{32AP}{m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

and
$$E = 32lAP. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

If we assume for a 3″ drill that $l=6''=\frac{1}{2}$ft. and $m=60$ lbs., and $P=60$ lbs. per sq.in, then

$$A=7.1 \text{ sq.in.}$$

the value of Eq. (6) is

$$\frac{32}{2}\times 7.1\times 60=6820$$

and that of Eq. (4) is

$$=7780,$$

a difference of 14% in striking energy in favor of the vertical holes, regardless of the sludging conditions.

The Convenience of the Arrangement for changing Bits on each Machine. In the United States the standard method for fastening bits in the chuck is by means of a U bolt with two nuts. It has been our experience that square nuts for this purpose are more satisfactory than the hexagonal ones, which are likely to slip in the wrench and require more time to tighten up, whereas the square nut can be drawn sufficiently tight in all positions to hold the bit.

The Weight of the Drill itself. This factor has a much larger influence upon the cost of drilling in the soft rocks with short holes than in the hard rocks with long holes, because in the former case the time of moving and setting up a drill is a very much larger percentage of the total working time than in the latter.

There are three standard mountings, namely,

1. Tripod.
2. Quarry bar.
3. Shaft bar.

Depth of Hole. Usually the depth of the holes is fixed by the exigencies of the blasting, or by the necessities of the loading organization. A steam shovel cannot easily take out a bench of more than nine to twelve feet in heigh, when loading upon cars running on the level of the unexcavated rock. Therefore, when the work is of a character necessitating this arrangement, the advantages from the use of very deep holes are not admissable. As the bit works in the hole there is a considerable amount of friction under the bit and around the sides of the hole, with the result that after cutting about two feet in the rock the diameter of the bit is somewhat less than at its start; therefore it has been the rule to make the diameter of each bit ⅛" less than that of the preceding one. Thus, with 10-foot holes with a 24-inch "feed," if the diameter of the first bit is 3", the diameter of the last bit would be 2½". Now the minimum diameter of the last bit is limited by the size of stick of explosive that must be inserted in the hole, and therefore the deeper the hole the larger the average diameter.

The following is a table giving the weight in lbs. of octagonal drill steel for different lengths:

Depth in Feet.	¾"	⅞"	1"	1⅛"	1¼"	1⅜"	1½"	1⅝"	1¾"
2	3.22	4.32	5.58	7.16	8.78	10.74	12.68	14.80	17.30
4	6.44	8.64	11.16	14.32	17.56	21.48	25.36	29.60	34.60
6	9.66	12.96	16.74	21.48	26.34	32.22	38.04	44.40	51.90
8	12.88	17.28	22.32	28.64	35.12	42.96	50.72	59.20	69.20
10	16.10	21.60	27.90	35.80	43.90	53.70	63.40	74.00	86.50
12	19.32	25.92	33.48	42.96	52.68	64.44	76.08	88.80	103.80
14	22.54	30.24	39.06	50.12	61.46	75.18	88.76	103.60	121.10
16	25.76	34.56	44.64	57.28	70.24	85.92	101.44	118.40	138.40
18	28.98	38.88	50.22	64.44	79.02	96.66	114.14	133.20	155.70
20	32.30	43.20	55.80	71.60	87.80	107.40	126.82	148.00	173.00
22	35.42	47.32	61.38	78.76	96.58	118.14	139.50	162.80	190.30
24	38.64	51.64	66.96	85.92	105.36	128.88	152.18	177.60	207.60

NOTE. 490 lbs. per cubic foot used as the weight for steel.

Where the moving parts of the "Baby" Ingersoll 2¼" drill (A–86) according to the makers weigh about 20 lbs., with ⅞" steel at a depth of 4′ the total moving weight is about 28.6 lbs., while at a depth of 12′ the total moving weight would be about 46 lbs.

The deeper the hole, the longer and harder the pumping process where no jet is used. The deeper the hole, the fewer the set-ups, thus tending to the partial elimination of that large element in the cost of drilling. Note that this is much more important where set-ups are difficult than when drills are moving along a practically level bench.

Diameter of Holes. The diameter of drill holes is an elastic factor that can be varied to suit the conditions.

A very careful series of experiments on drilling was conducted under the auspices of the Transvaal Institute of Mechanical Engineers in December, 1907, and published in the paper entitled "Stope Drills" written by Prof. J. Orr of that Institute. We have abstracted from this paper data, from which it would seem that the product of the area of the hole multiplied by the cutting speed is not far from constant for the "Baby" Ingersoll Drill with 50 lbs. of steam. This amount was 2.95 for the 1½" bit, 2.96 for the 1⅜" bit, 2.97 for the 1¼" bit, and 2.74 for the 1⅛" bit. At 60 lbs. the figure was practically constant for the first two sizes of bit and decreased rather rapidly down to the 1⅛". In the case of the hammer type of drill the rule does not hold so nearly true, the product of the area and rate in the case of the 1⅛" bit being but little over 78% of that for the 1½" bit.

When it is realized that the drill of the hammer type is at an increasing disadvantage, as the diameter of hole grows less on account of possible clogging of the bit, the steel so nearly filling the hole, the discrepancy does not seem so marked, and it will be noticed that the departure from this assumed rule seems very much greater with the smallest sizes of bits. Given a uniform rock and properly designed tools and machinery, it seems a reasonable assumption that with a constant air or steam pressure the performance per cubic inch of material drilled per unit of working time should be substantially constant. Precise experimental data, sufficient to include all the standard sizes of bits, are lacking; and it does not seem likely that the deficiency will be supplied in the near future. To-day the evidence is in favor of the proposition that the actual cutting speed is inversely proportional to the area of the hole, other things being equal.

The economic rule, therefore, in choosing the drilling equipment and tools, is to use the minimum diameter of hole in which the drill will freely work when the holes can be sprung, and as large a hole as can be conveniently drilled when the holes cannot be sprung, except where the rock must be broken out in blocks with a minimum of waste.

Rate of Decrease in the Diameter of Successive Bits. In fast-drilling rocks, there is no great wear to the bits and there is no reason why there should $\frac{1}{8}''$ difference in their successive diameters. Therefore with the same diameter at the bottom of the hole it is sometimes feasible, by instructions to the blacksmith, to reduce the diameter at the top of the hole considerably and thus increase the average cutting speed.

The Shape of the Bit. This has much to do with satisfactory progress. The following article, "Rock Drill Bits," by Mr. T. H. Proske, which we consider the best by far on this subject that has as yet appeared, has been abstracted from the "Mining and Scientific Press."

"The success of almost every drilling operation depends on selection and treatment of the bits. Too much attention cannot be given this important part of the work. If the bits have been properly formed, sharpened, and tempered for the work, and if they are changed just as soon as their edges and gauges are worn, the result will be found to be most economical. The power-drill sharpener has removed many of the shortcomings attendant upon the hand-sharpening process, with the result that where these machines are used it is possible to accomplish from 25 to 100% more drilling than under the old methods. The reasons for this are that the power sharpener turns out a much better bit. The saving in the blacksmith's wages should be a secondary consideration. The superior quality of the bits made in a machine will increase the capacity of the drilling machines sufficient to pay handsome dividends on the cost of the power sharpener.

"For the guidance of those unfamiliar with the forms of drill-bits used in the different sections, I have prepared a few drawings of those in use. Fig. 4 represents the square cross-bit adopted as the standard for American mining practice. It is made from either round, octagon, or cruciform steel. In the copper mines of Michigan it is usually made of a round steel. In the iron mines of Michigan and Minnesota and wherever this form of bit is used east of the Rocky Mountains, octagon steel is preferred, but in the Rocky Mountain and Pacific States cruciform steel is used. The reason for the adoption of this form of bit as a standard will be appreciated when the three requirements of a rock-drill bit are recalled. These are 'to chisel out a hole in the rock,' 'to keep this hole round and free from rifles,' and 'to mud freely.' There is really a fourth requirement, which is 'to do as much drilling as possible before being resharpened.'

"The different kinds of rock to be drilled affect the wear of the bit. Very hard rock will blunt the chisel and reaming edges. The softer rocks do not blunt these edges, but wear the outer sides so that it loses its gauge and size, still appearing to be quite sharp. For this reason a bit that is made with a square edge and a clearance angle of 8° will drill about four times as long in soft rock as a bit with round edges and a clearance angle of 16°, before being reduced to the size of the next bit that is to follow. Referring to Fig. 4 and Fig. 5, the latter being a round-edge bit with a clearance angle of 16°, it will be seen that in Fig. 4 the corners of the bit at the base of the bevel describe a circle that is equal to the circle that the chisel edges describe. This is as it should be, as it is impossible for the chisel edge to cut out all of the rock.

"The reaming edge, which is that part of the bit extending from the chisel edge to the base of the bevel, marked '*a*' in both Fig. 4 and Fig. 5, must ream the outer edge of the hole and keep it round and free from rifles. In Fig. 5 it will be noted that the circle described by the corners of the bit at the base of the bevel is much smaller than the circle described by the chisel edges. This causes an excess of wear on the corners of the chisel edges, the bit rapidly loses its gauge, as well as its efficiency, and it is almost impossible to keep the hole round. Rifles form, and these cause the rotation parts of the drilling machine to break, often resulting in the loss of the hole.

"The angle of the bevel of the face of the bit has to do with its life as well as with the property of 'mudding' freely. It is generally accepted that if this angle be 90° it gives strength and permits the bit to 'mud' or throw back the cuttings from the face of the bit when the drill is pointed downward. Bits made like Fig. 22 and Fig. 23 will not 'mud' freely. Another reason

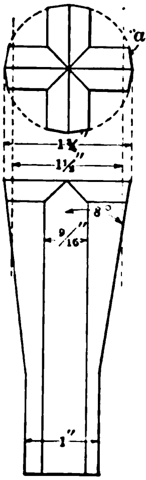

FIG. 4.

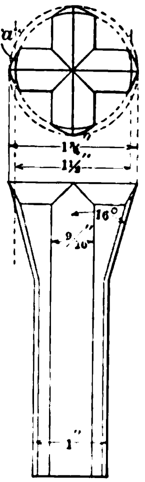

FIG. 5.

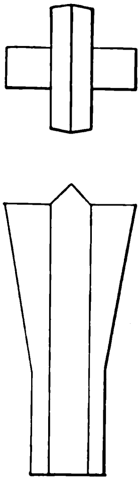

FIG. 6.

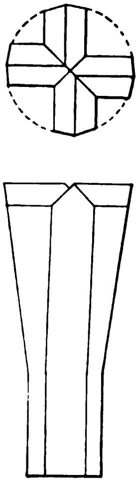

FIG. 7.

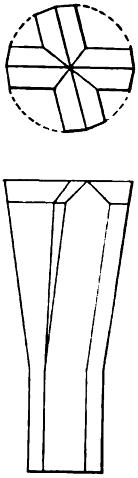

FIG. 8.

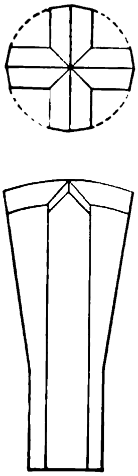

FIG. 9.

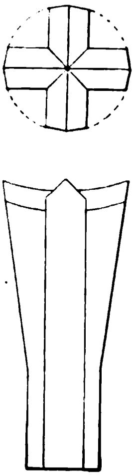

FIG. 10.

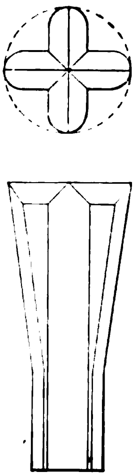

FIG. 11.

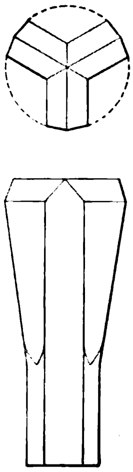

FIG. 12.

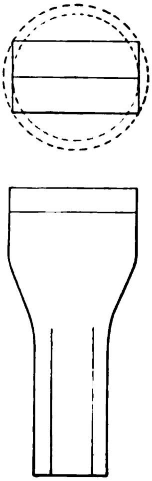

FIG. 13.

why bits such as is shown in Fig. 4 are preferable to those illustrated by Fig. 5, is that having a long wing they are stronger and will not break so readily as does a short bit.

"The Simmons bit, used at the Champion mine at Beacon, Mich., is shown in Fig. 6. In it two of the wings are devoted entirely to reaming and keeping the hole round and free from rifles. Some tests made several years ago in jasper, the hardest rock found in the Champion mine, using a 2¾ in. Rand drill with 60-lb. air pressure at the compressor, showed an average speed per minute of 0.28 in. for the ordinary cross-bit, and 0.659 in. for the Simmons bit. Both forms were hand-sharpened.

"The Brunton bit, the invention of the well known mining engineer, D. W. Brunton, is extensively used in Idaho and Montana. It is shown in Fig .7. The object of this bit is to obtain the advantages of the X-bit without the attendant difficulties of resharpening. With this bit, as in the case of the X-bit, the piston must revolve a half turn before the cutting edges will strike in the same place a second time. It is as easily resharpened as the regular square cross-bit. The X-bit itself is shown in Fig. 8. Since the invention of power-drill sharpening machines, this bit is fast disappearing. The reason will be understood when a comparison is made with the regular square cross-bit, as made with the power-sharpener, and the cross-bits as they are resharpened by hand, shown in Fig. 21, Fig. 22, and Fig. 23. The X-bit is designed to prevent rifles. This the hand-sharpened cross-bit would not do, but the machine-sharpened cross-bit effectually accomplishes. Fig. 9 shows what is commonly termed the high-centre bit. This was for many years accepted as the proper form. It is still used in the mines of Cornwall and where Cornish customs prevail. Since the introduction of hammer-drills this bit is again finding favor. It is of especial advantage in starting a hole, the high centre immediately making an impression on the rock, whereas the square-faced bit requires a flat face for ready starting. For a starting bit in hammer machines it has no equal. Here, however, its advantages over the square bit end. Used as a bit to follow the starter, it is liable to follow slips and seams in the rock, causing crooked holes, which are sometimes lost before being finished. This the square bit will not do. Fig. 10 shows a bit where the corners are in advance of the centre. This is a fast cutting bit. The corners break up the rock in advance of the centre and leave little for the centre to do; this causes the corners to wear fast, but still not to excess when it is considered that they do most of the work. This drill will not follow slips and seams, will drill a round hole, and is easy on the drilling machine. The weak point of this form is that the leverage is so great on the corners that they are liable to break off if tempered too hard. Fig. 11 shows the round-edge bit, which is a favorite with some. In soft rock this is good, but in hard rock it permits rifles to form in the hole because there are no reaming edges.

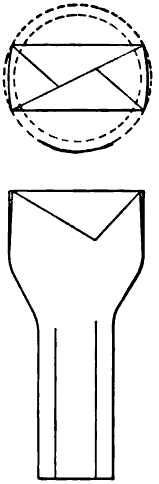

Fig. 14.

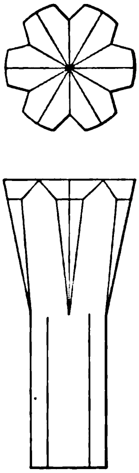

Fig. 15.

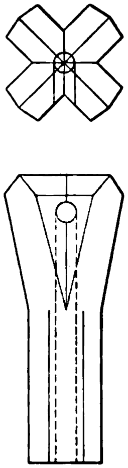

Fig. 16.

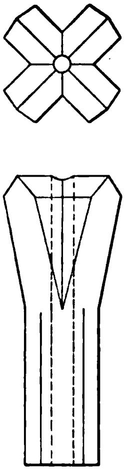

Fig. 17.

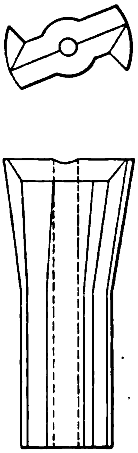

Fig. 18.

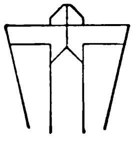

Fig. 19.

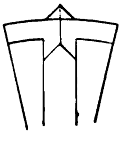

Fig. 20.

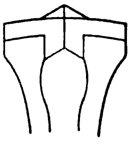

Fig. 21.

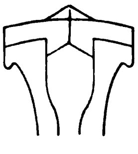

Fig. 22.

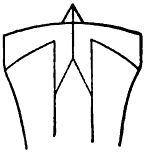

Fig. 23.

"The Y-bit shown in Fig. 12 gives the advantage of plenty of room for the cuttings to escape. It is however, quite difficult to make and re-sharpen by hand. With the power-sharpener it can be made as easily as any other form. Fig. 13 shows the " bull " bit in use in the lead and zinc mines of the Joplin, Mo., district, before the introduction of the power-sharpener. The extreme hardness of the limestone and flint in the sheet-ground of that district, caused the ordinary cross-bit as made by hand to wear too fast. This dull bull-bit therefore had to be adopted. Drilling here was not a matter of cutting the rock, but of shattering it by impact. The power-sharpener has changed all this, and the American standard cross-bit as made in these machines is now used. As a result the capacity of the drills has been materially increased. In mines where hand-sharpening is still done the bull-bit is yet in use. Fig. 14 shows the Z-bit used in hand-sharpening in the southeast Missouri lead district. This bit is also used quite extensively in Germany. In both places, however, the advantage of the standard square cross-bit as made with the power-sharpener is fast causing it to be displaced. Fig. 15 shows the " six-wing rosette " bit as made in the power-sharpener in use at the Penarroya mines of Spain. It is used in hammer drills only. Of all the rosette forms of bits this has been found to be the most satisfactory. Fig. 16 shows the square cross-bits when made up for hammer drills where a hole for the introduction of air or water to remove the cuttings apexes at a point back from the bevel of the bit in one of the recesses between the wings. Fig. 17 shows the same form where the hole ends in the centre of the cross of the cutting edges. This form of bit is extensively used. Its faults are that a core is formed by this

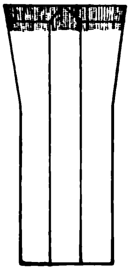

FIG. 24.

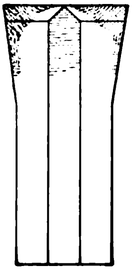

FIG. 25.

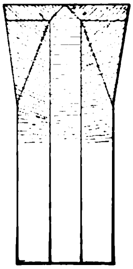

FIG. 26.

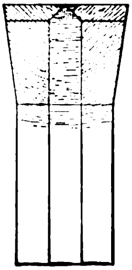

FIG. 27.

FIG. 28.

hole; this core fills the hole, and causes a stoppage of air or water. These cores have been known to become as much as 8 in. long, and are quite difficult to remove. To clear them away the core must be burned out by heating the steel the full length of the core in a slow fire; a sometimes slow and tedious process. This difficulty is entirely overcome by the use of the bit shown in Fig. 16. The Z-bit, Fig. 18, is extensively used in Germany. In hammer drilling machines, the steel is formed in bars having a Z shape. While I show this bar straight, it is usually twisted to form a spiral. It is an easy matter to form a Z-bit on the end of such a bar. The results obtained are excellent. Holes to a depth of 16 ft. horizontal have been drilled with this form of steel. The spiral draws out the cuttings much the same as an auger. Fig. 19 to Fig. 23 are given to show the evolution of the cross-bit where hand-sharpening is employed. There are two systems of hand-sharpening. One is known as the set-hammer system. In it the steel is hammered by placing a set-hammer on the bevels and driving the steel back. The results of this method are illustrated in Fig. 19 to Fig. 22. Fig. 19 shows a bit made by cutting the bevels with a chisel and is as it should be in form. Fig. 20 shows this bit after about the third sharpening. Fig. 21 is the

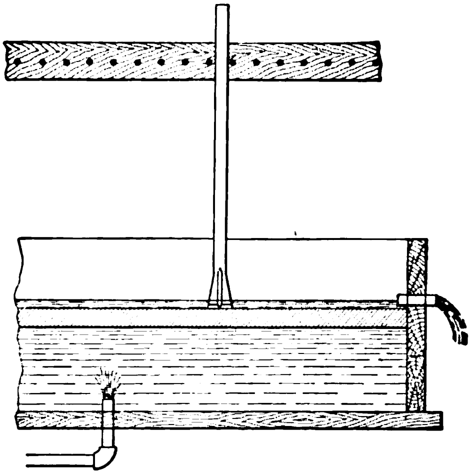

FIG. 29.

same bit after about the sixth sharpening, and Fig. 22 is the same bit at about the time that the original cross that was formed on the bar of octogan steel has become exhausted. The other system of hand-sharpening is known as the fuller and dollie system. By this system the stock is first drawn sharp at the corners as shown in Fig. 23 with the fuller, after which it should be set back in the centre with the dollie. Unfortunately the man swinging the sledge hammer gets tired before the bit is set back enough, the result is that the bit, partly finished, is left as shown in Fig. 23. It is because the power-sharpener has the staying power, and because it readily finishes a bit perfectly, that inferior bits like these are not to be found where machine sharpening is employed.

"After a bit has been forged, it should be properly tempered as in Fig. 24. Fig. 25 shows the result of the common method of tempering. The centre of the bit is soft, while the corners are hard. When the bit is immersed in the water about an inch the large mass of metal in the centre cools more slowly than the corners since the corners have three sides exposed to the water. Perhaps the centre had not chilled at all when the bit is withdrawn for annealing, and the final result is a soft-centre bit, which will flatten and retard the work of drilling. Fig. 26 and Fig. 27 show the result of trying to temper the bit with the forging heat, by plunging the whole bit into the water as soon as it is sharpened. The line of tension induced by cooling is indicated. At this place the drill will break. Fig. 28 shows the checking caused by first chilling the steel back of the bit and then plunging with the forging heat.

" For the purpose of tempering a bit as shown in Fig. 24 a tank should be provided, such as shown in section in Fig. 29. This should be about 12 deep by 12 in. wide, and of sufficient length to accommodate whatever number of drills are to be sharpened in a day with the machine. The water inlet should be at the bottom, and the outlet should be placed about ¾ in. above a grate which itself should be about 8 in. above the bottom. This permits the bit to be immersed to a depth of about ¾ in. With a tempering tank of this construction the bit can be hardened to any desired degree. This depends on the temperature of the bit when placed on the grate. It is essential that the drill stand in a vertical position. To lean either way would cause it to harden to a greater depth on one side than on the other, causing a tension that might lead to breaking of the wings. It is best to provide a rail around the tank about the distance required to hold the shortest drill, and to drive pins about 3 in. apart in this rail. By placing the drills between these pegs thay can be kept in a vertical position. When using this tank a small flow sufficient to displace the water heated by the cooling of the bits should be turned on to keep the supply always cool."

An unsymmetrical bit, in which the blades do not all strike exactly alike is preferable to the symmetrical kind, especially in the hard rocks, resulting in less sticking. A test[1] in the Champion Mine, Michigan, with a 2⅞″ drill under 60 lbs. of air showed a cutting speed with the Fitch bit 2.35 as great as with the cross bit.

Theoretically, the fastest cutting can be done with a chisel bit, but in hard rocks under a powerful drill, the grinding effect upon this bit is so great as to wear it down before the run is finished, and therefore the four-bladed bits have been developed. Again, theoretically in the soft rocks with a comparatively light drill the bull bit should be admirably adapted, and this would be so were it not that it breaks off pieces that are so large, and buries itself so deep in the rock, as to result in an immense amount of sticking. In one case in point a great many thousand dollars were lost because an enterprising friend of the contractor appreciated the theoretical advantages of this bit, but did not realize why it stuck in the hole. In general, with a light machine and in the medium soft rocks and sand stones the bull bit should be tried first. For the hard rocks the blades should have as sharp an edge and as hard a temper as will stand, because in this arrangement the amount of cutting per blow will be the greatest; while in the softer rocks the edges should be blunted so that the drill will break the material up into small pieces

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[1] Rock Work, p. 26.

and cut less at each blow. In shale we have had very good results by giving two of the blades of the X-bit a flat face of $\frac{3}{32}$ of an inch leaving the other two blades slightly projecting and very sharp.

Nature of the Drill Steel. This should be special steel made for this purpose and not tool steel, and should contain from .8% to 1% of carbon. Any alloy that will increase the toughness of this type of steel should be worth its weight in gold. It is probable that the use of steel treated with ferro-titanium, which has been found to have an enormous toughening effect upon the wearing surfaces of rails, will in the near future offer a marked improvement in the drill steels.

Skill of the Blacksmith. The blacksmith is usually a privileged person and very few superintendents have the ability or the nerve to instruct him. He is always an interesting character, generally intelligent, rarely well instructed, and invariably obstinate. A good blacksmith has a right to a good helper, to a sufficiently large and convenient shop, good tools, and the very finest materials. To emphasize the importance of having a good blacksmith perhaps it is enough to say that if the efficiency of the best blacksmith in the United States could be increased 50% by quadrupling his pay it would be economy to do so on any drilling work.

The average blacksmith with a helper can sharpen by hand about 140 bits a day, which ordinarily will supply about six machines in hard rock. An Italian blacksmith with a helper of the same nationality one winter sharpened 441 bits in 25 days or about 18 per day, this being one bit per 9.3 ft. of hole, being all that was necessary to keep 14 drills going in soft shale.

With a bit sharpening machine one man can average 50 drills per hour and the bits are harder, denser, and better formed than the hand sharpened ones.

The proper tempering of the bits is absolutely essential. On one job that we inspected on which the contractor wanted to know why he was losing money we found that the blacksmith heated his drills up to the lowest kind of a low red before quenching. He might as well have tried to harden them with cigarette ash. A full description of the methods of tempering is given in Gillette's "Rock Work," page 26.

The Blacksmith's Coal. Coal containing much sulphur will result in some of the carbon being burned out of the drill steel, thus lowering the effective hardness, and sometimes even the steel itself may be burned. While a cheap grade of coal may sometimes be economical under boilers which are underloaded, it is never anything else than the most expensive luxury in the blacksmith shop.

The Direction of the Hole. Various experiments have been made upon the effect that the direction of the hole has on the cutting speed. Prof. Hofer obtained the following experimental results, the time being that for cutting one inch of hole in a conglomerate with a hammer drill.

85° down (nearly vertical)	152 seconds
65° "	188 "
52° "	241 "
27° "	282 "
2° "	257 "
9° "	323 "
24° up	345 "

These results are confirmed by Jarolimel. The use of a water jet in the hole would probably alter them greatly.

CHAPTER III

DRILLING ON LAND—*Continued*

Comparative Costs of Operation by Steam and Compressed Air. The two following tables have been prepared to show: 1. Typical cost of operation of a six-drill plant by steam from an ordinary contractor's 65 H.P. movable boiler direct, and total cost of operating one drill by steam; 2. Typical cost of operation of a 10–12-drill plant by compressed air, and total cost of operating one drill by air. Of these costs the wages of the drill crew average 40%. It will thus be seen that a trifling increase in the wages of the drill crew is of small moment compared with a similar loss in the working time. To pay the men 10% more wages, which makes them feel much better, is only 40% as costly as to allow them to kill 10% of their time, which does not make them feel correspondingly better.

TYPICAL COST OF OPERATION OF SIX-DRILL PLANT AND TOTAL COST OF OPERATING ONE DRILL FROM A STEAM BOILER DIRECT.

Boiler	at	$700.00, 6% depreciation	$0.28
Interest	at	6%	0.28
Repairs	at	2.00 per month	0.10
Installation	at	50.00 for 150 working days	0.333
2½ tons coal	at	3.50	8.750
Hauling coal team[1]	at	3.39 at 2½ tons per team day	3.39
Handling coal labor[1]	at	1.50	1.50
Fireman	at	2.00 per day	2.00
			$16.633
Drill	at	$300.00, 33% depreciation per yr.	0.667
Interest	at	6%	0.120
Repairs	at	0.50 per day	0.50
2 pints oil	at	0.30 gal	0.075
Driller	at	2.50 per day	2.50
Helper	at	1.75 ‘‘	1.75
⅔ mucker	at	1.50 ‘‘	1.00
⅙ pipe fitter	at	2.00 ‘‘	0.333
⅙ blacksmith	at	3.00 ‘‘	0.50
			$7.445

[1] Higher than average; depends on condition of roads and length of haul.

Boiler cost for one drill, 16.633 ÷ 6			2.772
Total cost of operating one drill			10.217
Total equipment per day	$1.453	% of total	14.3
Total supplies per day	1.535	" " "	14.9
Total labor per day	7.23	" " "	70.8
			100.0%

TYPICAL COST OF OPERATION OF 10-12-DRILL COMPRESSOR PLANT AND TOTAL COST OPERATING ONE DRILL WITH COMPRESSED AIR.

Compressor, Rand, Class C, 24×30	at	$4000.00, dep. 5%, $200	$ 1.33
Interest	at	6% $240	1.60
Repairs	at	$5.00 per month	0.25
3 gallons of oil	at	0.30	0.90
Engineer	at	3.00	3.00
Installation for 150 working days	at	100.00	0.666
Two boilers at $700, depreciation	at	6%	0.56
Interest	at	6%	0.56
Repairs	at	$4.00 per month	0.20
6 tons coal	at	3.50	21.00
Hauling coal, 2 teams	at	3.39	7.78
Handling coal, labor	at	1.50	3.00
Fireman	at	2.00	2.00
Installation at $100 for 150 work days (Boilers)			0.666
			$43.512

Drill	at	$300.00, dep. 33%	0.667
Interest	at	6%	0.12
Repairs	at	0.50 per day	0.50
2 pints oil	at	0.30 per gal	0.075
Driller	at	2.50	2.50
Helper	at	1.75	1.75
2/12 pipe fitter	at	2.00	0.333
⅔ mucker	at	1.50	1.00
2/12 blacksmith	at	3.00	0.50
			7.445
Compressor cost for one drill		$43.512 ÷ 12	3.626

Total cost for operating one drill by air			$11.071
Total equipment per day	$1.773	% of total	16.0
Total supplies per day	1.90	" " "	17.2
Total labor per day	7.398	" " "	66.8
	$11.071		100.0%

The Amount of Mucking Necessary. This will depend largely upon the lay of the ground and the time of the year. It is an absolute rule of economics, generally violated in practice, never to allow the drill-runner and helper to do the mucking. Where a number of drills were operating in a narrow cut through which water was running and freezing to a depth of from 8″ to 13″, where also the rock surface had been badly shattered by previous blasting, requiring an average of not less than 8″ of mucking for each drill hole, one mucker at a cost of about 11% of the total cost of the drill operation was enough for each drill; and the cost of mucking in general will vary from this to nothing in the case of rock which has been previously stripped of its earth covering.

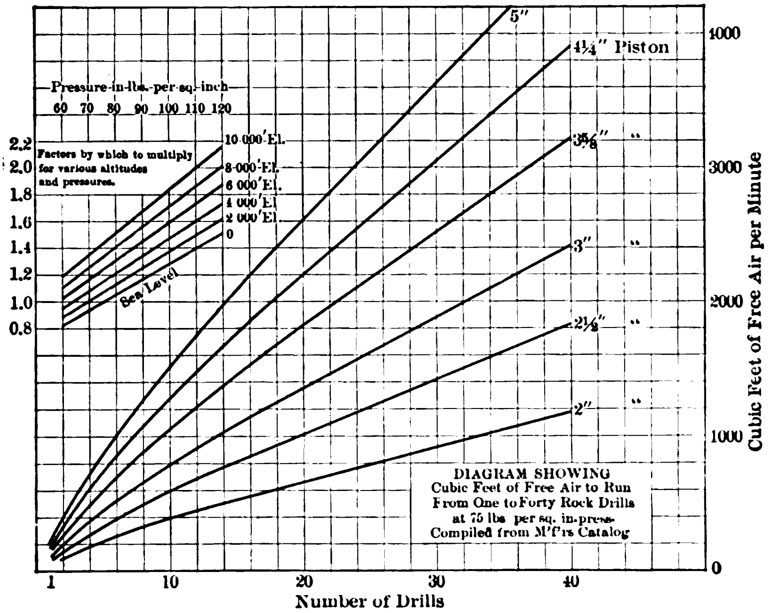

FIG. 30.

The Cost of Power. From the accompanying diagram (Fig. 30) the number of cubic feet of free air per minute to run from one to forty drills can be read directly. Assume that we are to operate six drills of 3¼″ size and the average make, at 60 lbs. pressure. From the larger part of the diagram interpolating between 3″ and 3⅝″ drills, the amount of free air required would be 625 cu.ft. per minute at 75 lbs. If the altitude and pressure were 2000 ft. and 60 lbs. respectively the small diagram gives the factor .9 which, multiplied by 625, gives 562.5 as the cubic feet of air per minute required for these drills.

By Table A, we have, under the worst conditions, the necessary H.P. for compression equal to 562.5×.1342=75.5 H.P., and under the best conditions 58.5 H.P. This amount must be actually effective in the compressor.

The efficiency of the air transmission line will average from 90% to 95%; and for compound engines one Brake H.P. for every 2.2 lbs. of coal burned per hour may be expected. Therefore, for the case under consideration, the coal consumption would be about 1700 lbs. per day for isothermal compression and 1300 lbs. per day for adiabatic compression.

To estimate the cost of coal, if a steam boiler is to be used directly, we must proceed as follows:

From Table B, at 60 lbs. pressure 1 lb. of steam equals about 5.7 cu.ft. of free steam or free air obtained by multiplying 28.9 and 0.1968 from the last column in Table A.

Therefore, if run from a boiler direct the amount of steam required would be 562.5÷28.9 or 19.4 lbs. per minute or 1167 lbs. per hour.

One boiler H.P. is the equivalent of 30 lbs. of steam per hour at 70 lbs. pressure, evaporated from water originally at 100° F. and is the equivalent of 33,305 B.T.U's. Since we need 1167 lbs. per hour, dividing this by 30, we get 38.9 as the theoretical boiler H.P. that we need. If the boiler efficiency is 60%, a fair average value for an exposed boiler of this size when fairly well cared for, the boiler rating should be 38.9÷.6 or 65 H.P. These figures check with our experience.

Now, as to the amount of coal used. From Kent's "Handbook" the heating value of 1 lb. of coal varies from 10,500 B.T.U. for Kansas bituminous, to 14,200 B.T.U. for the Cumberland semi-bituminous kind. Special coals often run above this, but the average that is likely to be obtained in ordinary construction work will not run much over 11000 or 12000. We need 1167 lbs. of steam per hour multiplied by 1176 B.T.U's. from "Table B." This divided by 12000, multiplied by 0.6 and 0.9 equals

TABLE A[1]

BRAKE (OR DELIVERED) HORSE-POWER REQUIRED TO COMPRESS ONE CUBIC FOOT OF FREE AIR PER MINUTE TO A GIVEN GAUGE PRESSURE. (HASWELL)

Gauge Pressure, Lbs. per sq.in.	B.H.P. required under the worst possible condition. (Without Cooling.)[2]	B.H.P. required under best possible condition. (With Constant Temperature.)[3]	Volume in Cubic Feet of Air after Compression at 60° F.
50	.1195	.0951	.2272
55	.1270	.0994	.2109
60	.1342	.1040	.1968
65	.1403	.1081	.1844
70	.1472	.1124	.1735
75	.1537	.1163	.1639
80	.1597	.1193	.1552
85	.1655	.1224	.1474
90	.1710	.1256	.1404
95	.1763	.1289	.1340
100	.1815	.1312	.1281

For the purpose of comparing compressed air with steam, Table B will be found useful.

TABLE B[1]

STEAM VOLUME AND TEMPERATURE AT GIVEN PRESSURES

Gauge Pressure, Lbs. per sq.in.	Temperature, Fahrenheit.	Lb. Degrees from Water at 32°.	Cu.ft. occupied by 1 Lb. of Steam.
50.3	297.8	1172.8	6.53
55.3	302.7	1174.3	6.09
60.3	307.4	1175.7	5.71
65.3	311.8	1177.0	5.37
70.3	316.0	1178.3	5.07
75.3	320.0	1179.6	4.81
80.3	323.9	1180.7	4.57
85.3	327.6	1181.8	4.36
90.3	331.1	1182.9	4.16
95.3	334.5	1184.0	3.98
100.3	337.8	1185.0	3.82

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[1] Gillette's Rock Excavation, p. 50. [2] Adiabatic. [3] Isothermal.

211 lbs. of coal per hour, being practically equivalent to one ton per day for 100 ft. of pipe lead. The factors .9 and .6 represent respectively the efficiency of the pipe line transmission and of the boiler.

LOSS OF ENERGY IN STEAM PIPES BY RADIATION IN DELIVERING 1,000 LBS. OF STEAM PER HOUR THROUGH A BARE WROUGHT IRON PIPE 100 FT. LONG, TERMINAL GAGE PRESSURE 75 LBS.[1]

Nominal Inside Diameter of Pipe in Inches.	Pounds of Steam Lost per Hour per 100 Linear Feet.		
	By Friction.	By Radiation.	Total.
1	177.7	22.9	200.6
1¼	58.2	29.0	87.2
1½	23.4	33.2	56.6
2	5.6	41.4	47.0
2½	1.8	50.1	51.9
3	0.7	61.1	61.8
3½	0.3	69.8	70.1
4	0.2	78.5	78.7

The formula for this work can be derived as follows:

From diagram, Fig. 30, N = number cubic feet free air per min. for the drills in question at 75 lbs. pressure and at sea level.

From small diagram, Fig. 30, n = coefficient for altitude and pressure.

C = B.T.U's. in one pound of coal, say 12,000.

From table, page 56, S = number cubic feet occupied by one pound of steam at the given pressure (Table B).

From table, page 56, v = volume of one cubic foot of free air after compression to the given pressure (Table A).

From table, page 56, W = number of B.T.U's. in one pound of steam from water at 32° F., say 1176.

E = percentage of boiler efficiency.

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[1] Rock Excavation, page 60.

From table, page 57, e = percentage of pipe line efficiency.

Then Nn = actual cubic feet of free air per minute to run the drills.

Nvn = number of cubic feet of compressed air per minute to run the drills.

$\frac{Nvn}{S}$ = number of pounds of compressed steam per minute to run the drills, not allowing for losses in transmission or boiler and

$\frac{60Nvn}{ESe}$ = number of pounds of steam per hour to run the drills, allowing for losses in boiler anp steam line.

$\frac{60NvnW}{ESeC}$ = number of pounds of coal actually consumed per hour to run the drills from a steam boiler.

Time Study and Costs of Drilling with Steam and Air. The following is the analysis of the operation of drilling with a machine.

Time to change bits and pump hole $= e$ min.
Time to drill one foot $= d$ min. per foot
Time to move drill and waste time $= l$ min.
Time to set up drill $= g$ min.
Length of feed in feet $= f$
Depth of hole in feet $= D$
Time to drill length of feed $= fd$
Number of bits per hole $= \frac{D}{f}$

Time to drill one hole $= (e+fd)\frac{D}{f} + (l+g)$ including moving and setting up drill.

Number of working minutes per day $= M$ (say, 600)

Number of holes per day $= \dfrac{M}{(e+fd)\frac{D}{f} + (l+g)}$

Feet drilled per day $= \dfrac{DM}{(e+fd)\frac{D}{f} + (l+g)}$

Cost per day $= C =$ on standard basis.

Cost per foot drilled $$= \frac{C(e+fd)\frac{D}{f} + (l+g)}{DM} = R,$$

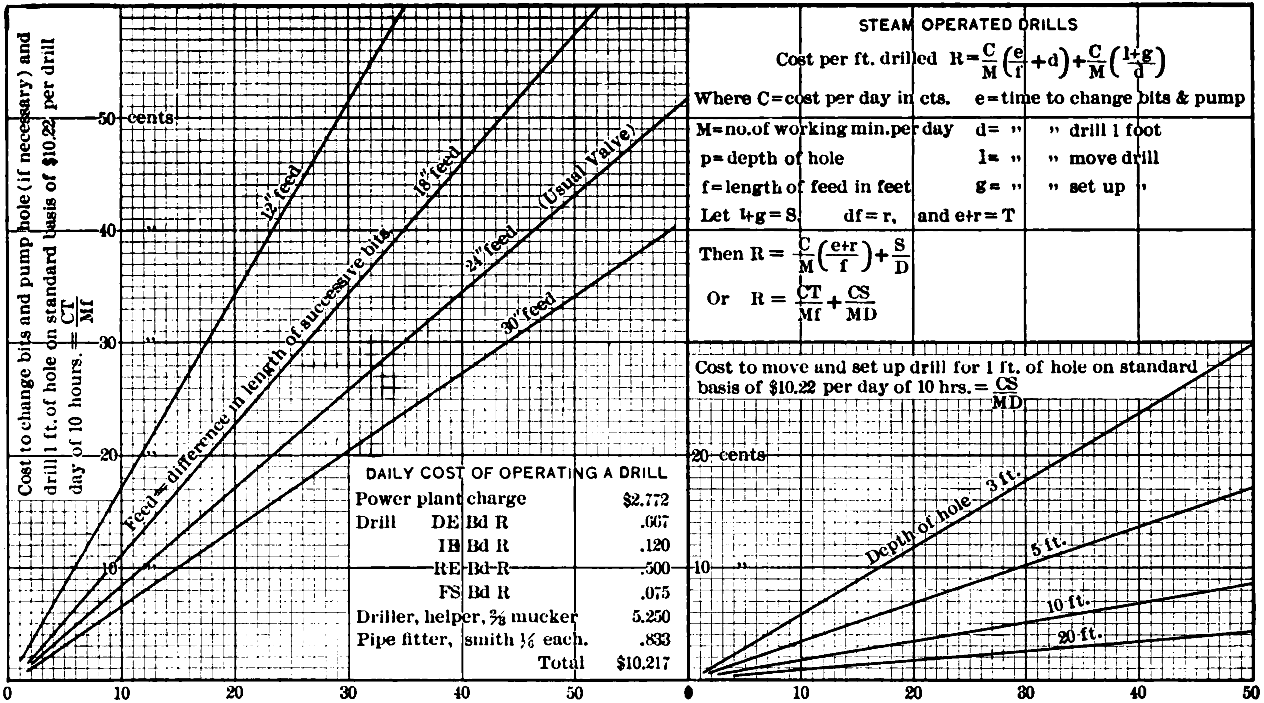
$$R = \frac{C}{M}\left[\frac{e}{f} + d + \frac{l+g}{D}\right].$$

If $l+g=S$, or the average time to move drill and set up;
$df=r$, or the time to drill the length of feed; and
$e+r=T$, or the time required on an average for changing bits, pumping hole, and drilling the length of feed, this formula reduces to the following:

$$R = \frac{CT}{Mf} + \frac{CS}{MD}.$$

These two expressions have been plotted for both steam and air operated drills, in the accompanying diagrams from which can be read directly the cost per foot of hole when these values are known, and the values can be obtained in a very short time in the field with an ordinary watch and note book, within a very small limit of error, so that by means of this diagram it is possible upon field inspection to tell about what the drilling is costing, and, by the application of the data of this volume, what it ought to cost.

It should be noted particularly that feed is the difference in length between the successive bits, which for ordinary work is 2′. It makes no difference in this formula whether the machine has a possible feed of 30″ or 12″, the value is effected by the successive lengths of the bits alone. Where it is difficult to get the following bit down into the hole a machine feed should be used several inches longer than the difference between the lengths of the bits, since this may effect the time of changing bits and pumping the hole.



STEAM OPERATED DRILLS

Cost per ft. drilled $R = \frac{C}{M}\left(\frac{e}{f} + d\right) + \frac{C}{M}\left(\frac{l+g}{d}\right)$

Where C = cost per day in cts. e = time to change bits & pump

M = no. of working min. per day d = " " drill 1 foot

p = depth of hole l = " " move drill

f = length of feed in feet g = " " set up "

Let $l+g = S$, $df = r$, and $e+r = T$

Then $R = \frac{C}{M}\left(\frac{e+r}{f}\right) + \frac{S}{D}$

Or $R = \frac{CT}{Mf} + \frac{CS}{MD}$

DAILY COST OF OPERATING A DRILL

Power plant charge			$2.772
Drill	DE	Bd R	.667
	IB	Bd R	.120
	RE	Bd R	.500
	FS	Bd R	.075
Driller, helper, ⅔ mucker			5.250
Pipe fitter, smith ⅙ each.			.833
		Total	$10.217

Average time in minutes to change bit and pump hole (if necessary) and drill length of feed.

Average time in minutes to move and set up drill for one hole.

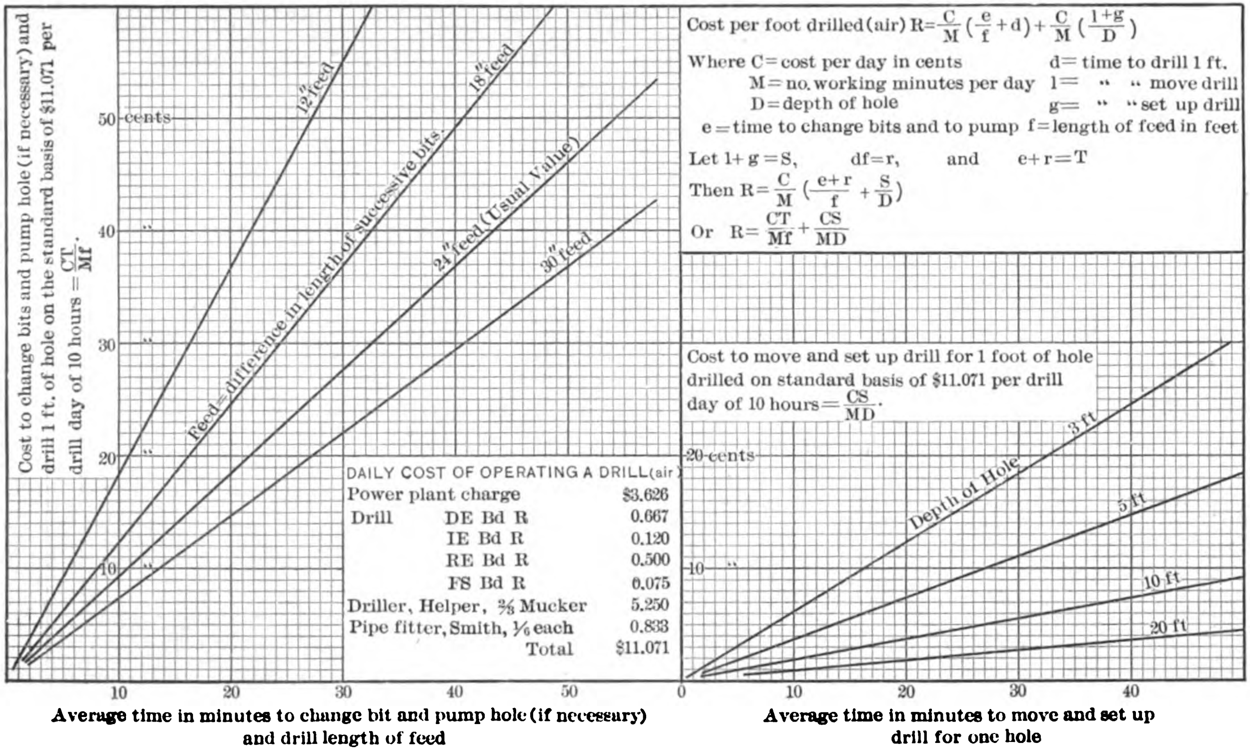
To obtain total cost (not including superintendence and overhead charges) add the values from these diagrams.

Where wages, length of day, etc. differ from the above assumptions multiply the final total cost by $0.585 \frac{C'}{M'}$

where C′ = new cost per drill day.

M′ = new number of working minutes per shift.

COST OF DRILLING ROCK STEAM BOILER DIRECT



Cost per foot drilled (air) $R = \frac{C}{M}\left(\frac{e}{f} + d\right) + \frac{C}{M}\left(\frac{l+g}{D}\right)$

Where C = cost per day in cents d = time to drill 1 ft.
M = no. working minutes per day l = " " move drill
D = depth of hole g = " " set up drill
e = time to change bits and to pump f = length of feed in feet

Let $l + g = S$, $df = r$, and $e + r = T$

Then $R = \frac{C}{M}\left(\frac{e+r}{f} + \frac{S}{D}\right)$

Or $R = \frac{CT}{Mf} + \frac{CS}{MD}$

Cost to move and set up drill for 1 foot of hole drilled on standard basis of $11.071 per drill day of 10 hours $= \frac{CS}{MD}$.

DAILY COST OF OPERATING A DRILL (air)

Power plant charge		$3.626
Drill	DE Bd R	0.667
	IE Bd R	0.120
	RE Bd R	0.500
	FS Bd R	0.075
Driller, Helper, ⅔ Mucker		5.250
Pipe fitter, Smith, ⅙ each		0.833
	Total	$11.071

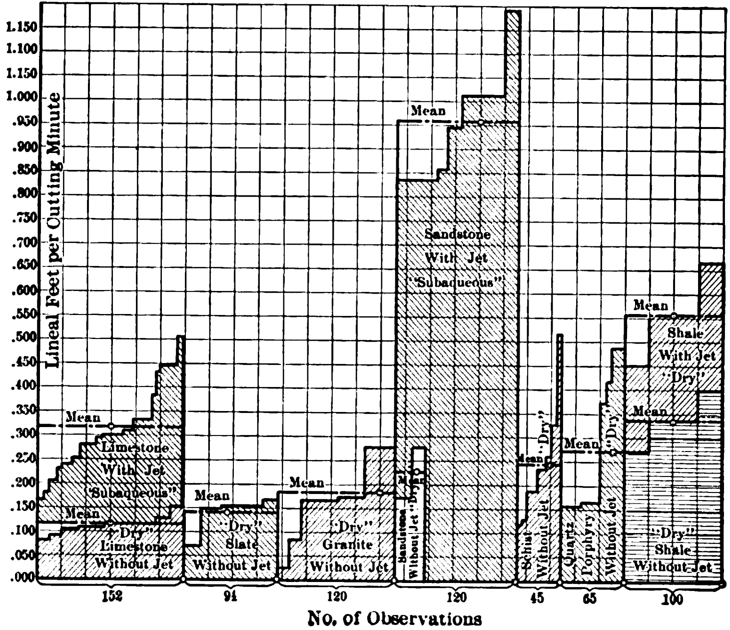
To obtain total cost (not including superintendence and overhead charges) add the values from these diagrams.

Where wages, length of day, etc. differ from the above assumptions multiply the final total cost by $0.542 \frac{C'}{M'}$ Where

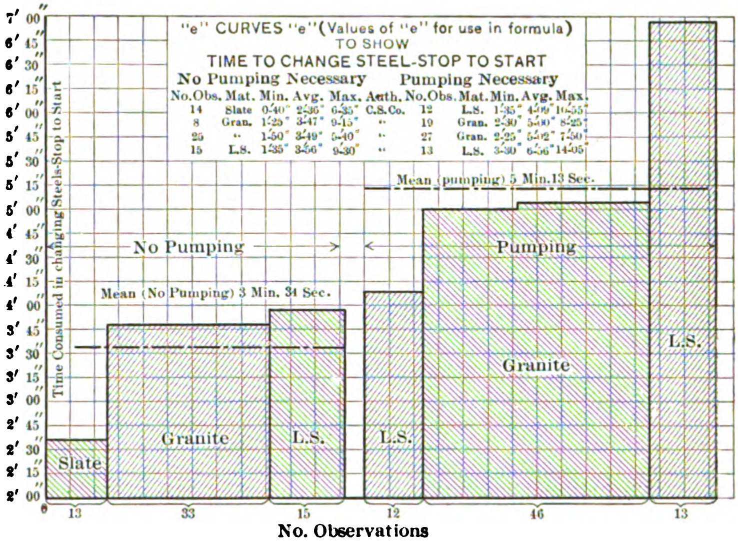
C′ = new cost per drill day
M′ = new number of working minutes per shift

COST OF DRILLING ROCK USING COMPRESSED AIR.

DIAGRAMS OF CUTTING SPEED IN VARIOUS MATERIALS WITH AND WITHOUT JET



Material.	Jet.	No. Obs.	Avg. Ft. Min.	Authority.
Limestone.....	Without jet....	152	0.117	Cons. Service Co.
Limestone.....	With jet.......	147	0.311	Cons. Service Co., H. P. Gillette
Slate..........	Without jet....	94	0.144	Cons. Service Co., Miscellaneous (10)
Granite........	Without jet....	120	0.181	Cons. Service (110)
Sandstone......	Without jet....	30	0.229	H. P. Gillette
Sandstone......	With jet.......	125	0.956	Cons. Service Co.
Schist, quartz. .	Without jet....	45	0.242	Miscellaneous
Porphyry......	Without jet....	65	0.273	Miscellaneous
Shale..........	Without jet....	100	0.335	Cons. Service Co.
Shale..........	With jet.......	100	0.556	Cons. Service Co.
Soapstone......	Without jet....	...	0.104	H. P. Gillette
Trap..........	Without jet....	...	0.146	H. P. Gillette

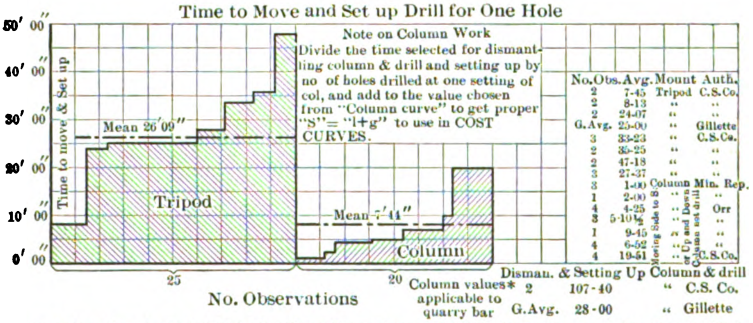


"e" CURVES "e" (Values of "e" for use in formula)
TO SHOW
TIME TO CHANGE STEEL-STOP TO START

No Pumping Necessary						Pumping Necessary				
No. Obs.	Mat.	Min.	Avg.	Max.	Auth.	No. Obs.	Mat.	Min.	Avg.	Max.
14	Slate	0′40″	2′36″	6′35″	C.S.Co.	12	L.S.	1′35″	4′09″	10′55″
8	Gran.	1′25″	3′47″	9′15″	"	19	Gran.	2′30″	5′00″	8′25″
25	"	1′50″	3′49″	5′40″	"	27	Gran.	2′25″	5′02″	7′50″
15	L.S.	1′35″	3′56″	9′30″	"	13	L.S.	3′30″	6′56″	14′05″

Values of 1+g = "S"

Time to Move and Set up Drill for One Hole



Note on Column Work
Divide the time selected for dismantling column & drill and setting up by no of holes drilled at one setting of col, and add to the value chosen from "Column curve" to get proper "S" = "1+g" to use in COST CURVES.

No. Obs.	Avg.	Mount	Auth.
2	7-45	Tripod	C.S.Co.
2	8-13	"	"
2	24-07	"	"
G. Avg.	25-00	"	Gillette
3	33-23	"	C.S.Co.
2	35-25	"	"
2	47-18	"	"
3	27-37	"	"
3	1-00	Column	Min. Rep.
1	2-00	"	"
4	4-25	"	Orr
3	5-10½	"	"
1	9-45	"	"
4	6-52	"	"
4	19-51	"	C.S.Co.

Moving Side to Side or Up and Down Column not drill

Disman. & Setting Up Column & drill

Column values* applicable to quarry bar	No. Obs.	Avg.	Mount	Auth.
	2	107-40	"	C.S. Co.
	G. Avg.	28-00	"	Gillette

*Unusualy long time due to fact that after dismantling column and drill had to be taken out of heading for blast.

Directions for Using Cost Curves

1. Estimating the Cost of Drilling on Proposed Work. Let us say that we wish to make an estimate of the cost of drilling under certain special conditions. Drills to be tripod mounted and operated by steam. The rock is solid limestone, holes to be 10 ft. deep and pumped after each length of feed is drilled. Feed 24″. Proceed thus:

On the diagram of cutting speeds (p. 62) we see that an average performance for limestone is 0.117 ft. = 1.4″ per cutting minute. Time to cut 24″ is then 17 minutes. On the diagram marked "*e*" Curves, we note that a fair time for pumping and changing steels is 5 minutes. The men to be employed being well trained we will allow 4 minutes for these operations. On the bottom of the same page in the "$l+g=S$" Curves, we note that 26 minutes is a fair time to move from one hole to another and set up and get started (for tripod drills). But with experienced men and solid material we expect to do this in say 12 minutes. The average time then to pump, change bits and drill the length of the 24″ feed will be 4 minutes, plus 17 minutes, or 21 minutes, and on the diagram for steam-operated drills the 21-minute line intersects the 24″ feed line opposite 18 cts. At the right of the diagram the 12-minute line for moving and setting up drill intersects the 10-foot line for depth of hole opposite the line representing 2 cts. This, added to 18 cts.. will give 20 cts. as the cost of the drilling on the standard basis, including plant, depreciation and repairs, but not including superintendence and overhead charges, the total charge assumed being $10.22 per drill day of ten hours. Where the working time of a shift, or the drill charges per day are essentially different from these assumptions the number 20 should be multiplied by the expression $0.585 \frac{C'}{M'}$ where C' is the actual cost per drill day and M' is the number of working minutes per shift. The figures can of course be obtained without the diagram, but it is useful in saving a good deal of time in computation.

2. Checking up the Cost of Drilling on a Job under Way.

Material..........................	Granite fairly solid. Pump used.
Drills..............................	Air—Tripod mount.
Feed...............................	24 inches
Holes..............................	10 feet

With ordinary watch take the following observations.

Obs. (1). Drilling 24″ of hole (start to stop), 16 minutes.

Obs. (2). Changing steels and pumping (start to stop), 7 minutes.

Obs. (3). Moving drill over to new hole, setting up and getting started, 35 minutes. Add (1) and (2) = 16 min. + 7 min. = 23 mins., and with 23 as abscissa, read opposite the 24″ feed line on the right side of page on "Cost Curves for Air-operated Drills," 21.3 cts. as the cost of drilling, pumping and changing steels for one foot of hole.

With Obs. (3) or 35 minutes as abscissa, read opposite the 10-foot hole line (on left of same sheet) 6.4 cts. as the cost of moving drill over, setting up and getting started for one foot of hole. Then 21.3 cts. + 6.4 cts. = 27.7, as the total cost of drilling per lineal foot (superintendence and overhead charges not included) on the standard basis of $11.07 per drill day of 10 hours.

Now to find what a fair average cost for this same work ought to be, proceed thus:

On the diagram of "Cutting Speeds" read the mean cutting speed for granite as 0.181′ per cutting minute or $12 \times .181 = 2.172''$ per minute. Use 2″ per minute. Then time to drill length of feed 24″ would be 12 minutes. On the diagram entitled "*e* Curves" we see that the average time for pumping and changing steels is 5 minutes 13 seconds, say 5 minutes. Using this value and adding to it the 12 minutes we get 17 minutes as a fair average time for cutting 24″, pumping and changing steels. On the "$(l+g)=S$ Curves" (p.63), we see that for tripod drills the average time for moving from one hole to another, setting up and getting started, is 26 minutes 9 seconds, say 26 minutes. We now have the two quantities to use in the "Cost Curves for Air-operated Drills," namely, 17 and 26.

With 17 as abscissa, read opposite the 24-inch feed line on right of "Cost Curve" sheet, 15.7 cts. as the cost of drilling, pumping and changing steel for one foot of hole. With 26 as abscissa on the left of same sheet, read opposite the 10-foot hole line 4.7 cts. as the cost of moving drill over, setting up and getting started per foot of hole. Then 15.7 cts. + 4.7 cts. = 20.4 cts. as the total cost of drilling one foot (superintendence and overhead changes not included) on the standard basis of $11.07 per drill day of 10 hours.

The actual cost was 27.7 cts. per foot, a difference of 7.3 cts. per foot drilled. If a plant of 12 drills did 32′ per day the excess cost above the average would be 12×32×7.3 cts. = $28.03 per day—a matter that might well be looked into.

"Experience Tables of Cost of Drilling and Blasting and Amount of Explosive," compiled from various sources, are given on pages 67–74.

Standard Rates on Dry Drilling. On the various pieces of work described in this volume there has been some difference in the rates of wages, so that the actual costs obtaining on the work are not a true index of the efficiency of the various field methods. To eliminate this discrepancy, and for the further reason that many contractors do not like to have the public informed of just what wages they are paying their men, the wage items have been reduced to a standard basis. Where the data here given are to be used for estimates, it is necessary only to substitute in the cost tables the new rates.

TABLE OF STANDARD RATES OF WAGES FOR DRILLING

	Rate per Hour.	Rate per Day.
Runner or driller....	25 cts. per hour	$2.50 per day
Runner helper.......	17½ "	1.75 "
Blacksmith..........	30 "	3.00 "
Blacksmith helper...	17½ "	1.75 "
Engineer............	30 "	3.00 "
Fireman.............	20 "	2.00 "
Pipe fitter.........	20 "	2.00 "
Powderman...........	20 "	2.00 "
Labor...............	15 "	1.50 "
Coal................	....	3.50 per ton
Oil.................	....	0.30 per gallon
Dynamite............	....	0.12 per pound

EXPERIENCE TABLE OF COST OF DRILLING

For the cost column all figures are given on the following standard basis. Drilling alone, not including mucking, superintendence, and overhead charges, etc.

Drill Runner: Dry work, 25 cts. per hour. Subaqueous, 27½ cts. per hour.
Helper: Dry work, $1.75 per day. Subaqueous, 22 cts. per hour.

1 Actual Drilling Labor per Foot of Hole, Cents.	2 Kind of Work.	3 Kind of Rock.	4 Kind of Drill.	5 Depth, Hole.	6 Starting Bit.	7 No. of Men to Drill.	8 Special Conditions.	9 Authority.
0.743	Anchor bolt holes	Green concrete	Steam	6′	1½″	....	Drill hung on a pile-driver allowing 1 long bit to be used Water jet used	G. & H.
1.62	Subaqueous	Sandstone	Steam	7′	4¾″	2	G. L. No. 5 at West Neebish Chan. See p. 159	Dana
2.00	Plug holes in quarry	Granite	Pneumatic plug drill	3″	....	1	250 holes in a good day's work	Gillette
3.53	Subaqueous	Limestone	Steam	10.5′	4½″ & 4″	2	"Exploder," see C. S. Co. report on same, p. 199	Dana
4.42	Subaqueous	Sandstone	Steam	6′	4½″	2	Edwards Bros. See C. S. Co. report on same, p. 171	Dana
4.50	Subaqueous	Limestone	Steam	11.0′	4″	2	Dynamiter. See C. S. Co. report on same, p. 206	Dana
4.86	Subaqueous	Limestone	Steam	8′	3½″	See rep. on Buf. No. 5	Buffalo Drill Boat, No. 5. See report on same, p. 244	Dana
5.1	Open cut work	Medium soft shale	Steam	11′	3¼×bit	2	It was difficult to set up drills on account of much débris, results for two weeks in March 1908. Freezing weather	Dana

EXPERIENCE TABLE OF COST OF DRILLING—*Continued*

1 Actual Drilling Labor per Foot of Hole, Cents.	2 Kind of Work.	3 Kind of Rock.	4 Kind of Drill.	5 Depth, Hole.	6 Starting Bit.	7 No. of Men to Drill.	8 Special Conditions.	9 Authority.
5.30	Subaqueous	Limestone	Steam	14.2	3½"	2	Earthquake. See C. S. Co. report on same, p. 220	Dana
5.58	Subaqueous	Limestone	Steam	12.1	3½"	2	Hurricane. See C. S. Co. report on same, p. 231	Dana
6.25	Crushed stone (quarry)	Bastard granite	Air	24' max.	2½"	2	Duluth Crushed Stone Co. See report on same, p. 132	Dana
6.45	Open cut work	Soft shale	Steam	11'	3¼×bit	2	With water jets on drills. Moderately cold, average 20° F. latter part of January	Dana
6.53	Subaqueous	Limestone	Steam	7.16' & 8.17'	....	2	No. 4, Buffalo boat. See report C. S. Co. on same, p. 260	Dana
6.96	Subaqueous	Limestone	Steam	12.5'	4½" & 4"	2	Destroyer. See C. S. Co. report on same, p. 187	Dana
6.98	Subaqueous	Limestone	Steam	5.4'	4½"	2	Buffalo No. 1, See report C. S. Co. on same, p. 269	Dana
7.1	Open cut work	Medium shale	Steam	11'	3¼×bit	2	Efficient organization sup. extremely cold varying from 20° to 10°. Much water and ice.	Dana
7.1	Subaqueous	Coral foundation	Steam	10'	....	1 runner ½ helper	See report on Cienfugos Harbor, Cuba, p. 291	Gilbert
7.14	Subaqueous	Limestone	Steam	10.1'	....	2	Buffalo No. 2. See C. S. Co. report on same, p. 266	Dana

EXPERIENCE TABLE OF COST OF DRILLING—*Continued*

1 Actual Drilling Labor per Foot of Hole. Cents.	2 Kind of Work.	3 Kind of Rock.	4 Kind of Drill.	5 Depth. Hole.	6 Starting Bit.	7 No. of Men to Drill.	8 Special Conditions.	9 Authority.
8.5	Cofferdam "dry	Limestone	Air	4.4–12.7′	3⅞″	2	Cofferdam work, see report, p. 75	Dana
8.9	Subaqueous	Soft shale	Steam	6′ 2″	2½″	....	Under 21′ of water in Detroit River	H. Hodgman
9.7	Open cut	Medium shale	Steam	11″	3¼″×	2	Extremely cold, varying from 20° to 10°; much water and ice. Efficient organization and superintendence	Dana
10.6	Open cut	Soft shale	Steam	11″	3¼″×	2	Poor supervision; drills in poor shape. Good weather last 10 days of Dec., 1907	Dana
10.9	Subaqueous	Limestone	Steam	8′2″	2¼″×	2	Under 18′ of water	H. Hodgman
11.05	Open cut	Dolomite (L.S.)	Steam	20′	3½″	2	J. A. Hart; see report p. 115	Dana
12.5	Tunnel heading	Bastard granite	Air	8′	2¾″	2	N. Y. Water Supply Aqued.; see p. 143	Dana
13.3	Tunnel heading	Bastard granite	Air	6′–10′	3″	2	D. M. Flickwir, see report, p. 100	Dana
13.5	Open cut	Bastard slate	Air	12′	3½″	2	R. C. & Hill, see report p. 107	Dana
9.3 to 17.63	Subaqueous	Limestone and flint; bedrock	Steam	3½′ to 10¾′	....	2	See report on improving Black Rock Harbor, p. 278	Gilbert

EXPERIENCE TABLE OF COST OF DRILLING—*Continued*

1 Actual Drilling Labor per Foot of Hole. Cents.	2 Kind of Work.	3 Kind of Rock.	4 Kind of Drill.	5 Depth, Hole.	6 Starting Bit.	7 No. of Men to Drill.	8 Special Conditions.	9 Authority.
14.4	Crushed stone (quarry)	Hard limestone	Air	12′–26′	$4\frac{1}{8}$″–$5\frac{5}{16}$″	2	Brownell Impr. Co., see report p. 125	Dana
15.0	Subaqueous	Limestone	Steam	5.1″	$2\frac{1}{2}$	....	Under 21′ of water	Hodgman
16.6	Tunnel	Tough sandstones	....	$1\frac{1}{2}$′	$\frac{7}{8}$″	1	....	Gillette
16.72	Subaqueous	Hard limestone	Steam	1.5–22′	....	2	See report on Hay Lake and Neebish Channel, p. 282	Gilbert
17.1	Quarry	Hard seamy trap	.... Steam drill	14	$3\frac{1}{4}$	2	....	Gillette
18.4	Subaqueous	Hard limestone	Steam	Av. $6\frac{1}{2}$	....	2	See report on Ship Channel of the St. Lawrence, p. 285	Gilbert
24.2	Subaqueous	Gneiss, quartz, mica schist	Steam	7′	....	2	See report on Improvements at Oak Point, p. 293	Gilbert
24.7	Subaqueous	Slate and flint	Steam	5′	....	2	See report on Improving Kennebec River, p. 297	Gilbert

EXPERIENCE TABLE OF COST OF BLASTING AND AMOUNT OF EXPLOSIVE

Cost column includes only the labor of blasting figured on the following basis. No superintendence, overhead, or preparatory charges allowed.

Powderman: Subaqueous, 30 cts. per hour. Dry work, $2.00 per day.
Helper: Subaqueous, 22 cts. per hour. Dry work, $1.50 per day.

Blasting Labor per			Amount of Nitro-glycerin per						Holes.			
Cu.yd. Loos-ened. 1 Cents.	Cu.yd. Pay. 2 Cents.	Lin.ft. Drilled 3 Cents.	Cu.yd. Loosened 4 Lbs.	Cu.yd. Pay. 5 Lbs.	Lin.ft. Drilled 6 Lbs.	Kind of Powder. 7	Kind of Work and Holes Fired at Once. 8	Kind of Rock. 9	Spacing. 10 Feet.	Depth. 11 Feet.	Remarks. 12	Authority. 13
0.73	1.34	1.02	0.322	0.563	0.429	60% Forcite	River channel. 1 hole	Sandstone	6×6	7	For particulars see p. 159	Dana
0.95	......	3.52	0.666	......	2.47	60% Dupont	Open cut	Bastard slate	10×10	12	See R. C. & Hill report p. 107	Dana
1.01	......	2.4	0.633	......	1.5	60% Dupont	Open cut	Dolomite (L.S.)	7×7	20	See report on J. A. Hart, p. 115	Dana
1.19	1.37	2.26	0.422	0.484	0.774	60 & 40% Pluto	40–50 holes. Cofferdam "dry"	Limestone	Various	12.7–4.4	See "Cofferdam," report, p. 75	Dana
1.3*	......	......	Supplies 2 cts. per cu.yd.	......	......	Dynam.	....	Blue sandstone boulder	....	....	7–10 cu.yd.	Hauer
1.54	2.34	1.29	1.266	1.920	1.056	60% Potts	River channel, 650 holes	Limestone	5×4½	8	For particulars see Buffalo No. 5, report, p. 244	Dana
1.55†	1.94	1.73	0.65	0.81	0.72	60%	Harbor work. Coral formation	Coral in Cienfugos harbor, Cuba	5×6	10	For particulars see Cienfugos Harbor report, p. 291	Gilbert
1.52	2.53	2.32	0.197	0.327	0.30	60% Pluto	River channel. 1 hole	Sandstone	6×6	6	For particulars see Edwards Bros., report, p. 171	Dana

* Labor at $1.50 per day for 10 hours.

† See report indicated for scale of wages.

EXPERIENCE TABLE OF COST OF BLASTING AND AMOUNT OF EXPLOSIVE—*Continued*

Blasting Labor per			Amount of Nitroglycerin per						Holes.			
Cu.yd. Loosened.	Cu.yd. Pay.	Lin. ft. Drilled	Cu.yd. Loosened	Cu.yd. Pay.	Lin. ft. Drilled	Kind of Powder.	Kind of Work and Holes Fired at Once.	Kind Rock.	Spacing.	Depth.	Remarks.	Authority.
1 Cents.	2 Cents	3 Cents.	4 Lbs.	5 Lbs.	6 Lbs.	7	8	9	10 Feet.	11 Feet.	12	13
......	......	1.47	....	......	0.123	60 & 75% Dynam.	Duluth crushed stone	Bastard granite	various	24 max.	See Duluth Crushed Stone report, p. 132	Dana
1.89	2.92	1.58	1.176	1.81	0.984	60% Potts.	River channel	Limestone	5×4½	7.16–8.17	See particulars report, p. 260	Dana
1.87	2.56	1.73	2.12	2.91	1.96	60% Pluto	River channel, 360 holes	Limestone	5×5	10.5	For particulars see Exploder, rep., p. 199	Dana
2.09	2.78	1.92	0.906	1.23	0.84	60% Pluto	River channel, 249 holes	Limestone	5×5	14.2	For particulars see Earthquake, report, p. p. 220	Dana
2.18	......	4.66	0.815	......	1.73	60% Forcite	Crushed stone quarry, 60–75 holes	Limestone	See rep.	10–26	For particulars see Brownell Imp. Co., report, p. 125	Dana
2.21	2.94	2.04	0.978	1.296	0.906	60% Pluto	River channel, 228 holes	Limestone	5×5	7.2	For particulars see Hurricane, report, p. 231	Dana
2.38	3.26	2.19	2.12	2.92	1.96	60% Pluto	River channel, 276 holes	Limestone	5×5	10.9	For particulars see Dynamiter, C. S. Co. report, p. 206	Dana
2.74	3.43	2.54	0.99	1.24	0.92	60% Pluto	River channel, 396 holes	Limestone	5×5	12.5	For particulars see Destroyer, report, p. 187	Dana
2.88*	......	......	....	......	......	40%	Cut 30'×9'. 15–40 holes	Soft shale	6½×7	12.14	Canal excavation mucked and cleaned by ¾" steam jet	Dana
3.41†	6.82	3.8	0.64	1.29	0.72	Atlas 60% Dynam.	River channel	Hard Limestone.	5×6	1.5–22	For particulars see Hay Lake report, p. 282	Gilbert

* Labor at $1.50 per day for 10 hours.

† See report indicated for scale of wages.

EXPERIENCE TABLE OF COST OF BLASTING AND AMOUNT OF EXPLOSIVE—*Continued*

Blasting Labor per			Amount of Nitroglycerin per						Holes.			
Cu.yd. Loosened. 1 Cents.	Cu.yd. Pay. 2 Cents.	Lin.ft. Drilled 3 Cents.	Cu.yd. Loosened 4 Lbs.	Cu.yd. Pay. 5 Lbs.	Lin.ft. Drilled 6 Lbs.	Kind of Powder 7	Kind of Work and Holes Fired at Once. 8	Kind Rock. 9	Spacing. 10 Feet.	Depth. 11 Feet.	Remarks. 12	Authority. 13
3.1	4.22	2.6	1.44	1.94	1.2	60% Potts.	River channel	Limestone	....	10.1	For particulars see Buff. No. 2, report, p. 266	Dana
3.6	......	......	Supplies 4 cts. per cu.yd.	......	......	Dynam.	....	Blue Sand Stone boulders	....	....	2½ cu.yds. Avg. size	Hauer
3.66*	......	......	....	......	......	40% Atlas	Cut 30'×9' deep, 15–40 holes	Plane of lamination 50° with hor. Soft shale	6½×7	12–14	Canal excavation mucked and cleaned by steam jet	Dana
4.4*	......	......	....	......	......	40% Atlas	Cut 30'×9' deep 15–40 holes	Soft shale	6½×7	12–14	Canal excavation mucked and cleaned by steam jet	Dana
......	......	......	2.06†	3.6	1.22	60%	Drilling in East River, N. Y.	Gneiss, quartz, and mica schist	4×4	7	For part. see "Impr. at Oak Point," p. 293	Gilbert
5.8	7.72	3.4	2.62	3.52	1.55	60% Potts	River channel 492 holes	Limestone	4×4	5.4	For particulars see Buff. No. 1, report, p. 269	Dana
5.86*	avg.	......	Supplies av. 14 cts.	......	......	Dynam.	....	Blue Sand Stone boulders		....	Average of 5 observation, 1.5 cu.yds.	Hauer
6.0	......	......	Supplies 14 cts.	......	......	Black powder	Undermining and shooting in railroad cut	Sandstone boulders	....	....	50 yds.	Hauer
......	......	......	1.5	3.00	0.346	75% Dynam.	River channel	Graywacke Hard Sil. Sand Stone	....	5.25	Rock not homogeneous, in layers about 24" in depth, see p. 182, Oswego Harbor Rep.	Gilbert

* Labor at $1.50 per day for 10 hours.

† See report indicated for scale of wages.

EXPERIENCE TABLE OF COST OF BLASTING AND AMOUNT OF EXPLOSIVE—*Continued*

Blasting Labor per			Amount of Nitroglycerin per						Holes.			
Cu.yd. Loosened. 1 Cents.	Cu.yd. Pay. 2 Cents.	Lin.ft. Drilled 3 Cents.	Cu.yd. Loosened 4 Lbs.	Cu.yd. Pay. 5 Lbs.	Lin.ft. Drilled 6 Lbs.	Kind of Powder. 7	Kind of Work and Holes Fired at Once. 8	Kind Rock. 9	Spacing. 10 Feet.	Depth. 11 Feet.	Remarks. 12	Authority. 13
......	......	......	1.83	......	1.41	60%	Rocketts reef	Shoals in James River	5½×6	avg. 4½	For particulars see Improving James River, p. 290	Gilbert
......	......	......	1.92	......	1.50	....	Goode Rocks	....	......	....	....	....
......	......	......	1.91	......	1.48	....	Richmond Bar	....	......	....	....	....
......	......	......	3.24	12.96	2.4	60%	Improving Lovejoy Narrows	Slate and flint	5×4	5	For particulars see Lovejoy Narrows, p. 297	Gilbert
......	......	......	Seamy 0.275	......	......	50%	Sandstone trench	Seamy S.S.	3	Seamy, 4–6	Gillette's "Cost Data," p. 127	Harrison Const. Co.
......	......	......	Hard 0.55	......	......	....	....	Solid S.S.	......	Hard 8–10	....	G.-H.
7.6*	......	......	Supplies cost 19.2 cents	......	......	Dynam.	Blasting from street car tracks	Concrete	......	8″	6558 cu.yds.	
9.9*	......	......	Supplies 10.8 cts. avg.	......	......	Dynam.	....	Blue Sand Stone boulders	......	....	Average of 6 obs. 1.6. cu. yds.	Hauer
10.5*	......	......	Supplies 9.45 cts.	......	......	Dynam.	....	Red Sand Stone boulders	......	....	Four obs., average 16.6 cu.yds.	Hauer
14.75	......	1.91	1.97	......	0.255	40 & 60%	Tunnel heading	Bastard granite, see rep.	See diagram	8′	For particulars see report on "Aqueduct," p. 143	Dana
16.0*	......	......	Supplies 4 cts. yd.	......	......	Dynam.	....	Blue Sand Stone boulders	......	....	2–13 cu.yds.	Gillette
20.0* avg.	......	......	Supplies avg. 21.7 cts.	......	......	Dynam.	....	Blue Sand Stone boulders	......	....	Average 7 obs., 1 cu.yd.	Hauer

* Labor at $1.50 per day for 10 hours.

† See report indicated for scale of wages.

CHAPTER IV

DRILLING ON LAND—*(Continued)*

Livingstone Improvement of the Detroit River, Cofferdam Work. The so-called Livingstone Improvement of the Detroit River is located near Amherstburg, Ontario, and is for the purpose of making a new channel 300′ wide and 23′ deep at mean water level, for down bound vessels. The whole job was divided up into four sections and was contracted for by the following firms:

Sec. No. 1, Great Lakes Dock and Dredging Co.
Sec. No. 2, Grant, Smith & Co., and Locher.
Sec. No. 3, O. E. Dunbar and T. B. McNaughton.
Sec. No. 4, G. H. Breymann and Bros.

4000′ of Sec. No. 2 comprise the so-called "dry work." The southern 1500′ of Sec. No. 1 are also dry work. Part of this cofferdam work adjoins Stony Island, and where such is the case no cofferdam need be built. The northern dam of the 4000′ before mentioned, instead of being built at right angles to the river, was made to follow the old line of the Michigan Central R. R. piers, which were on a curve. Due to this fact 300′ were left unenclosed at the eastern end of this dam which later was taken care of when the southern 1500′ of Sec. No. 1 were enclosed. The work of damming in the 4000′ began April 4, 1908, and as it progressed it was seen that all could not be enclosed before winter set in. For this reason an auxilliary dam was thrown across, 1200′ up stream from the end of the 4000′ section, so that the work of excavation could be carried on during the winter.

There were 112 acres of land in this final enclosure having an average depth of water of about 12′. It took 12 days to pump this dry. The apparatus used in removing this water was as

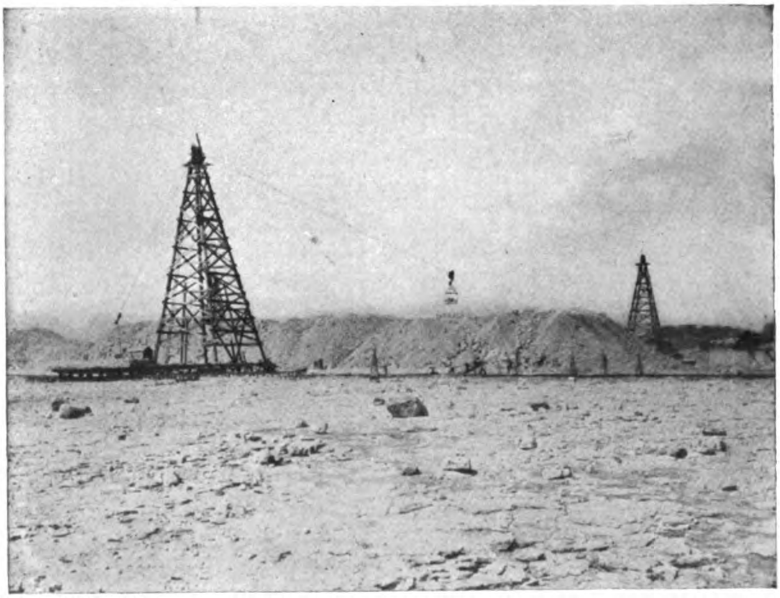


FIG. 31.—Livingstone Improvement.

FIG. 32.—Dry Work—Detroit River Cofferdam.

follows: 2 12-inch Morris centrifugal pumps, 49 8-inch water lift pipes. These pipes are also known as "Serpents." They are 8-inch cast iron pipes braced in an inclined position, their lower ends being about 2″ from the bottom and the upper ends emptying into the river. They are operated by a small air pipe that runs down along the side of the larger pipe, curls up around the bottom and into it. From 15 to 20 lbs. air pressure were used on these small air pipes. Their total lift was about 12′ and their capacity 40,000,000 gallons in 24 hours. The two 12-inch pumps were good for 10,000,000 gallons per day, making a total of 50,000,000 gallons in 24 hours.

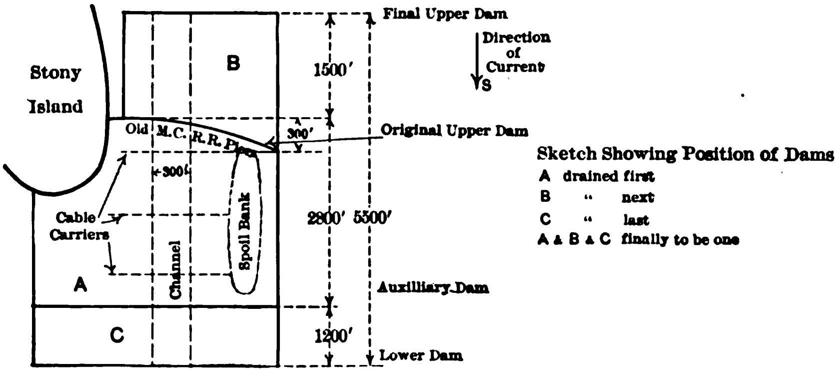


FIG. 33.

At the time of this investigation, August, 1909, the remaining 1200′ of Sec. No. 2 and the 1500′ of Sec. No. 1 had been enclosed.

These dams were, all told, some 16,000′ in length, contained about 300,000 cu.yds. of material, and took 12 working months to construct. Where the nature of the bottom permitted it, the bank was built by dredges. Where this was not feasible, scows loaded with broken limestone from the channel were dumped along the line of the dam until so much material had been deposited that the loaded dump scows would no longer float. The type of scow that carries a deck load was then used in conjunction with a derrick boat that unloaded them. This derrick boat has a long boom that overhangs the loaded scow. Near the ends of

Fig. 34.—Upper Section—Livingstone Improvement.

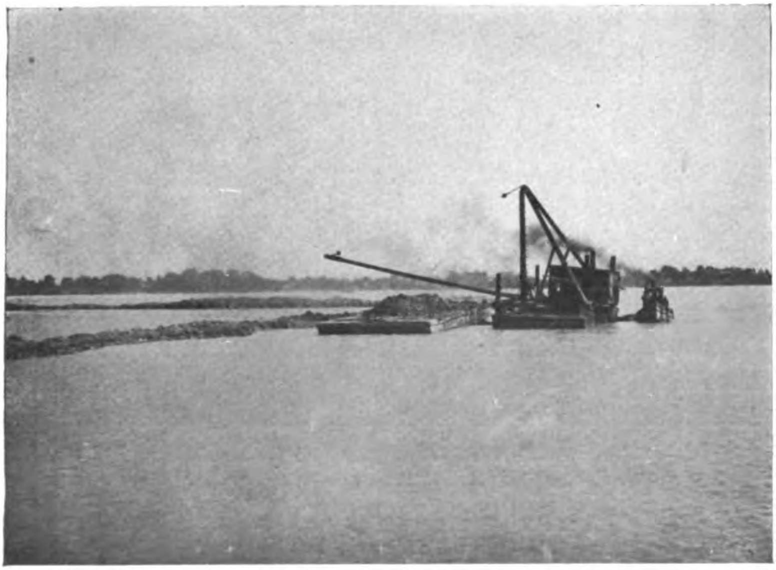


Fig. 35.—Derrick Boat on the Livingstone Improvement.

this boom are sheaves over which a cable passes. This cable passes around a drum and has its two ends secured to a scraper. As the drum is revolved by an engine, the scraper is operated back and forth across the deck of the scow, quickly unloading it.

As soon as the 2800′ section was enclosed, the work of taking out the rock began. Three similar plants were installed for this purpose. Each one, with the necessary pumps, consisted of a drilling and blasting outfit, a 60-ton Marion shovel, an aerial cableway and skips, and a channeling machine. One traction drill as an experiment was also in use. All drills, cableway engines and the four pumps were operated by air. This compressor plant was the one previously used by the same contractors on West Neebish Channel.

Drills. During the latter part of August, 1909, when these observations were made, there were 14 air drills working. The tripods elevate the drill cylinder so that there is a few inches over 2′ between the ground and the U-coupling or chuck. This of course necessitates the use of different sized bits. These bits range in even sizes from 2′ to 16′ in length. The drills are known as the Rand "Little Giant," and are marked 3 K.D.M.5. A feature of this drill is the "Sergeant rotating collar" that holds the dogs which mesh into the rifle nut. This is a friction collar which is held on by the friction cap. It is very useful when the bit becomes stuck. To take an extreme case, suppose that the bit enters a pocket in the rock that is nearly square in section. Obviously, since the bit has to revolve to work properly, it would in this square hole do one of two things if this "collar" were rigid and immovable: (1) stop the drill; or, (2) break the bit. When the bit first gets into this square hole, it naturally tends to stop or break the bit, but with this arrangement, when a certain twisting force is felt on the bit this collar slips. It slips before the twisting force is great enough to do either of the two things mentioned, but the pressure exerted in causing it to slip has the effect of causing the bit to take off some of the corners of the square hole. Then as the bit is raised and lowered a few times, the action is repeated and soon the

Fig. 36.—Drill at Cofferdam B.

Fig. 37.—Drilling at Cofferdam B.

square hole is round and the machine can go on with its regular work. In this drill also the rifle nut has an odd number of teeth. The effect of this is that only one of the dogs engages in the rifle nut at a time, and as a result, the twisting action of the rifle bar exists when the stroke is only half its normal length.

DRILL DATA:
Rand drill, Little Giant, 3 K.D.M.5.
Diameter of piston, 3¼″.
Stroke, about 7″.
Lift of cylinder, 2′.
U chuck
Air pressure, 90 lbs. at compressor.
Strokes per minute, 350.

The drill is moved by the runner. After a hole is finished, the bit is taken out of the hole and the weights are removed from the legs of the tripod. The runner then puts a cloth over his shoulder, gets under the tripod and moves the whole machine over until it is in its new position.

On this job there are two types of bits used: one for very hard rock, and the other for the softer grades of rock. The type for the hard rock is smaller in diameter at the point than the other type. The rock on this job is not hard and so the first type of bit is not used regularly, but only in the block holes. Block holes are used where grade has not been made by the regular drills but after the blast a "table" has been left. The small drills are then used to drill through these tables.

REGULAR BITS

Length, Feet.	Diameter of Steel, Inches.	Diameter of Bit Point, Inches.
Starter, 2	1¾	3⅞
4	1¾	3¾
6	1¾	3⅝
8	1¾	3½
10	1¼	3⅜
12	1¼	3¼
14	1¼	3⅛
16	1¼	3

HARD ROCK BITS (Block Hole)

	Length, Feet,	Diameter of Steel, Inches.	Diameter of Bit Point, Inches.
Starter,	2		2½
	4		2⅜
	6		2¼
	8		2⅛
	10		2
	12		1⅞
	14		1¾
	16		1⅝

The kind of point is the common + point.

Section of steel, octagonal.

Point tempered till file won't touch.

In drilling the holes no jet is used. The hole is kept well filled with water by the helper. At each change of bit the dirty water is taken out. The apparatus used for doing this is a piece of pipe about 2½′ long by 1½″ in diameter, through the inside of which runs a jointed rod terminating at one end in a handle, and at the other in a plunger that closes the lower end of the pipe. To remove the water the pipe is dropped into the hole and then drawn out by the handle. In doing this the plunger at the end of the rod closes the lower end of the 1½″ pipe, and the water is retained in it. To empty, the rod is simply forced out thus opening the end of the 1½″ pipe.

Holes, 13′ deep and 4½″ in diameter.

Longitudinal spacing, 8′.

Lateral spacing, 4′ and 6′, mostly 6′.

Material, limestone, solid and not very hard.

Forty to fifty holes shot per blast.

Pluto powder used.

Sticks, 1½′×8″.

Glycerine per cu.yd. loosened, 0.422 lbs.

Blasting battery used for setting off blast.

Two blasters, 2 helpers, 1 cleaner and 1 helper, compose a blasting gang.

The boilers used at the compressor plant are three in number, each 210 H.P. Each is 20′ long and 7′7″ across, having 84 4-inch tubes with a 30-inch steam dome. They were made by the Erie Iron Works.

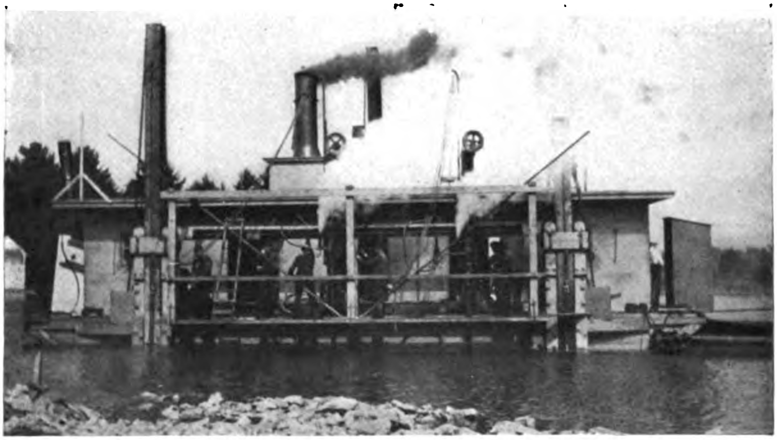


FIG. 38—Drill Scow—Thousand Islands, St. Lawrence River.

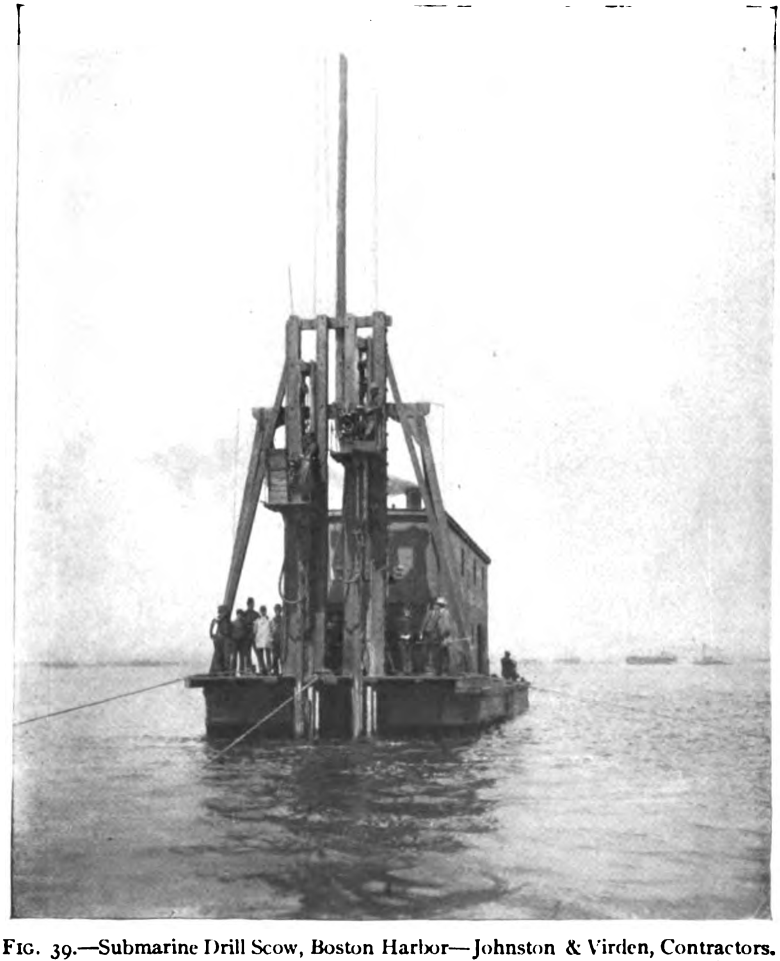


FIG. 39.—Submarine Drill Scow, Boston Harbor—Johnston & Virden, Contractors.

The compressor plant consists of two Rand Drill Co. units, each two-stage. The intakes of each low pressure are mechanical, and the outlets automatic. The capacity of the larger machine is 5725 cu.ft. per minute, while that of the smaller is 1900 cu.ft. per minute. Each low pressure raises the air to 30 lbs. and the high pressure can take it up to 95 lbs., but it usually runs at 90 lbs. The temperature of air at 95 lbs. is about 200° F. The numbers of the low pressure and high pressure respectively of the large machine are Nos. 2127 and 2126. The large machine is operated by 2 Newburg engines, having a pressure of 150 lbs.; 350 H.P.; 4′ stroke; large Cylinder, 40″; small cylinder, 22″; 75 revs. per min. The small machine is operated by two Hamilton Corliss engines running at 95 revolutions per minute and having a pressure of 150 lbs., and 400 H.P. The cylinders are respectively 30″ and 17″, and stroke of each 30″. This compressor plant is the same as that used on West Neebish channel, and depreciation was figured at 25% on that job, which is roughly 6% per year.

As has been said this compressor plant was used for the operation of the 3 cableway engines as well as the drills. It is estimated that half the plant capacity is used for each purpose.

The contract reads for 750 good working days. The contractors say that it will take a year to finish the work.

The drill crews of the two upper shovels work two 8-hour shifts, 8 A.M. to 5 P.M. and 6 P.M. to 3 A.M.

The drill crews of the lower shovels work three 8-hour shifts. The shovel crews work only two shifts, 8 to 5 and 6 to 3.

Each tripod drill has one runner and one helper. The traction drill also is operated by the same number of men.

The runners get $2 per day and the helper $1.75 per day.

The contract prices are, for rock, $1.24 per yd.; for earth, 60 cts. per yd.

The work of the smith is mainly repointing the drills and sharpening the channeling irons.

The coal is brought by boat to the dock and unloaded into a

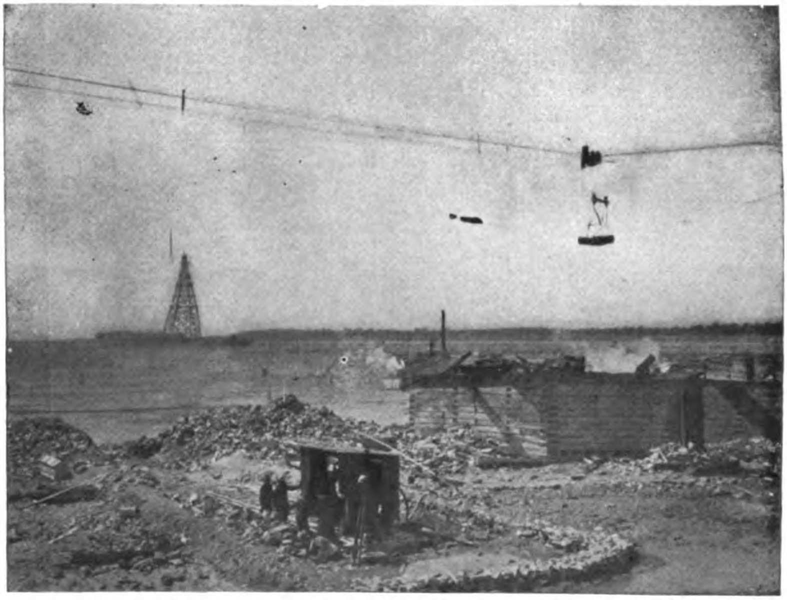


FIG. 40.—Livingstone Improvement.

FIG. 41.—Loading Holes for Blasting, Livingstone Improvement.

large chute. A dinkey, drawing a flat car which carries $1\frac{1}{2}$-ton dump boxes, gets a load and draws it about $\frac{1}{4}$ a mile to the boiler house supply. Here a jib crane lifts the boxes off the flat car, swings them over to the pile, where the boxes are emptied by turning them upside down. 18 tons per day at the compressor plant and $\frac{1}{2}$ of this or 9 tons, or 946 lbs. per drill per shift are charged to drilling.

Thirty cents per ton is the cost of handling the coal.

At the compressor about 3 qts. of oil are used per day. At the drills 2 pts. of oil are used per drill per shift.

FIG. 42.—Drilling—Livingstone Improvement.

The repairs on the West Neebish contract cost $9765 for 1000 working days. On this basis repairs per drill day were roughly $1. Interest and depreciation on the 10 drills, including the compressor and boiler plant, at 2% per working month on $16,000 $=\frac{320}{26}=\$12.30$ per day.

Superintendence. During the month of June, 1909, there was one superintendent on the job and 10 foremen. These men had charge of 20 drillers and also the other employees, such as shovel men (3 shovels), cableway men (3 cableways), pumpmen and laborers.

During this month there were also on the job one bookkeeper, one clerk and two timekeepers.

Moving Plant. 16% of the observed time was consumed in shifting the drills from hole to hole and in getting started. The average number of drills during the eight months (January to September), 1909, was 9½ in each of the 2 shifts, or 19 per day. The cost of moving drills per day on the above basis would be 16% of the daily drilling wages, which are $106.20, or $17.00, or 89½ cts. per drill per shift.

The lighting for the night work is done by portable acetylene gaslights in sets of two each. Each burner is provided with a reflector. Fifty pounds of carbide are burned during each night shift by a set of two lights. Handles on the wooden outer casing form an easy means of making the lamps portable. These lights seem to be a very satisfactory means of illumination.

The Traction Drill. Mr. C. H. Locher conceived the idea that a drill could be made to work in a frame on land in a similar manner to the marine drills. He therefore set about to construct one as a model, to test it and find its weak points and then make a good one that would satisfy every requirement. This traction drill presents a rather clumsy appearance, but it seems to do the work in a satisfactory manner. The whole mechanism is mounted on four heavily spoked wheels with broad rims, which have numerous ¾″ lugs of metal to furnish a good grip for moving about. The wheels are on 4-inch axles having an 8′ gauge and spaced about 9′ apart. In order to steer the machine properly it is so arranged that the runner may turn the rear axle independently of the front axle. Extending out some 3′ from each end of the front axle are two 4-inch timbers, in the ends of which are two jack-screws for anchoring the machine in position. The bed for the machinery is made up of 6″×8″ timbers resting on two 12″×12″ stringers. The frame in which the drill-slide moves up and down is made up of two well-braced vertical 12″×12″ timbers with a 12″×12″ cross piece at the top. At the top and bottom of this vertical frame are sheaves, and about 2′ above the lower one a drum shaft passes through the frame and terminates at each end in a worm wheel. A

¾-inch cable secured at one end to the drillslide passes upward over the top sheave, thence down, making several turns around the 10-inch drum, thence around the lower sheave, and thence up, terminating in the bottom of the drillslide. The worm wheel on the end of the drum shaft is rotated through suitable reduction gearing by a small double cylinder air driven engine which also furnishes transmission for the machine. A 4″ cog on the crank-shaft of the engine meshes into a 12″ cog on another shaft. On the latter shaft a 5″ cog meshes into a 24″ cog. The shaft on which this 24″ wheel revolves terminates at each end in a positive clutch that may be engaged with a cog having secured to it the gearing that operates the machine forward and backward. Transmission from these cogs to the forward axle is by chains passing over the cogs and a large sprocket wheel near each end of the front axle. Near the ends of the shaft that has this coupling arrangement are two 14″ bevel gears meshing into 5″ bevel gears each secured to an inclined shaft terminating in a worm. These worms each mesh into the worm wheels on the end of the drum shaft, before mentioned, in the drill frame. The

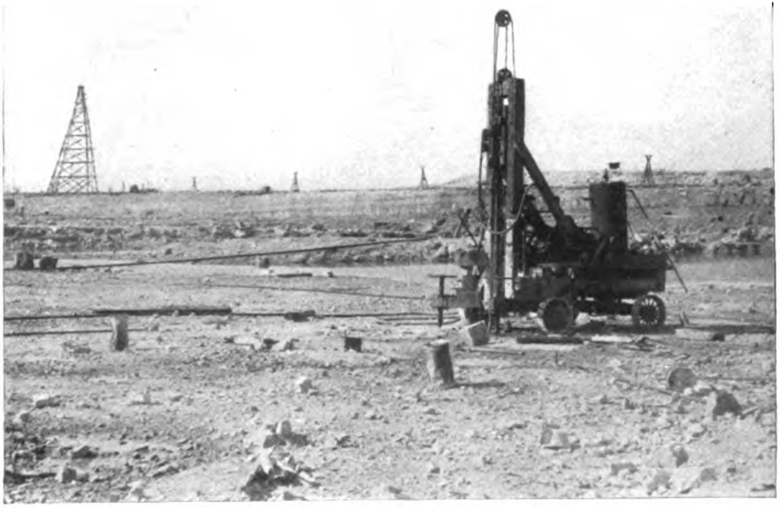


Fig. 43.—Traction Drill.

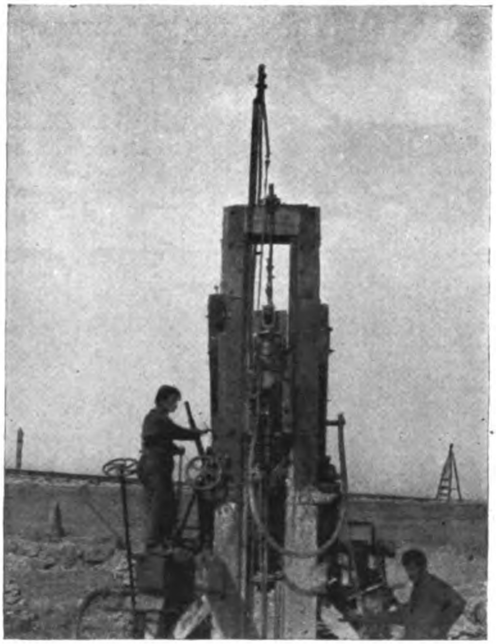


FIG. 44.—Traction Drill.

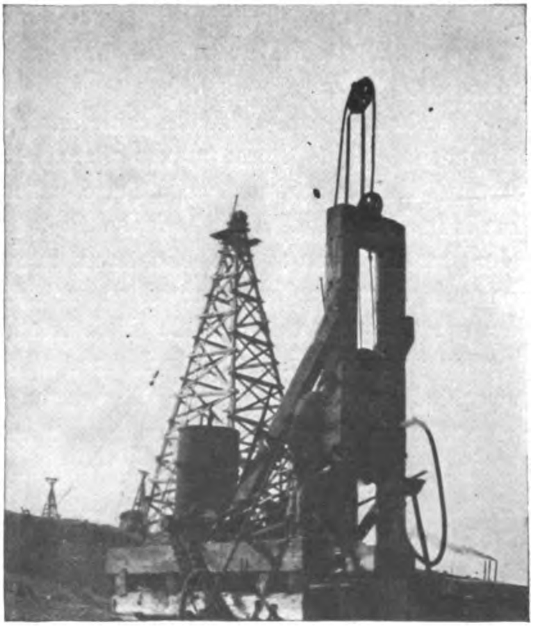


FIG. 45.—Traction Drill.

14″ bevel gears are so arranged that one lever operated by the runner throws the feed in and the transmission out, or vice versa.

Air is used for three purposes on this machine: (1), engine; (2), drill; (3), air wash-out. The feed pipe for these purposes is as follows: From a branch of the main line a 2″ pipe runs 50′ and from its end 50′ of 1½″ hose, coupled on by means of a reducer, extends to the side of the drill wagon into a 1½″ pipe 3′ long. By a system of pipes, right angles and tees, air is taken off, first for air wash-out, then for engine, and finally for the drill cylinder.

The drill used on this novel apparatus is the Ingersoll-Sergeant, Type C9. There is no regular water wash-out, only a slow stream of water being allowed to flow into the hole. The two great advantages of this traction drill over the small tripod drills, as will be pointed out later, in connection with the time study of each, are (1) increased cutting speed, and (2) saving of time by not having to change bits after each 2′ of drilling. A new steel traction drill is being constructed that is to have a special hot water heater, so that the water used for flushing the hole will not freeze in winter—a material advantage.

The Cable Cars. After the rock is drilled and blasted the shovels pick it up and dump it into 2½-yd. steel skips, that are then picked up by the cable cars and carried over to the spoil bank and dumped. There are, as before stated, three Marion shovels, and three sets of cables. Each cable has two supporting towers about 110′ high. These towers are each in the form of a derrick, and each is mounted on a large ballasted timber platform that is itself mounted on wheels, so that the cable can be moved along readily when the shovel enters a new cut. This is done by means of an engine mounted on each derrick platform. They are Compound Reversible Link Motion, 6¼×8″, capable of pulling 10,000 lbs. on a single line. To move the derricks long cable lines with numerous blocks are anchored ahead, and the engine takes in the cables so placed, on its cable drum.

The table on page 91 is a general summary of the data on file in the Government Office at Amherstburg, Ontario, obtained with the consent of the contractor. The items marked * are deductions from the data on file.

1909.	January.	February.	March.	April.	May.	June.	July.	August.
Number of days worked	25	21	27	26	27	26	26	26
Number of shifts	50	42	54	52	54	52	52	52
Av. no. of drills, each working two shifts.	10+	7	6	8−	9+	11−	11.5	14
Drill hours worked	3,520	1,960	2,469	2,899	3,751	4,322	4,227	5,403
Drill hours delay	592	392	123	353	245	174	583	399
Number of holes	2,316	1,316	1,531	2,281	3,190	4,818	4,677	6,248
Average depth of holes	12.7′	9.9′	9.8′	7.95′	7.5′	5.57′	4.63′	4.4′
Spacing of holes	5×5′	6×6&6×25 Av. 6×23′	6×8	6×8 & 8×8 Av. 7×8′	4×6 & 8×8 Av. 7½×7½	4×6 & 6×8 Av. 5×7′	4×6 & 6×8 Av. 5×7′	4×6 & 6×8 Av. 6.4×7.2
Linear feet drilled	29,433	13,092	14,948	18,134	23,922	26,854	21,613	27,469
Dynamite, 60%.......1 lb.	8,800	11,500	19,200	16,650	20,600	24,250	15,900	22,950
Dynamite, 40%.......1 lb.	7,550	11,300	19,100	15,350	18,250	17,500	12,700	18,900
* Linear feet per shift	590	312	276	348	443	516	415	529
* Feet per drill, per hr. worked	8.37	6.68	6.05	6.28	6.39	6.23	5.13	5.07
Feet per drill, per hr.	7.15	5.57	5.78	5.58	6.00	5.98	4.5	4.72
* Average drilling, labor, per day	$112.30	$84.30	$78.50	$91.30	$104.00	$117.50	$123.80	$145.50
* Labor, per foot drilled	9.53 cts.	13.5 cts.	14.2 cts.	13.1 cts.	11.7 cts.	11.4 cts.	14.9 cts.	13.47 cts.
* Cubic yards pay rock	25,100	59,800	24,000	33,850	44,500	28,500	22,000	36,000
* Cubic yards per shift	502	1,420	445	670	825	498	424	694
* Cubic yards per foot drilled	0.85	4.17	1.6	1.86	1.86	1.05	1.017	1.57
* Drilling, labor per cubic yard pay	10.79 cts.	2.96 cts.	8.8 cts.	6.82 cts.	6.31 cts.	11.8 cts.	14.6 cts.	10.5 cts.
* Nitroglycerin per linear foot	0.273 lbs.	0.87 lbs.	1.28 lbs.	0.375 lbs.	0.565 lbs.	0.752 lbs.	0.646 lbs.	0.947 lbs.
* Nitroglycerin per cubic yard pay rock	0.32 lbs.	0.19 lbs.	0.80 lbs.	0.468 lbs.	0.432 lbs.	0.710 lbs.	0.635 lbs.	0.570 lbs.
* Nitroglycerin per cubic yard blasted	0.296 lbs.	0.17 lbs.	0.718 lbs.	0.422 lbs.	0.372 lbs.	0.580 lbs.	0.50 lbs.	0.492 lbs.
* Ratio $\frac{\text{cubic yards blasted}}{\text{cubic yards pay rock}}$	1.08	1.118	1.114	1.11	1.16	1.22	1.27	1.158

Depth drilled to 24′ below mean water level: holes are drilled 1′ below pay grade.

FIG. 46.—Loading by Hand into Skip.

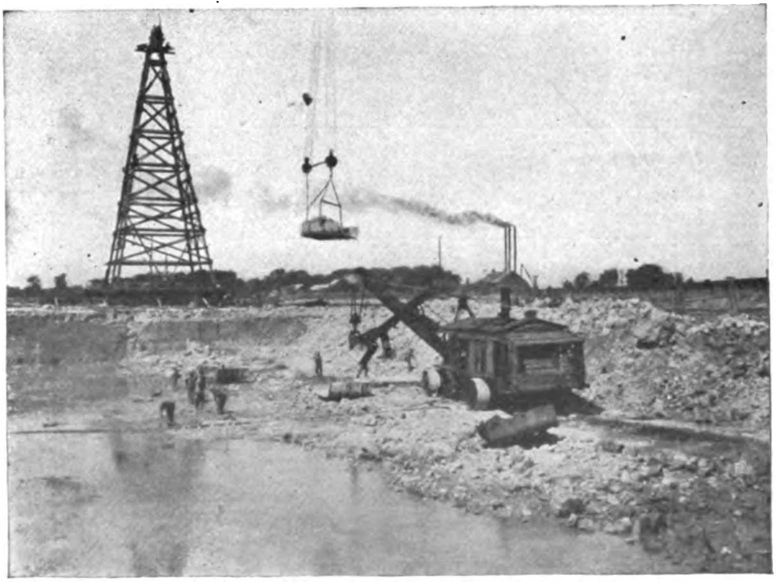


FIG. 47.—Loading Rock with Steam Shovel.

The following figures which give the cost with a tripod drill per lineal foot drilled and per cu.yd. of pay rock loosened are based on the average performance during 204 days, covering a period of 8 months, January to August inclusive, 1909.

MATERIAL—SOLID LIMESTONE

Days worked	204	Dynamite, 60%	139,850 lbs.
Total number of holes	26,327	Dynamite, 40%	120,650 "
Total lineal feet	175,501	Total dynamite	260,500 "
Total cubic yards of pay rock	273,750	Total nitroglycerin	132,170
Total cubic yards of blasted rock	314,000	Average dynamite per day	1,179 lbs.
Lineal feet per day	840	Av. nitroglycerin per day	650 "
Av. cubic yards pay rock per day	1,390	Av. nitroglycerin per cubic yard pay rock	0.484 "
Av. cubic yards blasted rock per day	1,538	Av. nitroglycerin per cubic yard blasted rock	0.422 "
Av. No. drills, 9½ (2 shifts of 8 hours) = 19 per day			

Force.	Standard Rate.	Amount.		Basis of Costs	
				Cost per Lin. Foot. Cents.	Cost per Cu. Yd. Pay. Cents.
19 drillers at	2.00	$38.00			
19 driller helpers	1.75	33.25	$71.25	8.48	5.13
8 nippers	1.50	12.00			
2 blacksmiths	3.00	6.00			
4 blacksmiths' helpers	1.75	7.00	$25.00	2.98	1.80
1 engineer, day	3.00	3.00			
1 engineer, night	3.00	3.00			
2 firemen	2.00	4.00	$10.00	1.19	0.72
Total drilling labor			$106.25	12.65	7.65
Coal, 9 tons at $3.50	31.50				
Oil, 2 quarts per drill at 0.30	1.43		32.93	3.92	2.37
Total drilling			$139.18	16.57	10.02
5 powdermen at $2.00	10.00				
6 helpers at $1.50	9.00		19.00	2.26	1.37
1179 lbs. dynamite at 0.12	141.48				
125 exploders at 0.03	3.75		145.23	17.30	10.43
Total loosening			$303.41	36.13	21.82
Int. and dep. on 10 drills and necessary compressor and boiler capacity at 2% per working month $16,000			$12.30	1.46	0.89
			$315.71	37.59	22.71
Total cost of drilling per drill per shift =			$7.34		

In the tabulation of costs on page 93 no account has been taken of contractor's overhead charges or superintendence, organization or preparatory expenses, insurance, accidents, charity, repairs, legal, medical expenses, etc.

TIME STUDY—Dec. 31, 1909

Lineal feet drilled during observations, 32
Observed time, 7 hr. 25 min. 25 sec.
Cycle time, 5 hr. 40 min. 20 sec.
Idle time, 1 hr. 45 min. 05 sec.

KIND OF ROCK—LIMESTONE

	No. of Obs.	Min.		Mean.		Max.		Time. Consumed		Per Cent of Total. Time.
		Min.	Sec.	Min.	Sec.	Min.	Sec.	Min.	Sec.	
Drill cutting	16	7	20	12	53	19	50	245	05	55.1
Raising drill	16	0	25	0	49	1	30	13	10	2.9
Loosening	16	0	10	0	34	1	45	9	05	2.0
Removing bit	16	0	10	0	23	0	40	6	05	1.4
Getting bailer	13	0	15	0	28	0	50	6	00	1.4
Bailing	13	1	45	2	55	5	30	38	00	8.6
Getting and dropping bit in hole	13	0	05	0	24	1	10	5	10	1.1
Inserting in chuck	13	0	10	0	20	0	40	4	25	1.0
Tightening chuck	13	0	25	0	54	1	40	11	25	2.5
Getting started	13	0	05	0	09	0	20	1	55	0.4
Cycle totals	......	10	50	19	49	33	55	340	20	76.4
Moving drill over and getting started, 2 obs.								70	50	15.9
Miscellaneous delays								34	15	7.7
Total time								445	25	100.0
								=7 hr. 25 m. 25 s.		

Cutting speed 0.1305′ per cutting minute = 7.830′ per cutting hour.

Ratio $\frac{\text{cutting time}}{\text{total time}} = 0.551.$ Ratio $\frac{\text{idle time}}{\text{cycle time}} = 0.31.$

Cycle time, exclusive of drilling, = 95 m. 15 s. for 32′ = 3 m. per lineal foot of hole.

FIG. 48.—Detroit River Cofferdam.

FIG. 49.—One of the Head Towers.

FIG. 50.—Pump.

TIME STUDY

Obs. time, 3 hr. Traction drill, type Ingersoll-Sergeant C9.
No. holes, 8. Lineal feet drilled, 56½.

MATERIAL, SOFT LIMESTONE

	No. of Obs.	Min.		Mean.		Max.		Time. Consumed		Per Cent of Total. Time.
		Min.	Sec.	Min.	Sec.	Min.	Sec.	Min.	Sec.	
Drill cutting	8	10	45	11	56	14	10	95	25	53.0
Raising drill	8	0	35	0	41	0	45	5	25	3.0
Preparing to move back	8	0	15	1	09	2	40	9	10	5.1
Moving back	7	0	15	1	11	2	30	8	15	4.7
Lowering jacks	8	1	00	1	16	2	15	10	10	5.6
In position, not working	8	0	00	0	07	0	35	1	00	0.6
Cycle total		12	50	16	20	22	55	129	25	72.0
Miscellaneous delays								27	00	15.0
Moving to new range								23	35	13.0
Total								180	00	100.0

Cutting speed = 0.59 ′per cutting minute.

Cutting speed, tripod drill, 0.1305′ per cutting minute.

Above due to the much larger type of drill.

Ratio $\frac{\text{cutting time}}{\text{total time}} = 0.53$. Ratio $\frac{\text{idle time}}{\text{cycle time}} = 0.389$.

Cycle time, exclusive of drilling, = 34 min. for 56½′ = 36 sec. per lineal ft. drilled. Same for the tripod drill 6 min. and 15 sec.

GOVERNMENT BLANK USED

Contract dated......................., 19 Appropriation for..
Report of Drilling for the Month of............................. 19......Drill boat.................... (....drills)...........
....Contractor. Section..

Date 19	Time			No. of Holes Drilled	Linear Feet Drilled	Average Length of Holes.	Distance between Holes	Average Depth of Water	Depth Drilled to	Pay Depth for Removal of Material	Amount of ......% Dynamite Used, Lbs.	Coal Consumed. Tons	No. of Men Employed ..hrs., ea.	Remarks Concerning Character of Material, Location, etc.
	Worked		Delayed											
	Hrs.	Min.	Hrs.											
1														
2														
3														
4														
5														
6														
7														
8														
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26														
27														
28														
29														
30														
31														
Month...														
Prior Mos.														
Year.....														
Prior Yrs.														
Contract.														

I certify that the above is a true and correct report..., Inspector
Respectfully transmitted...Assistant Engineer

This shows very clearly the great saving of time due to not having to change steels during drilling. The two great advantages of the heavy traction drill over the small tripod drill are this great saving in time due to not having to change steels during the process of drilling, and the much greater cutting speed due to the use of much larger drills. The above figures very clearly show this. It is to be noted, however, that there are not many cases where conditions are as ideal as they were here for the use of a traction drill. The surface of the limestone was here practically level, and the cut being 300′ wide and some thousand feet long a traction drill was indeed a great innovation.

CHAPTER V

DRILLING ON LAND—*Continued*

D. L. & W. Cut-off. The so-called D. L. & W. Cut-off is a new undertaking of the Delaware, Lackawanna and Western Railroad for the purpose of shortening the old line from New York to Buffalo. The cost of the work is estimated at $9,454,154 and the date set for its completion is August, 1911. This new line will be 28.45 miles in length and will join the old line at Hopatcong on the east end and Slateford on the west end. The purposes of this work are three-fold: shortening of distance, reducing the grade and avoiding tunnels. The distance saved is 11.12 miles eastbound and 10.53 miles westbound. The ruling grade eastbound is to be 0.55% compensated, or 29.04′ per mile, against 1.05%, or 55.44′ per mile, on the old line. This will be a saving of 26.4′ per mile eastbound. Westbound, the new ruling grade is to be 0.75% compensated, or 39.60′ to the mile, against 1.39%, or 73.39′ to the mile, on the old line. This means a saving westbound of 33.8′ to the mile.

Two tunnels, the Oxford and the Manunka Chunk will be avoided. It was originally intended that the new work should have no tunnels, but near Andover, N. J., the seamy nature of the rock made an open cut dangerous and so a tunnel is being driven there. In the line of bridges there are to be seventy structures from a 3′ box culvert up. The most handsome structure is that across the Delaware near Columbia, N. J. It is composed of concrete arches and is very artistic.

The contract for the whole work has been let in seven sections, approximately 4 miles in length.

Beginning at Hopatcong, the eastern end of the new work, the sections and contractors are as follows:

Sec. 1, Timothy Burke.
Sec. 2, Waltz and Reece.
Sec. 3, David M. Flickwir, Roanoke, Va.
Sec. 4, Gehagen.
Sec. 5, Hyde, McFarlane and Burke.
Sec. 6, Reiter, Curtis & Hill, Phila.
Sec. 7, Smith-McCormick.

On Sec. 7, the Smith-McCormick Co. are constructing the arches across the Delaware and have sublet the other work to James A. Hart of New York.

Due to the rocky nature of the work much drilling and blasting has been necessary. Sections 3, 6 and 7 are typical of this, and the following observations concerning them have been made.

D. M. Flickwir, Sec. 3, Andover, N. J. Engaged in drilling operations on Sec. No. 3, D. M. Flickwir has 17 Ingersoll-Rand drills operated by air pressure. Two compressors of 2250 cu.ft. capacity are used to furnish the necessary air at 110 lbs. pressure. On that part of this section nearest Andover, N. J., the rock loosened by drilling and blasting operations is used for making a large fill. The method employed in making this fill consists of a suspended track arrangement as follows: Two large cables about 7′ apart, and anchored at their ends, pass upward over wooden towers for abutments and furnish support for the vertical cables by which the track beneath is suspended. There are three sections of track thus suspended and the vertical suspending cables are so arranged that as the fill progresses the track may be pulled forward into its new position. It is on this section of the work that the only tunnel on the new line will be located. The dip of the rock, bastard granite, was here so sharp that on account of the earthy material between the strata it was feared that an open cut would be too dangerous. This tunnel is to be called the Roseville. At the time this work was investigated the heading on this tunnel had been nicely started and holes had been drilled for the next blasting. The scheme used in arranging the holes and the method of blasting are as follows: The curve of the arch was painted on the rock in red, and holes (so-called outside rounds) were drillied on this line about 3′ apart. Six feet each way from the center there is a row of holes placed about 15″ apart from bench to outside rounds. These holes, 10′ in depth, all point toward the center so that a V-shaped chunk of rock known as the "cut" may be loosened when blasted. To assist the cut holes another row of holes 6′ deep and similarly spaced is drilled midway between.

FIG. 51.—Drilling at Andover, N. J.

FIG. 52.—The Bench at Andover.

On each side and about half way between the "cut holes" and the "outside rounds" measured along the bench there is a row of holes in a plane at right angles to the face known as the "side rounds." They are spaced about 15″ apart from bench to outside rounds, 10′ in depth and drilled at an angle of 75° with the vertical. Midway between the "side rounds" and "cut holes" there is another similar row of holes on each side known as the "quarter rounds."

In blasting, the "cut holes" are first shot, the charge being 6 sticks of 60% dynamite (8″×1¼″). Quarter rounds are next shot, then the side rounds, the charge for both being 4 sticks. The outside rounds, each loaded with 3 sticks, are shot last. The idea of the small charge and this method of shooting is to make as clean a cut as possible without shattering the adjoining rock too badly. In work of this kind drills are in nearly a horizontal position and do not work, of course, as efficiently as when in a vertical position.

Drill Data: Ingersoll-Rand.
3¼-inch piston.
6-inch stroke.
Feed 2′.
U chuck.
100 lbs. pressure at compressor.
400 strokes per min.

In moving drills from one place to another the drill cylinder and slide are taken from the tripod and the drill cylinder and the slide separated. Bits are made of 1¼″ steel, tapered off to 1⅛″, to fit in the chuck. The 2-foot bit is 3″ in diameter at the point, and for each increase in length of 2′ the diameter at the point becomes ⅜″ less. Points are of this shape +. The steel is handled by workmen who carry it from the drill to the blacksmith shop. They are sharpened by hand with the aid of a smoother. No jet is used, but wash water is poured in by the helper from a can.

An air wash-out is used on the "outside rounds." These holes are drilled without water, being so nearly horizontal, and to get rid of the powdered stone, this air wash-out is used occasionally.[1] Holes are drilled on the tunnel heading 10, 8 and 6′ in depth, as already stated.

Holes 4″ at top.

Spaced about 15″ apart vertically.

About 3′ apart horizontally.

Holes drilled with drill, making an angle of about 75° with vertical.

Rock, hard bastard granite, very seamy and difficult to drill.

Holes shot as already stated.

Dupont Powder used.

Sticks 8″×1¼″. 100 sticks = 50 lbs.

17 drills.

Two compressors, Kiernon, capacity, 550 cu.ft. Ingersoll, capacity 1700 cu.ft.

Pressure, 100 lbs. at compressor.

Feed main, 1½ miles long, 6-inch main, 4-inch branch to 2″.

From the 4-inch branch a 2-inch pipe runs to a T from which 1½-inch flexible piping runs to the drills.

Work to be completed August, 1911.

Shift 10 hours. 1 shift per day.

DRILL LABOR—STANDARD WAGES

17 drill runners	at	$2.50 =	$42.50
17 drill runners' helpers	at	1.75 =	29.80
2 blacksmiths	at	3.00 =	6.00
2 blacksmiths' helpers	at	1.75 =	3.50
4 nippers	at	1.50 =	6.00
3 powdermen	at	2.00 =	6.00
1 engineer	at	3.00 =	3.00
1 fireman	at	2.00 =	2.00
1 water carrier	at	1.50 =	1.50
Total drill labor			$100.30

Superintendence. One man in full charge of field. One foreman for the drillls on the heading, 2 other foremen for the other two gangs of drillers.

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[1] It consists of an inch pipe about 15′ long connected by a rubber hose to the air line.

FIG. 53.—Ingersoll-Rand $3\frac{1}{2}''$ Piston Drill

FIG. 54.—Face of Rock, Andover.

The work of the smiths is to repoint drills and do odd jobs of repairing.

Coal used, 8 tons per day or 940 lbs. per drill per day, 1 shift.

Oil used at compressor, 4 gals. or 1.88 pts. per drill per day, 1 shift.

Oil used on drills, 2 pts. per drill per day, 1 shift.

Coal is dumped on trestle and costs $3.10 per ton delivered. (Standard assumed $3.50 per ton.)

Drilling plant of 17 drills and necessary compressor and boiler capacity valued at $14,300.

Interest and depreciation on same at 2% per working month, =$11.00 per day, =65 cts. per drill day.

Moving drill from hole to hole and getting started amounted to 22.4% of total time (drill working in tunnel heading), costing 22.4% of drill labor $6.11 = $1.37 per drill per day, 1 shift.

As said, there were three drills at work on the tunnel heading. The drill which was timed was set up on the bench on its tripod as usual. Another was set up on a cribbing of ties. The third was set up on a column.

The cost of drilling per lineal foot in hard seamy bastard granite in tunnel heading is based on the above performance of 24 lineal feet in 7 hours, 27 minutes, 20 seconds, or 32′ in 10 hours. No account is to be taken of overhead charges, superintendence, repairs, storage, organization and preparatory charges, charity, accidents, legal or medical expenses, etc.

No. of Drills, 1; Linear Feet, 32; Kind of Rock, Bastard Granite

Force.	Standard Rate.	Amount.		Cost per Lin. Foot, Cents.
1 drill runner	$2.50	$2.50		
1 drill helper	1.75	1.75		13.30
			$4.25	
2 blacksmiths for 17 drills	3.00	0.35		
2 blacksmiths' helpers for 17 drills	1.75	0.21		
1 nipper for 3 drills	1.50	0.50		
			$1.06	3.32
1 water carrier for 3 drills	1.50	0.50	0.50	1.56
1 engineer at comp. (17 drills), per day	3.00	0.18	0.18	0.56
1 fireman at comp. (17 drills), per day	2.00	0.12	0.12	0.37
Total drill labor	....		$6.11	19.11
Coal, 8 tons for 17 drills	3.50	$1.65	$1.65	5.16
Oil (at comp.) 4 gals. for 17 drills, per gal.	0.30	0.08		
Oil, (cylinder) 1 qt. per drill, per gal.	0.30	0.08	0.16	0.50
Total drill expense	....		$7.92	24.77
Int. and dep. at 2% mo. on ($\frac{1}{17}$ × 14,300)	....		0.65	2.0

TIME STUDY

Linear Feet Drilled, 24; Rock, Bastard Granite; Condition of Rock, very Solid

	No. of Obs.	Min.		Mean.		Max.		Total Time.		Consumed Time, Per Cent of Total.
		Min.	Sec.	Min.	Sec.	Min.	Sec.	Min.	Sec.	
Drill working	12	12	00	22	56	49	00	275	10	61.6
Raising drill	11	00	10	00	23	00	40	4	10	0.9
Loosening chuck	11	00	10	00	19	00	30	3	35	0.8
Removing bit	11	00	10	00	45	3	05	8	15	1.8
Putting bit in hole	8	00	15	00	32	1	05	4	15	1.0
Inserting bit in chuck	8	00	10	00	40	1	50	5	20	1.2
Tightening chuck	8	00	20	00	37	1	05	4	55	1.1
Getting started	8	00	10	00	31	1	00	4	10	0.9
Cycle totals	......	13	25	26	43	58	15	309	50	69.3
Shifting drills and getting started	3	..	..	33	23	..	..	100	10	22.4
Miscellaneous delays	3	..	..	..	..	..	..	37	20	8.3
Totals	......	....		....		....		447	20	100.0

(1) The cutting speed was 0.0872 ft. per min. Rock was very hard and seamy and drilling was done with drills in nearly a horizontal position.

(2) Ratio of cutting time to total time was 0.616.

(3) Ratio of idle time to cycle time was 0.444.

Reiter, Curtis & Hill, Sec. 6, Vail, N. J. Section No. 6 on this D. L. & W. cut-off is being constructed by Reiter, Curtis & Hill, of Philadelphia. Engaged in drilling operations on their section are 16 Ingersoll-Sergeant drills, Type F 24. They are being operated by air furnished by two 250 H.P. Ingersoll-Rand compressors at 100 lbs. pressure. The rock in the main cut is locally known as bastard slate, and on account of seams is very mean material for the drills to work in.

DRILL DATA. Ingersoll-Sergeant drills, type F 24.
3½-inch piston.
6-inch stroke.
2′ 9″ feed, but steels change in length by 2′ each time.
U chuck.
100 lbs. pressure at compressor.
350 strokes per minute.

When drills are moved, they are removed from the tripod and each moved separately and then set up again.

Starting bit 3½″ at point.
4′ bit 3¼″ at point.
6′ bit 3″ at point.
8′ bit 2¾″ at point.
10′ bit 2½″ at point.
12′ bit 2¼″ at point.
14′ bit 2″ at point.

Bits made of 1¼″ material; somewhat less at the end to fit in the chuck.

Points are this shape +.

Men carry the steel back and forth from the drills to the blacksmith shop.

The bits are tempered till a file will not touch them.

Points are put on by hand assisted by a smoothing iron the shape of the bit.

Wash-water is poured into the hole from a tin can by the helper.

An air wash-out is used, consisting of a ⅜-inch pipe connected to a small rubber hose which is in turn connected to a cock tapping the air line of the drill near the air chest. This agitates the wash-water, thereby keeping the point of the bit free from dirt. The hole is bailed after each 2′ section is drilled. The bailing device is a piece of pipe about 2′ long and 1½″ in diameter. A rod of steel, ½″ section, passes through this pipe and has a conical piece of metal on its end that closes the end of the 1½″ pipe. In operation the pipe is let down into the hole by the rod and by allowing the rod to drop a little, the dirty water comes into the pipe, seeking its own level, then the act of lifting out the pipe by the rod causes the stopper on the end of the rod to plug up the hole in the pipe. To empty, the pipe is rested

FIG. 55.—Tripod Drill at Vail, N. J.

on the ground, and the plug being forced out the water runs out.

Holes 12′ deep.
Spaced 10′ laterally.
Spaced 10′ longitudinally.
Holes about 4½″ at top.
Holes make angle of about 15° with vertical.

,Fig. 56.—Character of Rock, Vail, N. J.

Material—Bastard slate, hard and seamy, although somewhat shaken from previous blasts.

From 20 to 40 holes are shot at a blast.

Dupont dynamite used, 60%.

Sticks, 1¼″×8″, ½ lb. each.

The holes are first sprung with from 4 to 10 sticks of dynamite and then charged.

Charges are about 50 lbs. of dynamite to a hole.

Blasting machine used to fire the charges.

FIG. 57.—Charging Holes, Vail, N. J.

The foreman of each gang of drillers has charge of the blasting. Assisting him are 3 powder carriers and tampers.

Sixteen drills are in the outfit, but only 7 were working at the time of this investigation.

Two 250 H.P. compressors. Steam cylinder 24×30. Air cylinder 24¼×30.

Five Erie boilers of 100 B.H.P., also 1 extra Erie boiler of 100 B.H.P.

100 lbs. pressure at compressor.

Feed pipe about ¼ mile long; 10″ reducing to 6″, then to 4″ and 2″. The 2″ pipe leads to a T near each group of drills, from which separate lines run to each drill. These lines are made up of 1½″ piping terminating in a length of 1½-inch hose that connects to the air chest of the drill cylinder.

Job to be finished August, 1911.

Shift, 10 hrs. One shift per day.

The following drill force were at work at the time of this investigation.

	Standard Basis of Costs.	
	Cost per Day.	Total Cost.
7 drillers	$2.50	$17.50
7 drillers' helpers	1.75	12.25
4 muckers	1.50	6.00
1 blacksmith	3.00	3.00
1 blacksmith's helper	1.75	1.75
2 nippers	1.50	3.00
3 powdermen	2.00	6.00
1 engineer	3.00	3.00
1 fireman	2.00	2.00
Total labor	....	$54.50

Superintendence. One general superintendent, 2 foremen, one for each of the two groups of drillers.

Interest and depreciation on 16 drills and compressor and boiler of the necessary capacity, valued at $18,075, at 2% per working month, =$13.90 per day (1 shift).

Moving drill from hole to hole and getting started took 21.3% of the total time, and on the above basis of wages, exclusive of powdermen, cost $1.48 per drill per day (1 shift).

Coal used, 7 tons per day, or 875 lbs. per drill per day of 1 shift.

Oil used at compressor, 4 gals., or 2 pts. per drill per day.

Oil used at drills, 3 pts. per drill per day.

FIG. 58.—Vail, N. J.

FIG. 59.—Vail, N. J.

Cost of Drilling and Loosening in Bastard Slate. Based on the observed performance of 34 lineal feet in 7 hrs., 24 min., 35 sec. (see time study) or 46′ in 10 hrs., and the performance of 3 other drills at 42′, 40′, and 42′ respectively, the following deductions as to the cost of drilling per lineal foot have been made. Holes being spaced 10′ centers, average depth 12′ and 50 lbs. of 60% dynamite being used per hole, the following cost per cubic yard of material loosened has been deduced:

Fig. 60.—Vail, N. J.

No. of Drills, 4; Lineal Feet Drilled, 170; Cubic Yards Blasted, 630.

Total dynamite, 60%, 700 lbs. = 1.11 lbs. per yard.
Total nitroglycerin, 420 lbs. = 0.666 lb. per yard.
Total nitroglycerin, 420 lbs. = 2.47 lbs. per linear foot.

Material, Bastard Slate

Force.	Rate.	Amount.		Standard Basis of Costs	
				Cost per Lin. Foot in Cents.	Cost per Cu.yd. in Cents.
4 drill runners	$2.50	$10.00			
4 drill runners' helpers	1.75	7.00			
4 muckers	1.50	6.00			
			$23.00	13.50	3.66
½ smith	3.00	1.50			
½ smith's helper	1.75	0.87			
1 nipper	1.50	1.50			
			$ 3.87	2.28	0.62
4/16 engineer	3.00	0.75			
4/16 fireman	2.00	0.50	$ 1.25	0.74	0.20
Total drilling labor			$28.12	16.52	4.48
Coal 7/4 ton	3.50	6.14			
Oil at compressor plant 16/7 gal.	0.30	0.69			
Oil at drills, 3 pts. each drill	0.30	0.45	$7.28	4.29	1.16
Total drilling			$35.40	20.81	5.64
Dynamite, 700 lbs., 60%	0.12	$84.00			
14 exploders	0.03	0.42			
			$84.42	49.55	13.39
3 powdermen	2.00	6.00	6.00	3.52	0.95
Total drill and blasting			$125.82	73.88	19.98
Interest and depreciation on 4/16 of $18,075 (estimated value of drilling plant at 2% per working mo.)			3.48	2.05	0.55
Total			$129.30	75.93	20.53

The fact that four muckers had to be employed here accounts for the increase in cost per drill per day over the same items on the other two jobs on this work.

In the above tabulation of costs no account has been taken of contractors' overhead charges, superintendence, organization, or preparatory, repairs, insurance, accidents, charities, legal, or medical expense, etc.

TIME STUDY

Linear Feet Drilled, 34; Rock, Bastard Slate; Condition of Rock, Seamy and Badly Shaken in Places from Previous Blasts

	No. of Obs.	Min.		Mean.		Max.		Total Time.		Time Consumed Per Cent of Total Time.
		Min.	Sec.	Min.	Sec.	Min.	Sec.	Min.	Sec.	
Drill cutting	17	3	00	11	40	21	15	198	20	44.7
Raising drill	17	00	05	00	43	1	15	12	10	2.7
Loosening chuck	17	00	05	00	15	0	40	4	20	1.0
Removing bit	17	00	05	00	20	0	40	5	30	1.2
Putting bit in hole	14	00	10	00	31	1	00	7	20	1.6
Inserting bit in chuck	14	00	05	00	17	0	40	4	00	0.9
Tightening chuck	14	00	05	00	17	1	00	4	00	0.9
Getting started	14	00	05	00	13	1	20	3	05	0.7
Cycle totals	......	3	40	14	16	27	50	238	45	53.7
Shifting drills and getting started	2	..	..	47	18	..	..	94	35	21.3
Miscellaneous delays	3	..	..	..	..	..	..	111	15	25.0
Totals	......	..	..	..	..	..	..	444	35	100.00

(1) The cutting speed was 0.172′ per min.

(2) Ratio of cutting time to total time was 0.447.

(3) Ratio of idle time to cycle time was 0.863.

The large amount of idle time here was due to the bit getting fast in the rock several times, due to the rock's seamy nature.

James A. Hart Co., Columbia, N. J. Sec. 7 of the D. L. & W. cut-off has been contracted for by Smith, McCormick & Co., who have sublet part of their work to James A. Hart Co. of New York. Smith, McCormick & Co. are doing the bridge work over the Delaware, while Hart Co. have the grading work. At the present time[1] there are 14 drills at work, operated by steam furnished by two boilers of 125 B.H.P. each. Each boiler takes care of 7 drills, and it has been found by experience that the addition of one more drill impairs the efficiency of the other 7. The drills employed are the Ingersoll-Sergeant type F24.

Material being worked, dolomite, or hard limestone.

Drill Data. Ingersoll-Sergeant drill.

3½-inch piston.

6-inch stroke

---

[1] December, 1909.

FIG. 61.—Columbia, N. J.

FIG. 62.—Columbia, N. J.

Feed 2′9″, but use about 2′6″.
U chuck.
Pressure at boiler, 140 lbs.
Strokes, 350 per min.

When moved, the drill cylinders and slides are removed from their tripods and the cylinders from the slide. In this way two men can shift a drill from one position to another.

FIG. 63.—Columbia, N. J.

Bits are very irregular in size, due to breaking, repointing, etc.

Eight changes of steel will drill a 20′ hole, $2\frac{1}{2}$′ change.

Starting bits are made of $1\frac{5}{8}$″ material with $3\frac{1}{2}$″ points.

Length, Feet.	Material, Inches.	Point, Inches.	Length, Feet.	Material, Inches.	Point, Inches.
Starter	$1\frac{5}{8}$	$3\frac{1}{2}$	$12\frac{1}{2}$	$1\frac{1}{4}$	$2\frac{3}{4}$
5	$1\frac{5}{8}$	$3\frac{5}{16}$	15	$1\frac{1}{4}$	$2\frac{9}{16}$
$7\frac{1}{2}$	$1\frac{5}{8}$	$3\frac{1}{8}$	$17\frac{1}{2}$	$1\frac{1}{4}$	$2\frac{3}{8}$
10	$1\frac{5}{8}$	$2\frac{15}{16}$	20	$1\frac{1}{4}$	$2\frac{3}{16}$

Kind of point +.

Five men carry steel back and forth from drills to blacksmiths.

Tempered till file will not touch.

Sharpened by hand with aid of a smoother.

No jets used, helper pours water into the hole.

Holes 20′ deep; diameter 4½″ at top. Spaced 7′ laterally; 7′ longitudinally.

Cleaned by means of a bailing device, similar to the one described on the work of Reiter, Curtis & Hill. (See Fig. 66.)

Holes are drilled straight down.

Rock is dolomite, a hard limestone, solid, and offering a good face for drilling.

Thirty to forty holes shot per blast.

Dupont powder used.

Sticks 1¼″×8″, ½ lb., 60%.

Charge to spring holes, 4 sticks.

Regular charge about 100 sticks.

Blasting machine used to explode charges.

Number of drills at work, 14.

Boilers, Godfrey Keel and Howard W. Read. Each 125 B.H.P. at 140 lbs. gauge pressure.

Feed pipes are not over 400′ long.

Steam main from boiler, 2″, leads to a T from which separate 1″ lines are laid for each drill. The flexible connection for each drill from the end of the 1″ pipe is Mulconroy hose, costing 65 cts. per yard.

Job to be finished August, 1911.

Ten hour shift; one shift per day.

Following is the drilling force at work on the day of the investigation.

STANDARD BASIS OF COSTS

14 drillers........ at	$2.50 =	$35.00	2 firemen........ at	$2.00 =	$4.00
14 drillers' helpers at	1.75 =	24.50	1 pipeman....... at	2.00 =	2.00
5 nippers........ at	1.50 =	7.50	1 pipeman's helper at	1.50 =	1.50
2 blacksmiths..... at	3.00 =	6.00			———
2 " helpers at	1.75 =	3.50	Drilling total...		$84.00
			6 powdermen.... at	$2.00 =	$12.00

Superintendence. One general foreman and 2 foremen, one for each gang of drillers. Each of these foremen also had

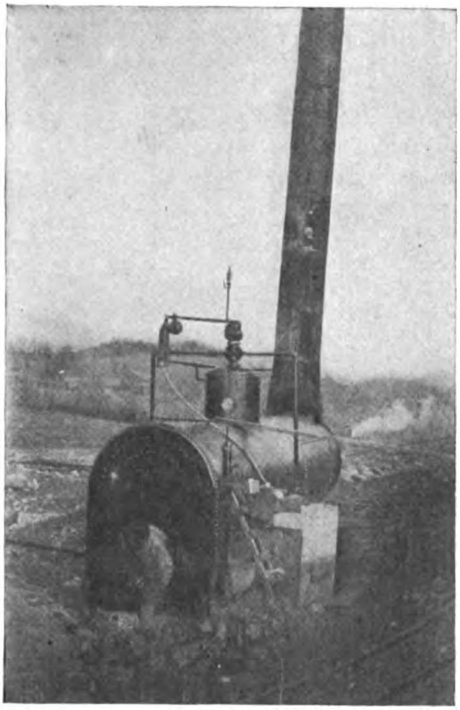


FIG. 64.—Steam Boiler.

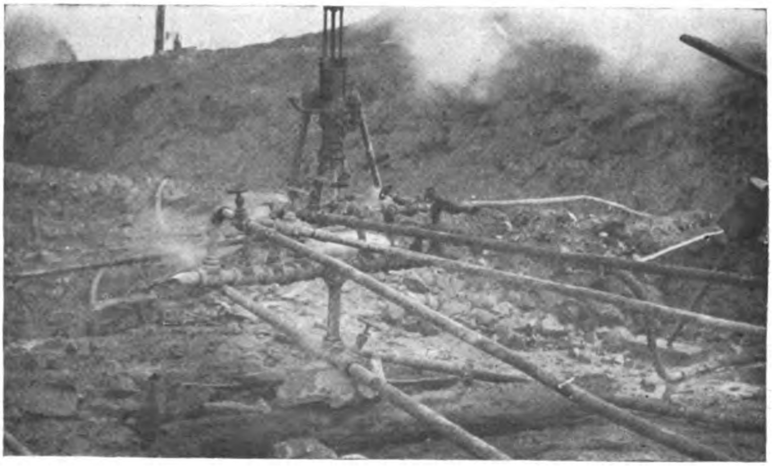


FIG. 65.—Steam Pipes.

charge of the blasting work. One timekeeper and one bookkeeper attended to the office work.

Interest and depreciation on drilling plant, valued at $6560, at 2% per working month = $5.05 per day (1 shift).

Moving drill from hole to hole and getting started, required

FIG. 66.—Bailing Holes.

9.2% of the total observed time, costing 9.2% of the drilling wages, as above, or 55 cts. per drill per day.

Oil, 4 gals. per day (14 drills), or 2.28 pts. per drill per day.

Coal, 5 tons ($3.10 to main line plus 10 cts. switching charge plus 75 cts. haul, per ton), 715 lbs. per drill per day.

The following figures for performance, oil and repairs were obtained from the office of the contractor and are used with his permission:

DRILL PERFORMANCE

Date.	Number of Drills.	Lineal Feet Drilled.
December 1, 1908	11	449
" 2, 1908	13	522
" 3, 1908	14	581
" 4, 1908	14	526
" 8, 1908	16	612
" 9, 1908	12	412
Total	80	3102
Average	13⅓	517=38¾'per drill day

FIG. 67.—Blowing Out Holes.

REPAIRS. Putting 9 drills in shape at the beginning of the present work, $1100. Repairs on 14 drills since that time, 13 months (Oct. 1, 1908–Dec. 1, 1909), $695.62. These two items are equivalent to 38 cts. per drill per day.

On one of the days of the investigation the observed drill did 37½′ in 8 hrs., 41 min., 40 sec., and would do 2½′ more that day, making 40 lineal feet; 13 other drills at the rate they were working would do 465′, making a total of 505′ for the 14 drills, or 36′ per drill per day of 10 hours.

Based on the office data the performance per drill day was 38¾′ per drill per day. Combining office data and observed data, we have

Working time, 7 days.
Drill days, 94.
Average number drills, 13$\frac{3}{7}$.
Lineal feet per drill per day, 38½.

Cost of Drilling and Loosening in Dolomite, or Hard Limestone. Based on the above performance and drill data on this job, heretofore given, the following costs per lineal foot drilled and per cubic yard loosened have been deduced:

515½ lin. ft. drilled by 13$\frac{3}{7}$ drills in 1 day.
Equivalent to 500 lin.ft. drilled by 13 drills in 1 day.

The spacing of the holes being 8′×8′, the corresponding cubic yards loosened $= \frac{500 \times 8 \times 8}{27} = 1185$.

Dynamite, 60%, 1250 lbs. or 750 lbs. nitroglycerine, = 0.633 lb. nitroglycerine per cu.yd. = 1.5 lbs. per lin. ft.

STANDARD BASIS OF COSTS

Force.	Rate.	Amount.		Cost per Lin. Feet, Cents.	Cost per Cu.yd., Cents.
13 drillers	$2.50	$32.50			
13 drillers' helpers	1.75	22.75	$55.25	11.05	4.66
5 nippers	1.50	7.50			
2 blacksmiths	3.00	6.00			
2 blacksmiths' helpers	1.75	3.50	17.00	3.40	1.43
2 firemen	2.00	4.00	4.00	0.80	0.34
1 pipeman	2.00	2.00			
1 pipeman's helper	1.50	1.50	3.50	0.70	0.29
Total labor (drill)	....		$79.75	15.95	6.72
Coal, 5 tons	3.50	17.50			
Oil (104 gals. per mo., 14 drills)	0.30	1.20	18.70	3.74	1.58
Total drilling cost	....		$98.45	19.69	8.30
6 powdermen	2.00	12.00	12.00	2.40	1.01
25 exploders	0.03	0.75	0.75	0.15	0.06
Dynamite, 1250 lbs., 60%	0.12	150.00	150.00	30.00	12.70
			$261.20	52.24	22.07
Int. and dep. on drills and boilers at 2% working month	....		5.05	1.01	0.43
			$266.25	53.25	22.50

In the foregoing tabulation of costs, no account has been taken of overhead charges, superintendence, repairs, interest, depreciation, storage, organization, or preparatory charges, charity, accidents, legal, medical expenses, etc.

Lineal feet drilled, 37½. Rock, dolomite, hard limestone. Condition, solid.

TIME STUDY

	No. of Obs.	Min.		Mean.		Max.		Time.		Consumed Time. Per Cent Total Time.
		Min.	Sec.	Min.	Sec.	Min.	Sec.	Min.	Sec.	
Drill cutting............	15	11	50	22	43	40	05	340	40	65.4
Raising drill............	15	00	15	00	46	2	40	11	30	2.2
Loosening chuck........	15	00	05	00	11	00	20	2	45	0.5
Removing bit...........	15	00	05	00	48	2	00	8	45	1.7
Getting bailer..........	12	00	10	00	20	00	40	3	55	0.8
Bailing hole............	12	00	30	1	00	2	35	12	05	2.3
Putting bit in hole......	14	00	05	00	20	1	10	4	45	0.9
Inserting bit in chuck . . .	14	00	10	00	20	00	35	4	45	0.9
Tightening chuck.......	14	00	10	00	17	00	40	3	55	0.7
Getting started.........	14	00	05	00	07	00	15	1	40	0.3
Cycle totals............	......	13	25	26	52	51	00	394	45	75.7
Mucking out...........	1	..	..	..	..	..	..	61	00	11.7
Shifting drill and getting started..............	2	..	..	24	07	..	..	48	15	9.2
Miscellaneous delays	5	..	..	..	..	..	..	17	40	3.4
Total...........	......	..	..	..	..	..	..	521	40	100.0

1. The cutting speed was 0.11′ per min.
2. Ratio of cutting time to total time was 0.654.
3. Ratio of idle time to cycle time was 0.321; mucking out, shifting drills from one hole to another and miscellaneous delays being called idle time.

CHAPTER VI

DRILLING ON LAND—*Continued*

Brownell Improvement Co., Thornton, Ill. The product of this company is crushed stone. The quarry is composed of hard, crystalline limestone, fissured on top, very solid on bottom. The process of preparing this stone for market consists in loosening, loading and crushing. The loosening is accomplished by means of drilling and blasting; the loading by two 95-ton Bucyrus shovels, and the crushing by McCully crushers. In front of each shovel are 4 Ingersoll drills, drilling top holes 26′ deep, operated by air at 120 lbs. from a single phase compressor, capacity 1200 cu.ft. per min. Top holes are spaced 6 to 6½′ longitudinally and are laterally 8 to 10′ from the unbroken face. In the rear of one of the shovels are 4 drills engaged in drilling "toe" holes from 10 to 14′ in depth. Two toe holes are drilled, one at about 15° and one at 60° with the vertical, the former being 2½′ in front of the latter and 6′ along the toe. Besides these drills, each shovel has a small one-man drill for quick service in breaking up large rocks that cannot be sledged. The rock is somewhat porous in places and in others as solid as feldspar. The top holes are each charged with 75 lbs. of 60% dynamite in the form of sticks 3½″×8″ of 4¼ lbs. This is equivalent to 12′ of dynamite per hole. The other 14′ of hole is filled and tamped with crushed stone. Based on the same ratio of depth to dynamite toe holes would be charged with 35 lbs. of 60% dynamite.

The shovels load into 5-yd. cars weighing about 4 tons and costing $150. Trains are made up of 10 of these cars and 35-ton dinkeys haul the cars from shovel to crusher. The product of the McCully No. 10 crusher is carried by an 18″ conveyor upward to a 3½″ screen near the roof, thence into a bin. The contents of this bin are crushed finer by 3 smaller McCully crushers.

FIG. 68.—Drilling Toe Holes—Thornton Quarry.

FIG. 69.—Loading Toe Holes—Thornton Quarry.

Belt conveyors, smaller machines, bins and screens form the rest of the crushing plant. Altogether there are 9 crushers in the plant and 7 different sizes of stone are produced and marketed.

DRILL DATA. Ingersoll drills, 13 D.F.A.

Feed, 2′.

U chuck.

325 strokes per minute.

Drills lifted from one hole to another by two men.

Holes two kinds, top and toe.

Diameter of starting bits, top $5\frac{5}{16}$, toe $4\frac{1}{8}$″.

Diameter of finishing bits, top $4\frac{1}{2}$, toe $3\frac{3}{8}$″.

Shape of bit, top z, toe +.

Steel, 2′ to 26′, in 2′ sections.

Octagonal section, top $1\frac{3}{8}$″, toe $1\frac{3}{4}$″.

Top bits handled by two men with hooks.

Toe bits handled by one man with hooks.

Bits tempered very hard with fish oil.

Sharpened by hand.

Depth of top holes, 26′, toe holes 10 to 14′.

Longitudinal spacing of each, 6 to $6\frac{1}{2}$′.

Lateral spacing, top 8 to 10′, back from unbroken face. Toe holes, a 15° hole $2\frac{1}{2}$′ in front of a 60°.

Cleaned by hand pump.

Toe holes, front row, make 15° angle with vertical. Rear row 60° with vertical.

Rock is a crystalline limestone, fissured at top, porous in some places and in others solid as feldspar.

Holes shot per blast, top 60, toe 75.

Powder, forcite.

Sticks, $3\frac{1}{2} \times 8$″; $4\frac{1}{4}$ lbs.

Charge, 75 lbs.

Fulminate of mercury battery used.

Blasting gang, 3 loaders, 6 tampers, foreman and assistant foreman.

Fourteen drills (2 drills used infrequently).

Single-phase compressor.

Capacity of compressor 1200 cu.ft. per min.

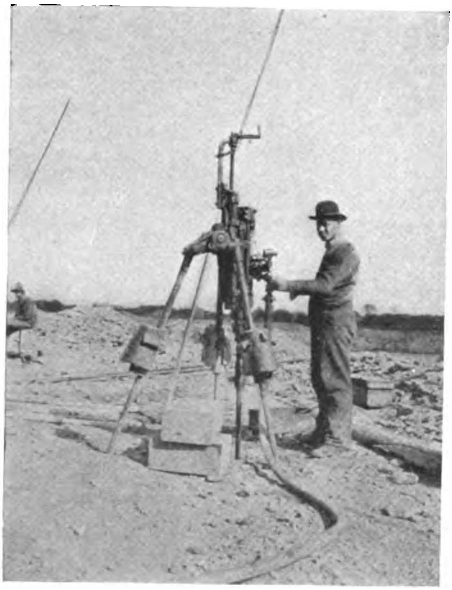


FIG. 70.—Drilling Top Holes—Thornton Quarry.

FIG. 71.—Drilling Top Holes—Thornton Quarry.

Air pressure at tank, 120 lbs.

Length of feed pipe, 1500′.

Diameter of feed pipe, 4″.

Branch pipes, 2″ in diameter.

Repairs and Drill Supplies (taken from office record with permission of superintendent). 14 drills, January 1, 1909, to September 30, 1909, 9 months.

$3058.47 during 3276 drill days.

Repairs, etc., per drill day, 93 cts.

Interest and depreciation on drilling plant estimated at $7700 at 2% per working month = $5.90 per day.

Drill performance, taken from office record, 7 days, 11 drills, 2258 lin.ft., or 29.3′ per drill day.

Moving drill from hole to hole and getting started required 4.6% of the total time, costing 4.6% of drilling wages, or 28 cts. per drill per day.

Length of shift, 10 hrs.

One shift per day.

Drillers work in pairs and are paid by the foot, 6 cts. per ft. for first 30′ of small holes, and 7 cts. a ft. for all over 30′. Large holes, 8 cts. a ft.

A crew consists of two drillers and one helper, the helper receiving 17½ cts. an hour.

Stone sells for from 75 cts. to $1.25 per cu.yd.

Work of smith is to sharpen drills and make odd repairs.

Coal estimated at 6 tons per day for 12 drills = 1000 lbs. per drill per day.

Coal cost $1.70 delivered.

Drills. On work, 10, 13 D.F.A.'s.
2, F 24's.
2, B 32's.

Oil at compressor, estimated at 3 gals. per day, or 2 pts. per drill per day.

The following costs per lineal foot drilled and per cubic yard loosened are based on an average performance of 2258 lin.ft. in 7 days, 11 drills at work. The cubic yards corresponding have been deduced as follows: Top holes 26′ in depth, being

FIG. 72.—Drilling Top Holes—Thornton Quarry.

FIG. 73.—Loading Top Holes—Thornton Quarry.

placed from 8 to 10′ back from the unbroken face, it is assumed that the rock will break back 14′ from the face. Toe holes average 12′ in depth and both toe holes are spaced about 6′ longitudinally. Therefore for each toe hole and top hole, or $26+12=38$ lin.ft. of drilling, the cubic yards loosened, will be, $\frac{26\times14\times6}{27}=81$ cu.yds., and for 2258 lin.ft. drilled, 4820 cu.yds. would be loosened. Dynamite being 75 lbs. per top hole and 35 lbs. per toe hole for each 38′ of drilling, there are used 110 lbs. of 60%. For 2258 lin.ft. 6540 lbs. will be used.

On the daily basis the above performance reduces to the following: Lineal feet 322½, cu.yds. 688½, dynamite 934 lbs. of 60%, or 560.4 lbs. of nitroglycerine = 0.815 lb. per cu.yd. loosened.

No account has been taken of contractor's overhead charges, superintendence, organization or preparatory, legal, medical, accidents, repairs, charities, etc.

Lineal feet, 322½; cubic yards, 688½; 60% dynamite, 934 lbs.; drills, 11; material, crystalline limestone.

A cycle for each 2′ of hole is here made up of the two items of drill working and changing steel. The time of "drill working"

TIME STUDY

Lineal feet drilled, 34. Total working time, 5 hrs. 32 min. 50 secs. Kind of rock, hard limestone.

	No. of Obs.	Min.		Mean.		Max.		Time.		Consumed Time, Per Cent of Total
		Min.	Sec.	Min.	Sec.	Min.	Sec.	Min.	Sec.	
Drill working	17	6	43	13	10	18	00	223	59	67.5
Changing steels	15	1	35	3	56	9	30	59	08	17.7
Cycle totals	......	8	18	17	06	27	30	283	07	85.2
Moving drill over to new position and setting up.	2	..	..	..	..	..	..	15	30	4.6
Miscellaneous delays	9	..	..	..	..	..	..	34	13	10.2
Total	......	..	..	..	..	..		332	50	100.0

Cutting speed in feet per cutting minute, 0.152.

Ratio $\frac{\text{cutting time}}{\text{total time}}=0.675$. Ratio $\frac{\text{idle time}}{\text{cycle time}}=0.174$.

STANDARD BASIS OF COSTS

Force.	Rate.	Amount.		Cost per Lin. Foot, Cents.	Cost per Cu.yd., Cents.
11 drillers	$2.50	$27.50			
11 driller's helpers	1.75	19.25			
			$46.75	14.49	6.80
2 smiths	3.00	6.00			
2 smith's helpers	1.75	3.50			
3 nippers	1.50	4.50			
			14.00	4.34	2.03
1 engineer	3.00	3.00			
1 fireman	2.00	2.00			
			5.00	1.55	0.73
1 pipeman	2.00	2.00	2.00	0.62	0.29
Total labor drilling			$67.75	21.00	9.85
Coal, 6 tons	$3.50	21.00			
Oil at 1 qt. per drill, per gal	0.30	0.825			
Oil at 3 gal. compressor, per gal	0.30	0.90			
			22.72	7.05	3.30
Total drilling			$90.47	28.05	13.15
3 powdermen	2.00	6.00			
6 tampers	1.50	9.00			
			15.00	4.66	2.18
934 lbs. of 60% dynamite	0.12	112.08			
20 exploders	0.03	0.60			
			112.68	35.00	16.36
Total drilling and blasting			$218.15	67.71	31.69
Int. and dep. on 11 drills, comp. and boiler capacity, estimated at $7700, at 2% per working month			5.90	1.80	0.86
Total			$224.05	69.51	32.55

is the actual time of cutting, i.e., the time between the turning on of the air to start the drill and the time of turning off the air when the section of the hole is finished. The time "changing steel" is from the time when the air is shut off and the drill stopped until the air is turned on and the drill begins cutting. This "changing steel" includes the following items: Screwing up, loosening chuck, removing steel, bailing, inserting steel, and tightening chuck.

Duluth Crushed Stone Co., Duluth, Minn. The Duluth Crushed Stone Company operates a quarry at the end of 57th Avenue West, in West Duluth. The rock is a hard bastard granite in its natural bed in the side of the rock hill that rises from Duluth Harbor and follows the shore of Lake Superior east, and the St. Louis River west from Duluth. In many places the rock outcrops, and above the present quarry, rock is to be seen on the surface where no stripping will be necessary. The maximum depth of stripping is in no place over 3′, except where faults occur, and the average depth is not more than 1′.

The condition of the rock varies greatly in different parts of the quarry, and also in the same part of the quarry as the face is worked back. In some places the rock is absolutely solid without a check or irregularity in structure other than is ordinarily found in this kind of rock, while elsewhere it will be badly cracked and full of seams, with its entire structure irregular and badly broken up. This latter condition exists especially in the west end of the quarry.

The product of the quarry is crushed stone in sizes from dust to 2½″ and rubble of any size as ordered. The structure of the rock does not permit of its being taken out for dimension stone or of its being cut easily, although it could without doubt be worked into regular shapes if occasion arose. The stone company does not undertake to furnish such stone, however, and so makes no effort to quarry it.

Beside its regular output of crushed stone and crusher dust the quarry is at present filling two contracts for rubble. One of these is with the Great Northern Railroad, and calls for quarry run rubble up to 6″ size. This material is loaded into skips by hand and is raised by a locomotive crane and dumped into gondolas. The other contract is for furnishing quarry run rubble up to 10 tons size, the number and amount of blocks of the latter size being regulated by the demand of the purchasers of the stone. This stone is being used in the construction of a breakwater at the Superior Entry of the Duluth-Superior Harbor, and as the portion now being constructed is in shallow water the amount of 10-ton stones being shipped is about 50% of the total amount. The heavy stones are used for paving the surface of the breakwater.

At the present time the rock in the quarry is running so unevenly and is so seamy and broken up in its bed that it is extremely difficult to obtain the desired amount of 10-ton stones. For the rest of this contract nothing as small as a two-man stone is shipped, but only large blocks which are handled by the crane. All this material is loaded on cars by the crane, being chained and lifted.

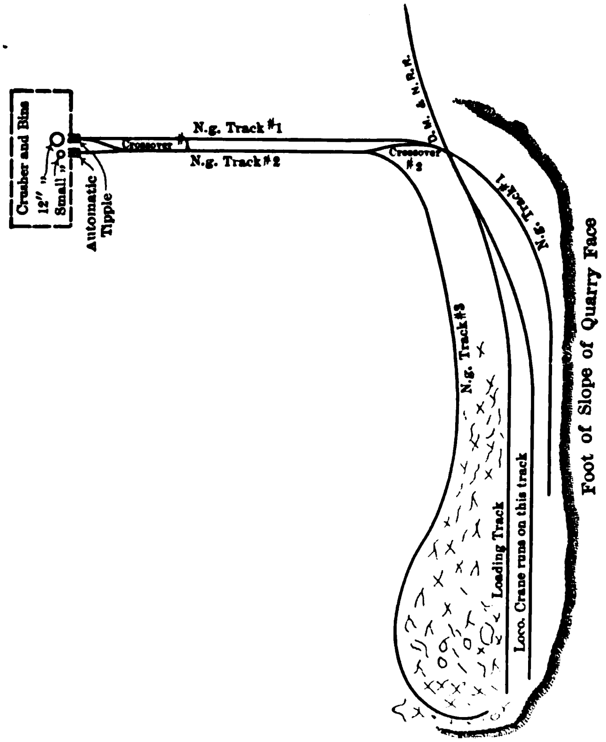


FIG. 74.—Duluth Crushed Stone Co., Duluth, Minn. Layout of Quarry and Tracks.

All material which is thrown down from the face of the quarry which is not used for the above contracts is sent to the crusher. The crusher takes 12″ rock, and anything larger than that is sledged to that size, and if too large to sledge is plug-holed with a hammer drill and shot.

The loading track for the crusher runs along the slope at the foot of the quarry face. The cleaning gang throws the stones down along this track and the loading gang throws them into the cars. The tops of these cars are about 30″ above the track, so that they can be loaded very easily. About 25 cars are placed on the loading track at a time and when these are loaded they are let down the track to the crusher in sections of three cars each, with one man handling a section. The loading track is on a slight grade down to the crusher, the grade being so slight that it is not visible to the eye.

Each car is provided with a brake, and one of the loading gang goes with the cars to brake them. While 6 or 8 men are thus engaged the rest of the men are busy piling up rock along the track for loading. The cars run to the crusher where they are dumped by an automatic tipple and then run back over a crossover to another track out of the way of the next load. As soon as all the cars have cleared the crossover (marked No. 2 on map, p. 134), they are drawn in sections of 3 or 4 cars from the narrow gauge track No. 2 to the main loading track by horses, and are returned to the quarry for loading. Two horses are used for this purpose, each horse drawing 3 to 4 cars. As soon as the cars are loaded they are again let down to the crusher.

In loading with the locomotive crane two methods are used. As before stated, the material for the railroad company is loaded into skips and raised by the crane and dumped into gondolas. The heavy stone of the breakwater is all loaded by chaining. The tracks are so arranged that flat cars can be placed beside the crane and the blocks swung onto the cars. The crane was made by the Industrial Works, Bay City, Mich., and has a capacity of 5 tons at 35′ radius and 17 tons at 12′ radius without outriggers. With the outriggers it holds 7 tons at 35′ and 30 tons at 12′ radius.

The drilling in the quarry is not very regular. There are generally at least two drills working. One may be working above the quarry and one below on the face, or both may be above. One is kept above all the time, and sometimes an extra one is put in on the face, making two there. The average drill performance is about 75′ per day when drilling above the quarry, where 24′ holes are drilled. On the day on which the time study was made No. 1 drill did a total of 70′. On the previous day 14′ were drilled before the time study began. No. 2 drill was working in the bottom of a fault, and was only doing 22′ holes. The total was 66′, but 1½ hrs. were used in getting the drill to the top from the bottom of the quarry and in setting up after cleaning out the fault. Each helper acted as his own nipper.

The plug-hole drilling in the quarry is done with three small hammer drills, one Ingersoll-Rand and two Murphy. There was no opportunity to observe the working of these drills, but the foreman said they never did less than 80′ a day, and generally did about 100′. The holes are from 8 to 12″ deep. These hammer drills are fed from 1″ lines run over the face of the quarry from the 2″ main above. These lines are often as long as 130′, and the air hose is sometimes 20′, making a very long line.

DRILL DATA. Rand "Little Giant" drills, 3¼″ piston.

Stroke, 6¾″ (the piston could be moved 7⅝″).

Feed, 2′ (11 steels were used in drilling 24′).

U chuck.

Strokes, 300 plus, per min.

When necessary to move from hole to hole the drill was swung to a horizontal position on the tripod, the starting steel was placed in the chuck, the feed screw raised to its extreme position, and then drill and tripod, without weights, were raised on the shoulders of driller and helper and carried.

Bits, 2½″ starting; 1″ finishing.

Points, + for first 10 bits, full for finishing.

Steels, 2′ 6″ to 24′ 8″.

Steel sections, first four, 1½″ hexagon; next four, 1¼″ hexagon; last three, 1″ hexagon, jumped at ends for chuck.

Handled by hand; helper acts as nipper.

Temper medium for all but last three steels, which were hard.

Hand sharpening.

No jets used.

Holes, 24′ maximum.

Holes, 2½″ at top.

Longitudinal spacing, 4 to 6′; not regular, but depending upon lay of rock.

Lateral spacing, 1st row back from 6 to 15′ from edge of face; 2d row from 7 to 10′ from first. This all depended upon the rock.

Cleaned by hand pump.

Holes vertical.

Rock, hard bastard granite.

Condition, natural bed under 12 to 36″ stripping; in some places solid and in others seamy and slightly checked.

Holes shot, depends entirely upon work and kind of stone wanted.

Ætna Powder Co.'s dynamite.

1×6″ sticks, about ¼ lb.

From 4 to 6 sticks of 75% put in bottom and 10 to 15 sticks 60% put on top of those.

Lion brand double strength exploder.

Blasting gang, 1 powderman and 2 helpers. This is not a regular gang, as shots are irregular and gang is needed only before a shot.

Number of drills, 3 maximum, only 2 ordinarily working.

Pressure 93 lbs. (gauge).

Compressor, Rand "Imperial," type 10.

Compressor capacity, 537 cu.ft. free air per min.

Seventy-eight pounds pressure at tank.

Feed line, 3″ pipe leads from the compressor to the air reservoir, a distance of about 10′. The tank is 10×4′. From this runs a 2″ main about 900′ along the hillside to the top of the quarry, and along the top about 20 to 30′ from the edge; 1″ branches run from this at intervals of 16 to 30′. If drills are working on top of the quarry these 1″ branches are about 16″ long, and the air hose fastens to them direct; if working in the quarry the 1″ leads may be 130′ long, reaching down over the face, which is 90′ high.

Size: Quarry has a face 90′ high and about 400′ long. The entire face is 500′ long, but earth slopes are left at the ends.

Shifts, 10 hrs.

One drill shift; 2 loading with crane.

Force.	Standard Wages per day.	Force.	Standard Wages per day.
2 drillers	$2.50	1 powderman loading plugs	$2.00
2 drillers' helpers	1.75	8 loading with crane	2.25
4 hammer drillers	2.00	1 smith	3.00
36 cleaning face and loading	2.00	1 smith's helper	1.75
1 engineer on crane, 2 shifts	3.00	2 drivers	1.50
1 fireman on crane, 2 shifts	2.00		

Interest and depreciation on the two working piston drills and necessary compressor and boiler capacity valued at $1200, at 2% per working month = $0.92 per day (2 drills).

Coal, 1000 lbs. per drill per day.

Oil, 3 pts. per drill per day.

General Notes. The layout of the air system has been given in the list of drill data, but a word more may be said about the compressor. This is a Rand Drill Co. Imperial type 10, duplex steam and compound air. The steam cylinders are 10×14 and the air 16×14 and 10×14. The speed is 144 R.P.M. The rated capacity is 537 cu.ft. free air per minute. The pressure at the compressor is 78 lbs. and the steam pressure is 105 lbs. (gauge).

The blasting of plug holes is done at noon and after six o'clock at night. The blasting of the rock from the top is done as needed. In one blast one evening 36 holes were shot. These holes were loaded as given in the drill data and exploded in the usual way. The blast was for the purpose of getting material for the breakwater contract, but owing to the seamy condition of the rock at that particular point in the quarry but few large blocks were thrown down, the foreman saying that there were only five in sight which would be in the ten-ton class.

When a blast is made from the top, heavy 12×12″ timbers are laid along each rail on the quarry side to prevent the rails being broken and twisted by the falling rock. Several sections of the crane track are also removed and carried some distance. The crane lifts these sections and moves back the desired distance with them. It also moves narrow gauge track No. 1 if the blast is to be in the middle of the quarry.

The crane and the loading gang on the heavy material were working a night shift, while only one shift was worked in the rest of the quarry. This was necessary, because the contractors on the breakwater worked at night and in two shifts could use more than the quarry could get out in one.

With regard to the time study on the two drills working above the quarry, No. 2 drill had been working on the face of the quarry previous to that day. It took three men, the driller, his helper, and one extra man 1 hr. 5 min. to carry the drill and steels from the quarry to the top. The longer steels were already at the top, not having been required below. The work for this drill was directly in line of a large fissure which was filled with earth and disintegrated rock to the depth of from 2 to 3′. The holes had to be mucked and the drill set up. This required 30 min. on the part of the driller and helper. They finally started their drill at 8:40. Drill No. 1 started a new hole at the same time, so observations were made on that drill from the start of the new hole. This drill had finished 14′ of the previous day's hole and moved and set up in 1 hr. 40 min.

No. 2 drill lost 31¾ min. waiting for the drill helper. Each helper acted as his own nipper, and when this driller finished a steel before his helper returned he would wait, making no effort to remove the steel or pump the hole.

When drilling his first hole the driller on No. 2 drill let his helper run the drill and he mucked the next hole. During the second hole he did not do this, and in consequence time had to be taken off for mucking. The third hole was finished at 5:27, and the driller spent the rest of the day mucking, but he was really "soldiering," so as not to start a new hole before quitting time.

No. 1 drill had much trouble with its first hole. The steel stuck constantly and time and again the tripod had to be loosened to allow the steel to find an easy position in the hole. The 6′ steel was stuck fast for 5 min., and all efforts to move it were useless until a long-handled Stilson wrench was put on and hammered with a heavy stone hammer. Cast iron was used in this hole and in the others as well.

At one time when the helper was away the driller on No. 1 took out the steel and pumped his hole. It took 3 mins. to do this alone, against an average of 2.19 mins. for two men. This was an 8′ hole; it would have been almost impossible for one man to pump the deep holes.

In working the quarry a large amount of loose rock, the smaller sizes of which are about one-man size, has been left on the bottom between the standard gauge loading track and narrow gauge track No. 3 (see map, p. 134). This was done so that if a blast covered the main narrow gauge track No. 1, the crusher could still be supplied by the small cars loaded on narrow gauge track No. 3.

There is beside the 12″ crusher a small crusher which crushes the pieces rejected by the 2½″ screen at the large crusher. This small crusher is also provided with a tipple and cars from the quarry can be dumped there. This is seldom done, as even when the cars carry only the sweepings from the quarry they are dumped into the large crusher with the rest.

Cost of Drilling. Based on the foregoing performance of the two drills observed, namely, 70 and 66′ respectively for the day of 10 hrs., the following costs have been deduced:

No account has been taken of contractor's overhead charges, superintendence, storage, repairs, preparatory costs, insurance, charity, accidents, legal, medical expense, etc.

Lineal feet drilled, 136. Kind of material, bastard granite. Number of drills, 2. 7½ lbs. of 75% and 18½ lbs. of 60% dynamite = 16.7 lbs. of nitroglycerin, or about 0.123 lb. per lineal foot of hole.

	Standard Basis of Costs.			
	Rate.	Wages.		Cost per Lin. Foot. Drilled. Cents.
2 drill runners	$2.50	$5.00		
2 drill runners' helpers	1.75	3.50		6.25
			$8.50	
2/6 engineer at compressor	3.00	1.00		
2/6 firemen	2.00	0.66		
			1.66	1.22
2/6 blacksmith	3.00	1.00		
2/6 blacksmith's helper	1.75	0.58		
			1.58	1.16
4 men 1$\frac{1}{12}$ hrs (carrying machine up to top)	0.17½	0.76		
			0.76	0.56
Total drill labor	....		$12.50	9.19
1 ton coal	3.50	3.50		
Oil 6 pts., per gallon	0.30	0.22		
			3.72	2.73
Total drilling	....		$16.22	11.92
1 powderman	2.00	2.00		
			2.00	1.47
26 lbs. of dynamite	0.12	3.12		
			3.12	2.29
Total	....		$21.34	15.68
Int. and dep. on the 2 piston drills at 2% per working mo. and necessary compressor and boiler capacity = $0.92 per day or 0.67 cts. per ft. drilled	....			0.67
Total	....			16.35

DRILL No. 1

Material, bastard granite. Lineal feet, 56. Total time of observation, 8 hrs. 13 min. 10 sec.

	No. of Obs.	Min. Min. Sec.	Mean. Min. Sec.	Max. Min. Sec.	Consumed Time. Min. Sec.	Consumed Time. Per Cent Total Time.
Actual cutting	26	4 20	12 14	25 20	318 45	64.6
Taking steel out and getting pump in	26	0 35	1 20	1 55	34 30	7.0
Pumping and cleaning	19	1 05	2 19	4 35	44 55	9.1
Putting steel in	23	0 50	1 21	1 55	31 00	6.3
Cycle totals	......	6 50	17 14	33 45	429 10	87.0
Setting up and adjusting	......	.....	......	......	30 05	6.1
Drill stuck or putting in cast iron	......	.....	......	......	20 40	4.2
Miscellaneous delays	......	.....	......	......	13 15	2.7
Mucking	......	....	....	....	....	....
Total	......	.....	......	......	493 10	100.0

Cutting speed in feet per cutting minute............ 0.175
Ratio cutting time to total time.................. 0.646
Ratio idle time to cycle time...................... 0.149

DRILL No. 2

Lineal feet, 66. Total time of observation, 8 hrs. 14 min. 30 sec.

	No. of Obs.	Min. Min. Sec.	Mean. Min. Sec.	Max. Min. Sec.	Consumed Time. Min. Sec.	Consumed Time. Per Cent Total Time.
Actual cutting	30	4 20	7 58	16 15	239 35	48.5
Taking steel out and getting pump in	30	0 45	1 31	3 00	45 35	9.2
Pumping and cleaning	26	1 00	2 24	3 00	62 30	12.6
Putting steel in	27	0 40	1 07	1 50	29 45	6.0
Cycle totals	......	6 45	13 00	24 05	377 25	76.3
Setting up and adjusting	....	.....	......	......	41 05	8.3
Drill stuck or putting in cast iron	......	.....	......	......	......	...
Miscellaneous delays	......	.....	......	......	31 45	6.4
Mucking	......	.....	......	......	44 15	9.0
Total	......	.....	......	......	494 30	100.0

Cutting speed in feet per cutting minute............ 0.275
Ratio cutting time to total time.................. 0.485
Ratio idle time to cycle time...................... 0.310

CHAPTER VII

DRILLING ON LAND—*Continued*

Contract No. 25 on New York Water Supply, Catskill Aqueduct. Contract No. 25 on the Catskill Aqueduct of the New York water supply is being executed by Blakeslee & Sons, of New Haven, Conn. This contract extends from the lower end of contract No. 24, just below the Croton Lake Siphon, to Millwood. Beside the usual cut-and-cover aqueduct the contract includes the Croton Tunnel about 3000′ long, and the shorter Chadcayne Tunnel. Both of these are grade tunnels, and there are no siphons or pressure tunnels on the contract.

The work in the Croton Tunnel is being carried on in three shifts of 8 hours each. A 7′ heading is being driven the full width of the required cut, and is being followed at a distance of about 50′ by the bench, which completes the full required section. This required section has a height of 19′ 3″ on the center line. This provides for a 17′ clear headroom in the completed concrete section and a 5″ concrete base, 9″ cap, which must be free from rock, and 13″ into which rock may project to some extent. The total width of the excavation is 16′—4″ at a point 6′—10⅝″ from the finished bottom, and this 16′—4″ provides for 13′—4″ clear concrete tube, 5″ clear concrete on each side, and 13″ of concrete on each side into which rock may project.

The rock being excavated is bastard granite of very even quality. There are few cracks and seams and the rock is very free from water. So little water comes in that about half the time it is necessary to carry water into the heading for the purpose of cleaning the drill holes. When this is necessary, a man carries the water in a pail and pours it into a tub which is placed between the drill columns.

The drilling in the heading is done with four Ingersoll-Rand drills, type E 24, mounted on two drill columns. In the case observed these columns were set 30″ and 42″ to the left and right of the center line respectively. The columns were 8′ long and 5½″ in diameter. They were rigged with double screws. The upper drill on the column was mounted on a 22″ arm, and the lower drill was on a 36″ arm. All arms were supported by safety clamps.

When the highest holes in the heading were being drilled it was necessary to have some elevation from which the men could work. This was provided by running two heavy planks from the rough face of the heading to the muck pile which had been thrown up before the columns could be set. These planks were run between the columns, as the two upper drills were rigged on the inside of the columns.

The drilling of the heading was on the following system (Fig. 75): Three sets of holes were drilled, 6 "cut" holes, 6 "inner-round" holes, and 10 " outside-round " holes, making 22 holes in all. The outside-round holes are driven on the arc of a circle 14′ in diameter, and are spaced at almost equal distances from each other, about 30″ apart. The bottom holes of each series are at the same elevation, and run as close to the bottom of the heading as possible. The first, second and third holes on this bottom row are spaced about 30″ apart, while the distance between the lower cut holes is about 6′. The second cut holes from the bottom are closer together and the distance between the top cut holes is about 2′.

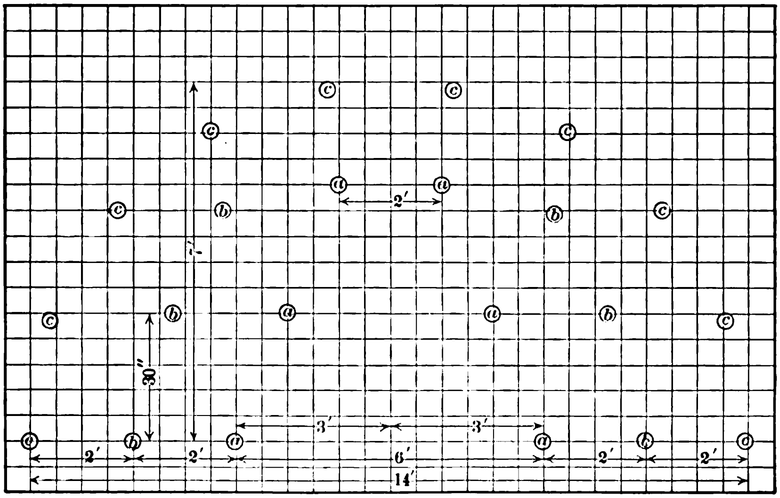
The two cut holes on the same level converge at the lower end, sometimes meeting. As a general thing it was attempted to have the end of one slightly above the end of the other. The bottom cut holes pointed down slightly while the others were nearly horizontal, the top holes having a slight downward pitch.

The inside-round holes converge very slightly toward their lower end and are nearly horizontal. The outside-round holes slope up and away from the center of the tunnel. The upper holes are drilled dry, but all the others are wet. They are watered by the driller or helper throwing water into them. This would, of course, be useless in the holes that pitch up.

All holes are drilled from one setting of the drill columns. The upper drills do five holes each round and the lower drills do six. A round requires from 6 to 8 hrs. to drill.

As soon as a drill finishes its last hole on a round, it is taken from the column arm, the arm is removed from the column, and if the other drill on that column has also finished its holes the column is taken down and the whole outfit is carried back over the bench and loaded on a flat car on the muck car track, to be carried out of the tunnel before blasting is done.

Arrangement of Holes in Heading



Holes marked ***a*** **are "cut" holes**
" " *b* " "inside-round" holes
" " *c* " "outside-round" "

Fig. 75.

The holes are all loaded before any of them are shot. The cut holes have from 8 to 10 sticks of 60% dynamite, and the inside- and outside-round holes have the same amount of 40%. When all are loaded the cut holes are connected and shot, each hole having an exploder. After the cut holes are shot the inner-round holes are connected, and if any of the cut holes are not totally shot what remains of them is loaded full and connected with the leads from the cut holes. After this second shot the outside cut holes are shot together with the ends of the inside cut holes which are left undestroyed. The leads to the blasting box are about 500′ long and the box is located just inside the portal. The current for exploding the blasts is taken from the mains which supply current to the tunnel and to the rest of this portion of the work.

There are no regular powdermen, the drillers, helpers and nippers all helping in the loading, blasting and consequent mucking. The time taken in loading the 22 holes is about 30 min. and for blasting 1 hr. The mucking then necessary before the drills and columns can be set up takes 3 hrs. on an average. The men so engaged comprise 4 drillers, 4 helpers, and 2 nippers, with 1 foreman for overseeing the work.

The deduced costs of blasting, powder, and mucking which follow have been based upon the above. The standard cost of drilling has been based upon the observed performance of 60′ in 16 and a fraction drill hours, or the equivalent of 2 drill days of 8 hrs. each.

Lineal feet drilled, 176. Cubic yards blasted, 22.8.

Dynamite per Blast.	Dynamite, lbs.	Nitroglycerin, lbs.	
6 cut holes at 9 sticks of 60% at ½ lb.	27	16.2	
6 inside round at 9 sticks of 40% at ½ lb.	27	10.8	
10 outside rounds at 9 sticks of 40% at ½ lb.	45	18.0	
Total	99	45.0	

Nitroglycerin per lineal foot drilled, 0.255 lb.
Nitroglycerin per cubic yard blasted, 1.97 lbs.

DRILL DATA:

Type of drill, Ingersoll-Rand, E 24; 8 drills, 4 on bench, 4 on heading.

Size of piston, 3¼″.

Length of stroke, 6½″.

Length of feed, 24″.

U chuck.

Drill moved by hand.

Bits, starting 2¾″, finishing, 2¼″.

Point shape, +.

Length of steel, 2′ to 10′ by 2′ increments.

Shank section, hexagonal.

Bit handled by hand by nipper.

Temper very hard.

Sharpened by smith by hand.

No jets used.

Depth of holes, 8′.

For spacing of holes, etc., see diagram, page 145.

Holes cleaned by throwing in water and then bailing out with bailer.

Rock, bastard granite.

Condition of rock, good.

Shooting of holes, 6 cut holes shot first, then 6 inside rounds, then, lastly, the 10 outside rounds. In each case all holes not fully shot are reloaded and shot on succeeding blast.

Dynamite used, 60% and 40% Forcite. Cut holes, 9 sticks at ½ lb. of 60%, others same amount of 40%.

The crew working in the heading is composed of 4 drillers, 4 helpers, 2 nippers, and a foreman. These men drill the 22 holes, then blast them and then muck out to get their drills going again.

The four drills are set up on two columns as heretofore mentioned.

Compressors, 2 Ingersoll-Rand, type 10.

Interest and depreciation on 8 drills (4 on bench and 4 on heading) and on compressors and boilers at $7315, at 2% per working month = $5.63 per day = $1.90 per shift = 24 cts. per drill per shift.

Superintendence: One general superintendent, 1 foreman per shift in heading and 1 assistant foreman per shift on bench. Moving drills from hole to hole, setting up on column, getting started (in heading), consumed 30% of the total observed time, costing 30% of drilling wages, or $1.72 per drill per shift.

Based on the observed performance of 60 lin.ft. in 16 and a fraction drill hours, the following costs in tunnel heading per lineal foot drilled have been deduced. To deduce the same items of cost per cubic yard loosened, it is necessary to know how many lineal feet have been drilled to loosen 1 cu.yd. This is done by dividing the lineal feet drilled for each shooting, or 22×8 or 176 by the cubic contents of the semicylinder, 7′ radius and 8′ deep, or $\frac{3.1416 \times 7 \times 7 \times 8}{2 \times 27}$ or 22.8 cu.yds. The desired ratio of lineal feet to cubic yards loosened is then 176 divided by 22.8 or 7.72. Therefore by multiplying the costs per lineal foot by 7.72, we can get the corresponding costs per cubic yard loosened.

DRILLING COSTS

Drill hours, 16. Lineal feet, 60. 1 cu.yd. = 7.72 lin.ft. Bastard granite.

Force.	Costs on Standard Basis.				
	Rate.	Amount.		Costs per Lin. Foot Drilled, Cents.	Costs per Cubic Yard Loosened, Cents.
2 drillers	$2.00	$4.00			
2 drillers' helpers	1.75	3.50			
			$7.50	12.50	96.5
¼ blacksmith	3.00	0.75			
¼ blacksmith's helper	1.75	0.44			
1 nipper	1.50	1.50			
			2.69	4.48	34.6
¼ engineer	3.00	0.75			
¼ fireman	2.00	0.50			
			1.25	2.10	16.2
Total drilling labor	....		11.44	19.08	147.3
1 ton coal	3.50	3.50			
6 pints oil	0.30 gal.	0.22			
			3.72	6.20	48.0
Total drilling	....		$15.16	25.28	195.3

The following costs of dynamite, blasting and mucking as aforesaid are based on all hands (4 drill crews and 2 nippers) working 1½ hrs. at loading and blasting for each shot of 22 holes, or 176 lin.ft., and the same crew working 3 hrs. at the consequent mucking:

	Amount.	Cost per Lin. Foot Drilled, Cents.	Cost per Cubic Yard, Cents.
Blasting (labor 1½ hrs.)	$3.36	1.91 cts.	14.75 cts.
Dynamite, 99 lbs. at 12 cts.	11.88	6.74 "	52.10 "
Mucking (labor 3 hrs.)	6.72	3.82 "	29.50 "
Interest and depreciation at 2% per working month on $7315 (2 drills)	0.56	0.003 "	0.023 "

In the above items of costs no account has been taken of superintendence or overhead charges, repairs, organization or preparatory charges, storage, insurance, accidents, charities, legal, medical expenses, etc.

TIME STUDY

Tunnel work. Material, bastard granite. Lineal feet, 60. Total time, 16 hr. 27 min. 30 sec.

	No. of Obs.	Min.		Mean.		Max.		Time.		Consumed Time, Per Cent Total Time.
		Min.	Sec.	Min.	Sec.	Min.	Sec.	Min.	Sec.	
Drill cutting	30	6	15	12	04	17	45	362	15	36.7
Changing steel	25	1	50	3	49	5	40	95	20	9.6
Cycle totals	......	8	05	15	53	23	25	457	35	46.3
Moving on columns and getting started	4	.....		......		......		79	25	8.0
Setting up columns and getting started	2	.....		93	10	......		186	20	18.9
Dismantling columns	2	.....		14	30	......		29	00	3.0
Miscellaneous delays	......	.....		......		......		235	10	23.8
Totals	......	.....		......		......		987	30	100.0

Average cutting speed in feet per cutting minute, 0.165.

$$\text{Ratio } \frac{\text{cutting time}}{\text{total time}} = 0.367. \qquad \text{Ratio } \frac{\text{idle time}}{\text{cycle time}} = 1.16.$$

The process of setting up a drill on a column and getting the drill started may be conveniently divided into the following items with average values for each:

	M.	S.
Carrying and setting base	17	52
Setting column on base	3	37
Putting in blocking at top	16	38
Preparing and setting jacks	10	25
Placing and adjusting arm	10	13
Placing and adjusting drill on arm	5	35
Attaching hose	11	00
Getting started	17	50
Cycle total	93	10 = 1 hr. 33 m. 10 s.

The process of dismantling may be divided up as follows with average values:

	M.	S.
Removing drill from arm	6	07
Removing arm from column	1	43
Taking down column	4	40
Taking out base	2	00
Cycle total	14	30

GENERAL NOTES. The columns used are 6″ in diameter. The two upper arms are on the inside and the drills on these arms drill the top outer-round holes. The two lower arms are on the outside and start on the second cut holes from the bottom. When a hole has been finished it is necessary to shift the drill on the arm, or the arm on the column, or to do both. When one shift alone is necessary a fair value for time is 7 min.; when a double shift is necessary a fair value is 33 min. When it is necessary to take down columns, etc., a fair value as before itemized for dismantling is 14 min. 30 sec., and for setting up again 93 min. 10 sec. These times, with the exception of that for dismantling, include the adjusting in new position, getting started, etc.

CHAPTER VIII

DRILLING ON LAND—*Continued*

Soudan Mine of Oliver Iron Mining Co. at Towar, Minn. The material in this mine is a very hard jasper and quartzite, in some cases being so hard that to drill a hole 4 or 5′ in depth from 50 to 85 steels are needed, and holes have to be blasted with powder every 8 to 10″ in order that steels may not bind. Steels are sharpened by a drill sharpening machine. Five drills of ⅞″ octagonal steel with 2¼″ points were sharpened in this machine in an average time per drill of 36 seconds.

No records of performance are kept in these mines, but an occasional test is made.

The following records of tests have been obtained from the office:

Type of drill, Ingersoll-Rand, No. 3. Steel, O.H. Air Pressure, 70 lbs.

Date.	Lineal Feet.	Cutting Time.	Feet per Min.	Material.
No. 1, March 8, 1908 . . .	107	210½	0.00847	Jasper
No. 2, March 8, 1908 . . .	104½	214½	0.00814	Jasper
No. 3, March 8, 1908 . . .	77¼	122	0.01055	Quartzite
No. 4, March 8. 1908 . . .	76	122	0.01038	Quartzite

NOTE. In addition No. 1 cut 5′ of soap rock and No. 2 27′ of soap rock.

On May 22, 1908, the following records were taken for work with Ingersoll-Rand hammer drills:

Type drill, Ingersoll-Rand hammer drill. Air pressure, 70 lbs. Material, quartzite.

No. Hole.	Angle.	Lineal Feet.	Drill Time.		No. Bits.	Feet per Min.
			M.	S.		
1	Vert.	4′ 0¾″	11	10	8	0.0364
2	80°	4′ 1″	14	40	8	0.0279
3	25°	3′ 7″	10	45	7	0.0332
4	Vert.	4′ 1½″	11	30	8	0.0357
5	Vert.	4′ 6½″	12	38	8	0.0359

In the Pioneer, Zenith, Savoy, and Solby Mines of the Oliver Iron Mining Co., at Ely, Minn., between 50 and 60 Ingersoll-Rand drills, No. 3 (3") are used. In these mines no records of performance whatever were kept.

Tunnel Driving at Low Cost.[1] The driving of the Chipeta adit at Ouray, Colo., was not especially notable, as an important operation; but on account of the rapid driving and the resultant low costs, attention was attracted to it and considerable inquiry has been made as to the methods employed.

The adit was projected as a working entry to simplify the mining of the American-Nettie quartzite stratum, which had faulted downward. The old entries were tortuous inclines terminating at the fault. The portal is in the face of the steep mountain forming one wall of the canyon north of the town of Ouray, at an altitude of nearly 9000', and 1700' above the bed of the river. For economic reasons the power plant was placed at the river and a line of 3½" standard pipe laid on the surface to carry compressed air to the adit. This pipe line, 3400' long, has given no trouble in summer or winter.

During the installation of the plant and pipe line, work was carried on by hand labor, the adit reaching a length of 263', including the portal section of 115', which was heavily timbered 7×7' in the clear. Machine-drilling was then started and a run, which lasted for five full months, was made, only two rounds of holes being lost in that period.

This run of five months (152 days) resulted in driving the heading 7½×7½' in the clear, a distance of 1712½' in hard rock; a monthly average of 342½'. The best weekly record was 85'; the best month (31 days) was 359'. But two 8-hour shifts per day were employed, economical considerations, not speed, being predominant always. Compressed air at about 100 lbs. was supplied to a pair of 3⅛" new Ingersoll drills, both mounted on one single-screw column set horizontally above the muck pile. The round, consisting of from 15 to 19 holes, was drilled —except the lifters—from this setting, the bar being reset for

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[1] We are indebted to Mr. Walter H. Bunce for this article, abstracted from the *Mining and Scientific Press*.

the lifters after the muck was away. The cut was taken from the bottom, uniformly. Three drill-men tended the two machines, drilling a full round each shift. An unusual system of mucking was employed, which, perhaps more than any other one thing, may account for the substantial rate of progress that was reached and maintained. The tunnel track, 18″ gauge, was carried close to one side of the adit, and a floor, consisting of steel plates and planks, was maintained with the greatest care for not less than 60″ back from the heading. This floor was moved forward every round. No switches or turnouts were used; cars measuring 20 cu.ft. capacity were specially designed, and these, although weighing, empty, 1000 lbs. apiece, were so perfectly balanced that the empty cars composing an incoming train were easily jumped off the track onto this floor, the loaded cars passed by, and then the empties replaced on the track in detail as required by the muckers for loading. Muck was handled with No. 6 square-pointed shovels. Four shovelers and a mule-driver composed each shift. Track was laid and leveled by the muckers. Each shift, composed of drill-men and muckers, started work together. No ventilating system was installed, the smoke being blown back with air from the compressor. The adit throughout its entire length was perfectly dry.

This adit was an independent operation, the employees having no other occupation, so that their total wages are a charge against the work. Their wages were: Foreman, $5; drill men and blacksmith, $4; blacksmith's helper, $3.50; muckers, $3; compressor engineers, $3.50 per 8-hour shift. No bonuses were paid except on Christmas Day, when double time was given. The following costs are computed from March 1st, when 1835′ (including the portal section) had been completed, and embrace every item outside of construction and equipment accounts, which were closed before the current accounts were opened. The "power" account covers labor, coal, oil, and lights, everything at the compressor station; "labor" covers all other labor except that charged into "lumber and timbers"; "tunnel expense" covers tool-renewals and repairs, blacksmiths' sundries, forage, oils and general sundries at tunnel. "Track and pipe" covers cost and transportation of rail, fittings, ties, pipe, and pipe fittings; "expense" covers city office, rent, furniture and incidental expenses. The compensation of the acting superintendent is nowhere included in the costs as shown.

Distribution of Costs.	Total.	Cost per Foot.
Tunnel expense	\$556.94	\$0.303
Track and pipe	1,532.26	0.835
Power	2,862.71	1.560
Lumber and timber	533.51	0.291
Labor	11,981.85	6.529
Lights	233.70	0.127
Explosives	3,522.06	1.919
Expense	836.11	0.455
Total, 1835′	\$22,059.14	\$12.02

Pipe line through tunnel is 3½″ standard black pipe. Track is 16-lb. section, on ties laid 20″ apart. Powder (40% dynamite) cost \$0.1315 at the portal. Close estimation places its consumption at 14.5 lbs. per foot for machine driving. Steam coal cost \$3 per ton at the boilers. The air pressure was nominally 100 lbs. and a recording gauge kept on the line proved of value in many ways. There was always plenty of air. No charge for depreciation of tools and equipment has yet been entered; renewals and repairs are made and charged currently to "tunnel expense," and the actual value of the outfit to the company is about equivalent to new, as nothing has been allowed to run down.

Large vs. Small Drilling Machines.[1] The purpose of this paper is to discuss the relative merits of the large 3⅛″ machine and the small 2¼″ tappet machine in driving development headings; although the data were obtained from crosscut headings alone, experience has shown that the results are equally true in drifting, raising and winzing.

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[1] A paper by Frederick T. Williams, Mining Engineer, Victor, Colo., entitled "The Relative Merits of Large and Small Drilling Machines in Development Work," published (subject to revision) in Bulletin No. 8, March, 1906, of the American Institute of Mining Engineers.

Recently we drove two parallel cross-cuts through the same formation, using a $3\frac{1}{8}''$ machine at the breast of one cross-cut, and a $2\frac{1}{4}''$ machine of the same make at the breast of the other. The results of this work afforded an ideal comparison, since in both cases the headings were advanced through rock practically of the same hardness and breaking properties; the amount of sludging was equal, and there was no difference in the condition of the steel or the machines, in the air pressure or in the experience of the operating crews.

Some operators in the Cripple Creek district contend that there is ground which cannot be handled with the small machine, the holes being too small to contain enough powder to pull the ground, etc. The results obtained in working the property of the Portland Gold Mining Co., however, show that the ground worked by them does not fall in this class. During a period of two years there have been driven, with the small machine, 4 miles and 308 ft. of development headings, through a diversity of ground, including Pike's Peak granite (a coarsely porphyritic type of granite), highly indurated, andesitic or phonolytic breccia, true massive andesite, trachytic phonolyte, tufas, and along dikes of decomposed basalt and hard phonolyte. In every instance a satisfactory record was made.

The headings here described were driven through highly indurated, andesitic breccia, having a hardness of from 5.2 to 7.2 and a specific gravity of from 2.2 to 2.8. The action of the breccia under the drill was not materially different from that of ordinary red granite. The breccia was not as free drilling as granite, and sludge accumulated very rapidly after a shallow depth of hole had been gained, but it broke better than granite.

Aside from the usual work of setting up, drilling, and loading, the machine-men or helpers mucked back, cleaning the floor of muck 3 or 4′ back from the breast in order to position the column properly. If the "lifters" acted properly at the previous firing, the muck was fairly well thrown back from the breast; but if either missed fire or were exploded before the other holes, considerable muck was left at the breast which required much additional labor. The usual time needed to

TABLE I

DEVELOPMENT REPORT OF THE PORTLAND GOLD MINING COMPANY FOR TWENTY DAYS ENDING OCTOBER 16, 1903

	Machine Men.	Machine Helpers.	Hand Miners.	Trammers.	Pipe and Trackmen.	Total Labor.	Cost of Labor per Foot.	No. of Machine Shifts Worked.	Cost of Operating Machines.	General Tramming Cost.	Explosives including Powder, Fuse and Caps.
Large machine (3⅛″)											
Cross-cut (5.5×7.5′)											
5-day run..........	$40	$35	....	$22.13	$3.00	$100.13	$3.51	10	$37.00	$0.99	$66.22
8-day run..........	64	56	....	31.13	3.75	154.88	3.33	16	59.20	1.42	90.20
7-day run..........	56	42	....	28.13	.....	126.13	3.55	14	51.80	1.10	72.84
Averages and totals	$160	$133	....	$81.39	$6.75	$381.14	$3.45	40	$148.00	$3.51	$229.26
Small machine (2¼″)											
Cross-cut (4.5′×7.0′)											
5-day run..........	$40	...	$0.75	$17.25	$1.88	$59.88	$2.49	10	$18.50	$0.63	36.55
8-day run..........	64	...	.....	31.88	3.75	99.63	2.49	16	29.60	1.09	53.01
7-day run..........	56	...	.....	30.38	3.75	90.13	2.69	14	25.90	1.10	36.71
Averages and totals ...	$160	...	$0.75	$79.51	$9.38	$249.64	$2.56	40	$74.00	$2.82	$126.27

TABLE I—*Continued*

	Cost of Explosives per Foot.	Cost of Pipe and Track.	Cost of Hoisting.	Cost of Supplies.	General Expense Bosses, Assaying, Surveying, etc.	Total Cost.	Cost per Foot.	Total Tons.	Cost per Ton.	No. of Feet Driven.	Feet per Shift.
Large machine (3⅛")											
Cross-cut (5.5×7.5')											
5-day run..........	$2.32	$11.69	$22.69	$0.79	$22.69	$262.20	$9.20	99.20	$2. 4	28.5	2.85
8-day run..........	1.93	19.07	32.57	1.14	32.57	391.05	8.41	142.40	2.75	46.5	2.91
7-day run..........	2.05	14.56	25.25	0.88	25.25	317.81	8.95	110.40	2.88	35.5	2.54
Averages and totals .	$2.07	$45.32	$80.51	$2.81	$80.51	$971.06	$8.79	352.00	$2.76	110.5	2.76
Small machine (2¼")											
Cross-cut (4.5×7.0')											
5-day run..........	$1.52	$9.84	$14.46	$0.52	$14.46	$154.83	$6.45	63.20	$2.45	24.0	2.40
8-day run..........	1.32	16.40	24.89	0.87	24.89	250.38	6.26	108.80	2.30	40.0	2.50
7-day run..........	1.09	13.74	25.08	0.88	25.08	218.62	6.53	109.60	1.99	33.5	2.39
Averages and totals ...	$1.29	$39.98	$64.43	$2.27	$64.43	$623.83	$6.40	281.60	$2.22	97.5	2.44

muck back was 1.25 hrs., but this varied considerably. Flat steel 48×96×⅜″ sheets were used, from which to shovel the material. These were placed in position 3 or 4′ back from the breast by the trammer, just before going off shift. The ground broke fine enough to require little or no sledging. A cubic foot of breccia in place will average 154 lbs. in weight as compared with 90 lbs. on the muck pile, giving an average of 42% of void space. All the waste was trammed to the shaft 800′ distant, and hoisted to the surface. No timber was used in either heading.

TABLE II

EXPLOSIVES—DETAILED REPORT OF THE PORTLAND GOLD MINING COMPANY FOR TWENTY DAYS ENDING OCTOBER 16, 1903.

	Pounds of Powder.	Pounds of Powder per Foot Driven.	Feet of Fuse.	Feet of Fuse per Foot Driven.	No. of Caps.	No. of Caps per Foot Driven.
Large machine (3⅛″).						
Cross-cut (5.5×7.5′)						
5-day run..........	491	17.23	872	30.59	116	4.07
8-day run..........	669	14.39	1179	25.35	158	3.39
7-day run..........	544	15.32	804	22.65	134	3.77
Averages and totals..	1704	15.40	2855	25.80	408	3.69
Small machine (2¼″)						
Cross-cut (3.5×7′)						
5-day run..........	264	11.00	672	28.00	96	4.00
8-day run..........	378	9.45	1129	28.22	151	3.77
7-day run..........	262	7.82	742	22.15	120	3.58
Averages and totals....	904	9.27	2543	26.08	367	3.76

CHAPTER IX

SUBAQUEOUS DRILLING

Standard Rates on Subaqueous Drill Work. For the same reasons that governed us in the case of dry work, we have in this chapter reduced the costs to the following standard basis:

TABLE OF STANDARD RATES OF WAGES FOR SUBAQUEOUS WORK

	Rate per Hour.	Rate per Day.
Runner	27½	$3.02½
Runner's helper	22	2.42
Blacksmith	33	3.63
Blacksmith's helper	22	2.42
Fireman	25	2.75
Powderman	30	3.30
Labor	22	2.42
Coal	....	3.15 per ton
Oil	....	40 cts. per gal.
Dynamite	....	12 cts. per lb.

Observations at West Neebish Channel, St. Mary's River, July, 1909. As part of the work on the improvement of the inland lakes the channel of St. Mary's River is being deepened by the U. S. Government. Part of this improvement, known as the West Neebish Channel, has been completed and opened to traffic for some time, and during the summer of 1909 work on that part known as the middle Neebish Channel was progressing rapidly.

On the completion of the present work there will be a channel from the U. S. Government Ship Canal at Sault Ste. Marie to Lake Huron, 300′ in width, and with a depth of 24′ at mean low-water level. The portion of the work covered by the contract of the Great Lakes Dredge Dock Co. is typical of the work east of Neebish Island and contains the following items of interest.

The drill plant was installed on a boat of 30′ beam and 120′ length, center to center of spud anchors. All machinery, with the exception of the drill machines, spuds, spud engines, and the windlasses, was housed in a shed 20′ wide. The blacksmith shop occupied one end of this building next to the coal bunker, which opened on the boiler room. Back of the boiler room was the pump room, containing two force pumps, one for working the hydraulic lifts and one for supplying the water jets. In the pump room were also a small engine and generator for supplying light for the night shift. Next to the pump room was a large room used for a work room and storage. In this there were kept the oil supply, waste, repair parts for the drills, and such small tools as were needed from time to time. There were also a couple of work-benches, one of which was used by the man who prepared the exploders and wires for blasting.

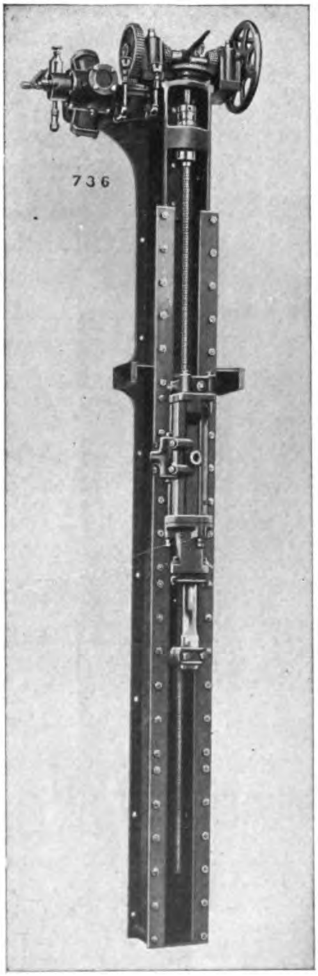

FIG. 76.—The "Auto-screw" Frame for Submarine Drilling.

An open "hall" extended the full length of the house on the side next to the drills, all the various rooms being partitioned off except the blacksmith shop and the workshop. The only obstruction in this passage was a hydraulic cylinder and piston 12″ in diameter and 15′ 6″ long, coupled to an endless chain, for use in moving

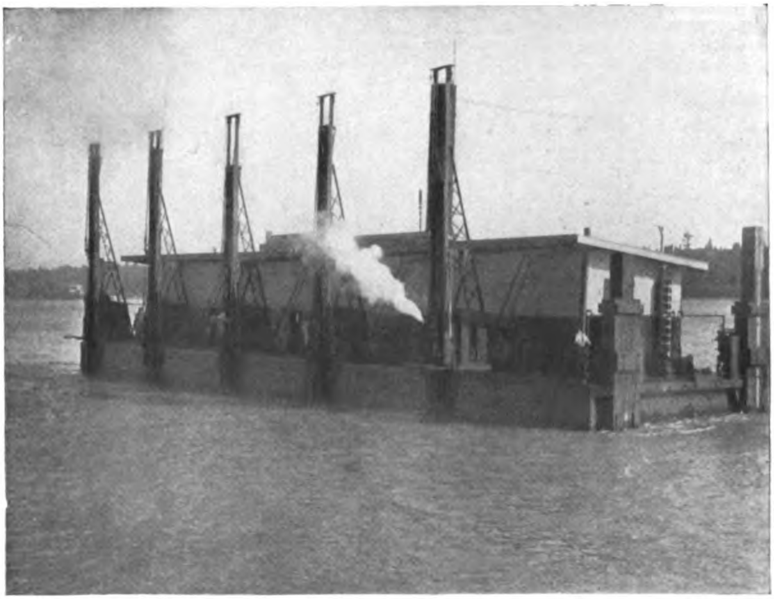

FIG. 77.—Drill Boat at West Neebish Channel.

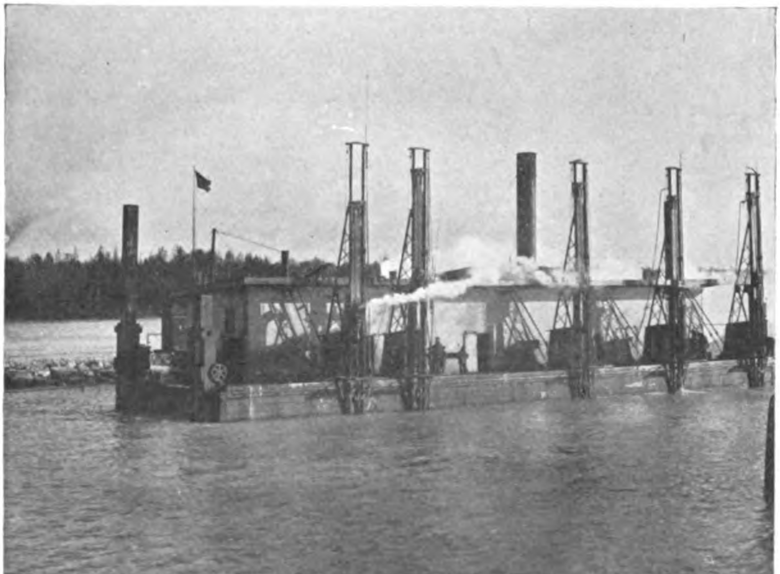

FIG. 78.—St. Mary's River, Mich. Great Lakes Dredge & Dock Co.

the drills along their rails. Drill steel was stored on the floor of this passage and steels were handled here by means of block and tackle at the forge.

The frame of the boat consisted of seven longitudinal trusses, two of them with wood top and bottom chords and steel web members, the others being all wood. The wood trusses were 6′ on centers and the extreme ones 3′ from the outside steel trusses. Between the trusses the deck was carried on 6×12″ sills supported at intervals of 5′ 10″ by 6×6″ posts, which rested on other 6×12″ sills on the bottom of the hull. Between the longitudinal wood trusses bracing was run at intervals of about 20′. The planking of the hull was fastened directly to one leg of the 6×6″ angles, which made up the vertical members of the steel trusses.

The boat seemed to be very tight and was almost absolutely dry. The space under deck was used for storing steel, pipe, hose, tools, blacksmith and other rough supplies.

The drill outfit consisted of five 6½″ Ingersoll-Rand drills, type K 6. These drills were mounted on a frame built of steel angles, an idea of their detail being given by the accompanying photographs. Each drill was raised by a hydraulic lift cylinder at the top of the frame, having a lift of 18′ and controlled by a triple valve operated by a hand lever, also shown by the views.

The steels used were 35′ long over all; 32′ of this length was 2½″ round material and had on its end 3′ of octagonal section. This end was of harder steel and was used as the drilling end; 4′ of the upper end of the steel was reduced slightly so as to fit the chuck. When first used the steel had an × point, 4¾″ to gauge, but with use it may wear down to 3″ before being sharpened. Thus the holes varied in diameter, from about 6″ at the top with a new bit to perhaps 3¼″ with a worn bit. A steel did about 225′ with one sharpening. The depth of water at this part of the channel was from 23 to 24′ with a current of 4 to 6 miles an hour. The channel being worked was 150′ wide, the other 150′ of the subsequent 300-foot channel having been completed. The current near the deep channel was much swifter than that at a distance from the old excavation and this, with the fact of the rock having been partly broken by the work on the other portion of the channel, made drilling near the deep channel quite difficult.

The following is a list of the principal efficiency factors observed on this work:

Diameter of piston, 6½″.

Length of stroke, 12″.

Kind of rock, Potsdam sandstone.

Diameter of bit at starting, 4¾″ gauge, but reduces to about 3″ in the work.

Length of feed, 18′ (6″ hydraulic jacks).

Steam pressure at boiler, 105 lbs.

Diameter of feed pipe, 1½″ (2″ discharge).

Length of steel over all 35′, this includes 32′ of 2½″ round steel and an octagonal end 3′ long which is harder than the shaft and on which the point is made. About 4′ of the upper part of the shaft is slightly reduced to be held in the chuck.

Weight of steel, 2½″ diam., 585 lbs.

Kind of chuck, U.

Number of drills, 5.

Type of drill and marks, Ingersoll-Rand, K6. (No. 7501.)

Depth of hole, 7′. The average hole is 7′ deep, but near east side of channel one row of holes varying from 3 to 4′ was drilled.

Diameter of holes, 6″ at top when finished, 4½″ to 3″ at bottom.

Longitudinal spacing of holes, 6′.

Lateral spacing of holes, 6′.

Nature and condition of material: This channel was worked over six years ago and is somewhat damaged and often seamy.

Length of shift, 11 hrs. (2 shifts per day).

Kind of boiler, Scotch marine, 3 fires, 14′ long by 13′ diameter.

Horse-power of boiler, 200.

Steel handled by hand when placing in drill or taking to blacksmith shop; while being sharpened, steel is suspended by chain at end away from forge.

Size of jet, ½″ diameter at point. 7520 cu.ins. water used per jet per cutting minute, 17.4 cu.ins. water per cubic inch of rock cut.

Connection of jet, kind and size, 30′ of 3″ pipe for main supply. From this for each machine there are 8′ of 1½″ pipe to hose, 30′ of ¾″ hose, 30′ of ¾″ pipe, and 8′ of ½″ pipe for jet.

Drill is moved on track by chain operated by hydraulic power.

Supplies brought from Soo by scow and tug.

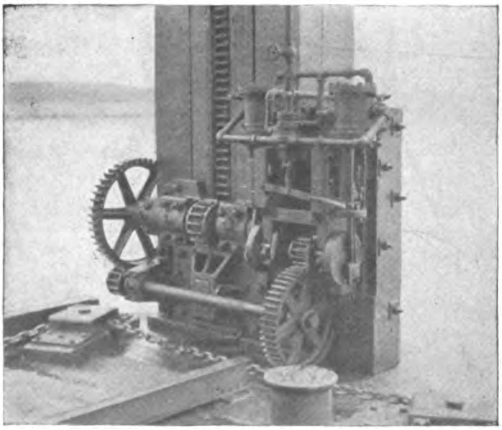

FIG. 79.—Spud Gear on Drill Boat at West Neebish Channel.

Coal consumption 25 tons per week, 12 shifts, 840 lbs. per drill per day (1 shift).

Oil used, ¾ pint per drill per range of four holes; average 9 pts. per drill per shift.

Equipment towed by tug; when moved from range to range, moved by anchors and current.

Blacksmith's duties, all ordinary repairs and all bit sharpening and welding.

Blasting charge, 2 sticks, at 2½ lbs.

Blacksmith's duties, size of powder, 60% Forcite gelatin.

Size of sticks. 2 × 16″.

Kind of fuse, Reliable double strength, 8′ wire. Also DuPont and Victor double strength.

One fuse to hole; 1 to blast.

Men blasting: 3 powdermen, 2 wiremen.

Drill strokes per minute varied from 144 to 300. Average running about 240.

Bit tempering: hard.

Interest and depreciation at 2% per working month on plant, valued at $35,000, $13.45 per shift.

Moving boat from range to range consumed 13.35% of total time costing 13.35% wages per shift = $7.90. This large amount is due to the speed of drilling, which causes frequent movings of boat.

Superintendence, 1 foreman at $5.00 per shift, 9.25% of hourly labor.

Cost of moving boat, $7.90 per shift, or $1.58 per drill per shift.

The following is a rough inventory of the plant in use on this work:

One scow, 30×126′.

One Scotch marine (3-fire) boiler, 14′ long by 13′ diameter.

One blacksmith's forge, blower and anvil with smokestack.

One blacksmith's bench, 1 vise, 1 pipe clamp (small).

Seventeen spare drill bits; full length 35′.

One hydraulic cylinder 12″×15′ 6″, with 3½″ piston and traction chain.

One Worthington feed pump (small).

Two Snow Steam Pump Co. force pumps.

One dynamo and switchboard driven by one cylinder belted engine; dynamo, 110 volts and 42 amperes, D.C. Westinghouse, 5 H.P., 1600 R.P.M.

One small vertical washout boiler.

Five drill machines, Ingersoll-Rand 6½″ on track of 2′ 6″ I-beams.

Two capstans, steam driven.

Four spud engines, each equipped with Superior Iron Works 6×6½″ engine.

Four mooring posts (iron).

Two double post sheaves.

General Notes. Spuds were operated by four two-cylinder Superior Iron Works 6×6½″ engines, fed by 1½″ pipe.

Drill steel. "Black Diamond" and "Colonial."

Pump for jets was 12″ diameter by 5×12″, giving 80 strokes per minute. Pump for hydraulic lift was 16″ diameter by 6×12″ stroke. The hydraulic cylinder used for moving drills was also supplied by this pump.

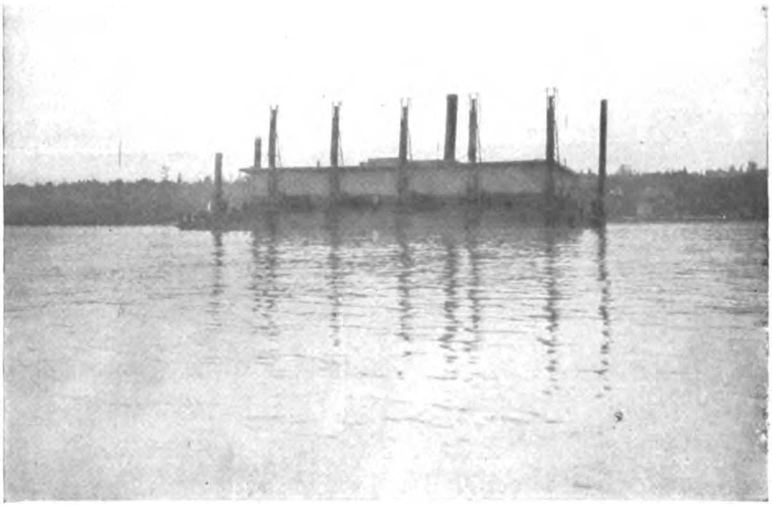

Fig. 80.—Drill Boat at West Neebish Channel.

The moving of the drill frame is done by means of a chain running through a + shaped hole in the steel base of the drill frame. A slotted block is dropped over the chain and it engages between the links, thus dragging the frame along when the chain is moved by its hydraulic cylinder.

In each "range" each machine drills 4 holes, therefore there are

20 holes to the range. A range generally takes 45 min. to finish. When a range is finished the boat is swung on the spuds by the current. When a cross range is finished the boat is worked diagonally across the channel to the next range below, next to the center line of the channel.

The following is a synopsis of the costs per cubic yard of pay rock and per lineal foot of hole while drilling 7′ holes as observed. It will be noted that the number of feet drilled per shift was remarkably high, due to the excellent organization of the work, and to the fact that there were few interruptions from accidental causes, and to the further fact that excellent hydraulic jets were in operation, and that the men were well trained.

TABLE OF COSTS ON STANDARD BASIS

	Amount per Shift.	Totals.	Per Foot Drilled. Cents.	Per Pay Yard. Cents.
5 drillers at 27½ cts. per hr. (11 hr. shift)...	$15.12			
5 helpers at 22 cts. per hr................	12.10			
		27.22	1.62	2.13
3 loaders at 30 cts. per hr................	9.00			
3 loaders' helpers at 22 cts. per hr.........	7.26			
		17.16	1.02	1.34
1 blacksmith at 33 cts. per hr............	3.63			
2 blacksmiths' helpers at 22 cts. per hr....	4.84			
		8.47	0.51	0.66
1 nipper at 1.00.........................	1.00	1.00	0.06	0.08
1 fireman at 25 cts. per hr..............	2.75	2.75	0.16	0.21
1 foreman at 9.25% per hr. of hourly labor.	5.00	5.00	0.30	0.39
Total labor..........................	....	61.60	3.67	4.81
Dynamite, 5 lbs. per hole, 1200 lbs. 60% at 12 cts. per pound.................	....	144.00	8.57	11.25
300 exploders at 3 cts..................	....	9.00	0.54	0.70
Coal, 2.1 tons at $3.15..................	....	6.62	0.39	0.52
Oil, waste, $\frac{3}{16}$ pint per hole, ⅛ bbl. at 40 cts.	....	2.60	0.15	0.20
Total for 1680 lin.ft., or 1280 cu.yds.	....	223.82	13.32	17.48
Plant, $35.000, interest and depreciation working month, 2%...............	....	13.45	0.80	1.05

Consumption of dynamite was on the basis of 0.56 lb. nitroglycerin per yard of pay rock.

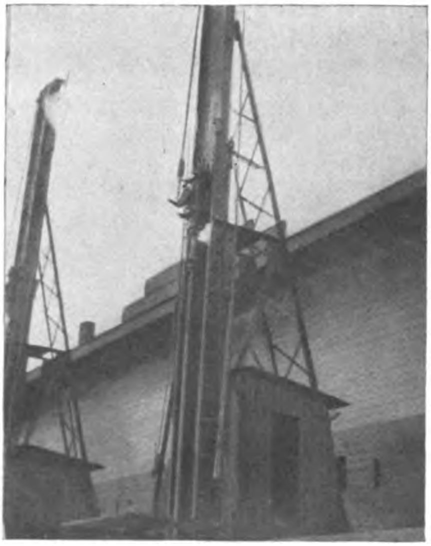

FIG. 81.—Drill Frame on Drill Boat at West Neebish Channe

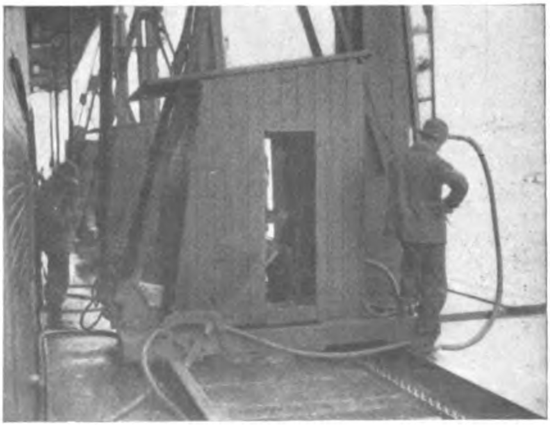

FIG. 82.—Foot of Drill Frame on Drill Boat at West Neebish Channel.

The above figures are based on an average performance of 240 holes, 7′ deep per shift, or 1680 lin.ft. drilled. Since the holes were drilled 3′ below grade and were spaced 6×6′, this corresponds to $240 \times 4 \times 1\frac{1}{3} = 1280$ cu.yds. of pay rock loosened. The average drill performance was 30.5′ per drill hour. This does not include contractor's overhead charges or profit, and no account is taken of the preparatory, charges, i.e., cost of getting ready to work in the spring and cleaning up in the fall, or storing equipment during the winter. Profit on the contractor's capital, legal expenses, insurance bond, and charity have been omitted.

The average cutting speed for the four drills was 2.52′ per cutting minute.

Ratio of cutting time to total time = 0.248.

Ratio of idle time to useful working time (cycle time) = 0.55.

The following is a general summary of average performance data with deductions therefrom:

Shifts	1
Hours	11
Number of holes	240
Depth of holes	7′
Lineal feet drilled	1680
Cubic yards pay rock	1280
Dynamite, 60%	1200 lbs. or 720 lbs. nitroglycerin
Coal, tons	2.1
Labor per shift	$61.60
Lineal feet per shift	1680
Lineal feet per drill hour	30.5
Lineal feet per man hour	6.95
Labor per foot drilled in cents	3.67
Cubic yards pay rock per shift	1280
Cubic yards pay rock per drill hour	23.3
Cubic yards pay rock per foot drilled	0.762
Labor per cubic yard of pay rock	4.81
Coal per drill per shift in pounds	840

Coal per foot drilled pounds in	2.5
Dynamite per foot drilled in pounds, 60%,	0.715 or 0.429 lb. nitroglycerin
Dynamite per cubic yard of pay rock,	0.938 or 0.563 lb. nitroglycerin
Dynamite per cubic yard of rock blasted,	0.536 or 0.322 lb. nitroglycerin
Cost per lineal foot drilled and loaded exclusive of dynamite exploders, interest and depreciation (cts).	4.21
Total cost per cubic yard pay rock, exclusive of interest and depreciation (cts)	17.48
Total cost per cubic yard pay rock, including interest and depreciation, estimated (cts.)	18.53
Total cost per cubic yard blasted (cts.)	10.6
Ratio of cubic yards blasted to cubic yards of pay rock.	1.75

TIME STUDY.—In drilling a range of 20 holes, with a 5-drill boat, each machine drills 4 holes, and when the longitudinal axis of the boat is parallel, or nearly so, with a swift stream, the debris that is washed out of the upstream holes by the jets or blown loose by blasts, drifts down upon the drills,which are working farther. down stream and clogs them, making an increase in the time necessary for drilling, cleaning and often loading the hole. For this reason the upstream drills are nearly always ahead of the others in their work, and the lowermost drill usually has to finish the range while the others stand idle. A time study is given below for the operation of this boat. No time was taken on drill No. 3. No. 1 was the downstream drill and No. 5 the upstream one.

Number of observations	39 holes.			43 holes.		
Lineal feet	273			301		
Average depth of holes	7 feet					
Drill number	No. 1.			No. 2.		
Process.	Min.	Av.	Max.	Min.	Av.	Max.
Drilling hole	2:00	3:27	7:00	1:25	2:30	5:00
Finishing hole	0:25	1:09	4:45	0:15	1:08	4:40
Waiting for loaders	0:05	0:43	3:00	0:00	0:32	1:50
Loading	0:25	1:19	3:15	0:15:	1:02	3:10
Waiting for shot	0:15	1:04	2:40	0:10	1:00	2:30
Getting into new position	0:30	1:10	2:40	0:20	1:04	1:45
Time of cycle	3:40	8:52	23:20	2:25	7:16	18:55

Number of observations	16 holes.			16 holes		
Lineal feet	113			112		
Average depth of holes	7 feet.					
Drill number	No. 4.			No. 5.		
Process.	Min.	Av.	Max.	Min.	Av.	Max.
Drilling hole	1:50	2:44	5:50	1:05	2:10	4:05
Finishing hole	0:20	0:38	1:45	0:00	0:29	1:05
Waiting for loaders	0:10	0:38	1:15	0:10	0:38	1:25
Loading	0:45	1:10	2:50	0:35	1:10	2:45
Waiting for shot	0:10	1:05	2:20	0:30	1:08	2:35
Getting into new position	0:35	1:11	1:50	0:25	1:03	1:10
Time of cycle	3:50	7:26	15:50	2:45	6:29	13:05

The limiting drill, therefore was No. 1, which averaged 8 min. 52 sec. per 7′ hole, while No. 5 averaged 6 min. 29 sec.

Edwards Brothers' Drill Boat (Observed, 1909).—This boat is working at deepening the channel of the St. Mary's River just east of Neebish Island, and a little above the Great Lakes. It is small, but sound and in good working trim. Her antiquated appearance would seem to belie this fact, but when her history is known there is really nothing contradictory in the two statements. It was built about ten years ago and was then equipped with the best up-to-date machinery. Upon completion, this boat was not put into commission, due to the fact that the company owning her got into some sort of litigation which prevented it. In 1909, Edwards Bros. purchased the boat and put her into commission in the summer. Their contract calls for 860 holes and the time limit is five weeks.

As said, the boat works very efficiently as far as the drilling machinery is concerned, but much time is consumed in shifting it. This is due to the fact that both the spud anchors and the windlasses must be operated by hand. The boat is of wood throughout, her hull being built on the regular scow lines. She is 80′ long and 24′ wide, and is equipped with two Ingersoll-Rand drills, type 13 D.H. 2. Spacing of the holes being 6′, each drill must do seven holes to a range (end holes being 4′ apart).

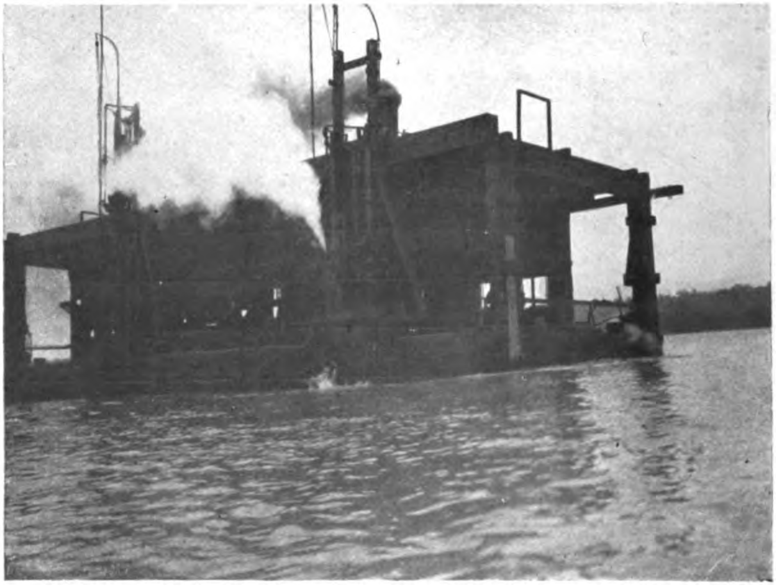

FIG. 83.—Edwards Bros.' Drill Boat, St. Mary's River.

The method of moving the drill frames along the deck is not by means of an hydraulic jack and an endless chain as is usual. Here there is a chain passing under each drill frame and winding onto a small steam windlass at each end of the boat.

Attached to each drill is a small chain and hook which, when it is desired to move the drill frame along the deck, is engaged in a link of the larger chain, and the proper windlass set in motion. The track on which the drill frame slides is made of flat steel strips. The face of an angle on the outer edge of the boat forms one of these and the other is a flat piece of steel attached to the deck some 3′ from the angle.

The drills are lifted by means of hydraulic jacks, which are fed by a 12×4¼×10 Worthington pump. Another Worthington pump, 6×4×6, working at 50 strokes per minute, furnishes water for the washout pipes at 250 lbs. pressure. The washout pipe which uses this high pressure washout water is composed of three sections of pipe of three sizes, ¾, ½, and ⅜″. The last section is so flexible and weak that the driller's helper has a very busy time keeping it straightened out and in operation.

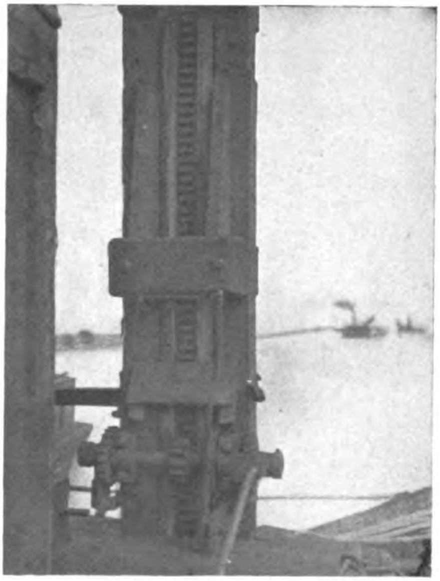

FIG. 84.—Spud Gear on Edwards Bros.' Drill Boat.

The drill bits used are of Black Diamond steel. These bits are 37′ in length and 2″ in section. The lower ends, however, are upset for the pointing to 2½″. The points are of this shape +, being, when newly sharpened, 4½″, but wearing away to 3½″ before resharpening. Drill steel is handled by hand, requiring about 11 min. to replace a dull bit with a sharp one. One of these bits weighs 387 lbs. and will generally drill 35 holes. Spare bits, as well as a pump, boiler, coal bin, and blacksmith shop and outfit, are all housed in a wooden shed covering the larger portion of the deck.

A rough inventory of the equipment of this boat is as follows:

One drill boat, 80×24′.

One powder boat.

One cutter.

Two drills.

Two steam winches for moving drill frames along deck.

Two hand winches for operating anchors.

Four hand operated spuds or anchor posts for mooring the boat.

One boiler working at 95 lbs. gauge.

One hydraulic lift pump, Worthington, 12×4¼×10.

One force pump for washout 6×4×6, 50 strokes per minute.

One forge.

One anvil.

One bench and vise.

Extra drill bits.

The following principal efficiency factors were observed:

Diameter of piston, 5½″.

Length of stroke, 10″.

Kind of rock, Potsdam sandstone.

Diameter of bit, 4½″, reduces to about 3½″ before sharpening.

Shape of bit, +.

Lift, 16′.

Steam pressure at boiler, 95 lbs.

Length of feed pipe and diameter of feed pipe, 2″ connections from main to standard, where 1½″ pipe slides inside of 2″ pipe. The maximum length on the standard was 32′ and up to that point the lead is about 25′.

Length of steel, 37′.

Weight of steel, 387 lbs., 2″ diameter.

Chuck is the same as the U in principle, only instead of a single U bolt to tighten drill there are two separate bolts and nuts.

Two drills.

Type of drill 13 D.H. 2.

Depth of hole, 6′ average, varies somewhat with bottom.

Diameter of hole at top, 5″.

Longitudinal spacing of holes, 6′.

Lateral spacing of holes, 6′.

Nature and condition of material: the bottom was worked over about six years ago and is somewhat broken up and is seamy from the previous blasting.

Cleaning of holes done by jets.

Length of shift, 11 hours, 2 shifts.

Size of job, five weeks, 860 holes.

An upright boiler.

Forty H.P. boiler.

Steel handled by hand entirely.

Jet, ⅜″, 24.2 cu. inches of water needed per cu. inch of rock cut by bit; 3760 cu. inches of water needed per jet per cutting minute.

Connection of jet, 1″ pipe, to which is connected ¾″ hose. The jet pipe is ¾″, with a ½″ section about 8′ long on the end. The ½″ pipe is reduced to ⅜″ at end.

Drill moved on standard by chain moved by steam windlasses.

Supplies handled by scow from Soo.

Four tons of coal per day = 2000 lbs. per drill per shift.

Oil used, 1 bbl. in 1½ weeks = 12¼ pints per drill per shift.

Equipment floated.

Blacksmith does repairs of drill boat, bits and dredge repairs.

Blasting charge, 1½ sticks, 3 lbs.

Pluto powder used, 60%.

Size of sticks, 2 × 16″.

Kind of fuse Victor, d. s. 12.

One fuse used per blast.

For time of blasting, see Time Study.

Two men blasting.

Day foreman, at 16.2% day's wages.

Interest and depreciation on plant, valued at $10,800 at 2% per working month = $4.15 per shift.

Working force: 2 drillers,
2 drillers' helpers,
1 powderman,
1 powderman's helper,
1 blacksmith
2 helpers,
1 fireman,
1 nipper,
1 foreman.

The observed performance of this boat was 8 holes of 6′ each in 255½ drill min. In a shift of 11 hrs. this is equivalent to 41 holes, or 246 lin.ft. The captain of this boat counts on 84 holes in 22 hrs., which checks well with the observed performance. The spacing of these holes being 6′ each way the cubic yards of material loosened would be $\frac{41\times6\times6\times6}{27}=328$. Holes being drilled about 2′ below grade the pay yardage would be 226. Based on this performance the following synopsis of costs per lineal foot drilled and per cubic yard of pay rock has been deduced. No account will be taken of contractor's overhead charges or profit, preparatory charges, legal, insurance, bond and charity, medical expenses, etc.

COSTS

	Amount.	Totals.	Per Foot Drilled. Cents.	Per Pay Yard. Cents.
2 drillers at 27½ cts. per hr. (11 hr. shift)	$6.05			
2 helpers at 22 cts. per hr	4.84			
		$10.89	4.42	4.82
1 loader at 30 cts per hr	3.30			
1 loader's helper at 22 cts. per hr	2.42			
		5.72	2.32	2.53
1 blacksmith at 33 cts. per hr	3.63			
2 blacksmiths' helpers at 22 cts. per hr	4.84			
		8.47	3.44	3.75
1 fireman at 25 cts. per hr	2.75	2.75	1.12	1.22
1 nipper at $1.00	1.00	1.00	0.41	0.44
1 foreman at $4.65 per day, 16.2%	4.65	4.65	1.89	2.06
Dynamite, 3 lbs. per hole, 123 lbs. 60% at 12 cts		14.76	6.00	6.53
50 exploders at 3 cts		1.50	0.60	0.66
Coal, 2 tons at $3.15		6.30	2.56	2.78
Oil, 0.6 pints per hole = 24½ pts. at 40 cts per gal		1.22	0.50	0.54
Total for 246 lin.ft. or 226 pay yards		$57.26	23.26	25.33
Plant, $10,800, interest and depreciation, 2% per working month		4.15	1.69	1.84

The following is a general summary of average performance data with deductions therefrom:

Shifts	1
Hours	11
Number of holes	41
Depth of Holes	6 ft.
Lin. ft. drilled	246
Cu. yds. pay rock	226
Dynamite, 60%	123 lbs.
Coal, tons	2
Labor per shift	$33.48
Lin. ft. per shift	246
Lin. ft. per drill hour	11.18
Lin. ft. per man hour	1.86
Labor per lin. ft. in cts	13.60
Cu. yds. pay rock per shift	226

Cu. yds. of pay rock per drill hour	10.27
Cu. yds. of pay rock per foot drilled	.92
Labor per cu. yd. pay rock cts	14.82
Coal per drill per shift in pounds	2000
Coal per lin. ft drilled, lbs	16.25
Dynamite, 60%, per ft. drilled, dynamite	½ lb.
nitroglycerin	3/10 lb.
Dynamite, 60%, per cu. yd. pay rock, dynamite	.545 lb.
nitroglycerin	.327 lb.
Dynamite, 60%, per cu. yd. blasted, dynamite	.375 lb.
nitroglycerin	.225 lb.

$$\text{Ratio}\ \frac{\text{cu. yd. blasted}}{\text{cu. yd. pay}} = 1.45.$$

Total cost per lin. ft. drilled and loaded, exclusive of dynamite exploders, interest and depreciation .... 16.66 cts.

Total cost per cu. yd. pay rock, exclusive of interest and depreciation .... 25.33 "

Total cost per cu. yd. pay rock, including interest and depreciation .... 27.17 "

Total cost per cu. yd. blasted, including interest and depreciation .... 18.73 "

Drill No. 1, number of holes drilled while under observation, 5. Average depth, 6′; lin.ft., 30.

Drill No. 2, number of holes drilled while under observation, 3. Average depth, 6′, lin.ft., 18.

TIME STUDY

	No. 1.				No. 2.			
	No. of Obs.	Min.	Mean.	Max.	No. of Obs.	Min.	Mean.	Max.
Drill working	5	4:25	6:35	8:50	3	3:30	8:02	12:35
Finishing hole	5	0:20	0:52	2:30	3	0:30	3:13	6:45
Waiting for loading gang	5	0:25	1:52	4:05	3	0:15	1:17	1:55
Loading	4	0:50	2:01	3:40	2	1:45	3:00	4:15
Waiting for shot	4	1:30	2:37	3:50	3	1:05	5:42	9:50
Getting into position	3	1:05	2:06	2:20	2	1:50	2:00	2:10
Time cycle		8:35	16:03	25:15	......	8:55	23:14	37:30

Drill No. 1 was the upstream and No. 2 was the downstream. The cutting speed of No. 1 was 0.915′ per cutting minute or 54.9′ per cutting hour, while the same time for No. 2 was 0.726 and 43.56. This shows that No. 1 worked the faster, and it was due no doubt to the fact that the debris from No. 1 washed downstream and impeded the drilling of No. 2. The average cutting speed for the two drills was 0.82′ per cutting minute or 49.2′ per cutting hour. The average ratio of cutting time to total time for both drills was 0.223. The delays amounted to 49.5% of total time and the ratio of idle time to useful (cycle) time was 0.98.

CHAPTER X

SUBAQUEOUS DRILLING (*Continued*)

Operations at Blyth, England.[1] The work at Blyth was for the breaking and removal of rock very similar in structure to the sandstone of the St. Mary's River. One dredge of the elevator type was in use and in a day of 24 hrs., all stops allowed for, the average performance was 158 cu.yds. Besides the dredge there were two outfits for breaking the rock. One was the Lobnitz rock-breaker and the other a drill barge having six drills that were lifted by steam power and guided by hand. The Lobnitz rock-breaker averaged 182 cu.yds. per day, while the drill boat averaged 81 cu.yds. per day. The cost per cubic yard drilled and blasted by the barge was 3*s.*, while by the Lobnitz rock-breaker it was only 1*s.* 2.5*d.* The cost per cubic yard for dredging by the elevator dredge, the rock being drilled and blasted by the barge, was 2*s.* 6*d.*, same for the Lobnitz breaker 2*s.* 2*d.* Allowing 4% interest and 2½% depreciation on the dredge, valued at £19,000, the additional cost per cubic yard for removal of rock broken by the drilling and blasting would be 8.2*d.*; same for that broken by the Lobnitz breaker was 7.1*d.*

COMPARATIVE COSTS IN ABOVE SYSTEMS (LOCAL WAGES)

	s.	*d.*
Drilling and blasting rock by barge per cubic yard	3	0
Dredging same, 2*s* 6*d*, plus 8.2*d*	3	2.2
Total	6	2.2
Breaking rock by Lobnitz rock-breaker	1	2.5
Dredging same, 2*s* 2*d*, plus 7.1*d*	2	9.1
Total	3	11.6

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[1] The information in this article was collected by Mr. Gilbert H. Gilbert.

Difference in cost per cubic yard in favor of removal of rock broken by means of the Lobnitz breaker 2*s* 2.6*d*.

Saving on 500,000 cu.yds. = £54,166.

An interesting comparison is furnished between the above two methods of breaking rock and that by use of Ingersoll-Rand submarine drills on the St. Mary's River.

Costs in cents per cubic yard of drilling and blasting, using Ingersoll-Rand submarine drills, 18.45 + 1.05 (interest and depreciation) = 19.50.

The drop drills on the barge at Blyth = 72.90.

Lobnitz breaker 1*s* 2.5*d* = 29.30.

Saving in cost of breaking 500,000 cu.yds. by means of the Ingersoll-Rand sumbarine drill as compared with the drop drills on barge at Blyth and the Lobnitz rock-breaker is as follows:

Saving in cost by use of Ingersoll-Rand drills compared to drop drills, $264,800.

Saving in cost by use of Ingersoll-Rand drills compared with the Lobnitz system, $49,600.

NOTE.—It will be noticed in the first comparison that rock broken by the Lobnitz system could be dredged about 15% more cheaply than rock broken by the drop drills at Blyth, due to the former method furnishing a smaller-sized rock. But with the use of the Ingersoll-Rand drills this 15% disappears, for the resulting rock by this process is of a size that the elevator dredge could handle as easily as that broken by the Lobnitz system.

Submarine Rock Excavation (Port Colborne Harbor Works, Welland Canal, Canada). This work was for the removal of 360,000 cu.yds. of hard stratified limestone containing some flint.

Two three-drill drill boats were used on this contract. The total time the drill boats were in operation was equivalent to 5200 days' work of one drill boat. The average depth drilled by each drill per hour was 4½'; this included all delays.

The total feet of drilling was 655,600 or 1.8' per cu.yd. Operations were carried on in an exposed position; much delay was caused by high winds, rough water, and the cold, inclement weather.

The average weight of explosive used was 1½ lbs. of 70% dynamite per cubic yard paid for. The dynamite cartridges were 1⅞×36″, weighing 5 lbs. each.

Owing to the uncertain weather conditions, each hole was blasted as drilled in shallow cutting, when the cutting was deep and the surface of rock close to the bottom of the boat, the boat was moved and the holes fired in batches. When holes were fired in batches the results were unquestionably better, but where the boats may be driven off by sudden storms it is not safe to have a number of holes loaded, as the connecting wires are liable to be broken, the hole lost, or the vessel endangered by the liability of the dynamite being exploded by the drill steel when operations are resumed.

The spacing of holes depended entirely upon the nature of the rock. In clearly stratified rock, holes were spaced farther apart. Spacing 6×8′ was tried, but was found too great and had to be redrilled. Five feet spacing and 6′ back was usually safe, but in the very hard material 5×5′ was not always sufficient.

The depth that holes were drilled below grade depended upon the nature of the rock. If stratified, one bed below, whatever the thickness of the strata, gave good results. It was usually found necessary to go 3′ below the grade line.

Improvement of Oswego Harbor, New York, Hingston, Rogers & O'Brien, of Buffalo, Contractors.[1] This contract was for the removal of graywacke, a hard silicious cemented sandstone, to form a channel 15′ deep. The rock formation was in horizontal beds of about 24″ in depth. It was not homogeneous, but of fragments of varying degrees of hardness, cemented together. At times the drill bits would make 10′ of hole without dressing, and again not more than 1′. The loss of steel through abrasion and dressing was 4 lbs. per 100′ of hole drilled. The contract price to grade was $2.75 per cubic yard, no allowance being made for material removed from below grade.

The drill boat employed was a wooden vessel 82×26×6½′,

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[1] The data on this article were collected by Mr. Gilbert H. Gilbert.

carrying two 5″ Ingersoll-Rand drills mounted on the side of the boat and fitted with an hydraulic feed with a stroke of 12′. The operating crew consisted of 6 men for each shift, a blacksmith and helper being carried in addition, but working in daytime only. Two shifts per day of 11 hrs. each.

The following costs are for 1000 cu.yds. of pay rock:

Linear feet, 8660. Cubic yards, pay rock, 1000. (Note local wages.)

Cost Items.		Cost per Linear Foot. Cents.	Per Cubic Yard Pay. Cents.
Labor, 33 days at $31	$1023.00	11.81	102.30
49½ tons coal at $3	148.50	1.71	14.85
42½ gals. of cylinder oil at 30 cts	12.70	.15	1.27
Shop repair, steel and other stores	80.80	.94	8.08
Total drilling	$1265.00	14.61	126.50
Dynamite, 4000 lbs. 75% at 17 cts.	680.00	7.85	68.00
Fuses, 1800 at 3 cts.	54.00	.62	5.40
Total drilling and blasting	$1999.00	23.08	199.90
Interest and depreciation on plant estimated at $15,000 at 2% wrkg. mo.	381.00	4.40	38.10
Total	$2380.00	27.48	238.00

In the above tabulation of cost no account is taken of contractors' overhead charges, organization or preparatory, insurance, charities, legal, medical expense, etc.

The following is a summary of the data obtained, based on the performance and costs in drilling and blasting 1000 cu.yds. of pay rock:

Number of drills, two 5″ Ingersoll submarine. Material, hard sandstone.

Shifts worked	66
Hours worked	726
No. of holes	1650
Depth of holes	5.25′

Linear feet drilled	8660
Cubic yards pay rock	1000
Dynamite, 75%	4000 or 3000 lbs. glycerin
Coal, tons	49½
Labor per shift (average)	$15.50
Linear feet per shift	131
Linear feet per drill hour	5.95
Linear feet per man hour (14 men, 2 shifts)	1.7
Labor per foot drilled, in cents	11.81
Cubic yards pay rock per shift	15.15
Cubic yards pay rock per drill hour	0.69
Cubic yards pay rock per foot drilled	0.116
Labor per cubic yard pay rock, cents	102.30
Coal per foot drilled, in pounds	11.4
Coal per drill per shift, pounds	750
Dynamite per foot drilled, 75%	0.462 lbs. = 0.346 lbs. glycerin
Dynamite per cubic yard pay rock, 75%	4 lbs. = 3 lbs. glycerin
Dynamite per cubic yard blasted	2 lbs. = 1½ lbs. glycerin
Cost of drilling and loading (all items exclusive of dynamite fuses, interest and depreciation) per lin. ft.	14.61 cts.
Total cost per cubic yard pay, exclusive of interest and depreciation	199.90 "
Dredging cost $500 = 1000 lbs. or 50 cents per cu.yd. of pay rock	50.00 "
Total drilling, blasting and dredging per cubic yard, pay rock, exclusive of interest and depreciation (38.1 cts. pay yard)	249.90 "
Same, including interest and depreciation	288.00 "
Contract price per cubic yard removed above grade	$2.75
Ratio of $\frac{\text{cubic yards blasted}}{\text{cubic yards pay}}$	2.00

Observations on Livingstone Improvement of the Detroit River. Improvements are now being carried on along the lower part of the Detroit River. This work bears the name of the Livingstone Improvement of the Detroit River. Upon its completion it will be no longer necessary for both up and down bound vessels to use the same narrow 300′ channel between

Bois Blanc Island and Amherstberg. Instead a new waterway will be at the service of downbound vessels. The whole job is of such magnitude, extending as it does from Limekiln Crossing out into the lake, that the contract for it was let in four distinct sections.

A very interesting section of this work is No. 3. The work is entirely subaqueous, and consists in cutting a channel 23′ deep, 300′ wide, and 18,250′ long, in the hard limestone forming the bed of the river at this place. O. E. Dunbar and T. B. McNaughton signed the contract for this portion of the work. But they, too, sublet their contract. The three sections so sublet are each 100′ wide and 18,250′ in length.

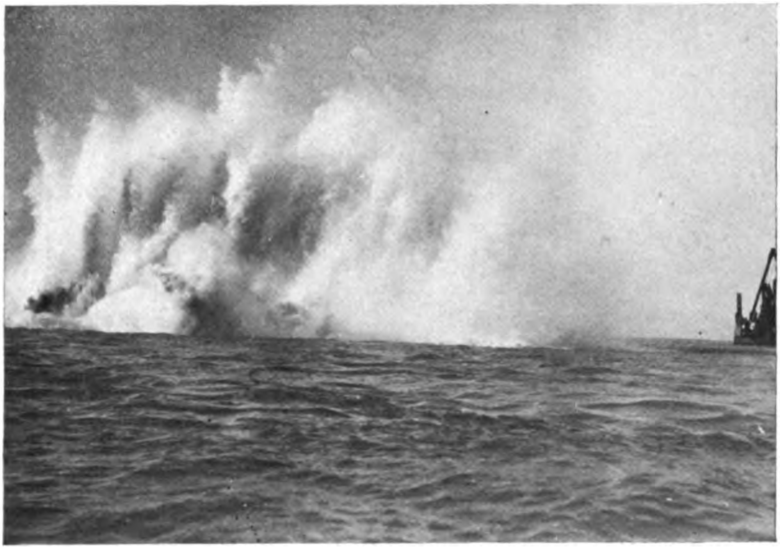

FIG. 85.—Blast: Five Tons of Dynamite. Submarine Rock Work, Livingstone Channel, Detroit River, Mich.

M. Sullivan has the eastern 100′ section. Dunbar and Sullivan the middle 100′, and the Buffalo Dredging Company the western 100′.

To carry out his part of the contract M. Sullivan has a plant of three large dredges, the *Gladiator*, *Hercules*, and *Old Glory*,

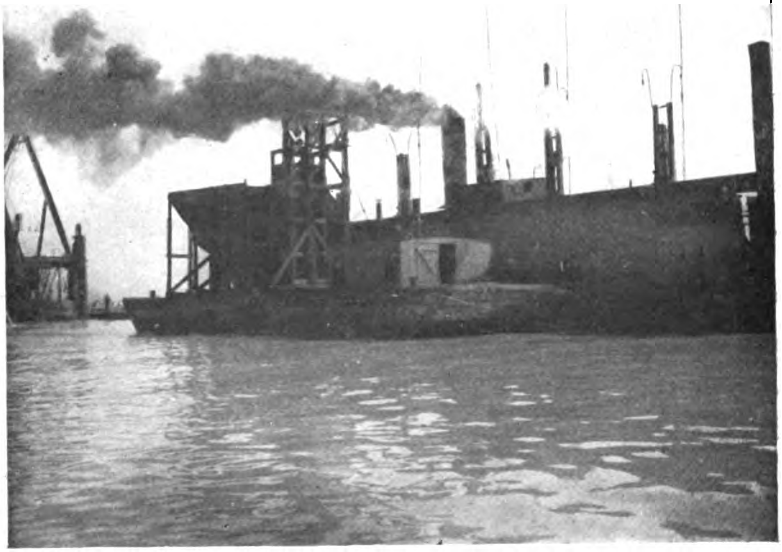

Fig. 86.—Drill Boat " Destroyer."

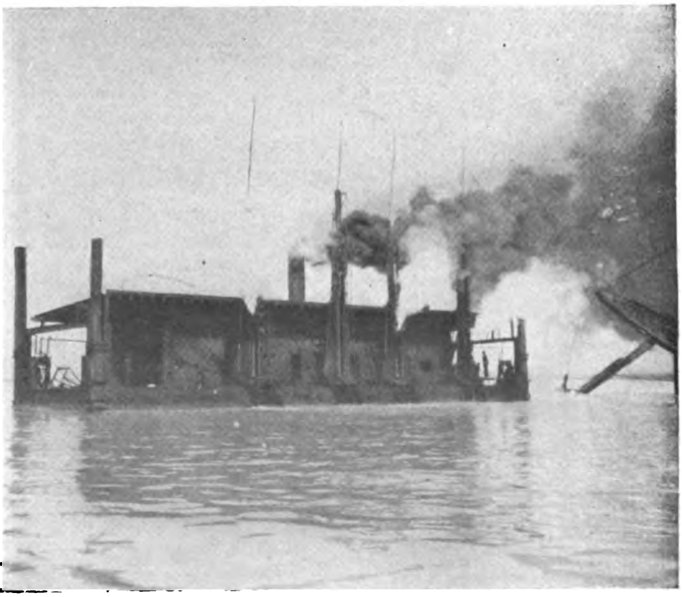

Fig. 87.—Drill Boat " Destroyer."

with their attendant scows and tugs, and also three drill boats, the *Destroyer*, *Dynamiter*, and *Exploder*. It was the *Destroyer* that was blown up during the summer of 1908, receiving damages at that time so severe as to necessitate her rebuilding.

The *Destroyer* is by far the most modern of the M. Sullivan drill boats. Her hull is built entirely of steel and the deck is of the same material. 100′ long, 33′ wide and 6′ deep, she is indeed a staunch boat. Three transverse bulkheads divide the interior into four watertight compartments, each 27½×33′. Two longitudinal bulkheads divide each of these 33′ compartments into 27½×11′ sections. Four manholes in these longitudinal bulkheads furnish a means of passing from one side of the ship to the other.

A wooden house 80′ long and 24′ wide incloses all machinery, excepting the 4 drills, 2 capstans, and spud engines. The spuds or anchor posts are operated by double 6×8 engines made by the Chase Machine Company of Cleveland, Ohio. The capstans, one at each end, are operated by small engines made by the Bath Iron Works of Bath, Me.

The drills are the Ingersoll-Rand K 61, having 6½″ cylinder.

Inside the wooden house near the center of the boat is a large Scotch marine boiler, and near it on the upstream end the coal bunkers are situated. Alongside the coal bunkers on the upstream end of the boat is the blacksmith's forge. At the other end are the two Worthington pumps. There is a passageway on the side of the house nearest the drills, clear excepting for the spare drills and the hydraulic cylinder used to move the drill frames along the deck. The house also contains the dynamo for the electric lighting and the small engine for running it.

DRILL DATA. Type of drill, Ingersoll-Rand, K 61.
Diameter of piston, 6½″.
Stroke, 9″.
Feed 19′, about.
U-chuck.
Steam pressure, 100 lbs. gauge at boiler.
Speed about 225 strokes per minute.

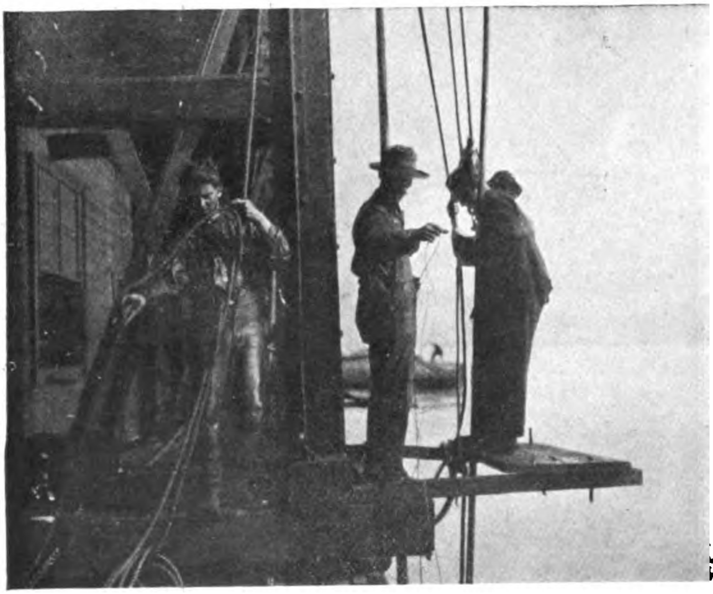

Fig. 88.—Changing Steels on Drill Boat "Destroyer."

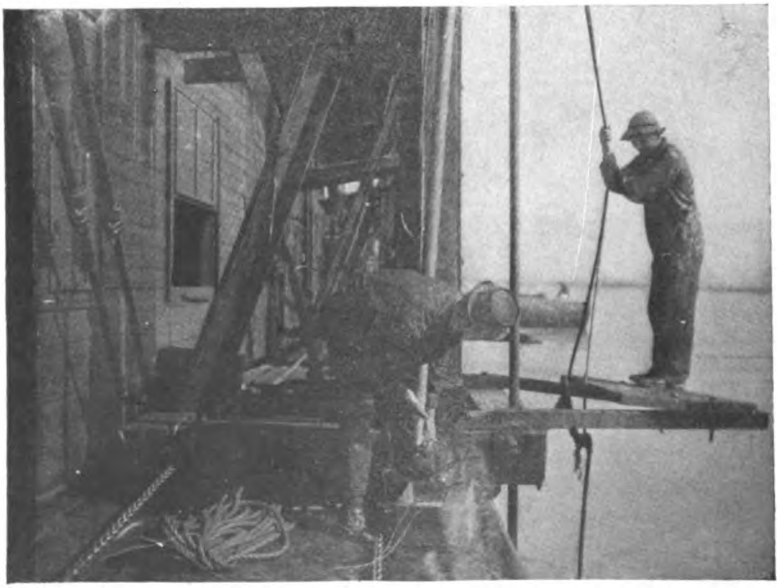

Fig. 89.—Changing Steels on Drill Boat "Destroyer."

The machine is moved up and down by hydraulic power. Worthington pumps, 14×6×10, 5″ suction, 4″ discharge, pressure about 300 lbs., are used for this hydraulic lift. The drill frames are moved along the deck by a chain that passes through the holes in the front ends of the frame of each machine to the ends of the boat where, by means of two sheaves about 5″ apart at each end of the deck, the chain makes two 90° turns, and then passes into the house, parallel to side of boat, and terminates in the piston rods of a double-acting hydraulic cylinder. To move a frame along, a pronged piece of steel is slipped over the link of the chain nearest the frame, so that when the hydraulic moves this pronged piece of metal bears against the frame and moves it along the deck its required distance. The tracks on which the frame slides are steel plates 4″ wide and ¾″ thick. The device for securing the frames in place after they have moved is as follows: A chain passes through holes in the rear of each frame, which chain is anchored at each end of the deck. The frame is secured to this anchored chain by means of two clamps, one at each end of the frame.

Drill point, best octagon tool steel, 4½″ and 4″.

Length of steel, 36′ 9″.

Circular section above tool steel point, 2¼″ and 2⅛″.

Bits handled by hand. They are taken out of machine and taken to blacksmith as follows: First the U-chuck bolts are loosened until the drill bit comes out. The drill cylinder is lowered by the hydraulic as low as possible and a chain slipped around the piston rod with its other end wrapped around the bit near the center of its length. The hydraulic is then used to raise the drill and attached bar, until bit overbalances. As it thus gradually overturns it is caught by five or six men and carried by hand and slipped through a near-by window into the house, where it is handled by blacksmith and helpers.

Steel is tempered till file will not touch.

Holes cleaned by ½″ jet; 60.7 cu.ins. of water needed per cubic inch of rock cut by bit; 2970 cu.ins. water needed per jet per cutting minute.

Water supplied by Worthington pump, 10×4×10, No. 193854, 4″ suction, 3″ discharge.

Pump speed, 47 strokes per minute.

Water pressure, 150 lbs.

A 2″ pipe runs full length of boat, and has a connection near its center to the pump. Opposite each machine a small piece of pipe runs to the outside of the boat through the wall of the house. A 1½″ flexible hose, wire-wound, runs some 20′ to a 6″ piece of pipe that is connected by a right angle to a ¾″ pipe about 12′ long, at the end of which is a reducer, plus about 10′ of ½″ pipe. A block and tackle suspends the washout apparatus at the top of the frame so that the apparatus is easily handled by one workman.

Depth of hole, 12.5′ average.

Diameter of hole, 4½″ steel makes about a 5⅜″ hole, 4″ about 4⅞″.

Longitudinal spacing, 5′.

Lateral spacing, 5′.

Limestone badly broken in spots.

Rock has about 1½′ of sand on top.

Holes shot, 396. Two drills make 5 holes to a range, and two make 4 holes = 18 holes. As a rule 22 ranges are drilled, therefore 22×18 = 396.

Pluto powder for blasting, 60%.

Sticks of powder weigh 18 oz. each, size 8×2″.

Charge, 17 sticks per hole.

Blaster and foreman did loading and blasting.

Four drills on boat.

Scotch marine boiler.

Pressure at boiler, 100 lbs. gauge.

Length of feed pipe, 60′ from steam chest of drill to main.

Diameter of feed pipe, 4″ main, slide 2″ and 1½″.

Contract reads 750 good working days.

Length of shift, 11 hrs.

Two shifts. The tug bringing the men to work leaves the dock morning and evening at six o'clock, Eastern standard time.

Three boats must be visited; at each leaving a crew and taking off a crew.

4 drillers	at $3.02½		=$12.10	per shift
4 helpers	at 2.42		= 9.68	"
1 blaster	at 3.30		= 3.30	"
1 foreman	at 4.65	12.8%	= 4.65	"
1 blacksmith	at 3.62		= 3.62	"
2 blacksmiths' helpers	at 2.40		= 4.80	"
1 fireman	at 2.75		= 2.75	"
1 shift, 14 men, total			=$40.90	"
2 shifts, 28 men, total			= 81.80	"

Contract price was: For rock $2.80 per cubic yard, earth 50 cents per cubic yard.

The work of the blacksmith is mainly repointing drill bits and welding broken ones. The points of the bits are of the best hexagonal tool steel. This must be welded to the shank of the bit. Then the pointing must be done. To assist in handling, the steel, wooden horses are used having a roller on top.

Eight tons of coal are used in 24 hrs. = 2000 lbs. per drill per shift.

Use 55 gals. of drill cylinder oil in 3 days 1 bbl. of cylinder oil in 4 weeks = 20½ pints per drill per day (1 shift).

Coal is brought alongside in a bunker with a chute mounted on a scow and is transferred from the chute to the drill-boat as follows: On the end of the chute there is a framework for an elevator in which a box or skip is raised and lowered by means of a cable, leading back to a dinkey engine on the stern of the scow. Starting with the skip empty on the deck of the scow, a door in the chute is pulled open by means of a lever, and enough coal is run out to fill the box. Signal is then given and the loaded skip is hoisted some 15′. An inclined trough leading into the bunker has in the meantime been prepared. As soon as the bottom of the skip is on a level with the top of the inclined trough, that end facing the trough falls and the coal runs out into the bunker of the drill-boat. The skip is then lowered and the trap-end automatically closes. All the Sullivan boats have the same method of getting coal that the *Destroyer* has. Reference will therefore be made to the *Destroyer* in the reports on the other two boats of M. Sullivan Co., the *Dynamiter* and the *Exploder*.

The cost of handling is not included in the cost of coal, for the reason that the company owns its tugs. The cost of the coal loaded on scows at the dock is $3.15 per ton, and the cost of handling would be 35 cts. if done by piecework or on a contract basis.

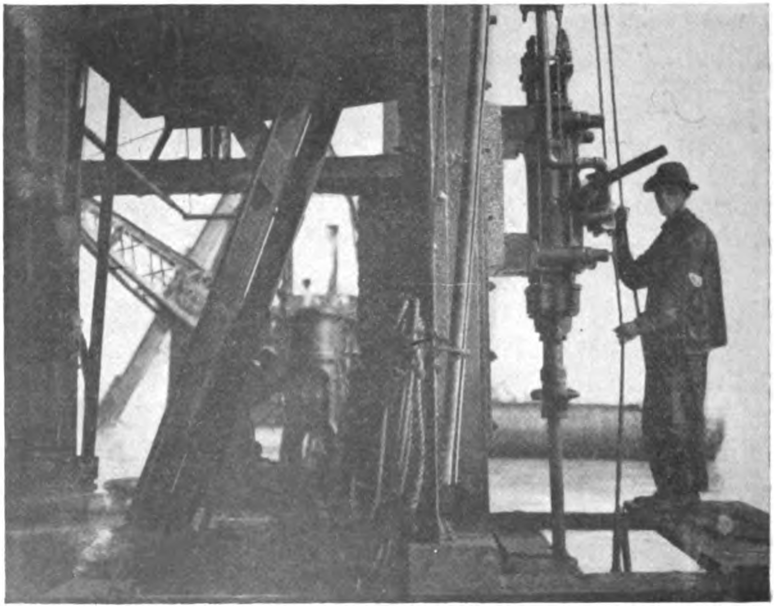

FIG. 90.—Drill and Drill Frame: Drill Boat "Destroyer."

No figures were obtained as to repairs, as no record was kept. When breaks were not too serious, the crew on board made repairs. When they were very bad and the crew could not make them, the spare drill was set up and the old one boxed and sent back to the factory. Each boat of the Sullivan fleet has two foremen:

a day foreman at 12.8% of the day wages; a night foreman at 11.7% of the night wages. Besides there is one man known as the walking boss who has charge of the three boats.

After their day's work is finished the men are taken ashore, where they live at their own expense. The walking boss is given quarters on board one of the Sullivan dredges, the *Old Glory*.

Lighting is furnished by a small dynamo operated by a 4 H.P. engine.

Interest and depreciation, figured at 2% per working month, on plant valued at $40,000, = $15.50 per shift.

Moving the boat from range to range consumes 3% of the total time, costing 3% of the shift's wages or $1.23 per shift (day) = $0.31 per drill per day (1 shift).

A rough inventory of the equipment of this boat is as follows:

Four drills and equipment.
Extra bits.
Four spuds, 4 spud engines, 6×8.
Two steam capstans.
One boat, 33′×110′.
One Worthington pump for hydraulic, 14×6×10.
One Worthington pump for washout, 10×4×10.
One Scotch marine boiler, 100 lbs. (gauge-pressure).
One hydraulic cylinder for moving frames.
One dynamo and 4 H.P. engine.
One blower, 1 forge, 1 anvil, 1 bench, 1 vise, 1 cutter.
One powder boat.
Four dry cells.
Three switches.

EXPLANATION OF TIME STUDY. The five headings on the left are the logical divisions into which a complete drill cycle separates. The minimum, mean and maximum periods of time consumed in each of these operations in the left-hand column is given under its proper heading. The entries under "Mean," "Max," "Useful Working Time," need the following explanation. Supposing four "Drill-cutting" periods for four holes

Drill No. 1, average depth 12.5′. Number of holes drilled while under observation, 6. Linear feet, 75.

	Observations.	Min.	Mean.	Max.	Useful Working. Time.		Excess Over Useful Time.	
		Min. Sec.	Min. Sec.	Min. Sec.	Min. Sec.	Per Cent of Total Time.	Min. Sec.	Per Cent of Total Time.
Getting into position	2	2:00	2:10	2:33	4:20	0.53	0:0	
Drill cutting	6	22:10	42:15	57:00	253:30	31.32	159:16	19.67
Finishing hole	5	0:30	14:29	37:30	72:20	8.93	180:05	22.25
Waiting for loading gang	4	1:00	2:26	5:42	9:45	1.21	0:0	
Loading hole	4	4:35	5:45	7:40	23:00	2.84	0:0	
Total of cycle		30:15	67:05	110:25	362:55	44.83	339:21	41.92
							Delays.	
Waiting, last hole							0:0	0.0
Moving boat							22:15	2.75
Miscellaneous delays							85:00	10.50
Totals					362:55	44.83	446:36	55.17
Drill No. 2, average depth, 12.5′. Number of holes drilled while under observation, 10. Linear feet, 125.								
Getting into position	7	1:00	2:20	3:30	16:20	2.03	0:0	0.0
Drill cutting	10	27:00	37:33	55:00	375:30	46.70	0:0	
Finishing hole	10	0:45	3:18	8:00	32:56	4.10	31:34	3.91
Waiting for loading gang	10	0:15	1:50	6:45	18:25	2.27	00:0	
Loading hole	10	2:00	3:42	8:10	37:00	4.60	00:0	
Total of cycle		31:00	48:43	81:25	480:11	59.70	31:34	3.91
							Delays.	
Waiting last hole							202:25	25.13
Moving boat							22:15	2.75
Miscellaneous delays							68:25	8.51
Totals					480:11	59.70	324:39	40.30

Drill No. 3, average depth, 12.5′. Number of holes drilled while under observation, 8. Linear feet, 100.

	Observations.	Min.	Mean.	Max.	Useful Working Time.		Excess Over Useful Time.		Average Per Cent of Total Time for 4 drills.	
		Min. Sec.	Min Sec.	Min. Sec.	Min. Sec.	Per Cent of Total Time.	Min. Sec.	Per Cent of Total Time.	Useful Time.	Excess. Time.
Getting into position	6	0:20	1:05	1:30	6:30	0.73	0:0			
Drill cutting	8	27:00	45:06	61:15	360:45	41.24	0:0			
Finishing hole	8	0:40	3:47	6:45	30:16	3.45	80:04	9.13		
Waiting for loading gang	7	0:30	0:49	1:00	5:40	0.65	0:0			
Loading	7	1:10	2:51	6:30	19:55	2.28	0:0			
Cycle total		29:40	53:38	77:00	423:06	48.35	80:04	9.13		
							Delays.			
Waiting, last hole							225:26	25.75		
Moving boat							22:15	2.57		
Miscellaneous delays							124:10	14.20		
Totals					423:06	48.35	451:54	51.65		

Drill No. 4, average depth, 12.5′. Number of holes drilled while under observation, 7. Linear feet, 87.5.

	Observations.	Min.	Mean.	Max.	Useful Working Time.		Excess Over Useful Time.		Average Per Cent of Total Time for 4 drills.	
		Min. Sec.	Min Sec.	Min. Sec.	Min. Sec.	Per Cent of Total Time.	Min. Sec.	Per Cent of Total Time.	Useful Time.	Excess. Time.
Getting into position	4	1:30	2:33	4:00	9:50	1.33	0:0		1.15	
Drill cutting	7	24:35	41:49	60:00	292:40	40.10	0:0		39.86	4.90
Finishing hole	7	1:45	5:34	12:30	38:59	5.34	16:11	2.21	5.46	9.38
Waiting for loading gang	6	0:15	2:22	7:00	14:14	1.94	25:46	3.53	1.52	0.89
Loading hole	6	1:30	3:48	8:30	22:50	3.11	0:0		3.19	
Total of cycle		29:35	56:06	92:00	378:33	51.82	41:57	5.74	51.18	15.17
							Delays.			
Waiting, last hole							199:35	27.31		19.54
Moving boat							22:15	3.04		2.78
Miscellaneous delays							88:15	12.09		11.33
Totals					378:33	51.82	352:02	48.18	51.18	48.82

were 5, 3, 4, and 10 min. respectively. The 5, 3, 4 being close together are summed $5+3+4=12$, and the average time $12 \div 3=4$ obtained; 10, being for some reason too high, is left out of the average. Still this 10 represents one operation, and so to take due account of it, it is given simply the weight of the average, 4. The total "Useful Working Time" is then $5+3+4+4=16$. The difference between 10 and 4 or 6 represents the "Excess over Useful Working Time." This system has been used in this Time Study. The "Useful Working Time" is given both in minutes and seconds and in percentage of the total time. This is true also of the "Excess Time." The latter is classed under Idle Time, in the same columns with which appear the time lost in the operations of Waiting for Last Hole, Moving Boat, and Miscellaneous Delays, together with the percentages of these to the total time. In this connection may be mentioned the fact that after a frame has drilled its required number of holes it must be idle until the slowest drill on the boat finishes the last hole in its range.

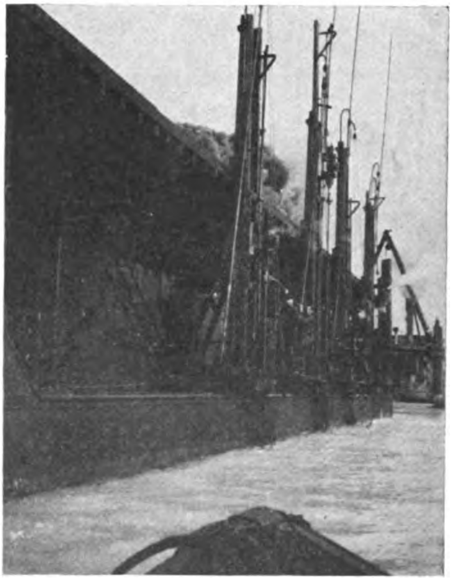

FIG. 91.—Drill Boat " Destroyer."

During an observed period of $3219\frac{53}{60}$ drill minutes, 31 holes at $12\frac{1}{2}' = 387\frac{1}{2}'$ were drilled. Per 4-drill minute or for the boat this would be $387\frac{1}{2}'$ in 804′ 58″. On the basis of an 11-hour day = 660 minutes, 25 holes would be put down during a shift $= 312\frac{1}{2}'$. The spacing of the holes being 5′ each way and drilled about $2\frac{1}{2}'$ below grade the cubic yards of rock loosened would be $\frac{25 \times 5' \times 5' \times 10'}{27} = 232$ cu.yds.

Based on the above performance and the before-mentioned supply and labor costs, and taking no account of the contractor's overhead charges or profit, preparatory charges, legal expenses, insurance, bond and charity expenses, the following costs per lineal foot drilled and per pay yard have been deduced:

COSTS

			Amt. per Shift.	Totals.	Per Foot Drilled. Cents.	Totals.	Per Pay Yard. Cents.	Totals.
4 drillers	at 3.02½ (11 hrs.)	= $12.10						
4 driller's helpers	at $2.42 "	= 9.68			6.96		9.40	
		——	21.78					
1 blaster	at 3.30 "	= 3.30			2.54		3.43	
1 foreman (12.8%)	at 4.65 "	= 4.65						
		——	7.95					
1 blacksmith	at 3.62 "	= 3.62						
2 blacksmith's helpers	at 2.42 "	= 4.84			2.71		3.65	
		——	8.46					
1 fireman	at 2.75 "	= 2.75	2.75		0.88		1.19	
Total			——	40.94	——	13.09	——	17.67
Coal, 4 tons, 12 hrs.	at 3.15	= 12.60	12.60		4.00		5.44	
Oil 3.30 pts. per hole = 10.30 gal., 11 hrs. at 40 cts. per gal.			4.12		1.31		1.78	
60% dynamite, 480 lbs., 11 hrs at 12 cts =			57.60		18.30		24.80	
			——	74.32	——	23.61	——	32.02
Total for 312.5′ or 232 pay yards			115.26		36.70		49.69	
Plant $40,000, interest and depreciation 2% per working month			15.50		4.93		6.68	

The average cutting speed for the four drills was 0.233 lin.ft. per cutting minute or 13.98′ per drill hour, including getting into position, etc.

The speed per minute for drill No. 1 was 0.206′, while that for No. 4 was 0.232′ per minute. No. 2 was the upstream drill and it would naturally be expected to do the best work, inasmuch as the current would tend to wash down the débris from the upper holes to the lower ones, thus impeding them. But here the upstream drill made the poorest showing of any. It not only made poor time itself, but it held up the other three drills over 3 hrs. waiting for it to finish its last hole. The explanation for this is that No. 1 was working on a face left shattered and covered with débris from a recent blast. The holes would refill almost as quickly as drilled.

The average ratio of cutting time to total time for the four drills was 0.5117, and the ratio of idle time to useful working time (cycle time) for the four drills was, 0.979.

"DESTROYER." The following performance data and deductions therefrom are based upon an average shift performance:

Shifts	1
Hours	11
Number of holes	25
Depth of holes, feet	12½
Lineal feet drilled per shift	312½
Cubic yards pay rock per shift	232
Dynamite, 60%	479 lbs. = 287.4 lbs. nitroglycerin
Coal, tons	4
Labor per shift	$40.94
Lineal feet per drill hour	7.1
Lineal feet per man hour	2.025
Labor per foot drilled	13.09 cts.
Cubic yards of pay rock per drill hour	5.27
Cubic yards of pay rock per man hour	1.505
Labor per cubic yard of pay rock	17.67 cts.
Coal per drill per shift	2000 lbs.
Coal per foot drilled, in pounds	25.6
60% dynamite per foot drilled, gross	1.53 lbs.; nitroglycerin 0.92 lb.
60% dynamite per cubic yard pay rock	2.06 lbs.; nitroglycerin 1.24 lbs.
60% dynamite per cubic yard blasted	1.65 lbs.; nitroglycerin 0.99 lb.

Ratio, $\frac{\text{cubic yards blasted}}{\text{cubic yards pay rock}}$	1.25
Total cost drilling and loading per lineal foot, exclusive of dynamite and interest and depreciation	18.40 cts.
Total cost per cubic yard of pay rock, exclusive of interest and depreciation	49.69 cts.
Total cost per cubic yard pay rock, including interest and depreciation	56.37 cts.

"EXPLODER." The second of M. Sullivan's drill boats on the Livingstone Improvement of the Detroit River, the *Exploder*, represents a very old type of craft. The hull of this boat is composed entirely of timber. Her construction differs but slightly from the ordinary type of wooden-decked scows. The *Exploder* is 79′ long and 27′ 4″ beam. The house is 12′ high at the front end and somewhat less at the back, 43′ long and 18′ wide. This boat is also provided with spuds operated by small double engines with 6×10 cylinders. These spud engines on the drill side of the boat rest on the deck, while on the other side they are on the posts that form the guide for the spuds. This boat spent the whole winter up at Alpena, working amid great cakes of ice. She has three drill frames.

DRILL DATA. The drills are Ingersoll-Sergeant type. H–15–9.

Piston diameter, 5½″.
Stroke, 8″.
Feed, 18′ about.
U-chuck.
Steam pressure 100 lbs. gauge at boiler.
Number of strokes, about 300 per minute.

The principle on which the drill frame is moved along the deck is the common hydraulic. The hydraulic cylinder in this case is 9′ in length. The tracks on which the frames slide are ⅜×3″ plate laid on a 4×6″ sill at the edge of the deck and a 45-lb. standard rail for the rear track. For holding the frame in any given position a chain passes near the rear of the frame. Each machine has one of these chains that is fastened at the ends to the deck. When the drill is in its desired position it is held there by snapping a clamp into a convenient link of the chain and thereby fastened securely to the rear part of the frame.

Steel bits have 4½″ and 4″ points.

Point is made of black diamond steel.

Length of steel, 37′ 6″.

Circular section of steel 2 and 2½″ in diameter.

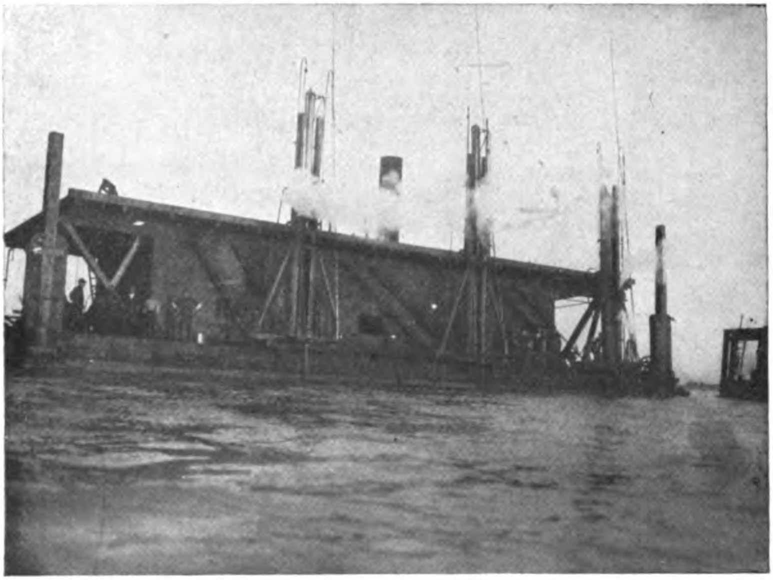

FIG. 92.—Drill Boat "Exploder."

Steel handled by hand with the assistance of a hook hanging from ceiling.

Steel tempered hard till file will not touch.

Holes cleaned by ½″ water jet.

Worthington pump 12×5½×10″ supplies water for jets.

Speed of pump, 21 revs. per minute.

Water pressure, 300 lbs.

The washout water comes from the same pump as does the water for the hydraulic lift. It is therefore necessary to be careful and not turn the washout water on full force.

Holes are 10½′ deep.

Holes have diameter of 4⅞ and 5⅜″ at top, but decrease in size a little towards the bottom.

Longitudinal spacing, 5′.

Lateral spacing of holes, 5′.

Material drilled, limestone.

Rock is hard in spots. Sand on top of rock is 1½′ to 2′ in depth.

Holes shot at one time 24×15=360, i.e., 24 ranges of 15 holes each.

Pluto powder used, 60%.

Size of sticks 8×2″, weight 18 oz.

Thirty-two sticks used for charging one hole.

All holes are shot at once. Leads run up from the last two or three holes loaded and when these are touched to the contact points all loaded holes go off.

Blasting gang consists of blaster and foreman.

Three drills used on boat.

Boiler is Scotch marine, 12×8′.

Steam pressure at boiler, 100 lbs.

Length of feed pipe, 60′ from main to drill.

Contract reads 750 good working days.

Length of shift, 11 hrs.

Two shifts.

Working force per shift is as follows:

3 runners	at	$3.02½	=$9.07½	per shift
3 helpers	at	2.42	= 7.26	"
1 blacksmith	at	3.62	= 3.62	"
2 blacksmith's helpers	at	2.42	= 4.84	"
1 blaster	at	3.30	= 3.30	"
1 fireman	at	2.75	= 2.75	"
1 foreman	at	$121.00 per mo.	= 4.65	"

Day foreman $121 per mo., 15.1% day wages..	$35.49½
Night foreman $110 per mo., 13.7% night wages	35.09½
Total, both shifts..................	70.59

Contract price $2.80 per yard for rock and 50 cts. for earth.

Smith's work is keeping the drill steel in shape.

Eight tons coal used in 24 hrs. = 2666 lbs. per drill per shift.

Fifty-five gals. of drill cylinder oil used in one week, lubricating oil, 5 gals. a week = 13⅓ pts. per drill per shift.

Coal is handled by the company's equipment and no cost added for this work. The manner of handling is described in report on the *Destroyer*.

Coal costs $3.15 per ton. The cost would be 35 cts. per ton more if company did not operate their own tugs.

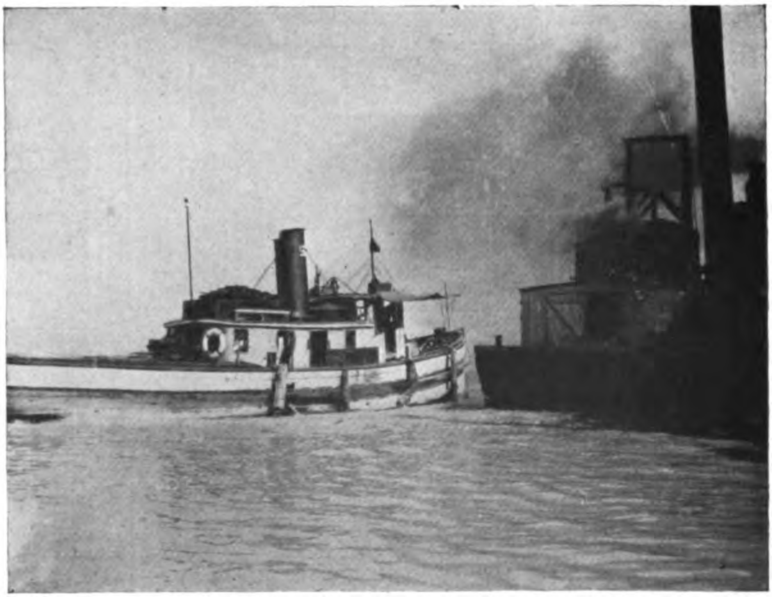

FIG. 93.—Drill Boat "Exploder."

Repairs were not kept track of, the crew making them when necessary. Two extra machines kept on hand.

Each boat of the Sullivan fleet has two foremen. There is also one man known as the walking boss who has charge of the three boats.

Quarters for crew were ashore, and were paid for by themselves.

Interest and depreciation on plant, valued at $25,000, at 2% per working month, = $9.60 per shift.

Moving boat from range to range, 3.6% time, costing 3.6% of day's wages or $1.28 per shift, = $0.43 per drill per shift.

A rough inventory of the equipment of this boat follows:

One wooden boat, 79′×27′ 4″.
Three drills and equipments.
Eleven bits.
Four spuds.
Four spud engines, 6×10″.
One steam windlass.
Two hand windlasses.
One boiler, 8×10′.
One force pump, Worthington, 12×5½×10.″
One blower.
One engine for blower, 6×8″.
One forge.
One anvil.
One bench.
One pipe clamp.
One hydraulic to move frame, 9′ long.
One Penberthy injector.
One small dynamo for lighting, with engine.
One powder boat.
One cutter.

The only record of performance obtainable on this boat was for one shift for a period of one week. It is as follows:

Date.	No. of Holes.	Depth.	Powder.	Hours.
August 27, 1909......	49	539′	1760 lbs. 60%	11
August 28, 1909......	47	517′	1690 "	11
August 30, 1909......	44	484′	1580 "	11
August 31, 1909......	35	385′	1260 "	11
September 1, 1909....	46	506′	1660 "	11
September 2, 1909....	31	341′	1120 "	11
Total..........	252	2772′	9070 "	66
Average per shift.....	42	462′	1512 "	11

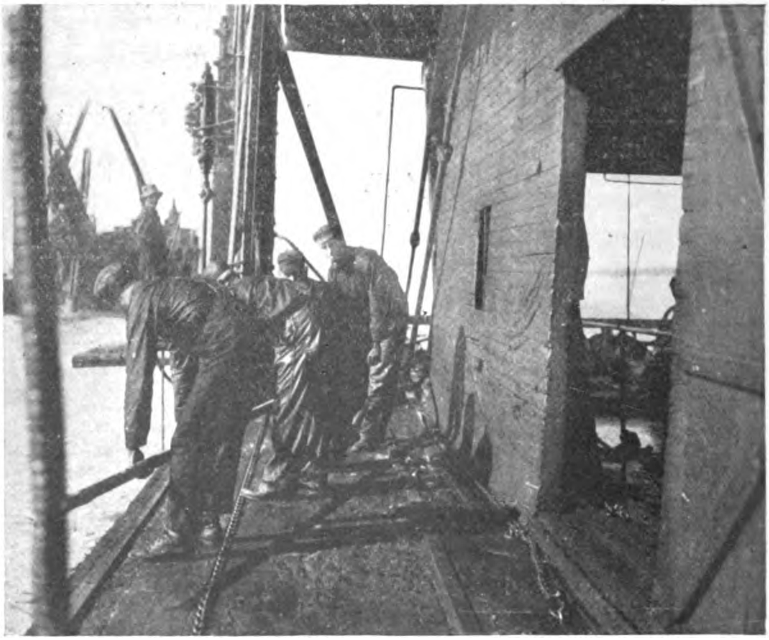

FIG. 94.—Handling Steels on Drill Boat "Exploder."

On a daily basis the cost would be as follows:

COSTS

Force.	Rate Standard.	Cost.	Cost per Foot in Cents.	Cost per Pay Yard in Cents
3 drillers	$3.02½	$9.07	1.96	2.92
3 helpers	2.42	7.26	1.57	2.34
1 blacksmith	3.62	3.62	0.79	1.17
2 blacksmith's helpers	2.42	4.84	1.05	1.56
1 blaster	3.30	3.30	0.72	1.06
1 fireman	2.75	2.75	0.60	0.89
1 foreman	4.65	4.65	1.01	1.50
Total		35.49	7.70	11.44
60% dynamite, 1513 lbs. at 12 cts.		181.56	39.20	58.20
Coal, 4 tons at 3.15		12.60	2.73	4.05
Oil, 5 gallons at 40 cts.		2.00	0.44	0.65
Total		231.65	50.07	74.34
Plant $25,000, interest and depreciation at 2% per working month		9.60	2.08	3.08

Pay yardage is based on the following: 11′ holes, less 3′ drilled below grade, equals 8′ pay drilling. Spacing of holes, 5′×5′.

$$\frac{5'\times 5'\times 8'\times 42}{27}=311 \text{ pay yards per day.}$$

In the above tabulation of costs, no account has been taken of contractor's overhead charges or profit, cost of getting plant into commission in the spring, and cleaning up in the fall, storing equipment during winter, legal expenses, insurance or charity, etc.

The following is a general summary of average performance data with deductions therefrom:

Shifts	6
Hours	66
Number of holes	252
Depth of holes	11′
Lineal feet drilled	2772
Cubic yards pay rock	1866
Dynamite, 60%	9070 lbs.; nitroglycerin, 5442 lbs.
Coal, tons	24
Labor, per shift	$35.49
Lineal feet per shift	462
Lineal feet per drill hour	14
Lineal feet per man hour	3.5
Labor per foot drilled, in cents	7.70
Cubic yards of pay rock per shift	311
Cubic yards of pay rock per drill hour	9.45
Cubic yards of pay rock per foot drilled	0.675
Labor per cubic yard pay rock, in cents	11.44
Coal per drill per shift, in pounds	2666
Coal per foot drilled, in pounds	17.3
60% dynamite, per foot drilled	Gross 3.27 lbs., nitroglycerin 1.962
60% dynamite per cubic yard pay rock	Gross 4.86 lbs., nitroglycerin 2.91
60% dynamite per cubic yard blasted	Gross 3.53 lbs., nitroglycerin 2.118

Average depth of drilled hole, 10.4′.

DRILL BOAT "EXPLODER"

	No. 1, Eight Holes.				No. 2, Eight Holes.				No. 3, Seven Holes.			
	No. of Obs.	Min. Min. Sec.	Mean. Min. Sec.	Max. Min. Sec.	No. of Obs.	Min Min. Sec.	Mean. Min. Sec.	Max. Min. Sec.	No. of Obs.	Min. Min. Sec.	Mean. Min. Sec.	Max. Min. Sec.
Getting into position............	5	1:25	2:10	3:30	4	1:25	1:40	2:15	4	1:30	1:40	2:30
Drill cutting....................	8	17:00	40:25	50:20	8	33:05	43:20	62:35	7	45:00	57:25	76:55
Finishing hole...................	8	0:30	1:25	4:50	8	0:30	1:05	2:00	5	0:30	1:20	4:00
Waiting for loading gang.........	7	0:45	1:15	1:35	7	0:25	0:50	1:35	6	0:15	1:05	2:50
Loading..........................	7	4:20	6:40	8:45	7	4:55	6:10	7:55	5	2:40	4:30	6:30
Totals...........................	....	24:00	51:55	69:00		40:20	53:05	76:20		49:55	66:00	92:45

In the above table is given the minimum, maximum, and mean time in minutes and seconds required to perform each of the operations into which the process of drilling is divided, together with the number of observations of which the mean was taken.

The total gives the total time of the cycle of drilling one hole but does not include any time lost during the cycle or after its completion.

Average depth hole 10.4′.

DRILL BOAT "EXPLODER"

	No. 1, Eight Holes.			No. 2, Eight Holes.			No. 3, Seven Holes.		
	Mean Time per Hole.	Total Working Time.	Total Idle Time.	Mean Time per Hole.	Total Working Time.	Total Idle Time.	Mean Time per Hole.	Total Working Time.	Total Idle Time.
Getting into position	2:20	10:50	7:05	1:40	6:40	....	1:40	6:40	128:15
Drill cutting	40:25	323:10	....	43:20	346:35	....	57:25	401:45	
Finishing hole	1:25	11:20	12:15	1:05	8:25	....	1:20	6:40	
Waiting for loading gang	1:15	8:30	10:55	0:50	5:50	3:10	1:05	6:30	
Loading	6:40	46:20	6:25	6:10	43:00	....	4:30	22:35	
Totals	51:55	400:10	36:40	53:05	410:30	3:10	66:40	444:10	128:15
Waiting, last hole	....	....	190:45	....	....	192:15	....	....	42:00
Moving boat	....	....	23:55	....	....	23:55	....	....	23:55
Miscellaneous delays	....	....	15:05	....	....	35:50	....	....	29:50

The above table shows the average time in minutes and seconds required for each of the operations into which the process of drilling has been divided and also the exact total time in minutes and seconds that the drill was engaged on the operation, and whatever time was lost during the operation. The total gives the total time working and idle. This total, together with the last three items of delays, makes up the day's work.

The cutting speed average was 0.232′ per cutting minute.

The average ratio of cutting to total time was 0.536.

The average ratio of idle to useful working time (cycle time) was 0.595.

DRILL BOAT "EXPLODER"

	No. 1.	Per Cent.	No. 2.	Per Cent.	No. 3.	Per Cent.	Average Per Cent Nos. 1, 2 & 3.
Useful (cycle) working	400:10	60.05	410:30	61.67	444:10	66.46	62.73
Drill idle during working	36:40	5.50	3:10	0.47	128:15	19.20	8.39
Idle miscellaneous delays	15:05	2.26	35:50	5.37	29:50	4.47	4.03
Waiting during boat move	23:55	3.59	23:55	3.59	23:55	3.58	3.59
Waiting last hole	190:45	28.60	192:15	28.90	42:00	6.29	21.26
Total idle time	266:25	39.95	255:10	38.33	224:00	33.54	37.27
Total time	666:35	100.00	665:40	100.00	668:10	100.00	100.00

The above table is a summary of the preceding one. The time for useful working is the sum of the first five items of the preceding table and represents the time of a cycle of drilling. The second item is the total time lost during this cycle. The percentages are percentages of total time worked during observation.

Ratio $\frac{\text{cubic yards blasted}}{\text{cubic yards pay rock}}$	= 1.37
Total cost per lineal foot drilled, exclusive of dynamite, interest and depreciation	10.87 cts.
Total cost per cubic yard pay rock, exclusive of interest and depreciation	74.34 "
Total cost per cubic yard pay rock, including interest and depreciation	77.42 "
Total cost per cubic yard blasted, including interest and depreciation	56.40 "

" DYNAMITER ": the *Dynamiter* is the third of Mr. Sullivan's boats on the Livingstone Improvement of the Detroit River. The work on which it is engaged is in the east 100′ of section No. 3 of the new government channel between Bois Blanc Island and Sugar Island. The hull is 67′×25½′ and the house over her is 50′×16′ 10″×12′ 1″ high. The boat is so short that in order to handle the drill irons easily, an extension has to be run out 10′ on one end, and the railing on this extension furnishes a means of support for the drill steel when being worked by the smiths.

One very bad feature of this old boat is that the boiler is placed below decks, and the fireman has to climb down a ladder in order to get to the doors. This makes firing on this boat very hot for the stoker.

DRILL DATA: The drills are H–15–9 Ingersoll-Sergeant. No. 1 drill was put on in July, 1908. The other two were put on nine years ago. Of course the cylinders now on these drills are not the original ones, but in all other respects they are just as they were nine years ago.

Diameter of piston, 5½″.

Stroke 8″, but do not get that much.

Feed 18′ lift.

U chuck.

Steam pressure 90 lbs., gauge at boiler.

300 strokes per minute.

Hydraulic lift and device for moving along deck very similar to those of *Exploder*, which have been described heretofore.

Diameter of starting bit, 4″.
Length of steel, 36′.
Circular section of steel, 2″.
Steel handled by hand.
Steel tempered till file will not touch.
Jet used for cleaning holes, ½″.
Worthington pump, 12×5½×10, supplies water for jets.
Speed of pump variable.

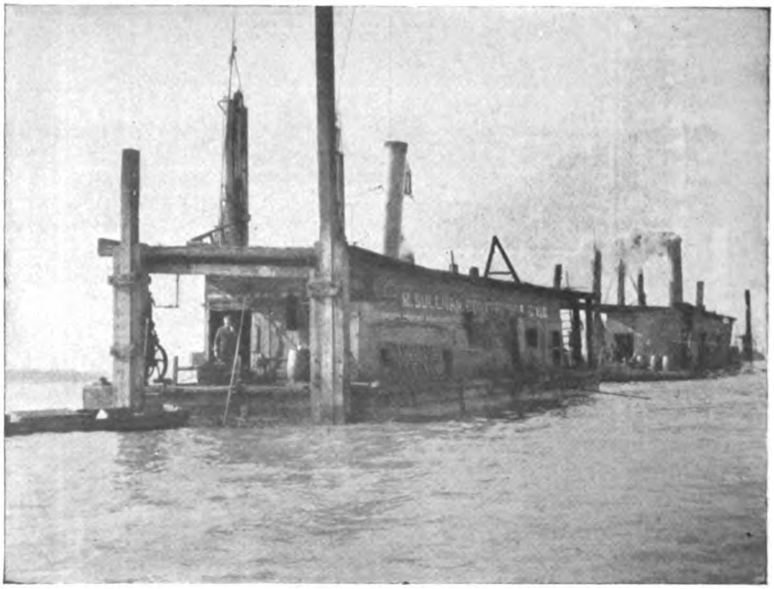

Fig. 95.—Drill Boat "Dynamiter."

Water pressure, 250–300 lbs.
Holes 11′ deep.
Holes are 4⅞″ diameter near top, but decrease downward.
Longitudinal spacing of holes, 5′.
Lateral spacing, 5′.
Rock, limestone.
Rock fairly clean, but broken near edges of cut.
Holes shot 12×23=276; 23 ranges at 12 each range.
Pluto powder used, 60%.

Size of sticks, 8″×2″, weight 18 oz.
Thirty-two sticks used for charging one hole.
Blasting gang consists of blaster and foreman.
Three drills making four holes each to a range.
Scotch marine boiler, 9′×6′.
Steam pressure of boiler, 90 lbs. gauge.
Contract reads 750 good working days.
Length of shift, 11 hours.
Two shifts.
Crew of boat is as follows:

3 runners	at	$3.02½	=$9.07½	per shift
3 helpers	at	2.42	= 7.26	"
1 smith	at	3.62	= 3.62	"
2 smiths' helpers	at	2.42	= 4.84	"
1 blaster	at	3.30	= 3.30	"
1 fireman	at	2.75	= 2.75	"
1 foreman, per month	at	$121.00	= 4.65	"
Total, per day shift			$35.49½	
Total, per night shift			35.09½	
		Total,	$70.59	both shifts

Contracts read, $2.80 per yard for rock and 50 cts. for earth.

Smith's work is taking care of drill and steel.

Nine tons of coal used in 24 hours = 3,000 lbs. per drill per shift. The price of coal per ton is $3.15.

Coal is handled by the company's equipment and no cost added for this work. The manner of handling is described in the report on the *Destroyer*.

Fifty-five gal. of oil (drill cylinder) used in 2 weeks = 6 pints per drill per shift.

Repairs are made by foreman and crew when possible. No account is kept of them, nor of lost time, because as long as one drill is working the whole boat is considered to be working. One extra drill is kept on hand.

Each boat of the Sullivan fleet has two foremen; a day foreman at 15.1% of the day wages and a night foreman at 13.7% of the night wages. Besides there is one man known as the walking boss who has charge of the three boats.

Quarters of men on shore, of the walking boss, on dredge.

NOTE.—The charging tube on this boat is similar to those on the other boats, and a description here will apply to the other two Sullivan boats. The part into which the sticks of powder are inserted is 12′ long, made of split 2″ piping. This terminates at its upper end in 12′ of 1¼″ piping. There is a ring attached to this last section to which a block and tackle is secured that passes over the top of the frame and has one rope coming down to the deck for operating. Through the pipes runs a wooden stick 25′ long by ¾″. It is used for ramming the powder out of the charger and into the hole. When not in use this stick is pulled up about half way and a wedge put in to hold it. The process of loading the hole and shooting is as follows, and applies to all this company's boats: First, the hole is thoroughly cleaned. After this the blaster is called and comes with the proper number of sticks for the hole. The charging pipe being unslung the blaster inserts a stick of powder into it, restraining it from falling out by his hand. He then puts the second stick against the

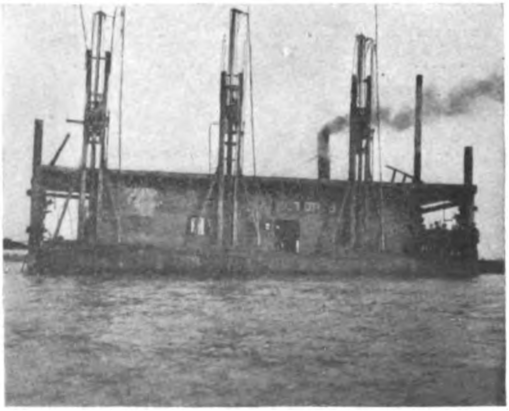

FIG. 96.—Drill Boat "Dynamiter."

bottom of the first and shoves them both up into the pipe. This process is repeated until the charger is full, all but one stick. This last stick has a piece of wire or rope around it or a small wedge is inserted to keep the sticks from falling. The charger being full, it is lowered into the cleaned hole and two men release the wooden stick and force it down on top of the sticks of powder, the other two pulling upward on the pipe with a jerky motion. The result is that the sticks of powder are rammed tightly down into the hole. On these boats two chargerfuls are jammed into each hole, and so the above process has to be repeated. When the hole is fully loaded the charger is hoisted out of the way by its tackle, the wooden stick having first been wedged in its proper place. In case the powder gets jammed, due to loose rock falling into the hole, the hole is said to be lost, meaning that it can not be loaded. In such a case, if possible, the powder is withdrawn and the hole redrilled. If, for instance, the first tubeful has been safely gotten in and the second one jams, or if part of the powder in the first has been gotten in and the rest gets jammed, a new hole has to be dug, since obviously it would not be safe to redrill with any powder in the old hole.

The wires of the last two or three of the total number of holes being loaded, instead of being tied around the last stick to hold it in place while loading, are spliced to the ends of the two fuse wires, and the fuse inserted in the powder in the usual way. These last holes have a fuse in the last stick of each hole so that if in the subsequent maneuvring one set gets lost the others may be used. When a boat is ready to shoot, proper signals are given and boats in the danger zone stop work and move away. This moving is generally accomplished by pulling in on an anchor line. The wires attached to the fuses are kept carefully clear until all is ready and then they are set off by a blasting box. When one hole is thus shot, the rest are thereby set off. After a large blast the boat is sometimes drawn back into position by a tug.

Interest and depreciation on the plant valued at $20,000 at 2% per working month = $8 per shift.

Moving the boat from range to range usually requires 3.6% of the observed time, on which basis the cost per day shift would be \$1.28 = \$0.43 per drill per shift.

A rough inventory of the equipment of this boat follows:

One boat, 67′×25½′.
Two spud anchors.
Two spud engines 6″×8″.
One blower.
One small 4″×6″ engine for blower.
Three drills and outfits.
Eleven bits.
One forge.
One bench.
One pipe clamp.
One anvil.
One small dynamo and engine.
One boiler 9′×6′, Scotch marine.
One hydraulic cylinder, 10′ long.
One force pump, Worthington, 12×5½×10″.
One powder boat.
One cutter.

The only obtainable record of performance on the "Dynamiter" was for one shift per day of 11 hours, the total covering a period of one week. It is as follows:

Date.	No. of Holes.	Av. Depth, 11 feet.	Powder, lbs. 60%.	Hours.
August 27, 1909......	40	440	1440	11
August 28, 1909......	38	418	1370	11
August 30, 1909......	35	385	1260	11
August 31, 1909......	26	286	936	11
September 1, 1909....	37	407	1330	11
September 2, 1909....	22	242	792	11
Total.........	198	2178	7128	66
Average per shift...	33	363	1188	11

On a daily basis the cost would be as follows:

COSTS

Force.	Rate Standard.	Cost.	Cost per Foot in Cents.	Cost per Pay Yard in Cents
3 drillers	$3.02½	$9.07	2.50	3.71
3 helpers	2.42	7.26	2.00	2.98
1 blacksmith	3.62	3.62	1.00	1.48
2 blacksmith's helpers	2.42	4.84	1.33	1.98
1 blaster	3.30	3.30	0.91	1.35
1 fireman	2.75	2.75	0.76	1.13
1 foreman	4.65 15.1%	4.65	1.28	1.91
Total		35.49	9.78	14.54
60% dynamite, 1188 pounds at 12 cts.		142.56	39.30	58.40
Coal, 4½ tons at 3.15		14.17	3.90	5.81
Oil, 2.29 gallons, at 0.40		0.91	0.25	0.37
Total		193.13	53.23	79.12
Plant $20,000. Int. and dep. 2% per working month		8.00	2.21	3.29

The pay yardage is based on the following:

11′ hole less 3′ drilled below grade equals 8′ pay drilling.

Spacing of holes $5\times5'$.

$5\times5\times8\times33=6600$ cu.ft. $=244$ pay yards per day.

In the above tabulation of costs, no account has been taken of contractors' overhead charges or profits, getting plant into commission in the spring, cleaning up in the fall, storing in winter, insurance, bonds, legal expenses, medical, charities, etc.

The following is a general summary of average performance data with deductions therefrom:

Shifts	6
Hours	66
Number of holes	198
Depth of holes	11′
Lineal feet drilled	2178
Cubic yards pay rock	1464
Dynamite, 60%, 7128 lbs. = 4276.8 lbs. nitroglycerin	
Coal, tons	27
Labor, per shift	$35.49

Lineal feet per shift	363
Lineal feet per drill hour	11
Lineal feet per man hour	2.74
Labor per ft. drilled, in cents	9.78
Cubic yards pay rock per shift	244
Cubic yards pay rock per drill hour	7.4
Cubic yards pay rock per lineal foot drilled	.672
Labor per cu. yd. of pay rock, in cents	14.54
Coal per drill per shift, in pounds	3000
Coal per foot drilled, in pounds	24.8
60% dynamite per foot drilled,	Gross, 3.27 lbs. nitroglycerin, 1.962 lbs.
60% dynamite per cubic yard pay rock,	Gross, 4.87 lbs. nitroglycerin, 2.92 lbs.
60% dynamite per cubic yard blasted,	Gross, 3.54 lbs., nitroglycerin, 2.12 lbs.
Ratio $\frac{\text{cubic yards blasted}}{\text{cubic yards pay rock}} =$	1.37
Total cost per lineal foot drilled, exclusive of dynamite, interest and depreciation, cents	13.93
Total cost per cubic yard pay rock, exclusive of interest and depreciation, cents	79.12
Total cost per cubic yard pay rock, including interest and depreciation, cents	82.41
Total cost per cubic yard blasted, including interest and depreciation	59.9

Average depth 10.9 ft.

DYNAMITER

	No. 1, Seven Holes				No. 2, Seven Holes				No. 3, Nine Holes			
	Obs.	Min.	Mean.	Max.	Obs.	Min.	Mean.	Max.	Obs.	Min.	Mean.	Max.
Getting into position	2	1:40	1:55	2:15	3	2:45	3:15	3:40	4	1:10	1:50	2:40
Drill cutting	7	26:00	35:35	49:45	7	24:40	36:25	55:10	9	25:55	32:45	58:45
Finishing hole	4	1:10	1:25	1:45	6	0:30	1:25	3:10	5	0:15	0:50	1:50
Waiting for loading gang	4	0:15	2:55	5:30	6	0:30	2:30	5:45	5	0:30	1:50	5:15
Loading hole	4	4:00	5:05	6:10	6	1:05	3:45	6:00	5	1:50	4:15	5:00
Totals		33:05	46:55	65:25		29:30	47:20	73:45		29:40	41:30	73:30

In the above table is given the minimum, maximum and mean time in minutes and seconds required to perform each of the operations into which the process of drilling is divided, together with the number of observations which were taken.

The total gives the total time of the cycle of drilling one hole, but does not include any time lost during the cycle or after its completion.

Average depth 10.9 ft.

DYNAMITER

	No. 1, Seven Holes			No. 2, Seven Holes			No. 3, Nine Holes		
	Mean.	Work.	Idle.	Mean.	Work.	Idle.	Mean.	Work.	Idle.
Getting into position	1:55	3:55	....	3:15	9:40	5:40	1:50	7:20	....
Drill cutting	35:35	249:00	....	36:25	254:45	0	32:45	294:50	76:20
Finishing hole	1:25	5:50	7:40	1:25	8:30	11:30	0:50	4:10	....
Waiting for loading gang	2:55	11:40	....	2:30	15:15	0	1:50	9:20	4:40
Loading hole	5:05	20:20	9:20	3:45	22:15	3 5:0	4:15	21:05	....
Totals	46:55	290:45	17:00	47:20	310:25	22:40	41:30	336:45	81:00
Waiting last hole	....	....	98:00	....	....	89:10	....	....	0
Moving boat	....	....	3:25	....	....	3:25	....	....	3:25
Miscellaneous delays	....	....	154:00	....	....	169:05	....	....	190:40

The above table shows the average time in minutes and seconds required for each of the operations into which the process of drilling has been divided and also the exact total time in minutes and seconds that the drill was engaged on the operation and whatever time was lost during the operation. The total gives the total time working and idle. This total, together with the last three items of delays, make up the day's work.

Average cutting speed = 0.314′ per cutting minute. Average $\frac{\text{cutting time}}{\text{total time}} = 0.45$. Average $\frac{\text{idle time}}{\text{useful time (cycle)}} = 0.89$.

DYNAMITER

	No. 1. Min. Sec.	Per Cent.	No. 2. Min. Sec.	Per Cent.	No. 3. Min. Sec.	Per Cent.	Av. Per Cent.
Useful (cycle) working time	290:45	51.63	310:25	52.20	336:45	55.00	52.94
Drill idle during working	17:00	3.02	22:40	3.77	81:00	13.30	6.70
Miscellaneous delays	154:00	27.35	169:05	28.48	190:40	31.16	29.00
Waiting for boat move	3:25	0.60	3:25	0.55	3:25	0.54	0.56
Waiting for last hole	98:00	17.40	89:10	15.00	0:00	0.00	10.80
Total idle time	272:25	48.37	284:20	47.80	275:05	45.00	47.06
Total time	563:10	100.00	594:45	100.00	611:55	100.00	100.00

The above table is a summary of the preceding one. The time for useful drill working is the sum of the first five items and represents the time of a cycle of drilling. The second item is the total time lost during this cycle. The percentages are percentages of total time worked during observation.

CHAPTER XI

SUBAQUEOUS DRILLING (*Continued*)

THAT portion of the Detroit River Channel Improvement known as the Livingstone Channel was divided into four contracts. The contract for section No. 3 was taken by O. E. Dunbar and T. B. McNaughton, and was sublet in three equal sections to Dunbar & Sullivan, Buffalo Dredging Company, and M. Sullivan. These sections for the sub-contract each include 100′ of the 300′ channel and extend the full length of the section. Dunbar & Sullivan have the sub-contract for the excavation of the middle 100′. They have on the work two drill boats, the "Earthquake" and the "Hurricane."

"EARTHQUAKE." The "Earthquake" is a steel boat with a wooden house, length 106′, breath 30′, and depth 5′ 9″. The house is 89×19×13′ in height, sloping down to 12′ at the back. The steel hull has a wooden deck of 2″ planking. The interior of the hull is divided into four compartments by three transverse bulkheads. One of these compartments is 28′ long and the other three 25′ long. These four water-tight compartments are each divided by three longitudinal bulkheads into four sections 7½′ wide. The method of framing the steel work together is by standard angles and bracket plates. The floor angles are 3½×3×⅜″ and they extend across the boat continuously. At the sides of the boat they are joined by bracket plates to 3½×3×⅜″ angles, which latter are a support for two longitudinal 6×8″ stringers running the length of the boat, one on each side. Where the floor angles pass through the longitudinal bulkheads, 3½×3″ angles extend up the buklhead vertically and connect at the bottom with the floor angles and at the top with the stringer angles running lengthwise of the boat. 49″ from each side of the boat is a wooden stringer 6×4″ to help support the deck,

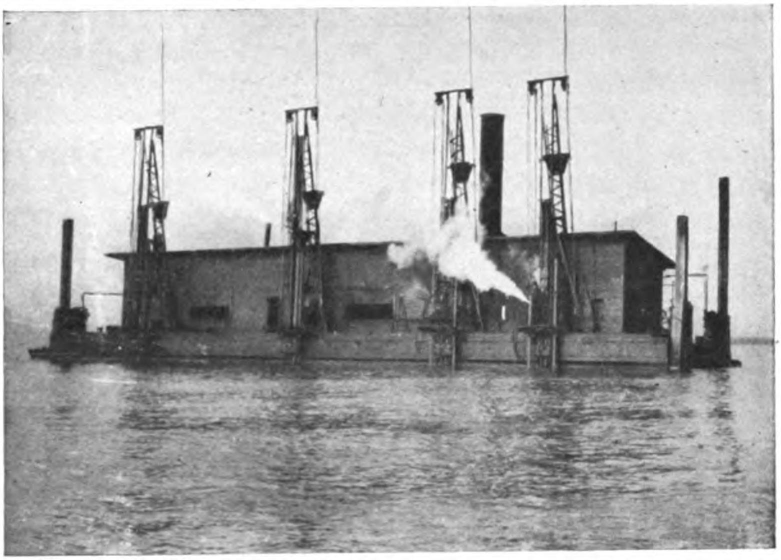

FIG. 97.—Drill Boat "Earthquake."

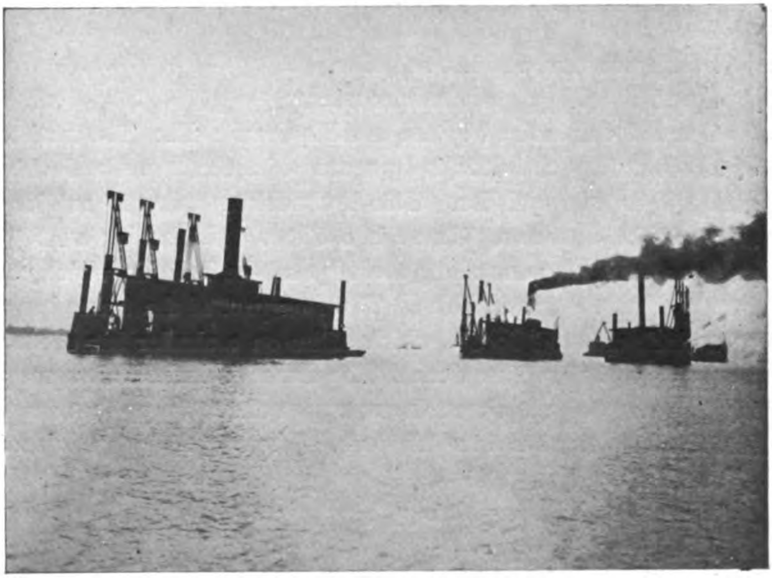

FIG. 98.—The "Earthquake" in the Foreground.

which is supported by vertical angles 4×3″, spaced 8′ apart, these being secured to the floor angles at their lower end.

In connection with the hull there is a steel tank about 7×21×3′ into which the exhaust water from the hydraulic lifts runs. This is used in winter, and the water so returned is heated by the exhaust from the pony feed pump and pumped back into the lifts again, thus keeping the machines thawed out. In the summer the tank connects with the river so that cool water is used in the lift.

Boiler. The boiler in this boat is a "Doghouse" Redwood. It has three possible ways of feed, (1) injector, (2) washout water pump, (3) regular boiler feed pump. At the back of the boiler is a feed-water heater, a tank about 4′ deep and 3′ in diameter, into which passes the exhaust steam from the washout pump and the hydraulic lift pump.

The following is a list of the factors observed in the operation of the boat and drills:

Ingersoll-Rand, H 61 drill.
Diameter of piston, 5½″.
Stroke, 6½″.
Drill feed, 19′, more or less.
U-chuck.
Steam pressure, 110 lbs. at boiler.
Speed of drill, 300 strokes per minute.

The drills are raised by the usual hydraulic lift. The method of moving along the deck is by means of a chain and a double-acting hydraulic cylinder. This hydraulic cylinder is 11′ long and 12″ in diameter. There is a 6″×8″ sill having a 4×¾″ plate on top that runs along the edge of the boat on which the front part of the frame slides. The rear part of the frame bears on a block of wood 6×8″, which slides on a similar bar of steel fastened to the wooden deck. The frame is locked after moving by means of a hook on the rear part of the frame that snaps into eyebolts screwed into the deck. These eyebolts are spaced 5′ between centers.

Diameter of starting bit is 3½″.
Plus point, +.
Length of steel, 34′ 7″.

Section of steel, circular, size, 1⅞″.

Handled by hand.

Tempered till file will not touch.

One-half inch jet cleans holes.

Worthington pump supplies jets.

Speed of pump, 17 R.P.M.

Water pressure, 200 lbs.

Connections, size and description: From 3″ main within the house various connections lead to a 1″ hose about 30′ long. This is attached by means of a nipple and elbow to a ¾″ pipe 15′ long which connects with the same length of ½″ pipe. This last section forms the end of the jet. The hoisting arrangement is attached at the elbow of the upper end of the ¾″ pipe.

Depth of holes, about 14′.

Diameter, 3¾″ at top.

Longitudinal spacing of holes, 5′.

Lateral spacing, 5′.

Material drilled, limestone.

First row of holes which overlaps old blast is bad digging.

Number of holes shot per blast, 249, or 12 rows of 20 to 21 each.

Powder, 60%, made by the contractor and called Pluto in the market. A 50% saving is said to result from this home manufacture.

Sticks are 15½×1¾″ and weigh 1¼ lbs.

Twenty sticks loaded in each hole.

Foreman, blaster, runner and helper do the loading.

Four drills make up drill outfit.

Doghouse Redwood Boiler, 7½×12½′.

Feed pipe about 75′ from drill feed to main.

Connection from a 3″ main within the house runs under the drill frame to a 2″ pipe, which runs half way up the frame. A 1½″ pipe slides inside of this 2″ section and connects with the steam chest of the drill.

Length of job, 750 good working days.

Eleven hour shift.

Two shifts.

Contract price, $2.80 per yard for rock and 50 cts. per yard for earth.

Blacksmith repairs drill bits, makes welds on broken bits and all repairs.

Twelve tons of coal used in 24 hours=3000 lbs. per drill per shift.

Fifty-five gallons of oil used in two weeks on drill cylinder =4.6 pints per drill per shift.

Coal is loaded on the deck of a scow at the Amherstburg coal dock and towed out by the company's tug to the boats, where it is shovelled by hand into the coal bunker.

Coal costs $3.15 per ton.

The cost of handling if the company did not own the tug would be 35 cts. per ton.

There is one walking boss to oversee both boats, also one foreman on each boat. Day foreman at 12.8% of day wages; night foreman at 11.7% of night wages.

Interest and depreciation on plant valued at $45,000 at 2% per working month=$17.75 per shift (day and night=$35.50).

Moving boat consumes 3¼% of total time, costing 3¼% of wages per shift=$1.33 per day shift=$0.33 per drill per shift.

A rough inventory of the equipnent of this boat is as follows:

One boat, 106'×30'×5' 9", built in 1904.

One cutter.

One powder boat.

Four drills and equipment.

Four spud anchors.

Four spud anchor engines.

Two steam capstans.

Seventeen bits.

One hydraulic cylinder for shifting drills, 11' long × 12" diameter.

One Doghouse boiler, 12½×7½'.

One feed-water heater.

One injector.

One small engine for boiler feed.

One small Worthington pump for washout water.

One Worthington pump for the hydraulic lift, 10×7×10″.

One anvil, one forge, one bench.

One vise and pipe clamp.

One blower and blower engine, small.

One dynamo for lights, with a small engine.

One tank for heating feed water for hydraulic lift, 7×21×3′.

The Sand Pipe. To facilitate drilling operations on the two Dunbar boats a device locally known as the sand pipe is used. It has three important functions: (1) It serves as a guide to the bit in starting a new hole; (2) it serves as a guide and protection to the charging tube; (3) it prevents sand from getting into the hole when the sand pipe has once been freed from sand by the washout jet.

The sand pipe is in itself really a large cast-iron funnel, being some 18″ across the top and having a spigot about 4′ in length. The sand pipe rests in position in a casting of the above shape. This casting is fastened at its ends by rivets to the ends of two tees that furnish a means of raising and lowering the sand pipe. Each of these tees passes upward and is free to slide through brackets attached at intervals to the side of the vertical frame of the drill. A small cable is attached to the upper end of each tee that passes upward over a sheave on top of the frame and downward, terminating in a box of counterweights. This box of weights is provided with small wheels on its under side so that it may move more easily over the inclined bracing of the frame upon which it bears. To the end of this weight box a rope is fastened which leads down to the deck. To raise the sand pipe and its supporting casting and tees, a chain is passed around the chuck of the drill and one of the tees. The usual hydraulic lift then raises both drill and sand pipe. The lowering is

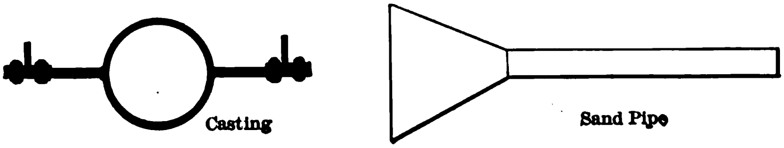

FIG. 99.

Fig. 100.—Throttle of Hydraulic: "Earthquake."

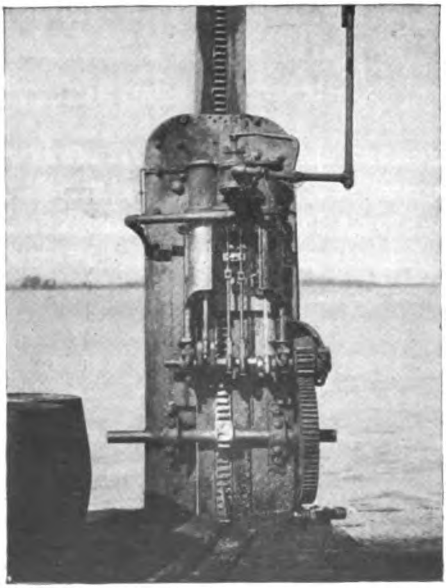

Fig. 101.—Spud Engine on "Earthquake."

accomplished by means of the rope on the end of the box of counterweights. In operation, the sand pipe is lowered first of all over the place where a new hole is to be drilled, and it is the last thing raised after loading before moving to the next hole.

The advantages derived from the use of the sand pipe are as follows: Ordinarily the drill bit is practically unsupported for its full length, and when the rock is very hard, it is difficult to start a hole. The end of the bit bounds around in all directions, destroys its point, bends it and sometimes necessitates the changing of the bit before the hole is actually started. The sand pipe eliminates this because it is allowed to slide down into the water before a hole is started. The end of the "funnel" comes in contact with the overlying sand and by its own weight soon works its way to the solid rock. Thus the drill steel which is now let down has a support and a sleeve to work in a distance below the surface of the water equal to the depth of the water and sand. The clearance between the steel and "funnel" should be about $\frac{1}{8}''$, but it is generally a little more. If the sand is deeper than the spigot of the funnel, the end of the sand pipe will of course not rest on the rock. But as far as forming a guide for the steel is concerned, it answers every purpose. There is one complication introduced when the hole to be drilled is very deep, and the top of the rock is near the surface of the water. The sand pipe cannot of course, be let down lower than the surface of the rock; the "lift" of the hydraulic is limited, and so for holes deeper than 13′ (on the *Earthquake*) the end of the bit would not be clear of the sand pipe when the "hydraulic" had raised it as high as it could. Hence in order to charge the hole the drill has to be disconnected from its steel and the steel has to be raised out of the "pipe" by means of a chain fastened to it and the piston rod. This has to be done for each hole of greater depth than 13′, but where the rock is very hard, it more than pays for the trouble in avoiding the delays arising from changing the steel several times in order to get a hole started, and also in the smith's work saved.

Again, after a bit has once started a hole, the complete drilling is generally accomplished without interruption. But if there is no sand pipe, as soon as the steel is raised, the small loose stones and sand tumble down into the hole and the drill has harder work the second time than the first. On one of the Sullivan boats a bit caught in such a hole and it was six hours before it could be disengaged and the hole charged. The sand pipe, when it rests on the rock, eliminates this. When it does not rest on the rock and there is a layer of sand between the spigot end and the rock, its value is not as great for this purpose, but it still helps, due to the depth of sand it does penetrate. But even when it does not rest on the bottom it does more than assist the steel in getting a clean hole; it

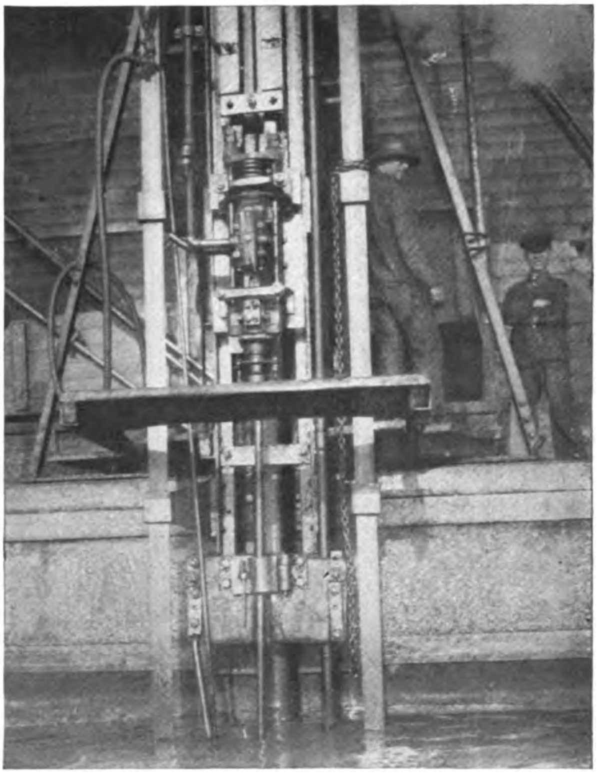

FIG. 102.—Drill on "Earthquake."

helps in charging. It is no trouble at all to start the charger, because the "funnel," with its 18″ opening, is easy to locate. The spigot does the rest and the time of charging should be much reduced. Where the current is swift the charging is very difficult ordinarily, and so a sand pipe would help materially. Again, with no sand pipe the charger in moving around the edge of the drilled hole often causes a small avalanche of stones and sand to completely fill it, necessitating redrilling.

FIG. 103.—Tender of the "Earthquake."

The use of the sand pipe is therefore, with the usual washout jet, recommended anywhere except when the rock is clean and soft or the drill bar has to be removed from its chuck before loading.

"EARTHQUAKE." The following figures for cost per lineal foot drilled and per cubic yard of pay rock are based on the average performance over a period of four months, or 206 shifts. The average depth of hole was taken as 12′. The holes were drilled about 3′ below grade and the cubic yards of pay rock are figured on that basis:

Average over 4 months, 821′ per day.
Average over 4 months, 411′ per shift.
Average over 4 months, 572 cubic yards per day.
Average over 4 months, 286 cubic yards per shift.

COSTS ON STANDARD BASIS

Force.	Rates of Wages, Standard.		Cost per Day.	Cost per Foot in Cents.	Cost per Cu.yd. in Cents.
4 drillers	$3.02½	$12.10			
4 drillers' helpers	2.42	9.68			
			$21.78	5.30	7.62
1 blacksmith	3.62	3.62			
2 blacksmiths' helpers	2.42	4.84			
			8.46	2.06	2.96
1 fireman	2.75	2.75	2.75	.68	.96
1 foreman, day, per. mo.	121.00 12.8%	4.64	4.64	1.12	1.62
1 foreman, night, per mo.	110.00 11.7%	4.24	4.24	1.04	1.48
1 powderman	3.30	3.30	3.30	.80	1.16
Day shift			40.93	9.96	14.32
Night shift			40.53	9.88	14.18
Total labor			$81.46	9.92	14.25
60% dynamite, 1150 lbs. at 12 cts.			138.00	16.80	24.20
Coal, 12.3 tons at 3.15			38.74	4.72	6.78
Oil, etc., 4⅔ gals. at .40			1.87	.23	.33
Supply total			$178.61	21.75	31.31
Total			$260.07	31.67	45.56
Plant, $45,000.00, interest and depreciation at 2% per working month			35.50	4.32	6.21

No account has been taken of the contractor's overhead charges, profit, cost of getting plant into commission in the spring, or clearing up in the fall, storing equipment during winter, legal expenses, insurance, charity, etc.

Dynamite per lin.ft. drilled 60%,
gross, 1.4 lbs.; nitroglycerin, 0.84 lb.
Dynamite per cu.yd. pay rock 60%,
gross, 2.05 lbs.; nitroglycerin, 1.23 lbs.
Dynamite per cu.yd. blasted 60%,
gross, 1.51 lbs.; nitroglycerin, 0.906 lb.

$$\text{Ratio } \frac{\text{cubic yards blasted}}{\text{cubic yards pay rock}} = 1.327.$$

The following is a general summary of the data on file in the government office at Amherstburg, Ont., obtained with the consent of the contractor. The items marked * are deductions from the data on file.

	May.	June.	July.	August.
Shifts worked	50	52	52	52
Hours worked	514	556	562	554
Hours delay	36	16	10	18
Number of holes	1,786	2,083	1,459	1,743
* Number of holes per shift	36	40	28	33
Lineal feet drilled	22,353	23,084	18,658	20,363
Depth of holes	12.52	11.08	12.80	11.68
Dynamite, pounds 60%	21,911	28,321	35,843	41,375
Coal, tons	324	328	332	327
* Feet per day	894	888	718	784
* Feet per drill per hour, working	10.89	10.39	8.30	9.19
* Feet per drill per hour, total	10.17	10.10	8.15	8.90
* Feet per man hour	2.90	2.88	2.33	2.54
Labor per day, dollars	81.46	81.46	81.46	81.46
* Labor per foot drilled, cents	9.12	9.18	11.36	10.40
* Coal per foot drilled, pounds	29.0	28.4	35.6	32.1
* Coal per cubic yard pay rock in lbs.	41.2	42	50	47.6
* Cubic yards pay rock	15,740	15,600	13,250	13,750
* Cubic yards pay rock per day	630	600	510	529
* Cubic yards pay rock per shift	315	300	255	265

"HURRICANE." The second Dunbar & Sullivan drill boat on section No. 3, of the Livingstone Improvement in the Detroit River Channel at Amherstberg, is known as the "Hurricane" Its history is rather interesting. It has two boilers, and this in itself is a rather unusual thing for so small a boat. About four years ago Mr. Dunbar had two 50′ frame boats on the coast, and when it was decided to bring them into the Detroit River it was found necessary to cut each boat into two 25′ sections, to get them through the canal. Later the steel sections were bolted together and it was then suggested that instead of having two very small boats it would be advisable to make one large boat. They were accordingly bolted together, making a 100′ four frame steel boat. This boat, like the "Earthquake," is provided with sand pipes. (See page 225). The wear on the inside of one of these pipes in a season enlarges it from 3″ to 3½″. This boat

DRILL BOAT, "EARTHQUAKE."

Depth of holes, 14.2′.

	No. 1, Eight Holes				No. 2, Six Holes				No. 3, Seven Holes				No. 4, Seven Holes			
	No. Obs.	Min.	Mean.	Max.	No. Obs.	Min.	Mean.	Max.	No. Obs.	Min.	Mean.	Max.	No. Obs.	Min.	Mean.	Max.
In position, not working...	7	0:05	0:45	1:10	4	0:10	0:40	1:10	5	1:00	1:15	1:30	6	0:35	0:30	0:45
Cutting................	8	27:15	32:20	36:15	6	25:50	32:25	40:40	7	28:30	32:00	39:05	7	27:30	32:05	36:40
Finishing hole............	7	0:30	1:00	2:10	6	0:45	1:15	1:50	7	1:10	2:30	4:05	7	0:30	1:10	1:50
Waiting for loading gang..	8	1:20	3:25	4:50	6	1:30	2:30	3:15	7	2:00	4:05	6:00	7	0:30	2:35	5:10
Loading hole............	8	3:45	5:15	8:00	6	3:50	5:05	6:40	7	4:45	5:40	6:25	7	4:15	5:00	5:30
Raising sand pipe........	8	0:40	1:25	2:30	6	0:40	1:35	2:45	7	0:45	1:30	2:00	7	0:55	1:10	1:35
Moving frame............	6	0:30	1:10	1:45	6	0:50	1:40	2:30	5	1:00	1:10	1:20	7	1:05	1:25	1:45
Putting in bit............	8	2:20	3:35	4:50	6	1:30	3:45	5:00	6	3:30	4:35	5:00	7	2:35	3:40	4:30
Total............		36:25	48:55	61:30		35:05	48:55	63:50		42:40	52:45	65:25		37:55	47:35	57:45

The above table gives the minimum, mean and maximum time in minutes and seconds required to perform each of the operations into which the process of drilling is divided, together with the number of observations of which the mean was taken.

The total gives the total time of the cycle of drilling one hole but does not include any time lost during the cycle or after its completion.

DRILL BOAT, "EARTHQUAKE."

Depth of hole, 14.2′.

	No. 1, Eight Holes.			No. 2, Six Holes.			No. 3, Seven Holes.			No. 4, Seven Holes.		
	Mean.	Work.	Idle.	Mean.	Work.	Idle.	Mean.	Work.	Idle.	Mean.	Work.	Idle.
In position, not working	0:45	5:10	2:15	0:40	2:40	3:33	1:15	6:10	1:15	0:30	3:05	1:50
Cutting	32:20	258:20	....	32:25	194:40	....	32:00	224:15	....	32:05	224:50	19:10
Finishing hole	1:00	6:50	7:50	1:15	7:35	5:35	2:30	17:25	6:30	1:10	7:55	20:55
Waiting for loading gang	3:25	27:40	10:45	2:30	15:00	16:20	4:05	28:35	15:35	2:35	18:05	5:40
Loading hole	5:15	42:00	7:15	5:05	30:45	....	5:40	39:45	11:30	5:00	34:55	5:10
Raising sand pipes	1:25	11:20	....	1:35	9:40	....	1:30	10:25	....	1:10	7:50	....
Moving frame	1:10	7:00	....	1:40	8:10	....	1:10	6:00	....	1:25	7:00	....
Putting in bit	3:35	28:40	....	3:45	22:35	....	4:35	27:30	....	3:40	25:40	....
Total	48:55	387:00	28:05	48:55	291:05	25:28	52:45	360:05	34:50	47:35	329:20	52:45
Waiting, last hole	28:20	....	57:40	....	....	74:50	....	....	65:15	....	....	10:00
Moving boat	7:15	....	14:30	7:15	....	14:30	7:15	....	14:30	7:15	....	14:30
Miscellaneous delays	....	....	4:00	....	....	....	....	....	....	4:55	....	9:50

The above table shows the average time in minutes and seconds required for each operation into which the process of drilling has been divided and also the exact total time in minutes and seconds that the drill was engaged on the operation, and whatever time was lost during the operation. The total gives the time working and idle and this total, together with the last three items, gives the entire day's work.

Average cutting speed = 0.444′ per cutting minute. Average $\frac{\text{cutting time}}{\text{total time}} = 0.505'$. Average $\frac{\text{idle time}}{\text{useful (cycle) time}} = 0.309$.

DRILL BOAT, "EARTHQUAKE."

	No. 1.		No. 2.		No. 3.		No. 4.		Average.
	Time.	Per Cent.	Time.	Per Cent.	Time.	Per Cent.	Time.	Per Cent.	
Useful (cycle) working	387:00	78.79	291:05	71.76	360:05	75.86	329:20	79.10	76.38
Drill idle during working	28:05	5.71	25:28	6.20	34:50	7.34	52:45	12.66	7.98
Idle, miscellaneous delays	4:00	.81	....	....	....	....	9:50	2.36	0.79
Idle, waiting boat move	14:30	2.95	14:30	3.58	14:30	3.05	14:30	3.48	3.26
Idle, waiting last hole	57:40	11.74	74:50	18.46	65:15	13.75	10:00	2.40	11.59
Time total idle	104:15	21.21	114:48	28.24	114:35	24.14	87:05	20.90	23.62
Total	491:15	100.00	405:53	100.00	474:40	100.00	416:25	100.00	100.00

The above table is a summary of the preceding one. The time for useful working is the sum of the first eight items and represents the time of a cycle of drilling. The second item is the total time lost during this cycle. The percentages are percentages of total time worked during observations.

is without the adjustable "slip joint" for the hydraulic lift. Instead a "swing joint," is used and as the drill moves along the deck this joint causes the two pipes connected to jack knife (see Fig. 104).

The following factors were observed in the operation of this boat:

Drills No. 1 and No. 4 are Rand H, 69. No. 2 and No. 3, are idea of Mr. Dunbar. They have the Rand cylinder and valve and bottom head, while the top heads are the Ingersoll-Rand.

Diameter of piston, 5½″.

Length of stroke, No. 1 and No 4, 6½″, No. 2 and No. 3, 5½″.

Lift, about 19′.

Two chucks are practically like the U, only instead of the U-bolt there are two separate bolts with heads imbedded to prevent turning. Two U-chucks.

Pressure at drill, 85 lbs.

Drills run about 300 strokes per minute.

Moved up and down by hydraulic lift operated by valves similar to those of the "Earthquake." One of the pictures of the "Earthquake" (Fig. 100) shows the runner at the throttle and the mode of operation of the valves.

Diameter of tip, 3½″.

Hard tool steel tips.

Length of steel, 35½′.

Section circular, 1¾″ diam.

Handled by hand.

Steel tempered till file will not touch.

One-half inch jet used for cleaning holes, 2,390 cu.in. of water per jet per cutting minute.

71.3 cu. in. of water per cu.in. of rock cut.

Worthington pump, 7×4½×6, 4½″ suction, 2½″ discharge, furnished water to the jets.

Speed of pump, 50 strokes per minute.

Depth of holes, 7′-2″, average of observations.

Longitudinal spacing of holes, 5′.

Lateral spacing, 5′.

Material, limestone.

Rock fairly hard and clean.

Nineteen holes shot to a row, 12 rows, or 228 holes.

Pluto powder made by Dunbar Co., 60%.

Sticks, $15\frac{1}{2}\times 1\frac{3}{4}''$; weight, $1\frac{1}{4}$ lbs.

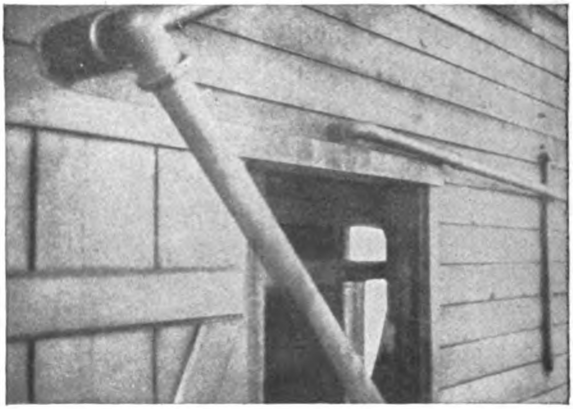

FIG. 104.—Swing Joint on "Hurricane."

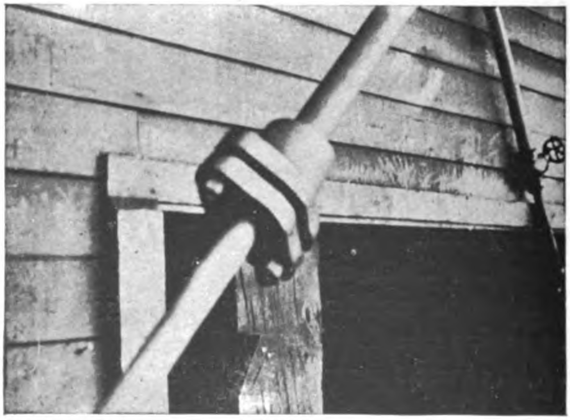

FIG. 105.—Feed-pipe Slide Joint.

Twenty sticks to the hole.

Blaster, foreman, runner and helper do loading and blasting.

Four drills on boat.

Two Scotch marine boilers comprise the power plant.

Horse power of boilers 80 and 140.

Steam pressure at boiler 100 lbs.

Length of feed pipe, about 75′ from main to drills.

Diameter, 3″ main, 2″, 1½″ slide joint (see Fig. 105).

Plant all afloat.

Size of job, 750 good working days.

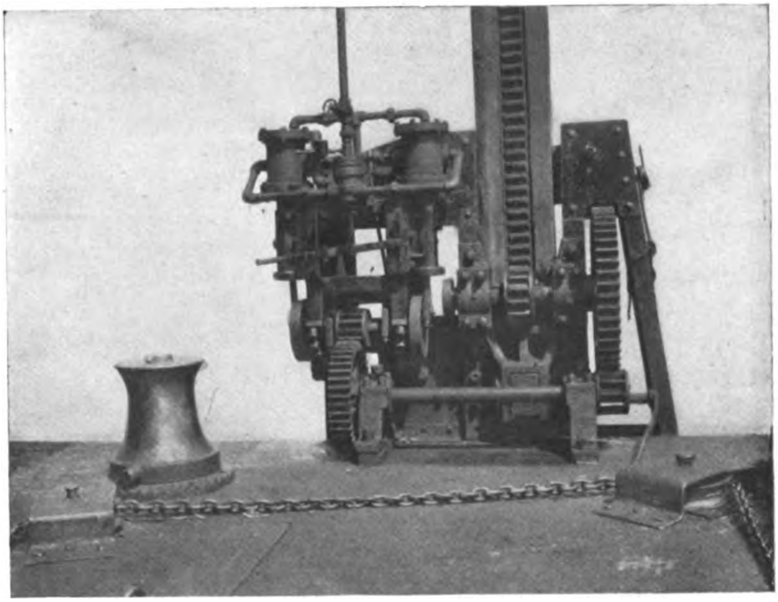

FIG. 106.—Spud Engine on "Hurricane."

Length of shift, 11 hours.

Two shifts.

Contract price, $2.80 per cubic yard for rock and 50 cts. per cubic yard for earth.

Blacksmith keeps drill bits in shape, makes needed nuts, bolts, etc., and necessary repairs.

Twelve tons of coal used in 24 hours = 3,000 lbs. per drill per shift.

One bbl. of drill cylinder oil used in ten days = 5½ pints per drill per shift.

A foreman on each boat and one walking boss for the two boats.

Men all live ashore.

Interest and depreciation on plant, valued at $45,000, at 2% per working month, $17.30 per shift.

Superintendence, one day foreman at 12.8% of daily wages, night foreman, 11.7% of nightly wages.

Moving boat consumes only 1.3% of total time and costs 1.3% of shift wages, or 53 cts. per shift. This is much below the average, and due to the fact that the nature of the work (on jagged face) made drilling slow and hence resulted in infrequent movings of the boat. Moving cost per drill per shift, 13 cts.

The following is a rough inventory of the equipment on board this boat:

Steel boat.
Four spud anchors.
Four spud anchor engines.
Two steam windlasses.
One hydraulic cylinder.
Two boilers, 80 and 140 H.P.
One dynamo and small engine.
One blower and small engine.
One washout water pump, Worthington, $7 \times 4\frac{1}{2} \times 6''$.
Two pairs of pumps, Worthington, $12 \times 5\frac{1}{2} \times 10''$.
One anvil.
One forge.
One bench and vise.
One pipe clamp.
One cutter.
One powder boat.
Two spare drills.

The following figures for cost per lineal foot drilled and per cubic yard of pay rock, are based on the average performance for a period of 4 months or 204 shifts. The average depth of hole was taken as 12.11′. The holes were drilled about 3′ below pay grade and the cubic yards of pay rock are figured on that basis.

Average over 4 months, 779′ drilled per day.
Average over 4 months, 390′ drilled per shift.
Average over 4 months, 541 cubic yards of pay rock per day.
Average over 4 months, 270 cubic yards of pay rock per shift.

COSTS

Force.	Rates of Wages, Standard.		Cost per Shift.		Cost per Foot in Cents.	Cost per pay yd. in Cents.
4 drillers	$3.02½		$12.10			
4 helpers	2.42		9.68			
			——	$21.78	5.58	8.06
1 blacksmith	3.62		3.62			
2 blacksmiths' helpers	2.42		4.84		2.18	3.14
			——	8.46		
1 fireman	2.75		2.75	2.75	0.70	1.02
1 foreman (day) per mo	121.00	12.8%	4.64	4.64	1.20	1.72
1 foreman (night) per mo	110.00	11.7%	4.25	4.25	1.10	1.58
1 powder man	3.30		3.30	3.30	0.84	1.22
Day shift				40.93	10.50	15.16
Night shift				40.54	10.40	15.00
Total labor				$81.47	10.45	15.07
60% dynamite 1172 lbs. at 12 cts., 2 shifts				140.64	18.05	26.00
Coal, 12.7 tons at 3.15, 2 shifts				40.00	5.15	7.40
Oil, 5.2 gals. at .40, 2 shifts				2.08	0.27	0.38
Total				$264.19	33.92	48.85
Plant $45,000, Interest and depreciation at 2% per working month				34.60	4.44	6.40

No account has been taken of the contractor's overhead charges, profit, cost of getting plant into operation in the spring and cleaning up in the fall, storing equipment during winter, legal expenses, insurance, charity, etc.

60% dynamite per ft. drilled,
gross 1.51 lbs. nitroglycerin, 0.906 lb.
60% dynamite per. cu.yd., pay rock,
gross 2.16 lbs. nitroglycerin, 1.296 lbs.
60% dynamite per cu.yd., blasted,
gross 1.63 lbs. nitroglycerin, 0.978 lb.

60% dynamite $\frac{\text{ratio cu.yds. blasted}}{\text{cubic yards pay}} = 1.33.$

The following is a general summary of data on file in the government office at Amherstberg, Ont., obtained with the consent

FIG. 107.—Drill Boat " Hurricane."

of the contractor. The items marked * are deductions from the data on file:

	May.	June.	July.	August.
Shifts worked	48	52	52	52
Hours worked	481	551	561	557
Hours delay	44	21	11	15
Number of holes	1,644	2,165	1,505	1,317
* Number of holes per shift	34	42	29	25
Lineal feet drilled	20,643	22,929	19,603	16,139
Depth of holes	12.56	10.59	13.02	12.28
Dynamite, 60%	18,517	29,926	37,865	33,219
Coal, tons	308	328	332	327
* Feet per day	860	882	754	622
* Feet per drill hour, working	10.72	10.41	8.75	7.25
" " including delays	9.83	10.03	8.58	7.06
Feet per man hour	2.79	2.86	2.45	2.02
Labor per day, dollars	81.47	81.47	81.47	81.47
* Labor per foot drilled, cents	9.48	9.24	10.81	13.10
* Coal per foot drilled in pounds	29.6	28.6	33.8	40.5
Coal per cubic yard pay rock, pounds	42.2	43.2	47.6	58.0
* Cubic yards pay rock	14,580	15,160	13,970	11,320
* " " per day	607	583	538	436
* " " " shift, 11 hours	304	292	269	218

DRILL BOAT, "HURRICANE."

Average depth 7.2′.

	No. 1, Four Holes.				No. 2, Four Holes.				No. 3, Five Holes.				No. 4, Five Holes.				Averages.		
	No. Obs.	Min. m. s.	Av. m. s.	Max. m. s.	No. Obs.	Min. m. s.	Av. m. s.	Max. m. s.	No. Obs.	Min. m. s.	Av. m. s.	Max. m. s.	No. Obs.	Min. m. s.	Av. m. s.	Max. m. s.	Min. m. s.	Av. m. s.	Max. m. s.
Cutting......	4	27:40	39:59	57:00	4	24:42	43:50	55:40	5	26:17	30:20	34:30	5	13:40	18:42	23:35	23:05	33:13	42:41
Finishing hole	4	00:30	00:33	00:40	4	00:20	00:32	00:45	3	00:30	1:05	2:10	[illegible]	00:30	2:35	5:40	00:28	1:11	2:19
Waiting for loading gang	4	00:30	1:00	1:40	4	00:15	00:43	1:05	4	00:30	1:12	2:30	[illegible]	00:30	1:41	3:45	00:26	1:09	2:15
Loading hole.	4	1:40	2:20	3:00	4	1:00	1:58	3:15	4	1:30	2:04	2:25	[illegible]	1:45	2:10	3:15	1:29	2:08	2:59
Getting into position. . .	4	3:00	5:28	9:00	2	3:20	3:22	3:25	2	3:15	3:32	3:50	5	4:00	4:10	4:15	3:24	4:08	5:03
Totals	..	33:20	49:20	71:20	..	29:37	50:25	64:10	..	32:02	38:13	45:25	..	20:25	29:18	40:30	28:52	41:49	55:22

In the above table is given the minimum, maximum, and mean time in minutes and seconds required to perform each of the operations into which the process of drilling is divided together with the number of observations of which the mean was taken.

The total gives the total time of the cycle of drilling one hole, but does not include any time lost during the cycle or after its completion.

DRILL BOAT, "HURRICANE."

Average depth 7.2′.

	No. 1, Four Holes.			No. 2, Four Holes.			No. 3, Five Holes.			No. 4, Five Holes.		
	Average. m. s.	Work. m. s.	Idle. m. s.	Average. m. s.	Work. m. s.	Idle. m. s.	Average. m. s.	Work. m. s.	Idle. m. s.	Average. m. s.	Work. m. s.	Idle. m. s.
Cutting	39:59	159:55		43:50	175:35		30:20	151:40	68:40	18:42	93:30	69:05
Finishing hole	00:33	2:13	5:32	00:32	2:07	4:20	1:05	4:20	20:25	2:35	12:55	
Waiting for loading gang	1:00	4:00		00:43	2:50		1:12	4:50		1:41	8:25	
Loading hole	2:20	9:20	39:25	1:58	7:45		2:04	8:14	9:34	2:10	10:50	
Getting into position	5:28	21:50		3:22	6:45		3:32	7:04		4:10	12:50	
Totals	49:20	197:18	44:57	50:25	195:02	4:20	38:13	176:08	98:39	29:18	138:30	69:05
Delay for moving			4:00			4:00			4:00			4:00
Delay for lost drill						43:00			111:30			177:45
Delay for miscellaneous			3:45						19:00			14:15

The above table shows the average time in minutes and seconds required for each of the operations into which the process of drilling has been divided and also the exact total time in minutes and seconds that the drill was engaged on the operation, and whatever time was lost during the operation. The total gives the total time working and idle. This total, together with the last three items of delays, makes up the day's work.

The average cutting speed of the four drills was 0.223′ per cutting minute.

The average ratio of cutting to total time was 0.444.

The average ratio of idle to useful working time (cycle time) = 0.70.

DRILL BOAT, "HURRICANE."

	No. 1.		No. 2.		No. 3.		No. 4.		Average.
	Time.	Per Cent.	Time.	Per Cent.	Time.	Per Cent.	Time.	Per Cent.	
Useful (cycle) working	197:18	78.90	195:02	79.17	176:08	43.00	138:30	34.25	58.83
Drill idle during work time	44:57	18.00	4:20	1.76	98:39	24.12	69:05	17.13	15.25
Delay for moving	4:00	1.60	4:00	1.62	4:00	0.98	4:00	0.99	1.29
Delay for last hole	....	....	43:00	17.45	111:30	27.26	177:45	44.10	22.20
Miscellaneous delays	3:45	1.50	....	....	19:00	4.64	14:15	3.53	2.43
Total delay	52:42	21.10	51:20	20.83	233:09	57.00	265:05	65.75	41.17
Total time	250:00	100.00	246:22	100.00	409:17	100.00	403:35	100.00	100.00

Per cent time working, four drills	58.83%
Per cent time idle from all causes	41.17

The above table is a summary of the preceding one. The time for useful working is the sum of the first five items in the preceding table and represents the time of a cycle of drilling. The second item is the total time lost during this cycle. The percentages are percentages of total time worked during observations.

CHAPTER XII

SUBAQUEOUS DRILLING (*Continued*)

Buffalo Boat No. 5. Observations, 1909. A strip of the 300′ channel 100′ wide on section No. 3 of the Detroit River channel improvement, known as the Livingstone Improvement, is being done by the Buffalo Dredging Company. There are four boats on this work, the largest and most interesting of which is called No. 5.

BOAT. No. 5 is an all-steel boat and is supposed to represent the best practice in drill-boat construction. It was built by the Empire Shipbuilding Company of Buffalo only a few years ago. The length on deck is 138′, beam 31′ 3″, depth 6′ 4″. The ends of the boat slope so that the length on the bottom is 130′. The house is also of steel, 110′×19′ 2″, height on drill side 12½′, sloping down to 11′ on the back. The roof overlaps the side walls some 3′. The internal arrangement of the hull is as follows: Four transverse bulkheads divide the hull up into five water-tight compartments. These bulkheads are secured to the side walls, ceiling and floor by the usual angle construction, here 3½×3×⅜″. Each one of these compartments is 26′ long and 31′ 3″ wide. Spaced 2′ apart and running across the boat, up the sides and under the deck, are 3½×3″ angles. These are connected at the sides of the boat by means of bracket plates. There are also four longitudinal bulkheads which divide each 26′×31′ 3″ compartment into five smaller ones, each connected to the adjoining one by a manhole. The boat is thus divided up into 25 compartments, each 6′ 3″×26′. The angles which secure these bulkheads in place are continuous longitudinally through the transverse bulkheads. Each of the five water-tight compartments is entered from the deck by means of a manhole. There is also in each a steam siphon for keeping the hull clear of water. The pipes through which the water is expelled are 4″ in diameter.

MANAGEMENT OF DRILLS. On this boat the usual hydraulic lift is missing, as is also the hydraulic cylinder for moving the frames along deck. Steam takes the place of water and gives entire satisfaction, doing away entirely with the various troubles of water. The Dake engines, made by the Dake Engine Company of Grand Haven, Mich., both hoist the drill and move the frame along deck. Each frame has one of these units, and is independent of all the others. The operation of these Dake engines is as follows: Steam enters one end of the machine and imparts a rotary motion to a shaft which has keyed to it a 6″ cog wheel. This cog meshes with a 3′ wheel mounted on the shaft that has on it a hoisting drum. A ¾″ cable fastened to this drum passes up over a large sheave on top of the frame and then down to the sliding block that holds the drill. When steam is turned on the drill is hoisted. It is lowered by gravity. On the same shaft with the drum is a band-brake operated by the feet of the runner. With this he can get a feed at any speed he wishes.

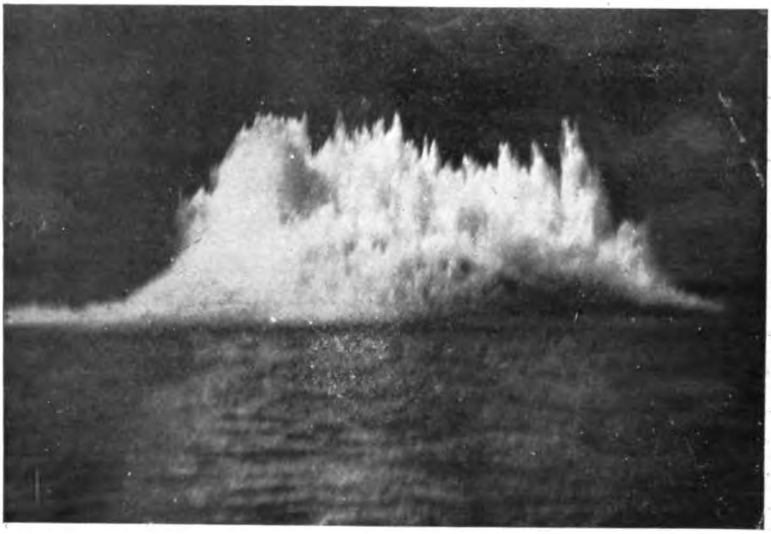

FIG. 108.—A River Blast.

On the same shaft with the drum and band-brake, and inside the bearings is a notched wheel into the notches of which a pawl may be slipped and the drill held secure in any position.

Moving the frame along deck is done by the same engine that operates the hoist. On the hoist-drum shaft outside of the bearings is a grooved chain wheel that ordinarily slips on the shaft. There is, however, a sliding coupling arrangement whereby this chain wheel can be made to revolve with the shaft and drum, or with the shaft alone, by operating a lever that disengages the hoist-drum gearing. Each frame has a heavy chain fastened to the deck at each end just a little beyond the limit of its deck range. This chain runs along deck to the floor frame of the drill, where it makes a quarter turn under a small sheave, passes upward over the chain wheel on the hoist-drum shaft, then downward, making another quarter turn under another small sheave and finally runs along the deck to where it is fixed. When the chain wheel revolves one way the chain is taken in and the whole frame slides along its track in that direction, and when the chain wheel revolves in the opposite way the frame slides in that direction. This arrangement may be operated in two ways. The usual way to move the frame 5′ along on deck is to throw in the chain wheel so that it revolves with the drum. Then according to the direction desired, the steam is either turned on or the band brake released, and as the drum hoists the drill or gravity puts it down the frame is moved along deck to the proper location. The second way to move the frame along deck is used when it is desirable to move the frame independently of the drill. To do so the clutch on the hoist cog wheel is thrown out and the clutch on the chain wheel thrown in. Then by turning on the steam the chain wheel is made to revolve in either direction, pulling the frame rapidly along deck in either direction.

BOILER. The coal bunker on this boat is made entirely of steel and has a capacity for 100 tons, more than one week's supply. There are two large hatchways in the roof through which the coal is poured from dump boxes. The boiler burns 10 tons of coal in 24 hours. It is a Scotch marine, $12\frac{1}{2} \times 9' \ 9''$ working at 90 lb. gauge pressure. So much steam is used, however, on this all-steam boat that when several of the drills are hoisted at once, the pressure falls off so that the other machines can hardly operate.

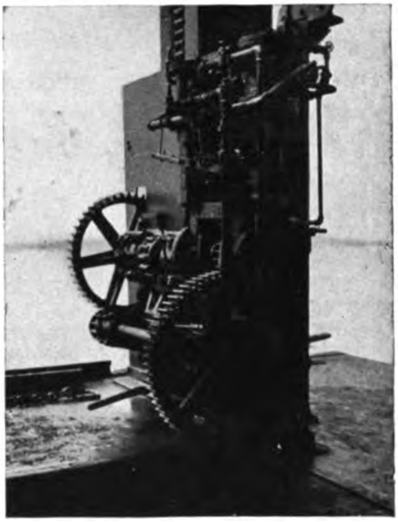

FIG. 109.—Spud Engine on Buffalo Boat No. 5.

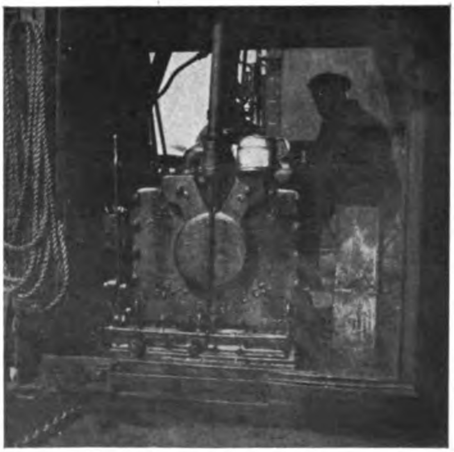

FIG. 110.—Dake Engine on Buffalo Boat No. 5.

GENERAL MACHINERY. The boat is provided with a steam hammer, two steam capstans and four steam spud engines.

On the wall of the house on the inside are steel lockers for the men's clothes. The blacksmith shop is equipped with a crane for handling the drill steel. The coal bunker, boiler, pumps, generator room, office, and forge are at the rear side of the boat, leaving a clear passageway of 10 or 12′ for moving about and handling the steel. It is in this clear passage that the crane works. It consists of a track on the flanges of an I-beam running lengthwise of the boat and suspended from the ceiling. On this track run two small cars from which hang block and tackle and hooks for handling the steel. Another thing that uses up more steam is a whistle on the feed pipe of each drill that is tooted the proper number of times, 1–2–3–4 or 5, to tell the blasters which frame is ready to load.

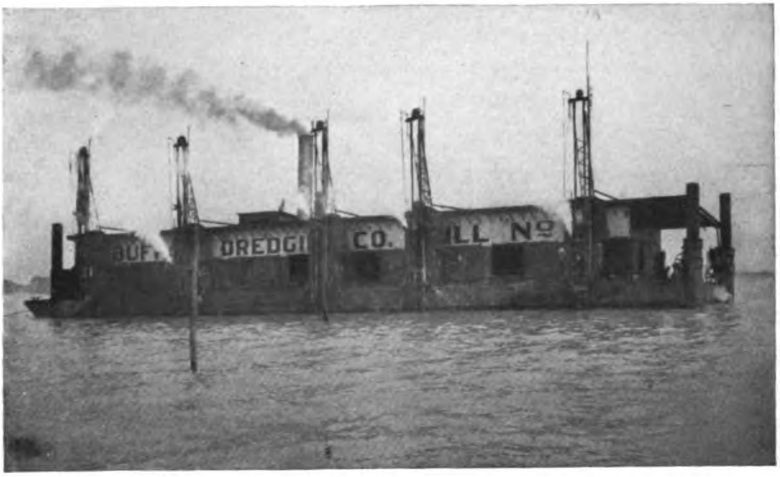

FIG. 111.—Buffalo Boat No. 5.

GAS PLANT. The boat is well equipped in other lines. At one end of the boat a small room partitioned off with steel walls contains the generating apparatus of a 100-light acetylene gas plant. The outfit is made by the Monarch Carbide Feed Acetylene Generator Company, Buffalo, N. Y. There are about 30 lights on board. Around the walls of the generator room are shelves that hold the large cans of carbide.

Spacing of Holes. Each machine drills holes 3′ apart on the first or outside row. When this row is completed the boat is moved over 3′. This second row is spaced 4′ on deck and the subsequent move-over is 4½′. The third row and all succeeding rows except the last are spaced 5′ on deck and the move-over is 4½′. The distance moved over each time is gauged on two wires stretched across the cut from two poles to the boat. The reason for the close spacing of the holes on the first row is that there are no cuts beyond, and it is desired to break the rock. The spacing on deck of the last row of holes on the other side is 4′, the close spacing of the other side not being needed here because there is another cut just beyond.

Drill Data. Ingersoll-Rand drill, type H 64.

Diameter of piston, 5½″.

Stroke, 10″.

Feed, about 19′.

U-chuck.

Steam pressure at drill, 95 lbs.

Number of strokes, about 300 per minute.

The cylinders are raised and the drill frames moved along the deck by means of the Dake engines as already described. The steam lines for each engine and for the drill cylinder are identical from the steam dome of the boiler to a T in the drill-frame house where the steam feed for the cylinder branches off. The platform of each frame is housed over and is very warm and comfortable in winter. The tracks on which these frames run along the deck are three in number. One at the outer edge of the boat, the second 10″ in and the third about 5′ in from the last. These tracks are standard 45-lb. rails.

Diameter of tip of bit, 3½″.

Length of steel, 34′.

Shaft is circular steel 2″ in diameter.

Steel handled by means of crane and tackle already described.

Jets were not intended to be used for cleaning holes, but they are used occasionally when one machine gets behind. The jet when used is ½″.

Steel tempered till file will not touch.

Deane pump 12×7×12, 6″ suction, 3″ discharge, supplies water for jets. This is not meant for a pressure pump, but for feeding the boiler.

Speed of pump about 16 strokes per minute.

Force of jet due to reduced size of nozzle and not to pressure on pump.

The connections of the jet are about the same as usual, only there is no block and tackle for hoisting and handling.

FIG. 112.—Buffalo Boat No. 5.

Holes about 8½′ deep, 4⅜″ in diameter.

Longitudinal spacing of holes, 5′, lateral spacing 4½′, but see previous description.

All frames have mud pipes.

Limestone is being drilled.

Condition of rock hard in spots; some sand on top.

About 650 holes shot per blast.

Potts powder used, 60%.

Size of sticks, 8″×2″. Weight 20 oz.

Twelve sticks per hole used for charging.

United States standard blasting machine used to shoot holes.

Blasting gang consists of 2 blasters. Runners and helpers assist.

Number of drills, 5.

Scotch marine boiler.

Size of boiler, 12½′×9′ 9″.

Steam pressure at boiler 90 lbs.

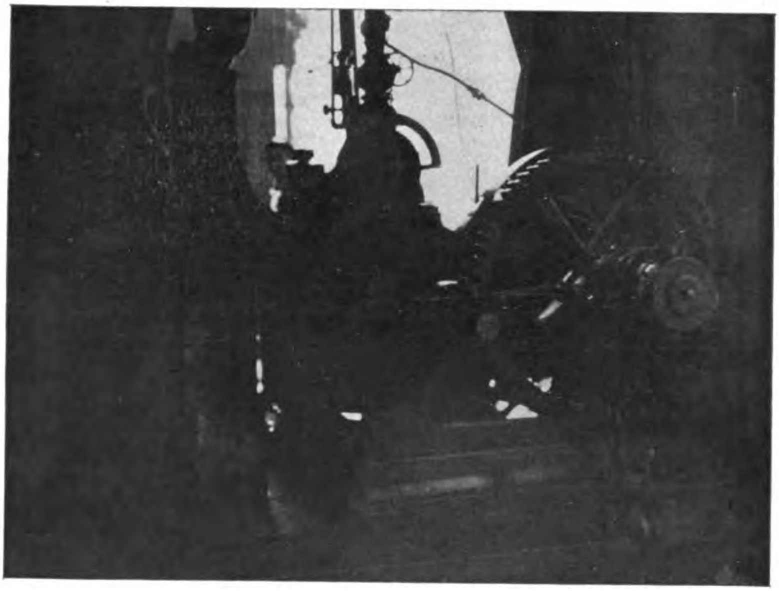

Fig. 113.—Buffalo Boat No. 5.

Length of feed pipe, 75′ from main to steam chest of drill.

Diameter of feed pipe, 6″ main, rest mostly 1¾″ and 3″.

Contract is 750 good working days.

Length of shift, 10 hours day shift, and 12 hours night shift. (Shift changes each week.)

Number of shifts, 2.

Force per shift is as follows (day):

5 runners	at $3.02½	=	$15.12½	per shift, standard basis
1 foreman	at 4.65	=	4.65	per day
1 fireman	at 2.75	=	2.75	per shift
2 blasters	at 3.30	=	6.60	"
1 smith	at 3.62	=	3.62	"
2 smiths' helpers	at 2.42	=	4.84	"
4 helpers	at 2.42	=	9.68	"
Total			$47.26½	

There is a total of 31 men for both shifts, which would mean that there is one less helper at night. The night foreman getting $110 per month = $4.25 a night, would make a total of $4.65 − $4.25 + $2.42 = $2.82 less at night. Total, 31 men, $91.71.

Contract price, $2.80 per cubic yard for rock and 50 cts. per cubic yard for earth.

Work of the smith is, as usual, taking care of the bits. The bits, with no accident, will drill from 12 to 18 holes without repointing. The nipples on the mud pipes last about a season. The smith, besides his bench outfit, has a pair of small emery wheels operated by the small Dake engine that turns the blower.

Use 10 tons of coal in 24 hours = 2000 lbs. per drill per shift.

Use 1 bbl. of drill cylinder oil in 6 days = 7⅓ pints per drill per shift.

Coal is brought out in boxes loaded on a scow. The crane on the scow hoists the boxes over the hatch of a 100-ton bunker and the boxes are dumped.

Coal costs $3.15 at dock.

If company did not own their own tug and had to pay handling charges coal would cost 35 cts. a ton more.

Repairs are said to be very few, 2 extra machines are kept on hand in case of need; also 13 extra drill bits.

Boat has a day and night foreman, and there is a superintendent for the four boats.

Quarters aboard the boat are not provided. Men live ashore, being taken back and forth to Amherstburg, Ont., day and night by the company's tug.

Interest and depreciation on plant, valued at $52,000, at 2% per working month = $20 per shift.

Superintendence: One day foreman at 10.9% of daily wages; one night foreman at 10.6% of nightly wages; also a superintendent for the four Buffalo boats.

Moving the boat from range to range requires 9% of the total time, costing 9% of the shift wages = $4.25 per shift. (day) = $0.85 per drill per shift.

A rough inventory of the equipment of this boat is as follows:

One steel drill boat.
One cutter.
One powder boat.
One marine boiler, 12½′×9′ 9″.
One feed-water heater.
One filter.
Five drill outfits equipped with Dake engines.
Four spud anchors.
Four spud anchor engines 6×8″ double, Superior Iron Works.
Two steam capstans.
One steam hammer.
One forge.
One bench, vise and pipe clamp.
One small Dake engine.
One blower.
Two small emery wheels 10×¾″.
One anvil.
One Monarch acetylene gas plant, capacity, 100 lights.
One Deane pump, 12×7×12″.
Lockers for men's clothes.
One water closet.
One desk.
One blasting machine, U. S. standard.
Thirteen extra bits.
Two extra drills.

THE MUD PIPE, BUFFALO DRILL BOAT NO. 5. The so-called "mud pipe" is the device used on the Buffalo boats to serve the same purpose that the "sand pipe" does on the Dunbar boats. The brackets on the drill frame in which the two rods supporting the mud pipe slide up and down are the same as those previously described for the sand pipe, with the exception that in this case the slide rods are circular in section, whereas, in the case of the sand pipe the slide rods were tee irons. The two circular slide rods of the mud pipe arrangement terminate at all ends much the same as do the tee rods of the sand pipe, i.e., the upper ends are arranged so that the slide rods and pipes can be raised, and the lower ends of these rods are connected across by a block of wood, through which the outer casing passes and upon which it rests by means of a collar.

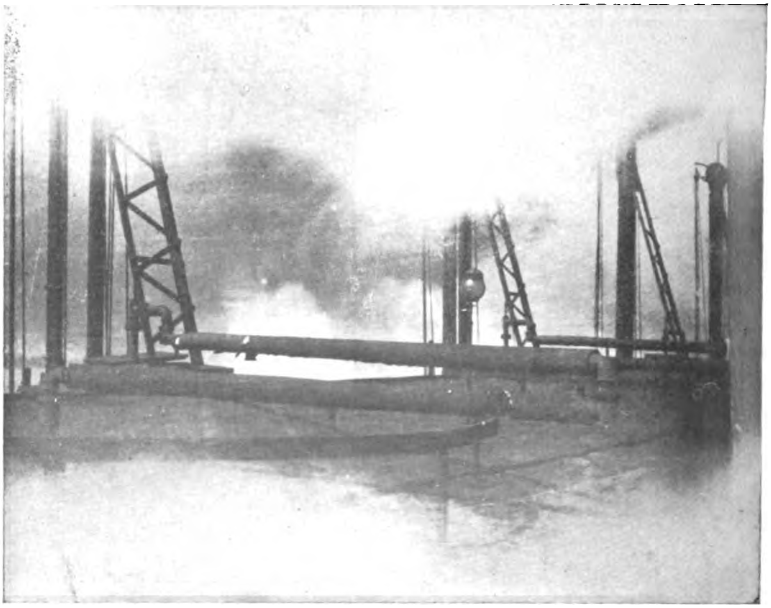

FIG. 114.—Swing Joints in Supply Pipe: Buffalo Boat No. 5.

The mud pipe proper starts from this cross timber. The one on Buffalo No. 5 consists of four parts, namely:

(1) Outside pipe, 8″ diam., 9′ 2″ long.
(2) Inside pipe, 6″ diam., 10′ 10″ long.
(3) Nipple, 6″ diam, 4′ 1″ long.
(4) A tee connecting the nipple and the inside 6″ pipe.

The whole thing is meant to be a telescope arrangement, and is put together as follows: The slide frames are first pulled up as high as possible, and then the 8″ pipe is slipped into the hole in the wooden block at the end of the slide rods until it rests on its collar. The 6″ pipe is then slipped inside the 8″ until its lower end just begins to protrude through the 8″. As soon as it does the tee having the nipple already screwed in is attached to the 6″ pipe. It is seen now that the 6″ pipe is free to be moved up or down in the 8″, up until the tee hits the 8″. The manner of making this 6″ pipe adjustable is by means of a chain that has one end secured around the nipple just below the tee. It then passes up over the outside of the 8″ pipe through a ring that is secured to the upper end of the 8″ by a clamp. The chain then passes upward along one of the posts of the frame over a pulley near the top and comes down to the deck where it can be operated by the workmen. The function of the tee at the junction of the 6″ pipe and nipple is in the stem of the tee which is open. Thus when the pipe is in operation the wash water can force the loose sand upward in the nipple until it reaches the open stem of this tee, when it is expelled into the water.

The operation of the mud pipe is as follows: The slides are let down until the top of the 8″ pipe is just clear of the water surface (see Fig. 115). The 6″ telescope pipe with its nipple and tee are then let down until the end of the nipple has pushed its way through the sand and rests on the bottom. The drill bit is then lowered inside the pipes and the hole dug as usual. The washout, as said, forces all the sand and debris out into the river through the open stem of the tee. If it should happen that the sand was deeper than the distance between the end of the nipple and the tee, its value in this case would be *nil*, because the sand being up over the tee there would be no way to get the sand on the inside out and so it would have to be churned and churned by the bit, making progress very slow.

A comparison between the mud pipe and the sand pipe can now be made. The clear distance between the end of nipple and tee in the case of the mud pipe is about the same as the spigot of the funnel in the case of the sand pipe. Then with a depth of sand such that the efficiency of the two is not

Fig. 115.—Foot of Drill Frame: Buffalo Boat No. 5.

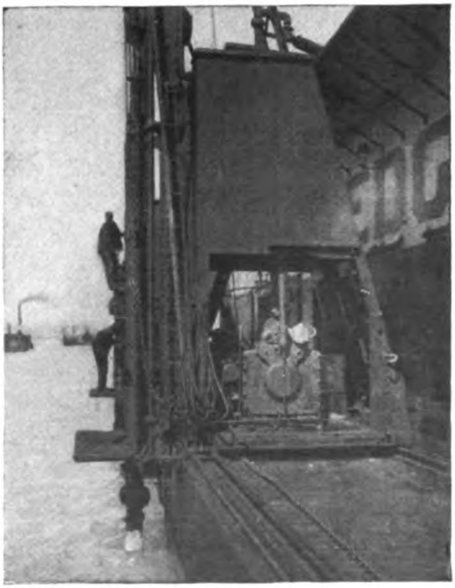

Fig. 116.—Drill Frame: Buffalo Boat No. 5.

impaired, it is obvious that they will each keep the drill bit equally clear of sand and will therefore be equally efficient. In case the depth of sand is too great for either to operate perfectly, it is believed that the sand pipe would give the better service.

The mud pipe, purposely made wide enough to allow charger and bit to be in the pipe together, can offer no particular support to the drill bit to keep it from jumping around at starting when the rock is very hard. With very hard rock, it would, therefore, seem economical to use the sand pipe, even if the hole were of such depth that the bit had to be uncoupled when loading. The time used in unbolting the bit, putting the chain around and hoisting up clear of the sand pipe is not lost time, because it is done while waiting for the blaster. The time used in replacing and bolting up after loading takes from 3–4 min. Now if with hard rock the mud pipe were used and a sharp bit had to replace the worn bit, taking 10 minutes, to say nothing of the time taken in resharpening, it is easily seen that it would be economical to use the sand pipe, even if with the mud pipe a sharp bit only had to be put in every third hole. Furthermore, a bit snugly supported near the bottom of the river would not cause so much wear in the drill cylinder as one that jumped around in a violent manner.

As to the third point, that of furnishing a guide to the charger, one answers just about as well as the other. After the hole is loaded, in each case the pipes have to be drawn up. The inside 6″ pipe is drawn up inside the 8″ by the proper tackle and the tee frame has to be raised with the sand pipe. Each of these operations requires about a minute.

The sand pipe (even if the removal of the bit is necessary for charging) is advisable in hard rock. The mud pipe is advisable where rock is soft and sandy on top. The sand pipe is best in any case if the boat is designed with a lift great enough for the bottom of the bit to clear the sand pipe in any depth of hole.

Buffalo Boat No. 5. The following figures for cost per lineal foot drilled and per cubic yard of pay rock are based on the average performance for a period of two months or 50 working days. The average depth of hole is taken as 9.5′. The holes were drilled about 3′ below grade and the cubic yards of pay rock are figured on this basis.

The plant is supposed to represent an investment of $52,000. No account has been taken of contractors' overhead charges or profit, cost of getting plant into commission in the spring and cleaning up in the fall, storing equipment during the winter, legal expenses, insurance or charity. Furthermore, it must be remembered that these observations and also the observations of Buffalo Drill Boats Nos. 4, 2 and 1 were taken during July and August, which are the best working months, as no time is lost on account of the high winds, which later in the season, add materially to the cost per cubic yard for breaking up the rock. Another fact that must be remembered is that the rock does not always break to grade, but many places are left above grade which must be redrilled, reblasted, and redredged. This is not always due to carelessness or bad judgment, but to the character and the nature of the rock, which cannot always be foreseen.

FIG. 11.7—Buffalo Boat No. 5.

Average over 50 days:

1022 lineal ft. drilled per day.

511 lineal ft. drilled per shift, assuming an equal performance by day and night shifts.

562 cu.yds. (pay) loosened per day.

281 cu.yds. loosened per shift, assuming an equal performance by day and night shifts.

COSTS

Force.	Rates of Wages.		Cost.	Cost per Foot in Cents.	Cost per pay.yd. in Cents.
5 drillers	$3.02½	$15.12½			
4 helpers	2.42	9.68	$24.80½	4.86	8.84
1 foreman, day	4.65	4.65	4.65 (10.9%)	0.91	1.66
1 foreman, night	4.25	....	.........(10.6%)		
1 fireman	2.75	2.75	2.75	0.54	0.98
2 blasters	3.30	6.60	6.60	1.29	2.34
1 blacksmith	3.62	3.62			
2 blacksmiths' helpers	2.42	4.84	8.46	1.66	3.02
16 men, day shift			$47.26½	9.26	16.84
15 men, night shift			44.44½	8.70	15.80
Total labor per day			$91.71	8.97	16.32
60% dynamite, 1800 lbs. at 12 cts.			216.00	21.12	38.40
Coal, 10 tons at $3.15			31.50	3.08	5.61
Oil, etc., 8⅔ gals. at 40 cts.			3.47	0.34	0.62
Total			$342.68	33.51	60.95
Plant, $52,000, interest and depreciation at 2% per working month			40.00	3.91	7.13

60% dynamite per linear foot,	Gross, 1.76 lbs., nitroglycerin, 1.056 lbs.
60% dynamite per cubic yard pay rock,	Gross, 3.20 lbs., nitroglycerin, 1.920 lbs.
60% dynamite per cubic yard blasted,	Gross, 2.11 lbs., nitroglycerin, 1.266 lbs.

Ratio $\frac{\text{cubic yards blasted}}{\text{cubic yards pay rock}} = 1.518.$

The following is a general summary of data on file in the government office at Amherstburg, Ont., obtained with the consent of the contractor. The items marked with a * are deductions from the data on file.

	1909.	
	July.	August.
Shifts	48	52
Hours worked	513	539
Hours delay	59	33
Number of holes	2,566	2,640
* Number of holes per shift	53	51
Lineal feet drilled	20,418	28,822
Depth of holes, feet	7.96	10.92
Dynamite, 60%, lbs	38,207	51,910
Coal, tons	250	270
* Feet per day	851	1,110
* Feet per drill hour, working	7.96	10.70
*Feet per drill hour, including delays	7.15	10.10
Labor per day, dollars	91.71	91.71
* Labor per foot drilled, cents	10.80	8.26
* Coal per foot drilled, pounds	24.4	18.7
* Coal per cubic yard pay rock, pounds	46.8	30.6
* Cubic yards pay rock	10,700	17,600
* Cubic yards per day	446	677
* Cubic yards per shift, 11 hrs	223	338

Buffalo Drill Boat, No. 4, Observations 1909. This boat, although owned by the Great Lakes Dredge and Dock Company, is at present under lease to the Buffalo Company. With the other three Buffalo boats, Nos. 1, 2, and 5, it is engaged upon drilling work on the western 100′ of section No. 3 of the Livingstone Improvement of the Detroit River.

No. 4 is a very roomy, modern and efficient drill boat. Made of steel throughout, including the house for covering the boiler, pumps, etc., its construction is much like that of Buffalo boat No. 5. No. 4, also, has five drills and frames, but the mode of operation of these is entirely different.

On No. 5 the drills are lifted by steam and the drill frames moved along the deck by the same agent. Anchor posts also are operated by steam. On No. 4, however, the drills are raised and lowered by the regular hydraulic lift and the frames are moved along deck by the usual hydraulic cylinder and endless chain arrangement. A noticeable point in regard to this hydraulic cylinder is its enormous size, it being nearly twice the usual diameter. Anchor posts on this boat are also operated by

BUFFALO DRILL BOAT NO. 5.

Holes 8′ average depth.

	No. 1, Five Holes.				No. 2, Six Holes.				No. 3, Six Holes.				No. 4, Six Holes.			
	No. Obs.	Min. m. s.	Mean. m. s.	Max. m, s.	No. Obs.	Min. m. s.	Mean. m. s.	Max. m. s.	No. Obs.	Min. m. s.	Mean. m. s.	Max. m. s.	No. Obs.	Min. m. s.	Mean. m. s.	Max. m. s.
Getting into position......	2	1:00	1:00	1:00	3	0:20	0:55	1:20	3	0:35	1:05	1:25	3	0:55	1:05	1:15
Drill cutting..............	5	16:30	25:10	37:00	6	14:45	25:20	37:00	6	20:45	28:45	36:20	6	27:25	34:35	38:35
Finishing hole............	5	1:00	0:45	1:55	6	0:30	0:55	3:00	5	0:15	0:30	0:40	6	0:30	0:45	2:10
Waiting for loading gang..	5	0:15	0:35	0:45	6	0:45	0:50	2:00	5	0:30	0:35	0:45	6	0:10	0:55	1:20
Loading.................	5	2:50	3:25	4:15	5	2:00	3:00	4:10	6	1:45	3:10	3:30	6	2:10	3:10	4:30
Total time of cycle.....	....	21:35	30:55	44:55	....	18:20	31:00	47:30	....	23:50	34:05	42:40	....	31:10	40:30	47:50

In the above table is given the minimum, mean, and maximum time in minutes and seconds required to perform each of the operations into which the process of drilling is divided, together with the number of observations of which the mean was taken.

The total gives the total time of the cycle of drilling one hole but does not include any time lost during the cycle or after its completion.

BUFFALO DRILL BOAT NO. 5.

Holes 8′ average depth.

	No. 1, Five Holes.			No. 2, Six Holes.			No. 3, Six Holes.			No. 4, Six Holes.		
	Mean. m. s.	Work. m. s.	Idle. m. s.	Mean. m. s.	Work. m. s.	Idle. m. s.	Mean. m. s.	Work. m. s.	Idle. m. s.	Mean. m. s.	Work. m. s.	Idle. m. s.
Getting into position	1:00	2:00	2:30	0:55	2:45	0:00	1:05	3:20	0:00	1:05	3:15	5:10
Drill cutting	25:10	125:35	0:00	25:20	152:00	0:00	28:45	172:20	0:00	34:35	207:25	0:00
Finishing hole	0:45	3:40	2:05	0:55	5:35	9:05	0:30	2:35	0:00	0:45	4:20	3:20
Waiting for loading gang	0:35	1:55	0:00	0:50	5:05	0:00	0:35	3:00	5:15	0:55	5:25	0:00
Loading	3:25	17:10	0:00	3:00	14:55	3:30	3:10	19:05	0:00	3:10	19:05	0:00
Total time of cycle	30:55	150:20	4:35	31:00	180:20	12:35	34:05	200:20	5:15	40:30	239:30	8:30
Waiting last hole	42:10	0:00	84:20	....	0:00	57:15	45:45	0:00	91:35	....	0:00	7:15
Moving boat	13:05	0:00	26:10	13:05	0:00	26:10	13:05	0:00	26:10	13:05	0:00	26:10
Miscellaneous	....	0:00	....	....	0:00	....	3:50	0:00	7:45	....	0:00	....

The above table shows the average time in minutes and seconds required for each of the operations into which the process of drilling has been divided and also the exact total time in minutes and seconds that the drill was engaged on the operation and whatever time was lost during the operation. The total gives the total time working and idle. This total together with the last three items of delays make up the day's work.

The average cutting speed in lineal feet per cutting minute was 0.280.

The average ratio of cutting time to total time was 0.577.

The average ratio of idle to useful working time (cycle time) was 0.496.

BUFFALO DRILL BOAT NO. 5.

	No. 1.		No. 2.		No. 3.		No. 4.		Average. Per cent.
	Time.	Per Cent.	Time.	Per Cent.	Time.	Per Cent.	Time.	Per Cent.	
Useful (cycle) working	150:20	56.64	180:20	65.25	200:20	60.54	239:30	85.10	66.88
Idle during working	4:35	1.70	12:35	4.56	5:15	1.60	8:30	3.02	2.72
Idle, miscellaneous delays	....	....	....	....	7:45	2.36	....	....	0.59
Waiting moving boat	26:10	9.86	26:10	9.46	26:10	7.90	26:10	9.30	9.13
Waiting last hole	84:20	31.80	57:15	20.73	91:35	27.60	7:15	2.58	20.68
Total idle time	115:05	43.36	96:00	34.75	130:45	39.46	41:55	14.90	33.12
Total time	265:25	100.00	276:20	100.00	331:05	100.00	281:25	100.00	100.00

The above table is a summary of the preceding one. The time for useful working is the sum of the first five items of the preceding table and represents the time of a cycle of drilling. The second item is the total time lost during this cycle. The percentages are percentages of total time worked during observation.

hydraulic power, so that while No. 5 may be called an all-steam boat, No. 4 is nearly an all-hydraulic power boat. Steam, of course, is used in the operation of the drills, which are Ingersoll-Rand, Type H 61.

The following figures for cost per lineal foot drilled and per cubic yard of pay rock are based on the average performance for a period of two months, or 104 shifts. The average depth of hole was 7⅝′. The number of cubic yards of pay rock loosened has been based upon the holes being drilled about 2⅝′ below pay grade and spaced 5′ longitudinally and 4½′ laterally.

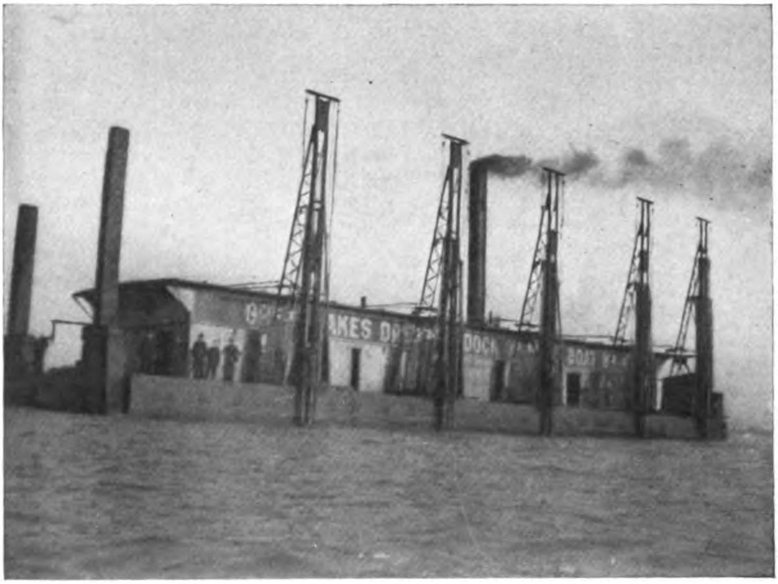

Fig. 118.—Buffalo Boat No. 4.

Average over 2 months 835 lineal ft. drilled per day.

Average over 2 months 418 lineal ft. drilled per shift, assuming equal shifts.

Average over 2 months 451 cubic yards pay rock loosened per day.

Average over 2 months 226 cubic yards pay rock loosened per shift, assuming equal shifts.

COSTS

Force.	Rates of Wages.		Cost per Shift.	Cost per Foot in Cents.	Cost per Pay yd. in Cents.
5 drillers	$3.02½	$15.12½			
5 drillers' helpers	2.42	12.10			
			$27.22½	6.53	12.05
1 blacksmith	3.62	3.62			
2 blacksmiths' helpers	2.42	4.84			
			8.46	2.02	2.74
2 blasters	3.30	6.60	6.60	1.58	2.92
1 fireman	2.75	2.75	2.75	0.66	1.22
1 foreman, day	4.65	4.65	4.65	1.11	2.06
1 foreman, night	4.25	4.25	4.25	1.02	1.88
Day shift			$49.68½	11.90	21.99
Night shift			49.28½	11.81	21.80
Total labor			$98.97	11.85	21.90
1365½ lbs. dynamite per day at 12 cts., 60%			163.86	19.60	36.30
Coal, 10 tons per day at $3.15			31.50	3.78	6.98
Oil per day, 8 gals. at 40 cts			3.20	0.38	0.71
Daily total			$297.53	35.61	65.89
Plant, $50000, interest and depreciation at 2%			38.40	4.60	8.53

No account has been taken of contractor's overhead charges, profit, cost of getting into operation in spring and cleaning up in fall, storing equipment in winter, legal expenses, insurance, charity, etc.

The following is a general summary of data on file in the government office at Amherstburg, Ont., obtained with the consent of the contractor. The items marked * are deductions from the data on file.

	1909.	
	July.	August.
Shifts worked	52	52
Hours worked	554	562
Hours delay	18	10
Number of holes	2,731	2,900
Number of holes per shift	52	56
Depth of holes, feet	7.16	8.17
Lineal feet drilled	19,582	23,724
Dynamite, 60%, lbs	29,021	41,997
Coal, tons	260	270
* Feet per day	755	914
* Feet per drill hour, working	7.07	8.45
* Feet per drill hour, including delays	6.85	8.30
* Feet per man hour	2.1	2.46
Labor per day	98.97	98.97
* Labor per foot drilled, cents	13.1	10.82
* Coal per foot drilled, pounds	26.6	20.8
Cubic yards of pay rock	11,350	12,100
* Cubic yards per day	437	465
* Cubic yards per shift, 11 hrs	218.5	232.5

* 60% dynamite per lineal foot drilled, Gross 1.64 lbs., nitroglycerin 0.984 lb.
* 60% dynamite per cubic yard pay rock, Gross 3.02 lbs., nitroglycerin 1.812 lbs.
* 60% dynamite per cubic yard blasted, Gross 1.96 lbs., nitroglycerin 1.176 lbs.
* Ratio $\frac{\text{cubic yards blasted}}{\text{cubic yards pay rock}} = 1.54.$

Buffalo Drill Boat No. 2. No. 2 is a four-frame boat, equipped with Ingersoll-Rand drills, type H 64. With Nos. 1, 5, and 4, this boat forms the fleet of Buffalo drill boats at present engaged in drilling operations on the western 100′ of section No. 3 of the Livingstone Improvement of the Detroit River.

Like No. 1, this boat is of the old wooden type of construction and is arranged to move the drill frames along deck, with a rack on the deck into which a pinion on an axle in the drill frames meshes, operation being by hand.

Like No. 1, No. 2 also has the convenient arrangement of steam and hydraulic-lift feed pipes on top of the roof of the house covering the boat and in addition a similar system of pipes for returning the exhaust to a hot-water tank in the hull of the boat. (Fig. 120 shows these systems of pipes on the

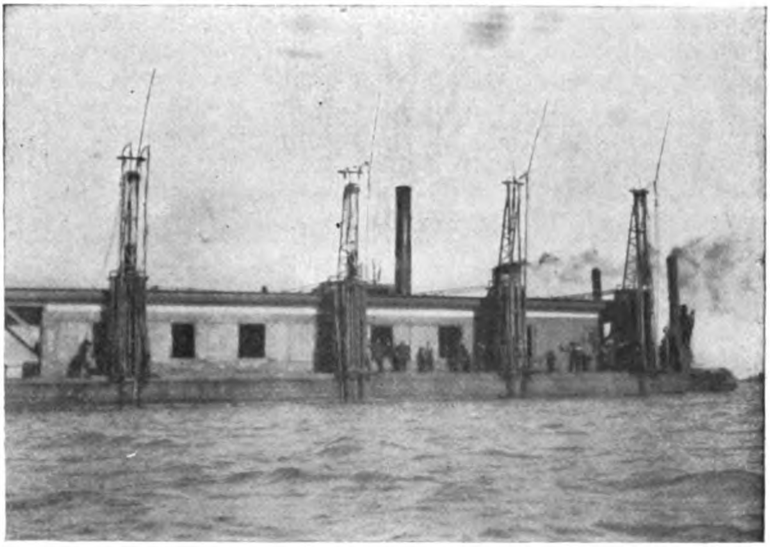

FIG. 119.—Buffalo Boat No. 2.

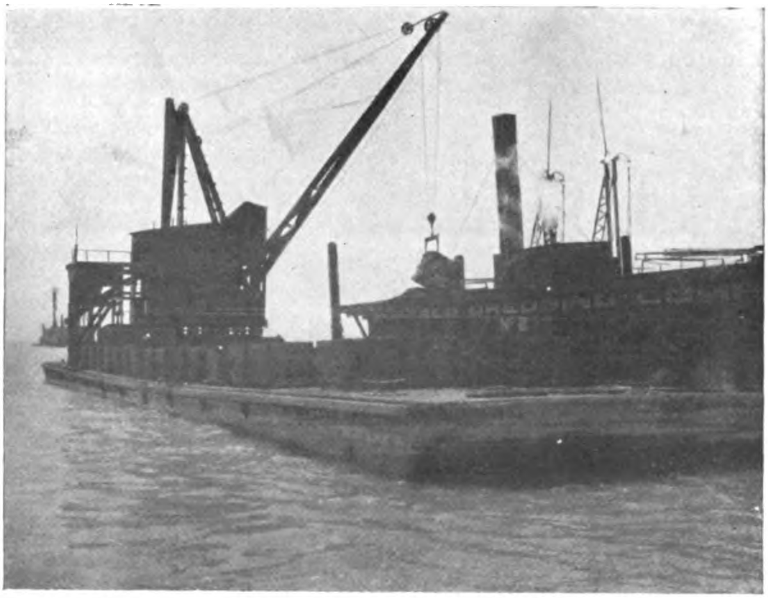

FIG. 120.—Coal Scow Loading Buffalo Boat No. 2

roof and Fig. 122 shows two of them in more detail.) As may be readily supposed, this hot-water tank is intended to eliminate all danger of the hydraulic-lift water freezing.

The following figures for cost per lineal foot drilled and per cubic yard of pay rock are based on the average performance for a period of one month, 52 shifts. The average depth of holes was 10.1′ and on the basis of the holes being drilled about 2.6′ below pay grade and spaced 5′ longitudinally and 4½′ laterally, the cubic yards of pay rock have been figured.

Average for one month, 610 lineal feet drilled per day.

Average for one month, 305 lineal feet drilled per shift, assuming equal shifts.

Average for one month, 376 cubic yards of pay rock loosened per day.

Average for one month, 188 cubic yards of pay rock loosened per shift, assuming equal shifts.

COSTS

Force.	Rate of Wage.		Cost per Shift.	Cost per Foot in Cents.	Cost per Pay Yard in Cents.
4 drillers	$3.02½	$12.10	$21.78	7.14	11.58
4 drillers' helpers	2.42	9.68			
1 blacksmith	3.62	3.62	8.46	2.77	4.50
2 blacksmiths' helpers	2.42	4.84			
1 fireman	2.75	2.75	2.75	0.90	1.46
1 foreman, day, per mo., $121, 12.8%		4.64	4.64	1.52	2.47
1 foreman, night, per mo., $110, 11.7%		4.25	4.25	1.39	2.26
1 powderman, $3.30		3.30	3.30	1.08	1.75
Day shift			$40.93	13.41	21.76
Night shift			40.54	13.30	21.55
Total labor			$81.47	13.35	21.66
60% dynamite per day, 1220 lbs. at 12 cts.			146.40	24.00	39.00
Coal per day, 8 tons at $3.15			25.20	4.14	6.70
Oil per day, 5 gals. at 40 cts.			2.00	0.33	0.53
Daily total			$255.07	41.82	67.89
Plant, $30,000, interest and depreciation at 2% per working month			23.10	3.79	6.14

No account has been taken of contractor's overhead charges, profit, cost of getting the plant into operation in the spring and cleaning up in the fall, storing equipment in the winter, legal expenses, insurance, charity, etc.

The following is a general summary of data on file in the government office at Amherstburg, Ont., obtained with the consent of the contractor. The items marked * are deductions from the data on file:

	August, 1909.
Shifts worked	52
Hours worked	553
Hours delay	19
Number of holes	1,570
* Number of holes per shift	30
Depth of holes, feet	10.1
Lineal feet drilled	15,850
Dynamite used, 60% lbs	31,743
Coal used, tons	218
* Feet per day	610
* Feet per drill hour, working	7.20
* Feet per drill hour, total	6.94
* Feet per man hour	2.25
Labor per day	$81.47
* Labor per foot drilled, cents	13.3
* Coal per foot drilled, tons	0.0137 = 27.4 lbs.
* Cubic yards pay rock	9,800
* Cubic yards per day	376
* Cubic yards per shift, 11 hrs	188
* 60% dynamite per lineal foot	Gross 2.00 lbs., nitroglycerin 1.200 lbs.
* 60% dynamite per cubic yard pay rock,	Gross 3.24 lbs., nitroglycerin 1.944 lbs.
* 60% dynamite per cubic yard blasted,	Gross 2.40 lbs., nitroglycerin 1.44 lbs.

$$\text{Ratio}\ \frac{\text{cubic yards blasted}}{\text{cubic yards pay rock}} = 1.35.$$

Buffalo Drill Boat No. 1. Observations 1909. The second of the Buffalo Dredging Company drill boats working upon the western 100′ of section No. 3 of the new Livingstone Improvement of the Detroit River is the so-called No. 1. Built some twenty years ago by the Heman & Wood Co. of Buffalo, it is one of the oldest drill boats of this company. Inconvenient and antiquated as it is, it still has one excellent feature, which is that the steam feed pipes and the hydraulic lift pipes for each drill are practically out of the way, being for the greater part of their extent upon the roof of the boat (see Fig. 122). This

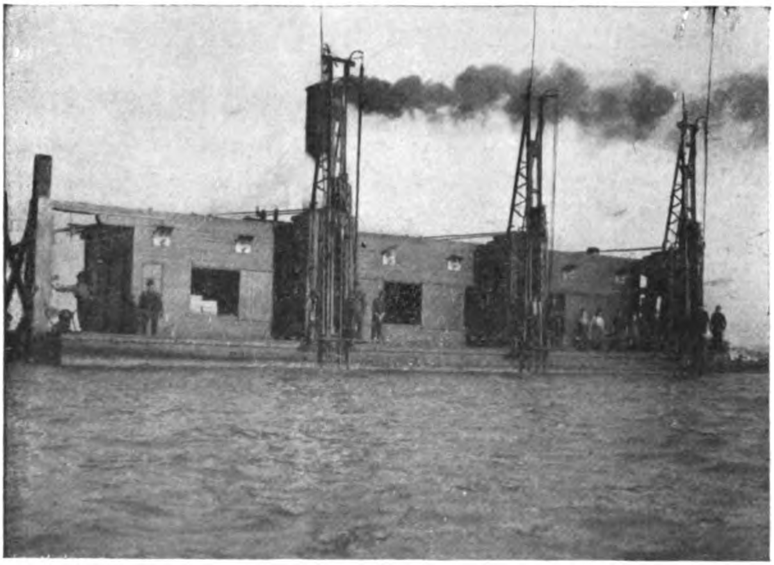

FIG. 121.—Buffalo Boat No. 1.

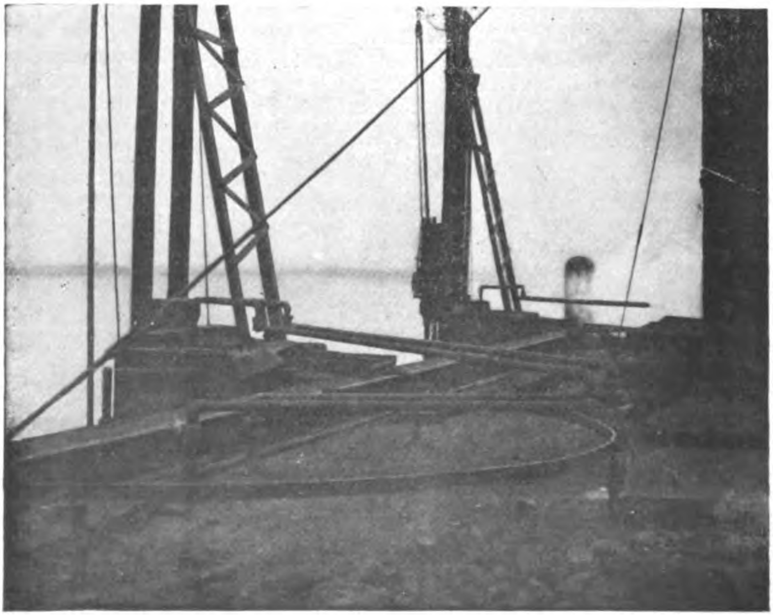

FIG. 122.—Swing Pipe Joints on Roof of Buffalo Boat No. 1.

boat was rebuilt during the summer of 1908, but is still essentially an old wooden craft. Spud anchors, capstans, and mechanism for moving the frames along deck are all operated by hand, and so their operation is very slow and inconvenient. It is 82½′ long and 25′ wide, and has a wooden house 63½×15½′ that covers all machinery except the three drills, capstans and mooring posts. The hull is of the regular wooden scow type construction, and the following description, although especially applicable to the interior bracing of this boat, will give a good general idea of the arrangement of all such types of wooden boat.

Spaced 72″, center to center, are 12×12″ floor beams running transversely. Alternate ones have wooden knee brackets on their ends and the others have vertical posts. Side planking is secured to these vertical posts and the vertical side of the brackets. Running lengthwise of the boat and resting on the tops of these vertical posts and the top of the vertical member of the knee are two 6×10″ timbers, one on each side. Running across these 6×10″ members are the rafters 8×4″, and spaced 72″ for the deck planking. Bolted to the 12×12″ floor beam members on their under side are 12×12″ stringers spaced 24″ center to center that run the full length of the boat and to the under side of which the bottom planking is secured. At the ends of these are posts to which the end planking of the scow is attached. The boat is divided into four compartments by longitudinal partitions of 5′ timbers. These are by no means water-tight, but they simply stiffen the boat and furnish additional support for the deck rafters. It may also be added that between the 12×12″ floor beams to which the 12×12″ longitudinal stringers are attached are 12×4″ timbers running across the boat, whose only function seems to be to furnish additional transverse stiffness to the boat. Into each of the longitudinal partitions are cut holes 2×2′ to afford access from one compartment to another.

The boat is equipped with three Ingersoll-Rand drills, Type H 61. Each frame has a range of 6 holes, their spacing along deck being 4′. Running along the deck are two 25-lb. rails upon which the frames slide. One of these rails is near the outer edge of the boat and the other about 3½' from it. Upon the deck midway between these two rails is a rack 5" wide into which a 5" cog wheel meshes, secured to an axle in the frame of each drill. This cog wheel is given the necessary rotary motion by means of a crowbar in the hands of the driller and his helper.

The steel bits used in drilling average 33' in length and some 400 lbs. in weight. The upper half of the bit is 2" steel, circular section, and the lower half 2⅛". The point of the bit is of hard octagonal tool steel, 24" long and 2½" in diameter. When sharpened and ready for use the bit is 4½" across and this shape: +. These bits will usually dig 15 holes without repointing, but of course accidents frequently happen, causing much more frequent sharpening. When the steel, for any reason, has to be changed, the handling of it is by hand up to the point where the workmen shove its end into the house. Here a hook fastened to a small trolley that slides on a suspended steel bar 2×½" assists, and for the same purpose there are also two blocks and tackle.

This boat is also equipped with the mud pipe as described on No. 5, but its section is so small that before a drilled hole can be charged the bit must be released from its clutch and drawn up by hand till its end is clear of the pipe. This is necessary, because there is not room at the same time for both charger and bit. The time consumed to thus take out and sling up a bit preparatory to loading is 5 min.

DRILL DATA. Type of drill, Ingersoll-Rand H 61.

Diameter of piston, 5½".
Stroke obtained, 7".
Lift, about 18'.
U-chuck.
Steam pressure, 100 lbs. at boiler.
Speed of drill, about 300 strokes.

The drills are raised in their frames by hydraulic lifts, the feed pipes of which are for the greater part of their length on the roof of the house covering the boat.

Bits have hard octagonal tool steel points, 4½" diameter.

Drill steel, circular section, 2 and 2⅛".

Steel handled by men with the aid of a hook fastened to a small trolley that slides on a suspended steel bar, section 2×½″. There are also two blocks and tackle whereby the steel can be more readily handled.

Steel tempered till file will not touch.

Three-eighths inch water jet cleans hole.

Worthington pump, 12×5½×10″ furnishes water to jets.

Speed of pump fluctuates when the machines are raised or lowered.

Water pressure is 425 lbs.; but dare not turn on full.

The washout pipe has 5′ of ¾″ pipe, reducing to 14′ of ½″, which in turn reduces to 10′ of ⅜″. A rubber hose 1″ in diameter forms a flexible coupling between the ¾″ pipe and a 1″ feed pipe.

Holes are about 6′ deep, and 5½″ in diameter.

Longitudinal spacing of holes, 4′.

Lateral spacing of holes, 4′.

Generally a washout pipe is not used. However, when one machine gets behind it is enabled to catch up by means of the washout water.

Material drilled is limestone, with about 2½′ of sand on top. Streaks of hard rock.

Holes blasted 26×18 plus 24=492; 26 rows of 18 each, plus 24 extra ones for closer spacing on outside rows.

Potts powder used, 60%.

Sticks of powder are 2×8″ and weigh 1¼ lbs. each.

Twelve sticks are used per hole.

Use a blasting machine, but have a dry battery in reserve for firing holes.

One blaster and foreman, also runner and helper do the blasting.

Three drills compose the outfit.

Oswego marine, 2-fire boiler.

Gauge pressure at boiler, 100 lbs.

Length of feed pipe, about 50′, from steam chest to main.

Diameter of main, 3″.

Length of contract, 750 good working days.

Ten-hour day and 12-hour night shifts are worked.

Two shifts.

Day shift:

3 drillers	at $3.02½	= $9.07½	per shift
3 drillers' helpers	at 2.42	= 7.26	"
1 blacksmith	at 3.62	= 3.62	"
2 blacksmiths' helpers	at 2.42	= 4.84	"
1 fireman	at 2.75	= 2.75	"
1 foreman at $121 per month	4.65	= 4.65	per day
1 blaster	at 3.30	= 3.30	per shift
Total		= $35.49½	

Night shift:

3 drillers	at $3.02½	= $9.07½	per night
3 drillers' helpers	at 2.42	= 7.26	"
1 blaster	at 3.30	= 3.30	"
1 fireman	at 2.75	= 2.75	"
1 foreman, $110 per month	at 4.25	= 4.25	"
Total		= $26.63½	"
		35.49½	day shift
		$62.13	both shifts

The contract price is $2.80 per cubic yard for rock and 50 cts. per cubic yard for earth.

As said before, each drill bit consists of three parts. The blacksmith has to make all these welds and keep the bits sharpened and in shape.

Eight tons coal used per 24 hrs. = 2666 lbs. per drill per shift.

Ten gallons of oil used per day = 13⅓ pints per drill per shift.

The coal is bought at the Amherstburg dock. It is loaded by clamshell buckets into square dump boxes. These dump boxes are placed in four rows on board a scow. In the center of the scow, on the deck, and between the buckets (two rows on each side) there is a track on which a crane moves back and forth. A tug takes the scow and its load of coal boxes out to the drill boats. Then the crane lifts each dump bucket by its bail until it hangs suspended over the coal chute in the roof. Workmen then release the catch on the dump box and it empties its coal into the bunker. The scow carries enough coal on one trip to supply the four boats of the Buffalo fleet two days, making a trip every other day (see Fig. 120).

Coal costs \$3.15 at the dock.

The company owns its own tug and considers the cost of handling to be nothing. If this work had to be paid for, handling would cost 35 cts. a ton.

No figures are kept as to repairs.

Each boat has a day and a night foreman, and besides a superintendent for the four boats. Day foreman at 15.1% of the day wages; night foreman at 19% of the night wages.

Men live ashore.

Interest and depreciation on the plant, valued at \$25,000, at 2% per working month = \$9.61 per shift.

A rough inventory of the equipment is given below:

Boat, 82½′ wooden scow type hull.
One cutter.
One powder boat.
Three mounted drills and equipment.
One spare drill.
Four spud anchors.
Two hand windlasses.
One forge.
One anvil.
One marine boiler.
One injector.
One auxiliary boiler feed pump, Hughes, 4½×5.
One Worthington pump, 12×5½×10″, 425 lbs.
Eleven drill steels.
One bench, vise and pipe clamp.
One acetylene gas outfit.
One feed-water filter.
One closet.

The following figures for cost per lineal foot drilled and per cubic yard of pay rock are based on the average performance for 14 days, or 28 shifts of 11 hrs. The average depth of hole is taken as 5.37′. The holes are drilled about 1.37′ below pay grade and the cubic yards of pay rock are figured on that basis.

Average for 14 days, 468 lin.ft. drilled per day.
Average for 28 shifts, 234 lin.ft. per shift, assuming equal shifts.
Average for 14 days, 206 cubic pay yards per day.
Average for 28 shifts, 103 cubic pay yards per shift.

COSTS

Force.	Rates of Wages.	Cost per Shift.	Cost per Foot in Cents.	Cost per Pay Yard in Cents.
3 drillers	\$3.02½	\$9.07½	3.88	8.82
3 drillers' helpers	2.42	7.26	3.10	7.05
1 blaster	3.30	3.30	1.41	3.20
1 fireman	2.75	2.75	1.17	2.67
1 foreman, \$121 per month.	4.65 15.1%	4.65	1.99	4.52
1 blacksmith	3.62	3.62	1.55	3.52
2 blacksmiths' helpers	2.42	4.84	2.07	4.70
1 foreman, \$110 per month	4.25 19.0%	4.25	1.82	4.13
12 men, day shift		\$35.49½	15.17	34.48
9 men, night shift		26.63½	11.38	25.87
Total labor		\$62.13	13.28	30.18
Plant at \$25,000, interest and depreciation at 2% per working month		19.22	4.11	9.34
60% dynamite, 1155 lbs. at 12 cts.		138.60	29.60	67.20
Coal, 8 tons at \$3.15		25.20	5.40	12.25
Oil, 10.0 gals. at 40 cts.		4.00	0.85	1.94
Total		\$249.15	53.24	120.91

The following is a summary of the record for this boat for the last two weeks in August as found in the government office at Amherstburg, Ont., used with permission of the contractor. The items marked * are deductions from the data on file.

Shifts work 11 hrs	28
Hours worked	298
Hours idle	10
Number of holes	1,219
* Number of holes per shift	43
Lineal feet drilled	6,555
Depth of holes, feet	5.4
Dynamite, lbs., 60%	16,960
Coal, tons	112
* Feet per day	468
* Feet per shift	234
* Feet per drill hour. working	7.33
* Feet per drill hour., including delays	7.10

* Feet per man hour	2.02
Labor per day	$62.13
* Labor per foot drilled, cts	13.3
* Coal per foot drilled, tons	0.0171=34.2 lbs.
* Coal per cubic yard pay rock, tons	0.0388=77.6 lbs.
* Cubic yards pay rock	2,890
* Cubic yards pay rock per day	206
* Cubic yards pay rock per shift	103

Cubic yards of pay rock are figured as follows: Holes are 5.37′ deep, 4′ of which depth is pay depth. Spacing is 4×4′. Number of holes 1219. 4×4×4×1219=78,000 cubic feet=2890 cubic pay yards.

* Dynamite 60% per lineal foot,	Gross 2.59 lbs., nitroglycerin 1.55 lbs.
* Dynamite 60% per cubic yard pay,	Gross 5.87 lbs., nitroglycerin 3.52 lbs.
* Dynamite 60% per cubic yard blasted,	Gross 4.37 lbs., nitroglycerin 2.62 lbs.

* Ratio $\frac{\text{Cubic yards blasted}}{\text{Cubic yards pay rock}} = 1.34$

CHAPTER XIII

SUBAQUEOUS DRILLING—*Continued*

Improving Black Rock Harbor and Channel at Buffalo, N. Y.[1] The Buffalo Dredging Co. and Empire Engineering Corporation are engaged upon this work of improvement; 350,000 cu. yds. of material are to be removed. Of this 22%, or 81,000 cu. yds., is sand, gravel, clay and boulders, and in addition there are 269,000 cu. yds. of limestone and flint bed rock. The flint is very hard material to drill and difficult to blast. For the latter reason the 3′ 6″ holes are spaced very closely together (3×2′). In the limestone the spacing is 6×5′ and depth 10′ 9″ and 9′ 9″, all holes being 3½″. Monthly estimates are made by scow measurement in order to get a rough idea of the amounts due the contractors. At the end of the season accurate surveys are made and errors corrected. The new channel is to be 23′ deep and 4020′ long by 200 to 240′ in width. The contract price for rock above 23′ grade is $2.70 per cubic yard. Holes are drilled 2′ below pay grade.

The following data and deductions are kept in separate columns for each different depth of hole. Special attention is called to the enormous increase in unit costs for the short closely spaced holes in the flint bed rock.

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[1] Data collected by Mr. Gilbert H. Gilbert.

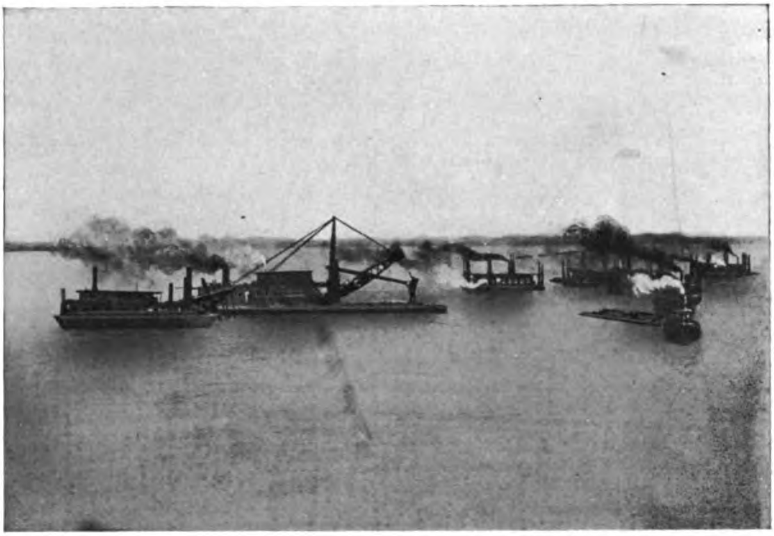

FIG. 123.—Black Rock Harbor.

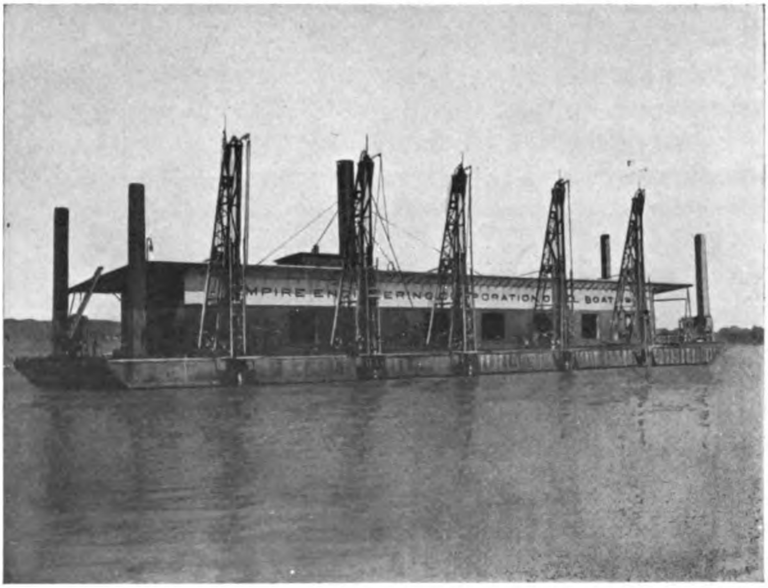

FIG. 124.—Black Rock Harbor, Buffalo. Empire Engineering Corporation.

Five Ingersoll-Rand drills, 6½". Material, limestone and flint bed rock. Bed rock holes, 3½", drilled 2' below pay grade.

	Depth 10' 9".	9' 9".	3' 6".
Shifts worked, 11 hrs............	28½	52	22½
Hours worked..................	298	552	232
Hours delay.....................	15	22	15
Number of holes...............	532	1,678	999
Lineal feet drilled..............	5726	15,224	3480
Cubic yards pay rock...........	5180	14,450	333
Dynamite, 60% lbs.............	Gly. 4014 lbs. =6690	Gly. 11,172 lbs. =18,620	Gly. 258 lbs. = 430
Coal, tons.......................	114	208	90
Labor, per shift.................	$46.38	$46.38	$46.38
Lineal feet per shift.............	201	293	154.5
Lineal feet per drill hr., working..	3.85	5.51	3.0
Lineal feet per man hr...........	1.3	1.62	0.924
Labor per foot drilled...........	23.09	15.85	30.16
Cubic yards pay rock per shift....	182	278	14.8
Cubic yards pay rock per drill hr..	3.32	5.06	0.269
Labor per cubic yard pay rock....	25.43	16.68	313.50
Coal per foot drilled in lbs........	39.80	27.30	51.8
Coal per drill per shift, lbs.......	1600	1600	1600
Dynamite per lineal foot drilled ...	1.17 lbs. Gly. 0.70 lb.	1.22 lbs., Gly. 0.73 lb.	0.12 lb. Gly. 0.07 lb.
Dynamite per cubic yard pay rock	1.29 lbs. Gly. 0.77 lb.	1.29 lbs. Gly. 0.77 lb.	1.29 lbs. Gly. 0.77 lb.
Dynamite per cubic yard loosened.	1.05 lbs. Gly. 0.63 lb.	1.03 lbs. Gly. 0.62 lb.	0.55 lb. Gly. 0.33 lb.
Total cost per lin.ft. drilled exclusive of dynamite and explod.,cts.	38.26	26.26	49.90
Total cost per cu.yd. pay including all items before listed, cts.......	61.99	50.01	557.30
Same per cubic yard blasted., cts..	50.40	39.70	239.00
Spacing of holes.................	6'×5'	6'×5'	2'×3'
Ratio cubic yards blasted to cubic yards pay.....................	1.23	1.258	2.33

NOTE. The difference in cost between the 10' 9" and 9' 9" holes is due to variations in the hardness of the rock. The large increase in cost per lineal foot of the 3' 6" holes is due to hardness of material and the enormous increase in cost per cubic yard pay is due to the small yardage per foot drilled due to close spacing of holes.

The following figures for cost per lineal foot drilled and per cubic yard of pay rock loosened are based on the average performance as follows:

Material, limestone and flint bed rock. Five-frame boat using five 6½" Ingersoll-Rand drills.

Holes 10' 9" Deep.		Holes 9' 9" Deep.		Holes 3' 6" Deep.	
Lineal feet,	5726 } 28½ shifts	Lineal feet,	15,224 } 52 shifts	Lineal feet,	3480 } 22½ shifts
Cubic yards pay,	5180 }	Cubic yards pay,	14,450 }	Cubic yards pay,	333 }
Lineal feet per shift,	201	Lineal feet per shift,	293	Lineal feet per shift,	154½
Pay cubic yards per shift,	182	Pay cubic yards per shift,	278	Pay cubic yards per shift,	14.8

Force.	Rate.	Cost per Shift.		Holes 10' 9" Deep.		Holes 9' 9" Deep.		Holes 3' 6" Deep.	
				Cost per Foot, Cents.	Per Pay Yard, Cents.	Per Foot Cents.	Per Pay Yard, Cents.	Per Foot Cents.	Per Pay Yard, Cents.
5 drillers at	$3.02½	$15.12							
5 drillers' helpers at	2.42	12.10							
			$27.22	13.55	14.92	9.30	9.80	17.62	184.00
1 smith at	3.62	3.62							
2 smiths' helpers at	2.42	4.84							
			$8.46	4.21	4.64	2.89	3.04	5.48	57.20
1 blaster at	3.30	3.30	3.30	1.64	1.81	1.13	1.19	2.14	22.30
1 fireman at	2.75	2.75	2.75	1.37	1.51	0.94	0.99	1.78	18.60
1 foreman at	4.65	4.65 (10.25)%	4.65	2.31	2.55	1.59	1.67	3.01	31.40
Total labor			$46.38	23.08	25.43	15.85	16.69	30.03	313.50
Coal 4 tons at $3.15		12.60	12.60	6.27	6.91	4.30	4.53	8.15	85.30
Oil, waste, cordage, smith coal at 22.7 per hour		2.50	2.50	1.24	1.37	0.85	0.90	1.62	16.90
Total drilling per shift			$61.48	$30.59	33.71	21.00	22.12	39.80	415.70
60% dynamite, 1.29 lbs. per yard loosened at 12 cts. lb.				17.30	19.05	18.50	19.50	3.46	36.10
Exploders 0.214 per yard loosened at 3 cts.				0.72	0.79	0.77	0.81	0.14	1.50
Total drilling and blasting				48.61	53.55	40.27	42.43	43.40	453.30
Interest and depreciation at 2% per working month on plant estimated at $40,000		$15.40	$15.40	7.66	8.44	5.26	5.94	9.97	104.00
Total				56.27	61.99	45.53	48.37	53.37	557.30

NOTE. The data from which the costs of dynamite and exploders are deduced as are follows: 24,194 lbs. of 60% for 18,700 cu.yds. blasted using 3998 exploders.

In the above deductions of cost no account is taken of contractors' overhead charges, organization or preparatory charges, insurance, charities, legal, medical expenses, etc.

Hay Lake and Neebish Channels, Improvement of St. Mary's River, Mich. Section 4. Standard Contracting Co., Cleveland Ohio, Contractors.[1] The area to be improved covers 190,000 sq. yds.; is 5400′ in length by 875′ in width, gradually reducing to 300′. The depth of the channel is to be 22′. Side slopes 1 to 1. The average cutting is 1.5′ to 22′ grade. The estimated quantities to 22′ grade are 60,700 cu. yds.; between 22 and 23′, 43,000 yds. Price per cubic yard above 22′ is $2.95, and between 22 and 23′, half that price. Monthly estimates of 90% are paid. The contract was dated Aug. 12, 1908, and called for the completion of the work in 275 working days, Dec. 1 to April 1 not included.

The rock formation is hard limestone, broken or loose rock, and glacial drift. At this point the rock has been blasted and dredged before, 3′ having been removed by contract at $2.43 per cubic yard.

The plant employed consists of 3 drill boats mounting 8 Ingersoll-Rand 5½″ drills, 2 dredges, 4 dump scows, 1 floating derrick, and 2 tugs. The estimated value of the plant is as follows: drill boats, $34,000, dredges, $45,000, dump scows $30,000, derrick, $6,000, tugs, $10,000. Total, $125,000. The drill boats are of the Lake type, the lifts being operated by hydraulic power. The wooden hulls are 98′×25′×6′, 90′×30′×6′, and 65′×16′×5′ 6″ fitted with spuds operated by hand, and drill frames operated two by hand and one by hydraulic power. Two boats carry three drills each and the third carries two. The drill steels are 34′ long and 2″ diam., machinery steel. The bit points are of 2½″ steel, 24″ long, welded onto the 2″ steel. Bits lose ½″ gauge in 80′.

The drill boats are operated 22 hrs. a day in 2 shifts of 10 and 12 hrs. The day crews number 35, night crews 29 men. Smiths do not work at night.

In the following synopsis of costs no account has been taken of contractor's preparatory charges, getting the plant into commission in the spring, cleaning up in the fall, storing in the winter, insurance, accidents, charities, legal, medical expenses, etc.

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[1] Data obtained by Mr. Gilbert H. Gilbert.

The following figures for costs per lineal foot drilled and per cubic yard of pay rock loosened are based on the total performance of the three boats, mounting 8 drills, for a period of one month or 550 hrs. labor and 406 hrs. actually operating. The average depth of hole is 5′. The number of cubic yards of pay rock loosened has been based upon the holes being drilled 2½′ below grade and spaced 5×6′.

BASIS OF COSTS

Material, hard limestone. Drills, 8. Hours, 406. No. of holes, 1925. Lineal feet drilled, 9625. Cubic yards of pay rock loosened, 5360.

Force.	Rate. Cents.	Hrs.	Amount.		Per Lineal Foot, Cents.	Cost per Cu.yd. Pay, In Cents.
8 drillers at	27½	406	$893.20			
8 drillers' helpers at	22	406	714.56			
				$1607.76	16.70	30.00
3 blasters at	30	406	$365.40	365.40	3.80	6.82
3 firemen at	25	550	412.50	412.50	4.29	7.70
2 blacksmiths at	33	203	133.98			
2 blacksmiths' helpers at	22	203	89.32			
				223.30	2.32	4.16
1 machinist at	35	250	$ 87.50	87.50	0.91	1.63
Carpenters at	local	local	100.00	100.00	1.04	1.86
6 foremen at $125 per month, aver. 21.1%			750.00	750.00	7.79	14.00
Total labor drilled				$3546.46	36.85	66.17
Coal (20 days at 23 tons) (11 days at 1 ton) =471 tons at $3.15				1480.00	15.40	27.60
Smith's coal				30.00	0.31	0.56
Oil				40.00	0.42	.75
Steel				75.00	0.78	1.40
Total supplies				$1625.00	16.91	30.31
Total drilling and supplies				5171.46	53.76	96.48
Dynamite, 60%, 11,550 lbs. at 12 cts.				1386.00	14.40	25.88
Exploders, 2500 at 3 cts. each				75.00	0.78	1.40
Total blasting drilling supplies				$6632.46	68.94	123.76
Office and superintendent				250.00	2.60	4.66
Interest and depreciation on plant estimated at $34,000 at 2% per working month				680.00	7.07	12.69
Operation, grand total				$7562.46	78.61	141.11

NOTE. 3216 pay yards were above 22′ and received full rate.
2144 pay yards were between 22′ and 23′ and received one-half full rate.
5360 yards were below 23′ and received no pay at all.

The following is a general summary of performance data secured on the job with deductions therefrom:

Eight Ingersoll-Rand drills, 5½″. Material, hard limestone. Holes, 4″ diam. Depth 5′. Below pay 2½′.

Average shifts worked	37
Hours worked	406
Number of holes	1925
Depth of holes, ft	5
Lineal feet drilled	9625
Spacing of holes, ft	5×6
Cubic yards of pay rock	5360
Dynamite, 60%	11,550 lbs., glycerine 6930 lbs.
Coal, tons	471
Labor per shift (average)	$95.20
Lineal feet per shift (average 11 hrs.)	260
Lineal feet per drill hr	2.96
Lineal feet per man hour (average 31 men per shift)	0.762
Labor per foot drilled, in cts	36.850
Cubic yards pay rock per shift	144.8
Cubic yards pay rock per drill hr	1.65
Cubic yards pay rock per foot drilled	0.557
Labor per cubic yard of pay rock in cts	66.17
Coal per drill per shift in lbs	3180
Coal per foot drilled, lbs	97.9
Dynamite per foot drilled	1.20 lbs., glycerine 0.72 lb.
Dynamite per cubic yard pay rock	2.15 lbs., glycerine 1.29 lbs.
Dynamite per cubic yard of rock blasted	1.07 lbs., glycerine 0.64 lb.
Ratio cubic yards blasted to cubic yards pay	2.00
Office and superintendence per shift	$6.75
Office and superintendence per lineal foot drilled, cts	2.60
Office and superintendence per cubic yard of pay, cts	4.66
Interest and depreciation per shift	$18.40
Interest and depreciation per drill per shift	$2.30
Interest and depreciation per lineal foot drilled, cts	7.07
Interest and depreciation per cubic yard pay, cts	12.69
Total cost per lineal foot drilled, all items including loading, but exclusive of dynamite and exploders, cts	63.43
Total cost per cubic yard pay including all items, cts	141.11
Total cost per cubic yard blasted, cts	70.53

Improving Ahnapee Harbor, Wisconsin.[1] The unusual feature of this work was that instead of a regular drill boat, a scow was used mounted with tripod drills. The scow was fitted up with four spuds operated by hand. The tripods were mounted on the side of the scow and were equipped with four No. 5 Ingersoll drills.

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[1] Data obtained by Mr. Gilbert H. Gilbert.

The rock formation was limestone of an average cut of 8′ 4″ to obtain a channel 13′ in depth; 9 lbs. of dynamite were used in each hole in about equal proportions of 40, 60, and 75%.

Lineal feet drilled	7426
Depth of holes	8′ 4″
Number of holes	890
Spacing of holes	6×4′
Cubic yards loosened	$\frac{6\times4\times7426}{27}=6600$
Total dynamite at 9 lbs. per hole:	8010 lbs., or 40% 2670 lbs., 60% 2670 lbs., 75% 2670 lbs.
Total nitroglycerin	4670 lbs.
Dynamite per lineal foot	1.08 lbs., nitroglycerin 0.63 lb.
Dynamite per cubic yard blasted	1.21 lbs., nitroglycerin 0.71 lb.
The total dredging (scow measurement)	10,765 cu.yds.
Cubic yards blasted	6600

$$\text{Ratio of } \frac{\text{scow measurement}}{\text{measurement in place}} = 1.63$$

Cost estimated from scow measurement as follows:

Drilling and blasting	\$0.64
Dredging	0.427

Taking the above ratio of scow measurement to measurement in place, the costs per cubic yard in place are as follows:

Drilling and blasting	\$1.042
Dredging	0.695

Ratio of lineal feet drilled to cubic yards in place being 1.124, the cost of drilling and blasting per lineal foot, is \$0.92.

Ship Channel of the St. Lawrence River through the Galops Rapids.[1] **Gilbert Bros. Engineering Co., Montreal, Contractors.** The work consisted of the removal of a very hard limestone bed rock by the submarine drilling and blasting process to form a channel 17′ deep and 200′ wide. The contract price was \$8.40 per cubic yard. The limestone occurred in heavy strata from 20 to 30″ in depth. The length of the channel was 3300′ and the aggregate length of shoals worked over was 1800′. The boundary between Canada and the United States runs through, and in the direction of, this channel.

These rapids commence about seven miles below Prescott, Ont., and extend downstream 1½ miles. They are caused by

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[1] Data from Mr. Gilbert H. Gilbert.

a ledge of limestone 7800′ in width that extends the width of the river at this point. The current varies from 8 to 12 miles per hour, and the water is broken and turbulent, with large breakers, eddies, and strong cross currents.

The drilling plant consisted of one drill boat designed to meet the conditions. It carried four 5″ drills and was fitted with four 20×20″ power-controlled spuds with gear and drums for handling five 1¼″ breasting chains. One of these chains led upstream and two over either side, each having anchors attached weighing from 15 to 20 cwt. apiece.

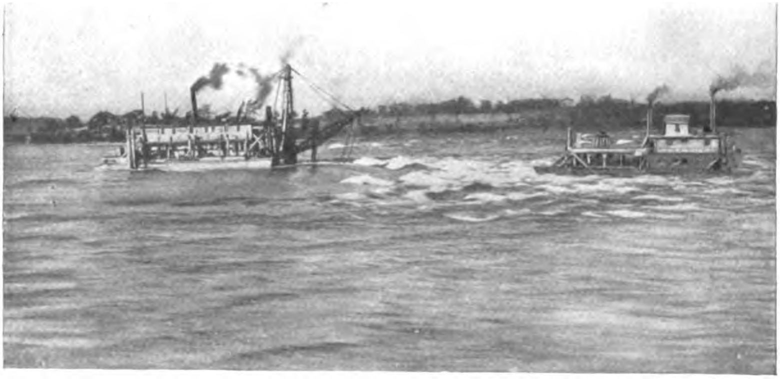

Fig. 125.—Galops Rapids, St. Lawrence River. Gilbert Bros. Engineering Co., Contractors.

Forward of amidships in the hull of the boat were four slots or wells 18′ long, by 18″ wide, by the depth of the boat. The drilling was done through these wells. The drill frames carrying steel drill spuds with pipe guides for the drill bars were capable of being moved the length of the wells, thus permitting a number of holes to be drilled by each drill without shifting the position of the vessel. It was found that the work could be effected much more expeditiously by keeping the boat steady and in a fixed position.

To maintain the drill boat in the fixed position essential to the operation of the drills, to adapt the spud and breasting gear to the rapid maneuvring of the vessel in shifting position and avoiding the large timber rafts shooting the rapids, and to obtain competent workmen who would risk the evident dangers of the situation, were some of the preliminary difficulties to be overcome. Owing to the mechanical and other modifications that were found to be necessary to better adapt the plant to the conditions, the first season's operations resulted in the accomplishment of but little work.

Because of the unusual and difficult circumstances under which the drilling was carried on, the cost of operation was greatly increased. Holes were drilled and blasted in batches of four. Loading and blasting, shifting the vessel for blasting and setting up consumed a large portion of the time. As the depth of water in a rapid will not increase to the same extent as that to which the bed of the stream is lowered, and as the slope or inclination of grade had to be provided for, much time otherwise available for drilling was used up in placing and setting up the vessel with the necessary accuracy. To insure this precision of position of the drill boat, instrument men were posted ashore at ranges or targets to indicate the exact position required. Depth of holes in each position was obtained and recorded by an engineer aboard and accuracy in records and drill boat position was maintained throughout the work.

Wire cables were tried as breasting lines, but it was found that the force of the current caused the wires to become foul of the rocks. In shifting position it frequently occurred that the cables became disentangled from the rock, causing a sudden slacking of the cable. This permitted the vessel to sheer, either breaking the cable or endangering the vessel. In the event of the vessel getting crossways of the current with the cables holding, the inevitable result would have been to capsize the vessel or break the cables. The breasting gear was so arranged, in case of the vessel sheering dangerously, that all side cables or chains were let go and allowed to run free. To obviate fouling on the bottom and to do away with the shock when wire cables became taut, a 1¼″ chain weighing 84 lbs. per fathom, tested to 44 tons breaking strain, was substituted for the wire. The chain, while more cumbersome to handle owing to its greater weight, was less subject to the effect of the current, and was less severe on the breasting gear, the weight of the bight permitting an amount of spring or elasticity.

The general rule observed in drilling and blasting this rock was to drill below grade to a depth equal to half the distance the holes were apart. (Never spaced more than 6′ centers.) The weight of dynamite was equivalent to 1 lb. of nitroglycerin per cubic yard of rock, measuring from the bottom of the hole. This rule produced the most satisfactory results, any points that may have been found above grade in dredging could invariably be accounted for by reference to the record, a bad shot or missfire usually being indicated.

COST OF OPERATING DRILL BOAT—(LOCAL WAGES)

Labor (12 hrs. per day)		
One captain $100, and board $12	$112.00	
Four drillers, $75, and board $12	348.00	
Four drillers' helpers, $30 and board $12	168.00	
One fireman $30, and board $12	42.00	
One machinist $65, and board $12	77.00	
One smith $70, and board $12	82.00	
One smith's helper $30, and board $12	42.00	
One blaster, $60 and board $12	72.00	
One blaster's helper $35, and board $12	47.00	
One cook $30, and board $12	42.00	
16		$1032.00
Coal, 60 tons per month, $4.00	240.00	
Oil and waste	40.00	
Smith's coal	15.00	
Steel, iron, and smith's supplies	52.00	
		347.00
Labor, fuel, etc., per month		$1379.00
Cost per drill hour	$1.105	

The average depth drilled per hour per drill was 2.25′.
The cost per foot of drilling was 49.1 cts.
The depth of cutting was from nothing to 11′.
The average cut was 6.5′.

The holes were spaced to average 20 sq.ft. per foot of drilling.

The drills averaged 1.66 cu.yds. per hour.

One and one-third pounds of 75% dynamite were used per cubic yard.

The cost of operating for the entire work, drilling, dredging, maintenance, etc., was divided in the following proportion:

Salaries and board	42.4%
Traveling and transportation	2.0
Fuel	12.2
Explosives	13.0
General repair and freight	16.4
Towing	5.0
Interest and insurance	6.6
Miscellaneous includes indemnity for accidents, law, rental, and other minor expenses	2.4
	100.0%

The total cost of drilling, blasting, and dredging the channel was $277,724.81.

The total revenue was	$629,113.60
Cost per cubic yard	3.71

Allowance was made for quantities excavated below the grade line specified, it being impossible under the circumstances to carry on the work with the same accuracy as in calm water.

This work is believed to have had the greatest natural difficulties of any large submarine project brought to a successful conclusion.

CHAPTER XIV

SUBAQUEOUS DRILLING—*Continued*

Improving James River, Va. P. Sanford, Inc., Jersey City, Contractors.[1] This work was for the removal of shoals in the James River to obtain a channel 18′ in depth. Operations were carried on in tidal waters of 6′ rise and fall. The drilling plant consisted of one boat, 45×32′, carrying one 5½″ Ingersoll submarine drill, mounted on a wooden spud and having the Sanford Ross type of frame and feed.

Holes were spaced 5½×6′ and drilled with 3¼″ bits. The average depth to grade was 0.75′, and average depth below grade was 3.75′. All material excavated was paid for at $4.45 per yard. Cost of operation of boat, including labor, fuel, and stores only, $2.35 per hour.

Work was carried on over the three following places, Rockett's Reef, Goode Rocks, and Richmond Bar. The drill performance on each with deductions therefrom is as follows:

LOCAL WAGES

	Rockett's Reef.	Goode Rocks.	Richmond Bar.
Hours worked	829	702	1,643
Number of holes	1,232	964	2,381
Depth of holes, ft.	4.66	4.42	4.42
Area of shoals, sq.ft.	52,660	46,925	105,228
Lineal feet drilled	5,741	4,461	10,524
Cubic yards rock	4,470	3,470	8,200
Dynamite, 60%	13,544 lbs., Gly. 8126 lbs.	11,147 lbs., Gly. 6688 lbs.	26,023 lbs., Gly. 15,613 lbs.
Operating per hour	$2.35	$2.35	$2.35
Lineal feet per hour (1 drill)	6.92	6.36	6.40
Operating per foot drilled, cts.	34	37.2	36.7
Cubic yards per hour (1 drill)	5.39	4.94	4.99
Cubic yards per foot drilled	0.78	0.78	0.78
Operating per cubic yard rock, cts.	43.6	47.5	47.1
Dynamite per foot drilled	2.36 lbs., Gly. 1.41 lbs.	2.50 lbs., Gly. 1.50 lbs.	2.47 lbs., Gly. 1.48 lbs.
Dynamite per cubic yard rock	3.05 lbs., Gly. 1.83 lbs.	3.21 lbs., Gly. 1.92 lbs.	3.18 lbs., Gly. 1.91 lbs.

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[1] Data from Mr. Gilbert H. Gilbert.

Cienfugos Harbor, Cuba. W. T. Dady Co., Brooklyn, Contractors.[1] The work was to excavate a channel 25′ deep through a coral formation. The tide here had a rise and fall of 20″; drilling and blasting were done by the submarine process.

For this purpose a drill boat was employed 80×34×6′, mounting two 5″ submarine drills on the stern. The Standard steel frame, with hydraulic feed, of the Great Lakes type, was used. The main spuds, four in number, were operated by independent engines through gears and racking bolted to the spuds. In this coral material the bits drilled about 600′ without dressing. These bits were 38′ long of 1¾″ material with a 3″ point. In drilling 100′, the bit points wore ⅛″ from gauge. No blacksmiths were carried; instead, two extra drill runners were on hand and they took care of the steel. This scheme was to provide against delay by having extra drill runners on hand. Skilled labor was imported, the contractor paying transportation both ways. Board was also provided.

Dynamite was used, 60%, four sticks at 3 lbs., 2×16″, or 12 lbs. per hole. Holes were 10′ in depth, spaced 5×6′, and drilled 2′ below grade. A dipper dredge with 16×20″ engines and a 4½-yd. bucket averaged 50 yds. bank measurement per hour.

In 12 hrs. the two drills averaged 40 holes at 10′. Counting 26 working days per month this is equivalent to a performance of 1040 holes at 10′ or 10,400 lin.ft. = 9250 cu.yds. pay.

The following costs per lineal foot drilled and per cubic yard pay rock loosened have been based on the above average monthly performance.

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[1] Data from Mr. Gilbert H. Gilbert.

Material, coral formation. Two drill-boats. Performance, holes 1040, average, 10,400 lin.ft. per mo. = 9250 cu.yds. pay rock.

Force.	Rate (Local).	Amount.	Per Lineal Foot. Cents.	Cost per Pay Yard. Cents.
1 captain............ at	$150 and board $15	$165.00	1.59	1.78
4 drill runners........ at	4.50 and board 15	528.00	5.08	5.70
2 helpers............. at	90.00 and board 15	210.00	2.02	2.27
1 blaster............. at	90.00 and board 15	105.00	1.01	1.13
1 helper............. at	60.00 and board 15	75.00	0.72	0.81
2 deckhands.......... at	45.00 and board 15	120.00	1.15	1.30
Eng. and mechanic.... at	140.00 and board 15	155.00	1.49	1.68
Watchman........... at	45.00 and board 15	60.00	0.58	0.65
Total labor................................		$1418.00	13.64	15.32
Coal and supplies at 37.5 cts. per drill hr..........		234.00	2.25	2.53
Total drilling...............................		$1652.00	15.89	17.85
Dynamite 12,480 lbs., 60%, at 12 cts............		1497.60	14.40	16.18
Fuses 13,000 at 3 cts...........................		390.00	3.75	4.21
Total drilling and blasting....................		$3539.60	34.04	38.24
Interest and depreciation on plant valued at $15,000 at 2% per working month..................		300.00	2.88	3.24
Total................................		$3839.60	36.92	41.48

In the above tabulation of costs no account has been taken of contractor's overhead charges, organization or preparatory, insurance, charities, accidents, legal, medical expenses, etc.

The following is a general summary of the performance data with deductions therefrom:

Number of drills, 2.
Type of drill, 5″ submarine.
Length of shift, 12 hrs.
Number of shifts per day, 1.
Shifts worked, 26.
Hours worked, 312.
Number of holes, 1040.
Depth of holes, 10′.
Lineal feet drilled, 10,400.
Spacing of holes, 5×6′.

Cubic yards of pay rock, 9250.

Dynamite, 60%, 12,480 lbs. = 7488 lbs. glycerine.

Coal and supplies (1 month), $234.

Labor per shift, $54.50.

Lineal feet per shift, 400.

Lineal feet per drill hour, 16⅔.

Lineal feet per man hour, 2.56.

Labor per foot drilled, 13.64 cts.

Cubic yards pay rock per shift, 355.

Cubic yards pay rock per drill hour, 14.78.

Cubic yards pay rock per lineal foot drilled, 0.889.

Labor per cubic yard pay rock, 15.32 cts.

Coal and supplies per drill per shift, $4.50.

Coal and supplies per foot drilled, in cents, 2.25.

Dynamite, 60%, per foot drilled, 1.2 lbs. = 0.72 lb. glycerine.

Dynamite, per cubic yard pay rock, 1.35 lbs. = 0.81 lb. glycerine.

Dynamite per cubic yard blasted, 1.08 lbs. = 0.65 lb. glycerine.

Cost of drilling and loading (but exclusive of dynamite, fuses, interest, and depreciation) per lineal foot, 15.89 cts.

Total cost per cubic yard pay rock, 38.24 cts., exclusive of interest and depreciation.

Interest and depreciation per cubic yard pay rock, 3.24 cts.

Total cost per cubic yard pay rock, 41.48 cts.

$$\text{Ratio } \frac{\text{cubic yards blasted}}{\text{pay yards}} = 1.25.$$

New York, New Haven & Hartford R. R. Improvements at Oak Point, New York City, East River. Atlantic Coast Contracting Co., Contractors.[1] The work consisted of drilling in the East River at Oak Point and at 137th Street, New York City. The rock formation is gneiss, quartz, mica schist, and granite, grading into one another. The schistose rock has a dip of from above the horizontal to vertical. The extreme hardness of

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[1] Data from Mr. Gilbert H. Gilbert.

the quartz formation, the easily disintegrated portions of mica and the dip, form a set of conditions, all of which may be met in drilling one hole. The variation of hardness with the inclination of strata causes the drill bars to run off the vertical, making drilling very difficult. The position of the work is exposed to the wash of passing vessels and the swell from Long Island Sound. The rise and fall of tide is from 5 to 7′. The drilling plant con-

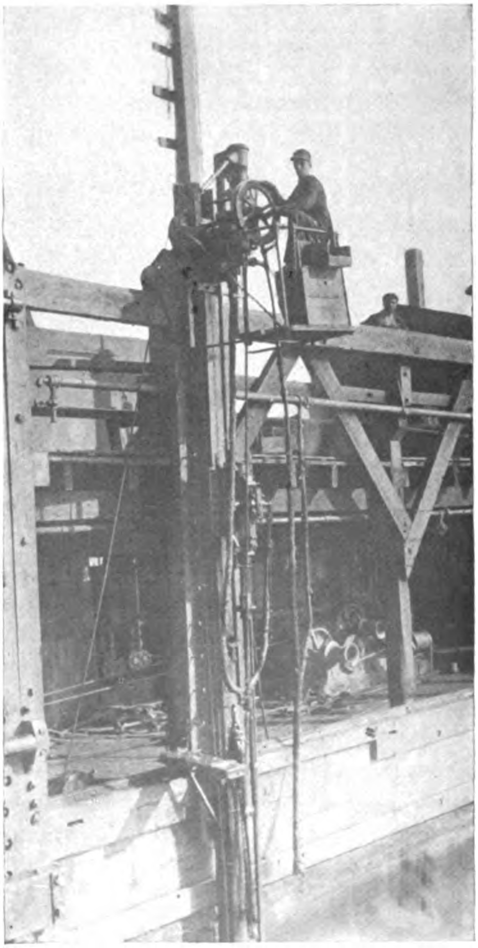

FIG. 126.—Submarine Drill, East River.

sists of one drill boat, carrying four 5½″ Ingersoll-Rand drills, type H-9.

The drill boat is designed to permit the operation of the drills in any state of tide or seaway. The mechanism is so arranged that the vessel is self-adjusting to any variation of level, due to high waves or tide, without interrupting or affecting the operation of the drills. The hull of the drill boat is of wood, 95×28×8′; at each corner there is a 15×15″ spud operated by 6×6″ engines geared to racking bolted to the spud. The vessel is maneuvered by means of wire cables attached to two double-drum hoisters with 7×9″ engines. The drills are mounted on structural steel spuds which rest upon the rock during operation; these spuds are hoisted by a cable connected with 6×8″ engines. The drill spuds are housed in guides overhanging the side of the vessel. These guides, 20′ in length, are suspended from a track 15′ above deck and are capable of being traversed 70′ fore and aft. The drill feed is a screw 12′ long, 2″ outside diameter;

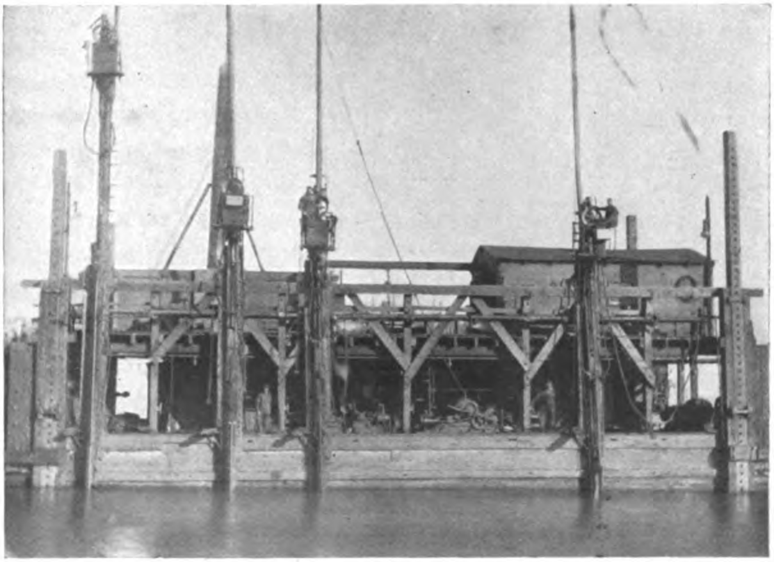

FIG. 127.—Atlantic Coast Contracting Co., Oak Point, East River above Hell Gate.

this feed screw is controlled by a vertical engine, 5⅞″ diameter by 4″ stroke, acting through miter gears.

Wages of the crew per month as follows:

LOCAL WAGES.

Shifts per day	2
Length of shift	10 hrs.
Crew	14 day, 11 night
Two captains, $175 and $125 =	$300 = 14.45% and 13.9%
Four drillers at $3.50	$728
Four drillers' helpers at $2.00	416
One fireman at $3.00	156
Two engineers, at $125	250
One smith at $3.50	91
One smith's helper at $2.50	65
One machinist at $4.00	104
Monthly total	$2110

Labor		$1.01½ per drill hr.
Coal at $470		0.22½ per drill hr.
Smith's coal,	$22	
Oil and waste,	20	
Steel and bits,	70	
Cordage,	12	
	$124	$0.06 per drill hr.
Operating total		$1.30 per drill hr.

Lineal feet per drill hour	2.25
Cost per lineal foot drilled, cts	58½
Holes	3½″ dia.
Spacing	4×4′
Drilling below grade	3′
Drilling above grade	4′ average

Dynamite, 60%, cartridges 2½×16″ at 3½ lbs. at 15½ cts. per lb.

Average dynamite per cubic yard above grade, 6 lbs. = 3.6 lbs. glycerin

Average feet of drilling per cubic yard above grade = 3′

Cost per cubic yard drilled and blasted	$2.70
Dredging sublet	1.25
Total cost per cubic yard	$3.95

Total yards = 30,000

Lovejoy's Narrows, Improving Kennebec River, Me. Eastern Dredging Co., Boston, Contractors.[1] The work consists of the removal of slate and flint covering an area of 65,000 sq.yds., to a depth of 18′ at low water. The average cutting over four shoals is 1¼′ to grade. The quantity to be removed to grade is 2994 cu.yds. The tops of ledges have been removed under previous contracts. At this point and through to the narrows, the channel is very crooked and narrow and navigation dangerous. A tide of 5′ rise and fall, together with the stipulation that navigation must not be obstructed, add to the difficulties of the work. The contract calls for the completion of the job in 14 months, December 1 to May 1 not included, and also for the contractor to furnish security for the proper performance of the work to the amount of 33% of the cost of the work. Monthly progress estimates of 90% are paid.

The drilling plant consists of one drill boat, Sanford Ross type, mounting two Ingersoll-Rand drills on the stern. The vessel is held in position while working by the two spuds upon which the drills are mounted and by bow and side lines. These spuds are fixed, and do not permit of any variation in the distance the drills are apart.

The average performance is 40′ per day of 10 hrs., or 8 holes of 5′. The spacing of the holes being 5×4′ and depth to grade being 1¼′, the performance per day of 10 hrs. in cubic yards of pay rock is $\frac{5\times4\times1\frac{1}{4}\times8}{27}=7.42$. 20 lbs. of 60% dynamite or 12 lbs. of glycerine are used at each hole.

In the following synopsis of costs no account has been taken of contractor's overhead charges, organization or preparatory, repairs, accidents, charities, insurance, medical, legal expenses, etc.

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[1] Data from Mr. Gilbert H. Gilbert.

LOCAL WAGES

Material, slate and flint. Number of drills, 2. Lineal feet drilled in 10 hrs., 40. Pay yards loosened in 10 hours, 7.42.

Force.	Rate per Hour.	Amount.	Cost per Shift.	Per Lineal Foot, Cents.	Cost per Cu. Yard, Cents.
1 captain and blaster	$0.50	$5.00	$5.00	12.5	67.4
2 drillers	0.27½	5.50			
2 drillers' helpers	0.22	4.40			
			$9.90	24.7	133.4
1 smith	0.35	3.50			
1 smith's helper	0.22	2.20			
			5.70	14.3	76.8
1 watchman 12 hrs	0.20	2.40	2.40	6.0	32.4
1 cook	0.25	2.50	2.50	6.3	33.7
Labor drilling			$25.50	63.8	343.7
Coal, 3 tons at $3.50		10.50	10.50	26.2	141.5
Smith's coal, oil, waste, steel, cord, etc.		2.20	2.20	5.5	29.6
Total drilling			$38.20	95.5	514.8
Dynamite, 160 lbs. at 15 cts			24.00	60.0	323.5
Exploders, 10 at 3 cts			0.30	0.7	4.0
Total drilling and blasting			$62.50	156.2	842.3
Interest and depreciation at 2% per working month on plant estimated at $10,000			7.70	19.3	103.7
Total			$70.20	175.5	946.0

Labor per day, 10 hrs, dollars	25.50
Lineal feet per drill hr	2
Lineal feet per man hr	0.445
Labor per foot drilled, cts	63.8
Cubic yards pay rock per drill hr	0.37
Cubic yards pay rock per lineal feet drilled	0.185
Labor per cubic yard pay rock	$3.44
Coal per drill per day, lbs	3000
Coal per foot drilled, lbs	150
Dynamite, 60%, per foot drilled,	4 lbs. = 2.4 glycerine
Dynamite per cubic yard pay rock,	21.6 lbs. = 12.96 glycerine
Dynamite per cubic yard blasted,	5.4 lbs. = 3.24 lbs. glycerine
Ratio $\frac{\text{cubic yards blasted}}{\text{cubic yards pay}}=4$	
Cost of drilling and loading but exclusive of dynamite, exploders, interest and depreciation	$0.955
Total cost per cubic yard exclusive of interest and depreciation	$8.423
Total cost per cubic yards including interest and depreciation	$9.460

CHAPTER XV

SUBAQUEOUS DRILLING BY THE PLATFORM METHOD

Submarine Drilling. The platform method, for use in rough water or where there is much rise and fall in tide, was devised and developed by Mr. W. L. Saunders.

This method has been successfully used in overcoming the more formidable obstacles to the removal of submerged reefs.

These obstacles are (1) sand, mud, or gravel overlying the rock; (2) swift currents; (3) rise and fall of tides; (4) rough water and high winds; (5) danger of collision with passing vessels.

The plant consists of a floatable platform provided with spuds by which it is elevated above the surface of the water. Tripod drills are mounted upon **A** frames or platforms to facilitate moving about the platform. Cylindrical telescopic tubes with a conical taper are fitted with an ejector attachment; these tubes rest on the rock, the upper end being above the surface and guided by trunk ways attached to the platform. Drilling, washing, and charging are performed through these tubes. The boiler, smith's shop, pumps, and diving apparatus are carried by a barge or scow moored to the platform and by anchors.

In the operations, preliminary to drilling, the telescopic tube is lowered to a bearing upon the bottom. Through the action of the hydraulic ejector, fitted to the lower end of the tube, the loose material overlying the surface of the rock is removed from the inside of the tube, permitting the tube to sink and rest upon the cleaned surface of the rock. The drill bar is then lowered into the tube and connected to the drill placed over the mouth of the tube. The conical form of the lower end of the tube guides the steel and prevents "stepping." The progress of drilling is very materially improved by the introduction of a 1¼″ pipe, carrying water, under pressure, into the drill hole and alongside the steel while the drill is in operation; a jet of water is forced to the bottom of the hole, removing the cuttings. It is no exaggeration to state that the removal of the Hell Gate rock, had this method instead of undermining been used, would have been accomplished in one-quarter of the time and at one-third of the cost.

The following is a report of the operations on Black Tom reef, New York harbor, where the platform method was used. Operations were commenced May 2, 1881:

Actual working days	344
Lineal feet of hole drilled	17,658
Number of holes drilled	1,736
Number of holes blasted	1,542
Average depth of holes	10.17′
Average distance between holes	4′
Area drilled over	32,100 sq.ft.
Rock removed	5,136 cu.yds.
Dynamite used	20,461 lbs.
Exploders used	1,844
Number of drilling machines used	3
Number of steels used (octagon $1\frac{1}{12}$″)	18
Longest steel used	28′
Shortest steel used	16′
Largest diameter of bit	3¾″
Smallest diameter of bit	2½″
Average depth drilled to each dressing of steel	9′
Average loss of gauge per ft. drilled, ins.	0.03
Total loss of steel by abrasion and dressing 59½′	394.5 lbs.
Greatest number of lineal feet drilled in one day	169
Expenditure for coal, 200.2 tons	$823.03
Expenditure for water	$500.55
Expenditure for hose	$491.18
Connecting wire, 77¼ lbs.	$52.08
Rubber tape for connections, 7 rolls	$12.25
Expenditure of steel for each lineal foot drilled 0.36 oz.	$0.0032
Explosive used per foot drilled, 1.16 lbs.	$0.53
Rock removed per foot drilled	0.29 cu.yds.
Cost per lineal foot drilled, labor	$0.52
Cost of coal and water, per lineal foot drilled	$0.075
Cost of repairs to plant per lineal foot drilled	$0.089
Cost of repairs of drills per lineal foot drilled	$0.0053
Cost of repairs of ejector pipes per lineal ft. drilled	$0.015
Cost of hose per lineal foot drilled	$0.028
Cost of wire and tape per lineal foot drilled	$0.004
Average total cost per lineal foot drilled	$1.27
Average cost per hole charged	13.82
Average depth of hole drilled to each cubic yard of rock removed	3.44 lin.ft.

Average cost of explosive per cubic yard removed, 3.98 lbs	$1.84
Expenditures in steel per cubic yard removed, 1.22 oz	$0.018
Cost of labor per cubic yard removed	$1.79
Total cost per cubic yard, drilled and blasted	$4.37

Cost of plant, including alterations and additions:

Barge No. 4, hull and equipment		$6,640.00
Drill float No. 1		4,095.70
Drill float No. 2		4,987.40
Storeroom account, including repairs, alterations, coal and water, cost of machinery, etc.		5,663.49
		$21,386.59
Expenditure in labor	$9,203.88	
Expenditure in explosives	9,461.00	18,664.88
		$40,051.47
Cost per cubic yard of total expenditure		$7.79

Operating Expenses.

Labor	$9,203.88
Explosives	9,461.00
Actual repairs to plant	1,575.57
Repair to Ingersoll drills	93.31
Steam and water hose	491.18
Repairs to ejector pipes	267.54
Wire and tape used	64.33
Coal and water	1,323.58
Operating expense	$22,480.39
Cost per cubic yard	4.37
Pay roll per day	$26.76
Coal per day, 0.58 ton	2.39
Water per day	1.45
Explosive per day 59.48 lbs	27.50
Daily repairs to plant	4.58
Drill repairs per day	0.27
Loss of steel per day, 1.15 lbs	0.16
Repairs on ejector pipes per day	0.78
Loss in hose per day	1.43
Loss in wire per day	0.15
Loss in tape per day	0.03
Average cost per day	$65.50
Average cubic yards per day	14.93
Average cost per cubic yard	4.37

Many items in this report, notably the cost of plant, are very much higher than need be. The prices given include all the experimental work done prior to the introduction of the improved methods of operation.

The rock was situated in New York Bay, near Bedloe's Island. It was of granite formation, ranging in texture from soft muddy pyrites to a hard mixture of hornblende and quartz. The surface was covered by a deposit of mud, sand, and gravel, which at first interfered with the progress of the work to such an extent that but little headway was effected. After the use of the ejector pipes no further difficulty from this source was experienced.

CHAPTER XVI

HINTS AND SUGGESTIONS FOR ROCK DRILLING AND BLASTING

Hints in Drilling and Blasting Work. Cultivate the habit of learning new methods from published accounts and then do not wait to see them used, but apply them yourself, even if you have to devise some details which were not described. The man who avails himself of published data becomes a centenarian in experience before he is thirty years old.

Foremen are generally men of some considerable force of character, and they are instinctively opposed to "new-fangled ideas"; consequently their opposition to improvements reflecting, as they think, upon their own perfection, is long and bitter.

One of Gilbreth's rules: No superintendent, walking-boss, engineer, timekeeper, or other employee is permitted to give an order direct to any workman, except in case of great emergency. Not even a member of the firm is exempt from this rule. The foreman in direct charge of a gang is the only man permitted to instruct his men what to do. He is the officer in charge, and his superior officers must not intentionally or unintentionally degrade him in the eyes of his men by issuing orders over his head.

The timekeeper must not gossip on the work. It is a sure cause of dissatisfaction. The men should know as little of the politics of the work as possible. Dissensions at headquarters are bound to affect the men and their work. If unity is lacking in high places it will also be lacking lower down.

Do not let the executive do any avoidable detailed work.

It may be economical to pay higher wages than the prevailing rate. This attracts the best class of labor. Men will do 10% more work for 5% more pay.

A cut of 10% in wages may mean a reduction of 20% in output.

To avoid demoralization, pay must be paid promptly on regular pay day. No matter how sure the men may be of their pay, failure to meet them on pay day affects their work badly.

Gilbreth requires all monthly men or steady pay men to arrive on the job before the first whistle is sounded and remain on the job until quitting time, regardless of weather.

All sources of dissatisfaction should be immediately and impartially investigated, and the men must know that although they are responsible for the quantity and quality of their work to the immediate foreman they are absolutely in touch with the management as far as justice to the men is concerned.

Object lessons are necessary in order to convince workmen of the desirability of changes, and it requires great ingenuity in preparing the right kind of object lessons.

Each foreman should keep a small diary in which to jot down the principal events of the day. Such a diary may be of great value in case of a lawsuit. How to make the foreman keep the diary written up is another story.

In order to get the most work out of a man for his money it is necessary to offer him a stronger incentive to do his best than the mere fear of discharge for incompetency.

Cultivate the habit of instinctively thinking of and looking at work in terms not of quantity and time, but of time and dollars.

An economic rule in choosing the drilling equipment and tools is to use the minimum diameter of hole in which the drill will freely work when the holes can be sprung, and as large as can be conveniently drilled when the holes cannot be sprung, except where the rock must be broken out in blocks with a minimum of waste.

The economic result of springing holes lies in the fact that the holes can be placed much further apart, of a smaller diameter and a low and cheap grade of powder used.

In tunneling through soft rock the objection to springing is that it produces fumes from the dynamite, which otherwise would not be used. To prevent this a good way is to spray the air with water after each shot if the water is available.

Under normal conditions water-washout jets will increase the output from 30 to 100%.

Plot the location of all drill holes on cross-section paper and write thereon the depth of each hole and the powder charge in it.

In drilling open-cut work it is wise to pitch the holes down away from the face. The explosion will then throw the rock away from the face and tend to avoid throwing loose rock over the unblasted portion.

Quarry bars are very economical for drilling in open cuts and for plug drilling.

Where long transmission pipes are used, air is more economical than steam.

A steam line can be lagged 600′ or 700′ with economy.

Air hose lasts longer than steam hose.

Poor coal supply causes serious delay and loss of money.

Cheap blacksmith's coal containing much sulphur is an expensive luxury, the reason being that some of the carbon will be burned out of the drill steel, thus reducing its effective hardness.

Locate a forge away from sunshine or you are apt to burn the steel without knowing it. A white sparking heat usually means a spoiled tool.

Keep parts of all machines together in storage, so that they can be found easily.

If a 500-volt current is used to explode caps there will be many misfires.

In blasting, use a 3-wire connection with a 3-wire machine, thus developing its full power.

Where $1\frac{1}{4}''$ sticks of dynamite are used, the drill hole should be $1\frac{7}{16}''$ at the bottom.

In dynamite water has a greater affinity for the *guhr* than nitroglycerin has, therefore in wet holes the nitroglycerin will slowly leave the cartridge if it be not reasonably water-proof. Not so, however, with nitrogelatin.

One of the most satisfactory rules in blasting is to avoid so loading the holes as to throw much rock into the air. If a dense brown smoke with pieces of rock be thrown high in the air with each blast, the holes are too heavily loaded or the bulk of the charge is not low enough in the hole.

Do not mistake activity for work.

There should be the same sizes of tools for men competing, for example: A man who is paid for his performance on the 3¼″ drill should not be obliged to compete with another man paid on the same basis who is running a 3⅛″ drill.

When drilling in sandstone the drill-bit should be tapered somewhat and then flattened instead of drawn to a cutting edge. If a chisel-bit is used in drilling sandstone, the bit will wear very sharp, and will frequently become fissured.

In forging rock-drill bits, those for medium hard rock should have sharp chisel-bits. As the hardness of the rock increases, the angle of the bit may be made more blunt, and the cutting edge shaped from a straight line to a curve, to prevent the corners being chipped off.

An unsymmetrical bit, in which the blades do not all strike exactly alike, is preferable to the symmetrical kind, especially in hard rocks, resulting in less sticking.

When the drill bit has become stuck run a powerful water jet through a half-inch pipe down to the bottom of the hole and work up and down. This is very effective in loosening up the bit, and will also enable a new bit to descend promptly to the bottom of the hole.

If the bit is inclined to stick, churn up and down in the hole with a thin strip of hickory while drill is working.

A handful of pieces of cast iron the size of hazel-nuts dropped into the hole, especially if the material varies much in hardness, will often prevent the bit from sticking.

At a 45-ton blast in Manila the fumes killed several men.

Ammonia should be inhaled where men are overcome by dynamite fumes.

Blowing unexploded dynamite out of a hole with a steam jet—Don't! Use air instead.

Never use a nail-puller to open a box of dynamite.

Dynamite in a wooden box containing no metallic nails can be burned up without exploding, but any nail or metal is likely to so conduct the heat as to explode the dynamite.

If a cap is pointed at a stick of dynamite an inch away it will explode, if pointed to one side it will not explode.

In springing for black-powder work, it is important not to load the hole until after the rock has cooled off, as the springing charge develops considerable heat.

When fuse is used in cold weather it becomes hard and stiff, very often cracking and causing a misfire. Fuse should be thawed before using.

Dynamite, when frozen, can be exploded by extra strong caps.

Caps of different makes should never be used in the same charge.

There should be no air cushions in the blast hole. To accomplish this slit the cartridges with a knife lengthwise on two sides, being sure not to do this to a frozen or partly frozen stick, and place it well home with a wooden rammer.

When mucking or drilling takes place and badly shatters or pulverizes the rock and the holes are close together, short pieces of drain tile can be erected over each hole to prevent small pieces of rock from falling into the holes until after the hole has been charged. These can be used repeatedly.

For blasting out old piles and stumps average 30–40% dynamite is very effective.

Four pounds of dynamite exploded 5′ beneath the surface will break ice 2′ thick to a distance of 30 or 40′ around the shot.

Instead of digging holes in which to plant trees, it is cheaper to churn a drill hole in the ground and charge with about one-half stick of 40% dynamite.

The usual size of a case of dynamite is ¾ of a cubic foot, therefore an old powder box is often more convenient for measuring coal than a bushel basket.

For gaskets on pumps, the thinner the better.

Upon laying up rock drills, hoists, etc., cover the bright surface with a mixture of paraffin and vaselin heated and applied with a brush. The mixture is readily rubbed off.

Look out for air in water pipe at top of a grade. Provide a blow-off cock.

In cold weather at night drain all water and oil from cylinders and lubricators of engines and pumps. The common lard oils are full of acid and will cut machinery.

Cylinders of engines and steam drills are frequently cracked in cold weather by suddenly letting in steam. To avoid this open drip cocks and cocks on steam chest and blow in steam for a few minutes to warm up the cylinder before starting the machine. A broken cylinder may delay work for a day.

Hints for Estimators. Look out for misleading "costs."

The achievement of high wages for the workman and low labor cost for the owner is what can be obtained by proper economizing methods, accurate costkeeping, and timekeeping.

Do not let precedent govern unless it is wise precedent, and see that when it does govern, the preceding conditions are representative of the present ones.

A plant should be designed to do the work in say 20% less than the contract limit, making allowance for bad weather, delays in delivery and installation and delays due to breakdowns.

In 22 days 86 channeler bits were used to channel 3779 sq.ft. in shale containing frequent "nigger heads." This is at the rate of 43.94 sq.ft. per bit.

Test pits in shale are uncertain and will generally show more earth and less rock than they should.

A letter from a contractor in *Engineering News*, October 23, 1902, p. 337, says the contractor, by making borings costing about $100, found earth where everyone expected rock, bid accordingly, and made $30,000.

In bank blasting with black powder the general rule is, one pound of black powder will break 2–3 yds. of gravel.

In figuring on rock bear in mind that a contractor will have to take off more rock than is paid for unless he is going to a great deal of expensive "sand-papering," and therefore his measurement when he gets to the edges of his excavation or to the bottom of it will usually be more than the amount of the engineer's monthly estimate.

Channeling is advantageous for quarrying large dimension stone except granite. Broach channeling is cheaper for granite.

The weight per cubic foot (zinc ore) is dependent upon the percentage of mineral as well as upon the percentage of powder used in breaking the ore.

In one experience the range in weight of dirt which has very nearly the same mineral content may be between 92 and 108 lbs. per cubic foot; in this case the variation was due entirely to a change from 30 to 40% dynamite.

It is often cheaper to use a high grade of dynamite rather than to increase the diameter of the hole so as to secure a big charge of low-grade dynamite.

Acknowledgment should be made of the excellent work in gathering the data contained in this volume by Messrs. W. T. Ball, A. C. Haskell, Chas. Houston and H. C. Lyons, and the marked courtesy rendered us by all the contractors to whom we applied for information.

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