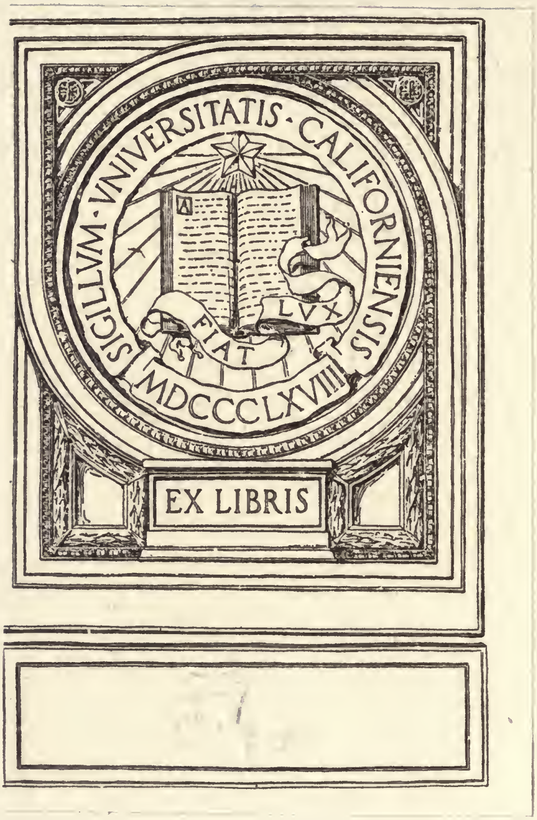
Rock Excavating
and
Blasting

By J. J. Cosgrove



ROCK EXCAVATING AND BLASTING

By

J. J. COSGROVE

* * *

Author of

"PRINCIPLES AND PRACTICE OF PLUMBING"
"SEWAGE PURIFICATION AND DISPOSAL"
"HISTORY OF SANITATION"
"WROUGHT PIPE DRAINAGE SYSTEMS"
"PLUMBING ESTIMATES AND CONTRACTS"
"DESIGN OF THE TURKISH BATH"
"SANITARY REFRIGERATION AND ICE-MAKING"
"SANITATION AND HYGIENE"

* * *

Published by
National Fire Proofing Company
Pittsburgh, U. S. A.

PREFACE

THIS work was called forth by a real and urgent demand for a book that would help the young engineer, the superintendent, the rockman and miner to understand the mysteries of explosives; how to handle them; and how to get the best results in the various kinds of rock excavating.

It is a well-known fact that schools of engineering teach the design of engineering works, but not their construction. A few strokes of the pen show how a tunnel is to be driven through a mountain, but there is nothing shown on the drawings or taught in school, that will point out how the work is to be accomplished. This part is left for the contracting engineer to work out for himself, and the young engineer in charge of the work, if he has had no previous experience, must pick it up as he goes along from the rockmen in charge of the blasting.

As most of the graduates of engineering colleges follow the contruction branch of their calling, and in the course of their work are soon put in charge of rock excavating, either open-cut work, tunnel driving or shaft-sinking, this work will be found invaluable to them as well as in the class room, and in the hands of anyone interested in quarrying or blasting rocks or other hard materials.

It is believed that by following the text a person wholly unfamiliar with blasting and explosives could intelligently superintend rock excavating or do it himself. Text and illustrations show how to drill bore holes to get different results; how to charge the bore holes; how to drive a tunnel; how to sink a shaft; blasting in quarry-work and open-cut excavating; care, handling and storage of explosives; and the tools and machines required in rock excavating.

A copy of this book should be found on the shelves of every library. It will also be found invaluable at mines and quarries, in the class room of engineering colleges, and in the offices of engineers, architects and contractors.

J. J. COSGROVE.

Philadelphia, Pa., September, 1913.

PUBLISHERS' NOTE

THIS is an age of vocational training. The old system of apprenticeship having passed away left a lack of skilled workers without which no nation can be truly prosperous. Schools and colleges have been established to supply this lack of technical training, but schools and colleges can help only those who come to their doors, thirsting for knowledge.

The great host of workers, however, the very backbone of the industrial Commonwealth, are left to shift for themselves, and carve out of the hard rocks of experience their own futures and fortunes. Such a system injures not only the worker, but the employer and State as well; and within recent years large industrial concerns have turned their attention toward providing vocational training for all those interested in their calling.

Railroads not only have traveling instructors and courses of study for the trainmen, but some of them have schools for apprentices in their shops; and most of the railroads do not stop at that, but reach out to help the farmers, manufacturers and tradesmen along their lines to produce bigger crops, increase their output, and in every way improve their methods and make greater profit.

Manufacturers of type-setting machines maintain free schools to teach the care and operation of their machines. Manufacturers of plumbing and heating goods have textbooks and free publications of an educational nature prepared, to help and instruct those connected with their calling; and all along the line is found the same awakening to the importance, the duty, and the benefit of a like course.

In keeping with the spirit of the times, we, as the pioneer manufacturers of fire-proofing materials for buildings, and the largest manufacturers in the world of NATCO hollow tile building blocks, have accepted the responsibility thus imposed upon us, to do our share towards furnishing reliable and readily-available information regarding all phases of building construction. In carrying out this undertaking our monthly magazine, BUILDING PROGRESS, was started, and the work, "Rock Excavating and Blasting," first appeared in its pages as a serial article. The value of the information contained in the series prompted us to put it out in more enduring form, suitable for ready reference; and this we do just as it left the author's hands, without one word of advertising anywhere in the book.

NATIONAL FIRE-PROOFING COMPANY,
Pittsburgh, Pa.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

⁂

ROCK EXCAVATING AND BLASTING

PART I.

DRILL HOLES

CHAPTER I.

FORCE AND DIRECTION OF A BLAST.

Direction of a Blast.—There is a popular belief that different explosives behave differently when fired, some expending their forces downwards, others sidewise, while still others have a lifting, or upheaving, direction. Nothing, however, could be further from the truth. All explosions of blasting agents of whatever composition follow the line of least resistance, although more or less execution is done along the line of greatest resistance. For example, if a heavy charge of an explosive be fired close to a stone slab standing on edge along the side of the charge, the slab would be shattered. It would likewise be shattered if it were below the charge or above it at the time of firing. While the direction of a blast cannot be changed, different effects can be produced by the use of different explosives, or by varying the charge, as will be explained later.

The form of cavity produced when a single charge of explosives is fired in a vertical drill hole is shown in Fig. 1. Following the line of least resistance, the blast would produce a cone-shaped cavity, the size of the cavity depending upon the strength and size of the charge. If the strength of the explosive or the size of charge were not sufficient to dislodge a large amount of rock, still the cone shape would be adhered to, only the cone in that case would be smaller, for instance, that shown by the dotted lines. In case too small a charge or too weak an explosive were used, a blowout would occur, carrying with it a small cone-shaped fragment from near the mouth of the drill hole. In that case the blast would act just as a charge of powder in a gun—it would simply blow out the tamping.

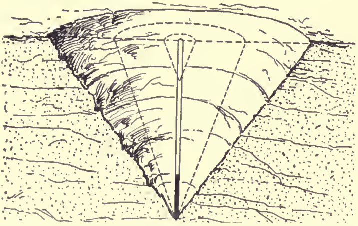


Fig. 1.
Hole Made by "Grip" Shot.

Inclination of Drill Holes.—A vertical position is the worst position in which a drill hole can be made for a key-hole or cut-out blast, for the reason that there is only one free face for the force of the blast to break, as the downward and side pressures are opposed by solid rock. Action and reaction being equal but opposite, it follows that in a cavity made by firing a charge of explosive in a vertical drill hole, the resultant of all the forces would be along the line of the drill hole, or from the apex of the cone to the center of the base, which would represent the line of least resistance. That being true, a better method is to drill the hole at an angle as shown in Fig. 2. This brings the drill hole away from the line of least resistance and gives an enlarged free face for the explosive to act upon, with the result that there is less danger of a "blow out," and greater amount of rock will be dislodged.

The limiting inclination of the drill hole is 45 degrees with the free face. With a hole of less inclination less rock will be broken and the amount will grow less as the hole approaches the free face, until, if discharged at the surface, the result would be practically zero.

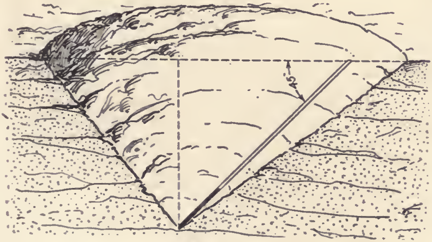


Fig. 2.
Inclination of Drill Hole for "Grip" Shot.

This inclination of a drill hole is important to keep in mind, for it is the starting point for all plane surfaces. In the starting of an excavation for a cellar, for instance, beginning at the center a grip shot of this description could be fired; then with this cavity to work from the drills could be started radiating in all directions, using the surface for one free face, and the cavity for another, and inclining the drill in whatever direction necessary to get the best result.

FREE FACES IN BLASTING.—The more free faces exposed in the rock to be removed the more easily can it be blasted. This is particularly important where the rock taken out is to be used for building purposes, for it can be taken out without shattering it to the same extent that would follow blasting with only one free face. Further, the cost is kept down considerably by the greater ease of quarrying from rock having two or more free surfaces.

The effect of a blast in rock having two free faces is shown in Fig. 3. If the charge were placed where shown in the illustration and the top were the only free face exposed the blast would remove the rock from a cone indicated by the triangle *a b c*. If, on the other hand, the top were solid rock and the side face free the cone removed by the blast would be represented by the triangle *a b d*. In this case, however, both the top and side faces are free, and the rock removed by the blast may be indicated by the dotted lines which almost parallel the solid line *c b d*. It will be noticed that, with two faces exposed, the blast will remove practically twice the quantity of rock that would be displaced with only one face free—that is, it will if the charge is of the right size and located equally distant from both faces, so that the bounding surface of the two craters that would be formed by different blasts in single face explosions will be along the line *a b*. If the charge were located as shown in Fig. 4 at unequal distances from the faces of rock, the charge acting on each face separately would break the cones *a b c* and *d b e*, respectively, the wedge-shaped piece indicated by shaded lines not

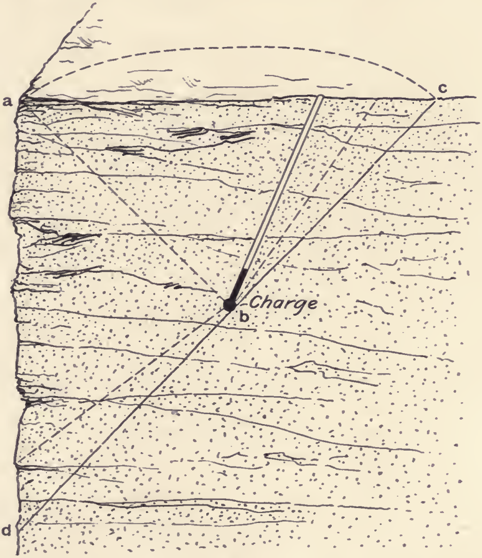


Fig. 3.
Effect of Blast in Rock Having Two Free Faces.

being included in either. When the two faces are exposed, however, part of the force of the blast is used to break down the rock in this wedge-shaped piece, and the crater actually broken out is that bounded by the dotted lines *f b g*.

It will be observed that in figuring the rock removed by a charge the cone-shaped crater formed by a single drill-hole blast is used as a base, and from this the amount of rock that can be broken down by a single shot is calculated or, rather, judged. The greater the number of free faces the greater the amount of rock that can be broken down by a single shot, or, in other words, a smaller charge can be used to break down a

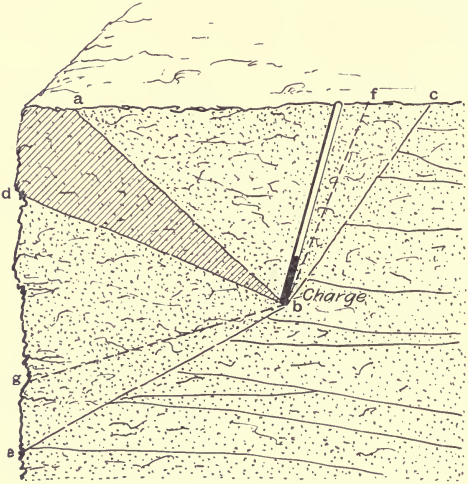


Fig. 4.
Effect when Charge is Unequal Distance from Two Free Faces.

certain amount of material when there are two or more faces exposed than when there is only one free face; but the amount of rock loosened will not be proportional to the number of free faces.

In drilling for a blast, where two or more free faces are exposed, it may be taken as a rule that the longest line of resistance, or the distance back from any one of the free faces, should not be greater than one and a half times the shortest line, or line of least resistance, if the maximum effect of the explosion is to be obtained. Further, it is better, if possible, to so place the charge that the shortest line, or line of least resistance, will be horizontal and the longest line vertical, so that the weight of rock loosened by the blast will help break down the mass.

TERMS USED IN BLASTING.—The terms, or names, used in quarry work and blasting can be readily understood by a reference to Fig. 5, which shows a bench, or open ledge, of rock having two free faces, one the top surface and the other the front face. It will be noticed that the new face of the bench of rock is some distance back of the bore hole, a certain amount of rock being loosened from that place at each blast. The "burden of rock" is the mass loosened or broken down by the charge, while the line of least resistance in this case is the shortest distance from the center of the charge of explosive to a free face.

In open-cut work the best and most economical plan is to break the rock into regular benches. This rule holds true whether quarrying for the stone itself or simply breaking out the rock to remove it. When broken into regular benches the condition of the rock can be carefully observed, the subsequent bore holes can be more intelligently placed and the machine drills can be more easily set up and handled.

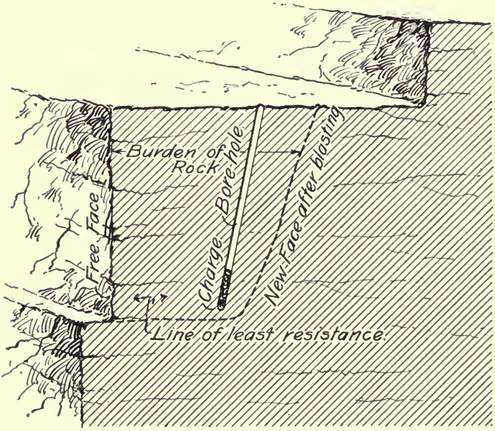


Fig. 5.
Showing Terms Used in Blasting.

In Fig. 6 can be seen regular bench work in a quarry, with men at work with "Plug" drills, cutting plug and feather holes for splitting out the blocks. The smooth deck space on the several benches show clearly how much easier this rock would be to work upon than a space of similar size broken into irregular surfaces.

Fig. 6.
Regular Bench Work in a Quarry. At Work with Drills.

DIAMETER AND DEPTH OF DRILL HOLES.—There is an intimate relation between the diameter and depth of a drill hole used in blasting. The drill hole should not be filled more than half full of the explosive, while as a general rule the charge should be about twelve times as long as the diameter of the bore hole at the bottom. For instance, a bore hole 2 inches in diameter at the bottom would have a charge of about 24 inches in length. The diameter of the bore hole should likewise be proportioned to the line of least resistance, for if a drill hole of small diameter be carried down too deep in the rock, or too far from the free face, the charge will fail to break down the mass and a blow-out shot will result. Ordinarily a hole sufficiently large can be made by using a larger drill than the ordinary when the drill hole is to be extended to unusual depths. This increased diameter of the hole, which by doubling the diameter quadruples the charge it will accommodate, will suffice for ordinary blasting operation. Sometimes, however, in quarry work, preparing sites for buildings, in side cuts of earthwork, railroad and other engineering works, drill holes twenty feet or more—sometimes as much as sixty feet—in depth are made and hollowed out at the bottom to form a chamber or pocket, into which several kegs of powder or other explosive are introduced to charge for the breaking-down blast. This form of drill hole is shown in Fig. 7. The chamber is made by first drilling a hole to the required depth, then exploding a stick of dynamite at the bottom of the drill hole, *with little or no tamping.*

This operation can be repeated *with increased charges* until a chamber of the right size is obtained. A caution that must be observed, however, in this method of working, is never to put the powder or dynamite in the chamber until the rock has cooled to its normal temperature. Any attempt to charge the hole immediately after a chambering or squibbing blast might lead to a disastrous explosion.

In large operations, like the blowing up of Hell Gate, New York, a chamber is excavated in the rock at the required point, or place, and a tunnel constructed leading into the chamber, so it can be charged with kegs and bags of powder or other explosives, ready for the blast. In ordinary building and engineering construction, however, the drill hole, or drill hole and chamber, are about all that will be necessary in the way of a pocket to hold the charge.

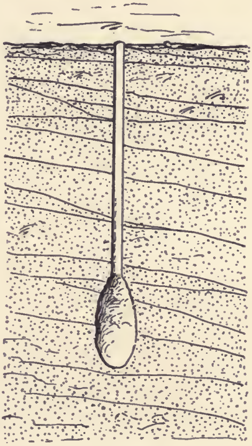


Fig. 7.
A "Chambered" Drill Hole.

Experience shows that drill holes having diameters varying from three-quarters of an inch to 1½ inches are the best for hard rock, if charged with the strongest high explosives. For soft rock, on the other hand, charges of weaker explosives are best, and they should be in drill holes 1½ to 2½ inches in diameter.

The depth of drill holes will generally vary with the character of the rock. As low as 4 feet and as high as 12 feet are not extremes, while depths of from 5 to 7 feet would probably be considered the average in built-up districts where great care must be exercised.

The line of least resistance may be proportioned to the size and diameter of the bore hole, according to Table I.

TABLE I.

Size of Drill Holes.

Diameter of Drill Hole	1¼ inches	1½ inches	1¾ inches
Line of least resistance	3½ feet	4 feet	5 feet
Depth of drill hole	3½ feet	4 feet	5 feet
Line of least resistance	3¾ feet	5 feet	6 feet
Depth of drill hole	5¾ feet	7½ feet	9 feet
Line of least resistance	5 feet	6 feet	7 feet
Depth of drill hole	10 feet	12 feet	14 feet

According to this table shallow bore holes are made of a depth equal to the line of least resistance; medium depth drill holes are one and one-half times the length of the line of least resistance; while for deep holes, 10 feet or more, the line of least resistance is only half of the depth. In open-cut work in outlying districts, however, the practice is generally followed of drilling the holes one and one-half times the length of the line of least resistance. For instance, in work on the Chicago Drainage Canal the holes were drilled 12 feet deep and back 8 feet from the face of the bench.

EFFECT OF MULTIPLE BLASTS.—A greater mass of rock can be dislodged by firing two or more blasts simultaneously than would be broken down by firing the same shots independently. This greater effectiveness of the multiple blasts can be seen by referring to Fig. 8. If the blasts *a* and *b* were touched off separately, they would break out, approximately, the amount of material shown by the triangles in which they are situated, leaving the inverted triangular mass of rock *c* intact; while if these two charges were exploded simultaneously, they would blow out not only the two triangular masses of rock, as when exploded

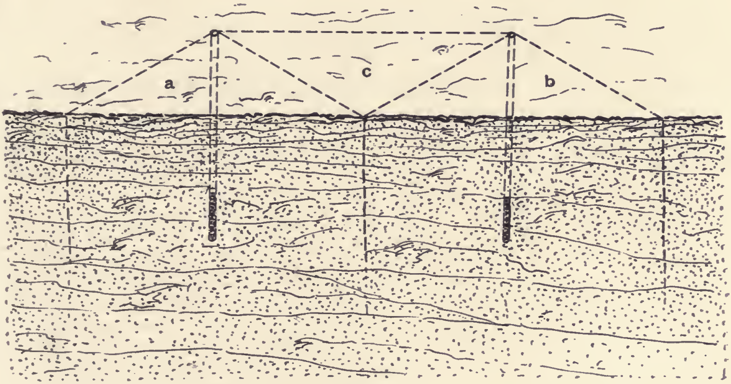


Fig. 8.
Effect of Multiple Blasts.

separately, but they would dislodge the mass of rock represented by *c* as well.

In order to get the maximum results in the case of multiple blasts, the drill holes must be approximately right, or right if possible. In the case represented by Fig. 8 the distance between the drill holes *a* and *b* should not be more than twice the distance they are back from the face of the rock. Naturally the distance would have to be varied to suit the character of the rock, being less in soft than in hard materials. In average strong rock the holes would be spaced from one and one-half to two times the distance back from the free face; for moderately strong rock from one to one and one-half times, and for weak rock the distance apart should not exceed the line of least resistance. Unfortunately, there is no middle ground between theory and practice in the formulation of rules as to the form of cavity and amount of material dislodged by a shot or multiplicity of shots; consequently, the quantities given can only be approximate, and used comparatively as a guide. Experience, which comes only with time, is the only safe guide. An experienced quarryman or miner will study the character of the rock, so as to take advantage of slip, cleavage and dip of the rock, and be able to place his holes at such angles as to get the maximum effects and avoid blow-out shots.

In working on hard rock, it is well, when possible, to get hard-rock quarrymen or workmen who have had experience on hard rock; while for soft rock, workmen with experience on soft rock are to be preferred. However, the superintendent must often work with the labor available, and it is then his knowledge of rock excavating will be invaluable.

The effect of multiple blasts is still further shown in Fig. 9. In this example three holes are drilled close together, and each charged with a shot that if fired separately would not break down the wall of rock between it and the free vertical face. By firing three charges together, however, all that mass of rock bounded by the lines will be displaced. This method of blasting will be found useful in many cases, and by means of it greater masses of rock can be removed with smaller drill holes than would be possible were it not for the combined effect of the several charges. To secure the effect of a multiple blast

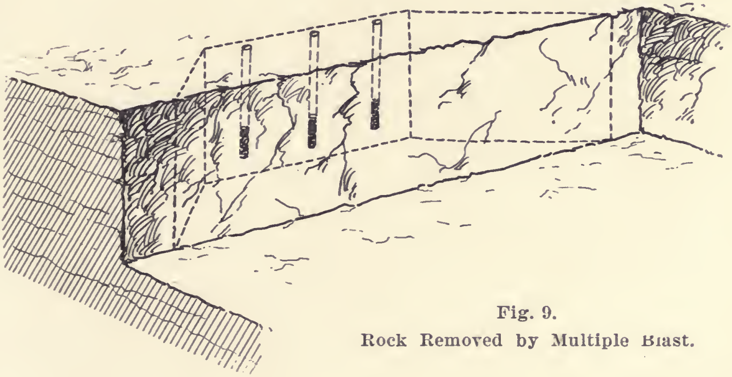


Fig. 9.
Rock Removed by Multiple Blast.

however, the charges must all be fired simultaneously, not one after the other in close succession. When explosions follow one another, even with but a fraction of a second between blasts, the effect is lost, for the blow of an explosion is almost instantaneous. After the first shock the rock becomes shattered sufficiently to reduce the pressure, and with shots following one another, the force of one blast is liable to be spent before another comes into action. Electric firing of blasts is the only way in which the charges can be exploded simultaneously. No matter how experienced and careful a rock-man may be, he cannot time fuses so the charges will all fire together. Differences of a little in length; slower or quicker burning of some of the fuses, or delay of some of the fuses in taking fire will all contribute more or less to the scattering of shots.

CHAPTER II.

SINKING SHAFTS THROUGH ROCK.

DRILL HOLES IN SHAFT SINKING.—There is considerable latitude allowed the quarryman in the placing of drill holes for shaft sinking and tunnel driving, but whatever their arrangement, they all are based on the principle that there is but one free face in that class of work, and to get the best results two faces must be exposed. In order to get two free faces, *key holes*, or *cut holes*, are drilled and fired in order to blow out a portion of the rock, and the workmen then arrange the drill holes to take advantage of this cavity. It is not necessary to actually drill and blast those cut holes first, for the effect of the blast being known, the key holes can be drilled at the time all the other holes are drilled, then they can be fired first to make a second free face for the other blasts.

The location of drill holes for shaft sinking and tunnel driving is practically the same. The key holes may be arranged in a circular form to take out a cone of rock, and the drill holes arranged in concentric circles outside of this cone, or the key holes may be arranged in straight lines to take out a wedge-shaped core of rock. One method of arranging drill holes for shaft sinking through a white limestone is shown in Fig. 10. The approximate dimensions are given on this illustration as a guide to the judgment in arranging drill holes and spacing them in similar work. The rows of drill holes are numbered 1, 2, 3 and 4 for convenience in reference. The depth of the cut was 6 feet, and the dimensions of the shaft

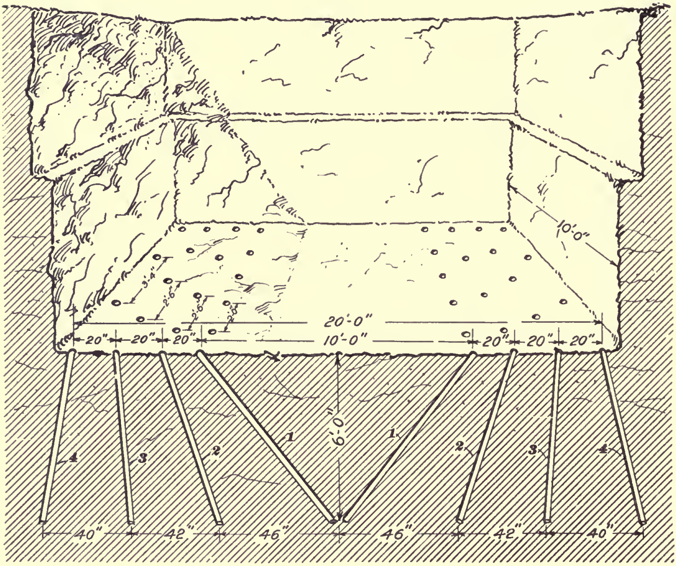


Fig. 10.
Arrangement of Drill Holes in Shaft Sinking.

20 by 20 feet, one-half only of which is shown. In sinking a shaft of this kind, the holes would all be drilled in one shift. The rows of holes 2, 3 and 4 would then be protected so they would not fill with dirt; the double rows of holes 1-1 be charged with the explosives, and the charges fired simultaneously. This would cut or blow out its wedge-shaped mass of rock bounded by the lines of drill holes at the sides and the free face on the top. The removal of this wedge of rock exposes two free faces on each side of the cavity, and the double row of holes 2-2 would then be charged and fired. After the rock from this blast had been cleared away the double rows of holes 3-3 would in like manner be charged and fired, and after clearing out the rock dislodged by the blast the squaring-up rows of holes 4-4 would be fired.

After the first level of the shaft has been blasted and the rock removed, the experience gained ought to show whether a different arrangement of the drill holes or a heavier or weaker charge of explosive were necessary.

The object is, of course, to remove all the rock necessary, so holes will not have to be hand-drilled for squaring-up purposes, and at the same time to use charges of explosive of only sufficient strength to remove the rock at each blast without shattering the side walls of the shaft or blowing the removed material to atoms.

It will be noticed that the squaring-up drill holes, 4-4, are slanted so as to bring them a little outside of the plumb line of the shaft. This is because the drill operator cannot place his machine close enough to the shaft wall to drill a truly perpendicular hole, and, in order to take

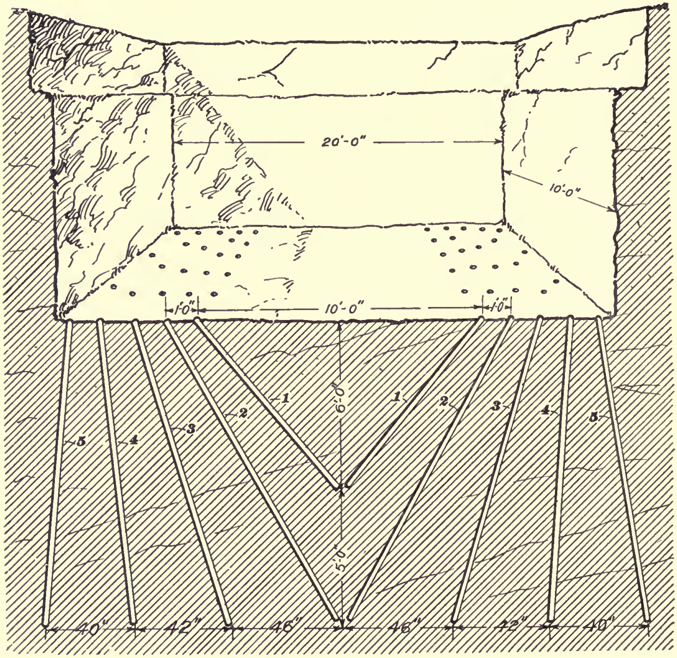


Fig. 11.
Deep Drill Holes for Shaft Sinking.

out enough rock so as not to necessitate subsequent cutting and blasting, the drill hole is put in at a slight angle to bring the bottom of the charge of explosive outside of the plumb line of the shaft, or the side line of the tunnel, as the case may be.

In this example the cut is a shallow one, only 6 feet of material being removed for each cycle of operations. In the method shown in Fig. 11, eleven feet of the same material can be removed by one cycle of operations. In working according to this plan of shaft sinking, the primary rows of cut-out holes, 1-1, are drilled as in the preceding case, but reaching to a depth of 6 feet only. Secondary rows of cut-out holes, 2-2, are then drilled, meeting at a depth of 11 feet from the surface, and the ordinary rows of blast holes, 3-3 and 4-4, together with the squaring-up rows of holes, 5-5, are next drilled.

After protecting all the other holes, the double row of cut-out holes, 1-1, are charged, fired and the rock cleared away.

Having two free faces for part of the depth, the double row of secondary cut-out holes, 2-2, are then charged and fired and the rock cleared away.

There are now two free faces for the remaining blasts to operate on, and the rows of drill holes are charged and fired in their consecutive orders, 3-3, 4-4 and 5-5, each battery of charges in the like double rows being fired simultaneously to get the maximum effect of the shots. In shaft sinking there are two operations besides the drilling and blasting which must be considered. As the shaft goes deeper and deeper, more and more water will seep into it, just as it would in a well, and provision must be made to pump out this water as fast as it accumulates. Sometimes, in high places, this is a simple matter, while in other localities in low-lying land pumps must be kept constantly at work to maintain the shaft in working condition.

A hoist must be rigged up, too, with which to remove the rock loosened by blasting. Ordinarily there is but little danger of rock from the walls falling into the shaft on top of the workmen, provided they inspect the walls closely as the shaft is deepened, and see that no loose pieces of stone are left hanging to the walls, to be jarred out of place later on.

* * *

CHAPTER III.

TUNNEL DRIVING.

DRILL HOLES FOR TUNNEL DRIVING IN SOFT ROCK.—In driving tunnels about the same system of drilling would be followed as for shaft sinking. The methods previously explained would be found quite satisfactory for a medium sized tunnel, while that shown in Fig 12 may be successfully followed for small tunnel driving in medium hard rock. It will be noticed in this system of drilling that three drill holes are bored in a circle, or so as to form a triangle, and the other holes are drilled around the edge of the tunnel close to the sides. The center triangle holes are drilled toward a central point about 6 feet below the face of the rock. These three holes form the key holes, or cut holes, which are to be charged and fired first, the other holes then being charged after the rock has been cleared away, and the charges fired simultaneously.

In this illustration, on account of the small size of the tunnel, only one row of holes is drilled outside of the cut holes. In a large tunnel, however, if this method were used, two, three or more rows of holes would be drilled, according to the size of the operation and the quality of the rock.

In one respect, the drill holes for tunnel work differ slightly from the system of drill holes used for shaft sinking. In the case of tunnel driving in soft or shaly materials, the drill holes are not spaced uniformly. This can be easily seen by referring to Fig. 13, which is a diagram showing the location and surface arrangement of drill holes in the tunnel illustrated in Fig. 12. It will be observed that there are more drill holes in the bottom half of the diagram than in the top half. Beginning with the bottom row, there are three

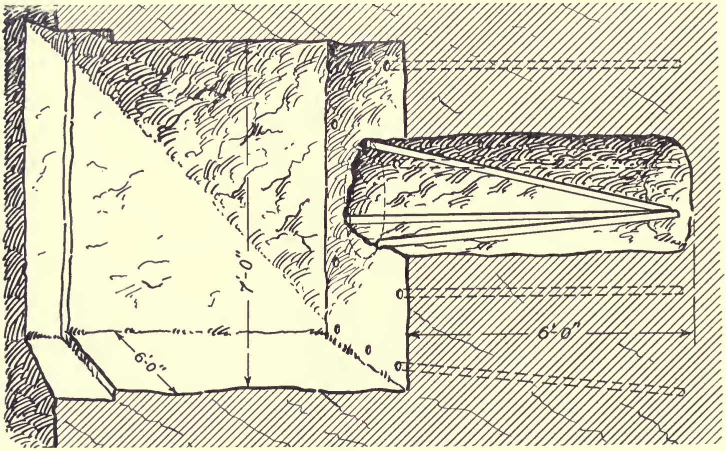


Fig. 12.
Rock Drilling in Small Tunnel. Soft Rock.

holes, as against two holes in the top row; while the second row from the bottom has four holes to three holes in the third row. The reason for this is, gravity helps to bring down the mass of rock from the roof of the tunnel, while the rock from the bottom of the tunnel must be shattered and

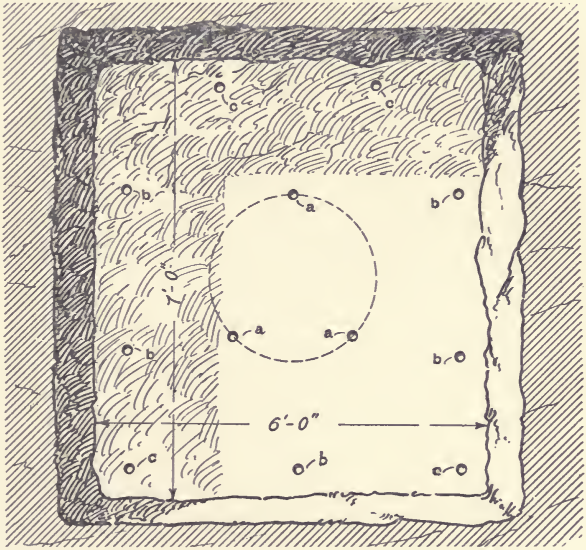


Fig. 13.
Diagram of Drill Holes in Tunnel. Soft Rock.

torn away in spite of the resistance it encounters and the weight of rock above. The moment soft rock or shaly material is shattered along the roof of the tunnel, it falls by its own weight, therefore a greater amount of rock can be torn loose by a blast than if in the bottom of the tunnel, where the shot has not only to rend the rock, but lift it as well.

Further, the roof of the tunnel does not want to be shattered too much by numerous or large blasts, or masses of rock might be loosened and hang suspended without being noticed, until a subsequent jar detaches it and allows it to fall to the floor, endangering the lives of the workmen. For these reasons, it is better to use only enough explosive and as many drill holes in the upper half of the tunnel as will remove the right amount of rock, without subsequent hand drilling.

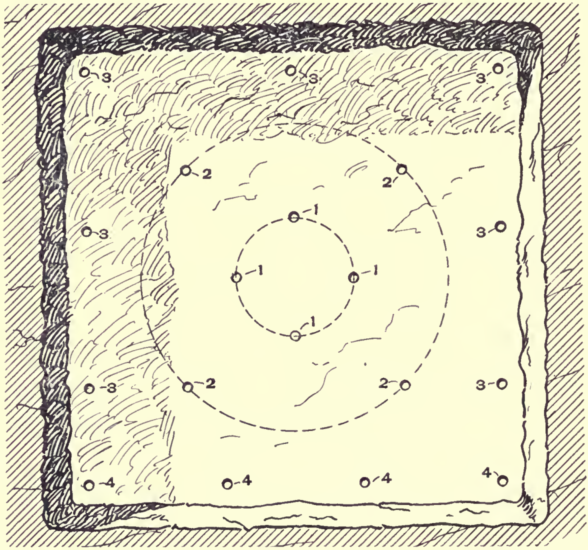


Fig. 14.
Drill Holes for Small Tunnel in Hard Rock.

In blasting, according to this system, the holes *a a a* would first be charged and fired. Next the holes *b b*, and finally the finishing holes *c c*. Some quarrymen fill the holes *b b* and *c c* simultaneously. It is better though to fire holes *b b* first and remove the rock before charging.

In drilling the cut holes, the practice differs among quarrymen. Some rockmen drill the holes so they will not meet, with the view of making a wide end to the cavity broken out by the blast. Other quarrymen, on the other hand, drill the cut-out holes so they meet at a common point. Where drill holes meet in that manner they form an enlarged chamber in which a large quantity of powder can be placed, consequently, a more effective blast can be had than from single drill holes.

DRILL HOLES FOR TUNNELING IN HARD ROCK.—A system of drilling for tunneling through hard rock is shown in Fig. 14. This system does not differ much from the one for soft rock and shaly formations, other than having a greater number of drill holes. In this case there are, first, four cut-out holes, 1-1, to blast out a cone-shaped cavity. Next, there are four enlarging holes, 2-2, for the purpose of enlarging the cavity and giving a larger free surface to work upon. Last comes the row of holes around the sides of the tunnel. The four holes numbered 1 would be charged and fired at one time. After the rock removed by the blast had been cleared away, the holes numbered 2 would be charged and fired. Next, after having cleared away the loose rock, the drill holes numbered 3 along the roof and sides of the tunnel would be charged and fired, and finally the row of drill holes along the floor of the tunnel would be charged and fired. The drill holes 3 and 4 are fired simultaneously by some quarrymen, but better results will be obtained by firing the number 3 holes and follow with the number 4.

The foregoing illustrations of drilling for blasting cannot be accepted as the proper system to use in all cases, but only as fair averages, showing the *principles* of rock excavation. Differences in the hardness of rock, veins of harder or softer material crossing the shaft or tunnel, fissures or faults in the strata would all necessitate changes from the order shown, and the experience of the rockmen must be the guide in such cases. No rules can be given that will be applicable to *every* case, and no illustrations can possibly show the right thing to do every time. At best, the principles are all that can be successfully taught in any line. Experience must improve that knowledge to make it of practical value. For example, in extremely large tunnel work the upper part of the tunnel would be driven as explained in the foregoing paragraphs, and the lower portion worked in benches similar to open-cut or quarry work.

DRILLING NEAR FAULTS OR FISSURES.—A method of drilling rock in a shaft or tunnel where there is a fault, fissure, slip in the rock or a semi-free face of any kind is shown in Fig. 15. The usual cut-holes in the center of the face are omitted, and instead side cuts, or drillings, are made in the heading, in the direction of the slope or fissure. Care must be exercised, however, not to drill through the rock into the fissure or too close to its face, or when the blast is touched off a part or most of its force, depending upon the size and openness of the rock, will be expended without doing any good. In this method of drilling, two holes, 1-1, are the cut-holes. They are not ex-

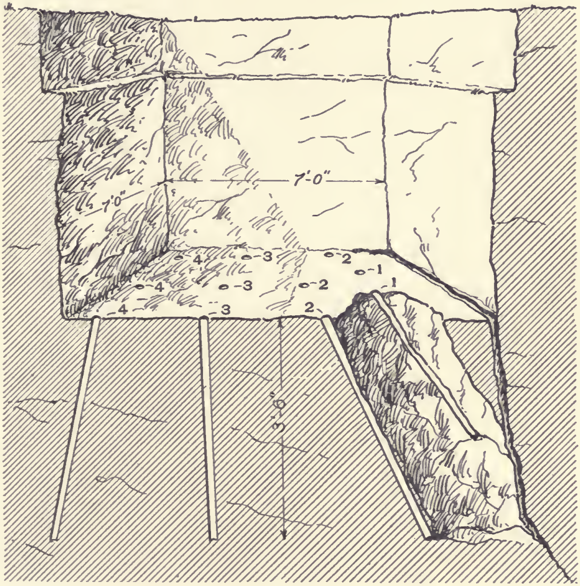


Fig. 15.
Drill Holes Near Fissures or Faults.

tended clear down to the bottom of the cut, but only a sufficient distance to dislodge a large enough wedge of rock to give a large free surface for the subsequent blasts to work upon. The rest of the drill holes are carried the full depth of the cut, which, in this method, would perhaps not exceed 4 feet, at about the angles shown in the illustration. In blasting they would be fired in volleys, according to the way they are numbered.

In the first volley the charges in holes 1-1 would be fired. After the rock had been cleared away, holes 2-2 would be charged, and fired simultaneously. When the rock from that blast had been removed, holes 3-3 would be charged and fired; and, finally, the squaring holes, 4-4, would be loaded and fired.

In some rock formations a thin seam of soft or rotten stone, or soft coal, from 4 inches to 12 inches thick, is encountered. Where such is the case, the soft material can be cut out with a pick, blown out with a small shot or otherwise removed for a distance of 4 to 6 feet, thus forming an undercut which gives a large, free surface and double face to work upon. Under such conditions cut holes can be omitted, and the shot placed in the best position to bring down the greatest amount of material, according to principles previously explained for blasting where two free faces are exposed.

Driving Large Tunnels.—In Fig. 16 is shown the way a large tunnel is driven, the work being

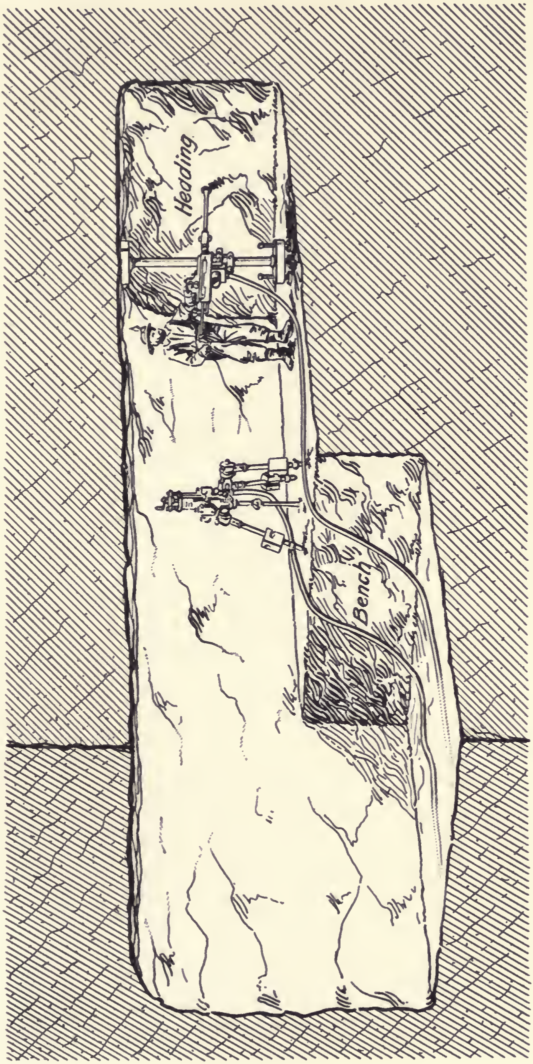


Fig. 16.
Method of Working Large Tunnel.

done in two operations, driving the heading and blasting the bench. The heading is driven by drilling the breast of the rock and blasting it the same as for a small tunnel. Indeed, this part of the operation may be considered as driving a small tunnel. This takes out only part of the material that must be removed, however, and the second operation which is in the nature of enlarging the opening first made, consists of blasting out the bench, a process which is carried on in much the same manner as would be done in open-cut work, only smaller charges of explosive are used.

In order to condense the principle features of tunnel driving into a one-page illustration, the drawing is made out of proportion. In the first place, the heading and bench would not be so close together. In very large operations the heading and bench are so far apart that working on one does not interfere with work on the other. Again, the bench is generally deeper in proportion than the heading, a condition which is reversed in the illustration.

In large tunnel operations, instead of one rockman operating a drill in the heading, two, and sometimes three work simultaneously with power drills mounted on mining columns; and instead of starting operations at one side of a hill or mountain and driving through to the opposite side, the tunnel is started at both ends at the same time, and the workmen meet with the tunnel in the middle of the mound they are driving through.

Back of the bench is the "muck-heap," as the material loosened by the blast is called, and the workmen engaged in removing the "muck" from the working are known as "muckers."

No support or lining is shown in the illustration, as the operations of rock blasting and excavating only are intended to be shown. However, as the heading progresses, props or posts are put up to support the roof of the tunnel, and prevent rock loosened by the blasting from crushing down on the workmen. After the bench is blasted, the tunnel is lined, either with temporary or permanent lining; and when permanently lined, the space between the masonry lining and the rock walls of the tunnel is flushed full of concrete or grout. During the driving of a tunnel, particularly through wet or seamy ground, provision must be made to take care of the seepage which in some cases is considerable. Indeed, in limestone localities, underground streams are often encountered when driving tunnels below the hydraulic gradient.

Between the dangers of falling roof; of premature blasts; accidents to the storage magazine; gas; fumes from the explosives and poor air generally of the underground workings, it requires the most watchful care on the part of those in charge to prevent damage, injury or death to those in their care. As soon as the heading is driven a short distance, the roof should be held up with good stout props. Then, as the bench work follows the heading and props have to be removed to make way for the workmen, the roof back of the bench must be supported until the lining, temporary or permanent, is in place.

The removing of the rock blasted out of the tunnel is no small task, and a clear runway must be maintained for the tracks and the muck cars which take the rock out of the tunnel. In the case of large tunnels driven in mountains or hills, the muck is carted out on dump cars, and deposited in muck heaps at convenient points. In driving tunnels under the streets of cities, however, the disposal of the rock removed sometimes is a problem in itself. Some of it can be disposed of for building purposes, but getting it to the surface and carting it away without interfering too much with the ordinary traffic is one of the problems that must be considered.

PART II.

ROCK-DRILLING TOOLS AND MACHINERY.

CHAPTER IV.

HAND AND AIR DRILLS.

Rock Drill on Tripod.—Hand drilling of rock, with sledge and chisel bar or drill steel, of course everybody is familiar with, but under present-day conditions economy of time and labor will not tolerate that old-time method, which has been supplanted, so far as large operations are concerned, by rock drills operated by power.

The commonest types of power drills, and the ones most extensively used, in general engineering work are the reciprocating, or striking, machines, operated either by steam or by compressed air. A rock drill of this type, mounted on an adjustable tripod is shown in Fig. 17. The legs of the tripod on which this machine is mounted are provided with universal joints, so they can be adjusted to the uneven surface common to all operations, and are weighted with heavy castings to hold the machine firmly in place, and prevent

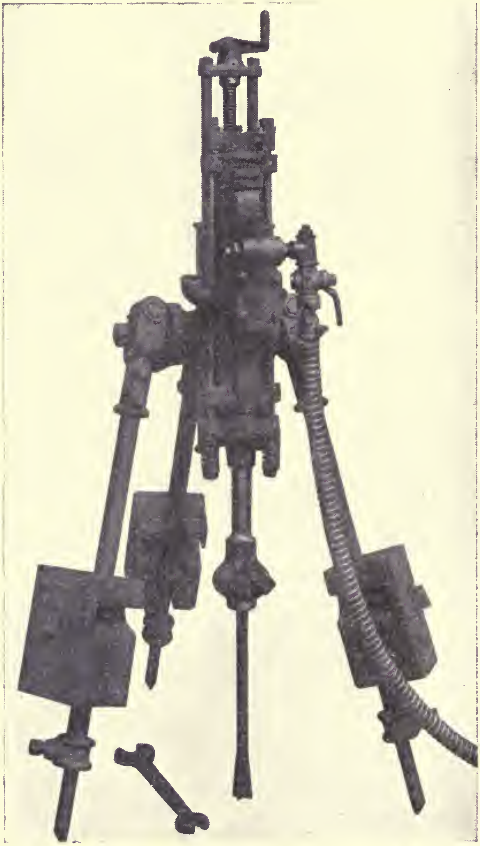


Fig. 17.
Rock Drill on Tripod.

it being raised from the surface every time the drill strikes the rock at the bottom of the hole.

Rock drills are made in various sizes, with lengths of stroke ranging all the way from 4 inches to 8 inches, and that will drill holes of diameters ranging from ⅝-inch up to 6 inches.

Further, a machine of this type will drill holes from 1 inch to 32 feet in depth, while larger machines of similar type have been successfully and economically used to drill holes 50 to 60 feet deep, and ranging in size from 6 inches at the top to 2 inches at the bottom.

In drilling with a power drill only a certain depth of hole can be drilled, depending on the length of feed of the machine, when the feed must be readjusted, a longer drill fitted in the chuck, and the hole extended down as far as the feed will permit, when the operation of readjusting must be repeated until the hole is carried to its final depth. Twelve inches is the length of feed, or depth that can be drilled without changing steels, for the smallest machines, and from that minimum the length of feed is gradually increased in the various sizes until the maximum, 30 inches, is reached.

In holes that are drilled to a considerable depth different sizes of steels are used, the diameter becoming smaller as the holes grow deeper, so there will be no binding of the drill steel in the holes. The length of stroke, length of feed, depth of hole a machine will drill, diameter of hole, number of drill steels required to drill the maximum

TABLE II.

Weights and Specifications of Sullivan Rock Drills (Unmounted).

Letter Indicating Size	UA	US	UB	UC UC11	UD	UE2 UE11	UF2 UF11	UH UH11	UH2	UK	UL
Diameter of cylinder....in.	2	2¼	2½	2¾	3	3⅛	3¼	3⅝	3⅝	4¼	5
Length of stroke........in.	4½	5	5	6⅛	6½	6½	6⅝	7⅝	7¼	8	8
Length of feed (depth drilled without changing steel) ....in.	12	15	20	24	24	24	24	30	24	30	30
Depth of hole machine will drill easily, ft. from 1 to	4	5	6	10	12	14	16	20	20	28	32
Diameter of holes that may be drilled ....in.	⅝ to 1¾	⅞ to 2	1 to 2¼	1¼ to 2½	1¼ to 3	1¼ to 3	1¼ to 3	1½ to 4	1½ to 4	2 to 5	3 to 6
Diameter of drill steel, in.	¾ to ⅞	⅞ to 1	⅞ to 1	1 to 1⅛	1⅛to1¼	1⅛ to 1¼	1⅛ to 1¼	1¼ to 1⅜	1¼to1⅜	1½to1⅝	1⅝to1¾
Number of pieces in set of steel to drill holes to depth above stated	4	4	4	5	6	7	8	8	10	10	13
Diameter of steam inlet, in.	¾	¾	¾	1	1	1	1	1¼	1¼	1¼	1¼
Size of hose to connect to drill ....in.	¾	¾	¾	1	1	1	1	1¼	1¼	1¼	1½
Size of steam pipe to carry steam 100 to 200 feet, in.	¾	1	1	1	1¼	1¼	1¼	1½	1½	1½	1½
Size of boiler to supply steam for one drill, H. P.	5	6	8	8	8	10	10	12	12	15	15
Weight of drill, unmounted..................lbs.	110	145	165	240	265	260	280	390	345	560	900
Shipping weight of drill, boxed ....lbs.	145	180	200	280	310	305	325	475	420	775	1110
Price of drill unmounted ..	$200.00	$220.00	$240.00	$265.00	$300.00	$330.00	$350.00	$430.00	$430.00	$465.00	$500.00
Size of tripod.............	U1 or U2	U2	U3	U3	U3 or U6	U6	U6	U7	U7	U7	U9
Size of mining column or shaft bar	U21	U21	U24	U24	U27	U27	U27	U29	U29	U29	U29

depth, as well as a lot of other information regarding these drills, can be found in Table II.

The drill steel is kept well down in the hole it has formed by means of the feed screw shown at the top in the illustration, and the steam or air supply may be attached either to the right or left side of the machine. In this case it is connected to the right side by means of a flexible tubing wound with wire, and the supply of steam or air is controlled by a stop cock convenient to the operator's hand. In ordering rock drills the order should state whether steam or compressed air is to be used. Drills are always supplied with packings for steam unless air is specified as the motive power.

ROCK DRILL ON QUARRY BAR.—The rock drill on quarry bar is practically the same as the ordinary rock drill, the principal difference being the mounting. For plug and feather work in quarries, channeling or any other kind of drilling where it is necessary to have the holes in a line and parallel with one another, the quarry bar is used. A mounting of this description may be seen in Fig. 18. Once this bar has been properly set up and secured in place, the drill can be moved along from place to place, drilling holes as close together or as wide apart as the operator pleases. Holes can be drilled so close together, in fact, that they form almost a continuous channel, and can be used for channeling by breaking out the core or partition between the holes by means of a special broaching bit. Large blocks of stone can

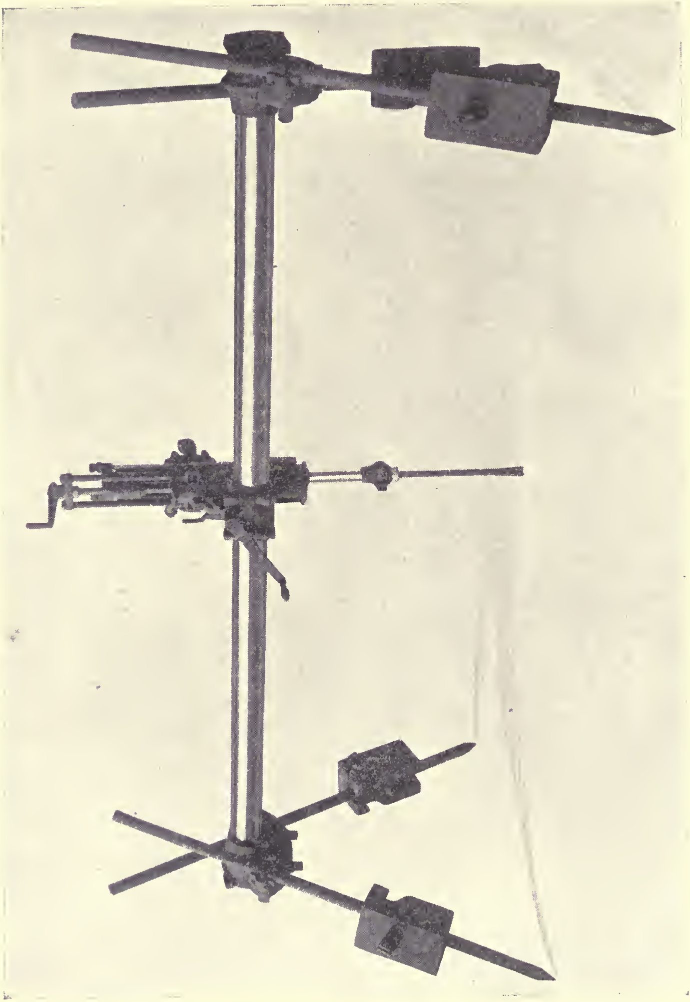


Fig. 18.
Rock Drill on Quarry Bar.

likewise be taken out of the quarry, without breaking or shattering, by the plug and feather method—that is, a series of holes are drilled in a row and a break is made along the line of holes by means of wedges.

Quarry bars of this type are made in lengths of 8, 10 and 12 feet, and the carriage is so constructed that it can be easily and quickly moved along the bar, thus changing the position of the drill without loss of time, as would occur with the tripod mounting. The quarry bar is frequently used for channeling in engineering and architectural works where the nature of the rock prevents the use of channeling machines.

ROCK DRILL ON MINING COLUMN.—Both the drill mounted on the tripod and that on the quarry bar are designed for cutting or drilling holes downward, either vertically or at slight angles from the vertical. In driving tunnels, mining and similar works it is necessary to have a drill that can be pointed in any direction, up or down, or straight overhead. In the mining column shown in Fig. 19 we have such a machine. These columns are made in several lengths, to suit different heights of drifts, and are secured in place by tightening the jack screws at the bottom to jam the top of the column tight against the roof of the tunnel if set upright, or against the side of the working if set on side. The usual length of column is 6 feet, with the jack screws drawn in.

The drill is perfectly adjustable when mounted on one of these columns, as it may be swung tc

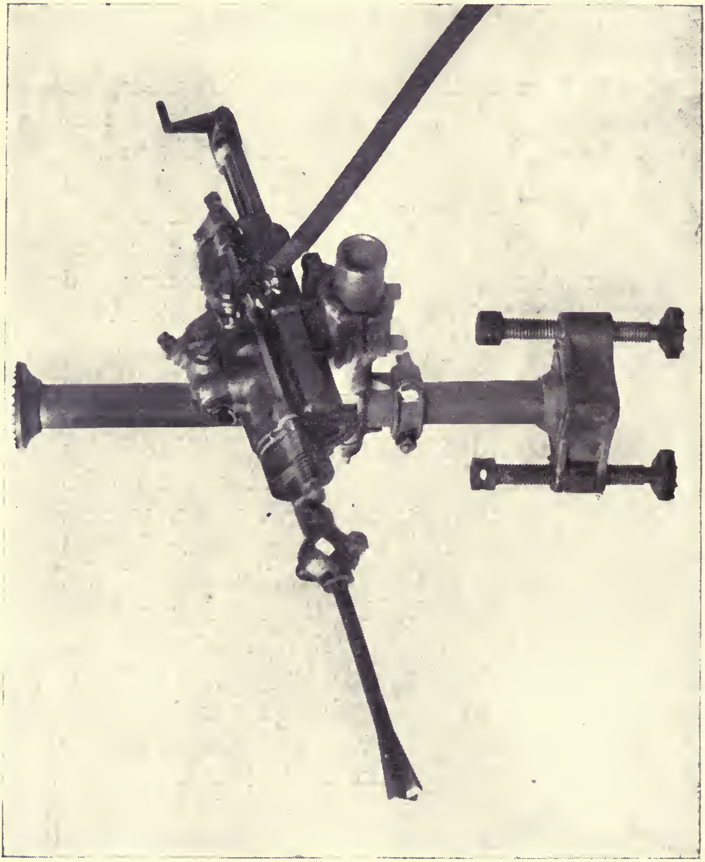


Fig. 19.
Mining Column or Shaft Bar.

drill in any direction. It may also be moved up or down on the column, and as a further adjustment may be revolved in the saddle. In fact, there is no position in which the drill cannot be set up.

In using a column, wood blocking should always be placed at the ends to give an even binding surface.

Rock drills are operated by compressed air for all mine and tunnel work, and air is also replacing steam to a constantly increasing extent for quarrying and other work above ground. The mounting principally employed for the former purposes is the mining column or shaft bar, while tripods, quarry bars, etc., are used on the latter work. The operation of columns is, therefore, described using air, and the operation of tripods with the instructions for running when using steam. Instructions regarding the setting up and operating of steam and compressed-air drills, furnished by the manufacturers from their extensive experience, are given in the following chapter. In operating a rock drill, no matter what its mounting may be, it is necessary to so handle the machine that the drill steel will not bind or stick in the drill hole. There is not so much danger of this in drill holes which point down, for the rotation of the drill steel will keep the hole large enough and in sufficient alignment, particularly when the drill steel is properly made with the right gauge of wings or vanes. As the hole to be drilled varies from the vertical to the overhead angle, however, the liability of the drill steel sticking increases. This is because the dust and chippings fall to the lower side of the drill hole, thereby protecting the lower side, and forcing the drill steel against the upper part of the hole all the time. The result of this is, the hole describes more or less of an arc as the depth increases, and to compensate for this upward movement, the drill must be lowered on its mountings from time to time.

The inclination or tendency of a drill steel to curve the hole upward can be checked to a great extent by keeping the hole free from dust and chippings. In horizontal holes and those with but a slight upward tilt, a wire with hook on end will enable the operator to rake the cuttings out.

CHAPTER V.

OPERATING DRILLING MACHINES.

RUNNING WITH COMPRESSED AIR—SETTING UP AND STARTING.—In setting up a mining column or shaft bar it is well to set the jackscrews on a solid block of hardwood. In drifting always set the jackscrews parallel with the direction of the tunnel. Run the jackscrews back as far as possible, set the column or bar in position, and place blocks or wedges tightly between the top plate and the rock. Draw up on the jackscrews, and as the drill is started keep tightening the screws until the column or bar is secure. In a drift or tunnel the columns should be as long as possible, so that resetting of the column when the bottom holes are reached may be avoided. The mounting being in place, fasten the machine rigidly to it. The connections to the mounting should always be firm and tight, as the slipping of a clamp or saddle will make the drill "fitcher," or stick, frequently causing the loss of a hole. Always blow out the hose before connecting it to the drill. Before starting, the rock should be squared off where the hole is to be put.

Dry Holes.—Start the drill slowly and on a short stroke. In drilling dry holes, or those at a small angle above the horizontal, it should be remembered that such holes have a tendency to turn upward, due to the accumulation of cuttings on the lower side, which tends to raise the drill bit at each stroke. It is well to start the hole a little below the desired angle, and it is often necessary to lower the drill on the column in order to keep the steel from binding in the top of the hole. Care should be taken that the cuttings are continually running out of a dry hole while drilling. If allowed to accumulate in the hole they tend to pack behind the bit, and often cause difficulty and loss of time in getting the steel out, as well as reducing the progress of the drilling. The flow of the cuttings in a flat or horizontal hole may be assisted by means of a long wire picker. If the cuttings stop running, close the throttle until the drill reciprocates slowly, then crank the drill backwards out of the hole the full length of the feed screw. This clears away the cuttings from behind the bit, leaving the hole free for further drilling. The tendency of cuttings to pack in the hole increases in damp ground, and especial care should be used in this case. Steels should be dry when inserted in the hole, for if a wet steel be put into a dry hole the dust adheres to it and clogs it.

DOWN HOLES.—In drilling down holes or those at any angle below the horizontal, care should be used to feed water at such a rate that there will be a continual dash of mud out of the hole. If too much water is used the hole will fill up, and the dashing will be prevented, quickly resulting in a clogged or mudded hole. If too little water is used the drill wastes most of its energy in stirring up the heavy mud in the bottom of the hole. Deep holes should be cleaned with a sand pump, similar to that shown in Fig 20, or spoon at each change of steel, and if the hole becomes mudded the cleaning must be done frequently.

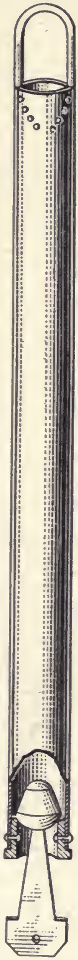


Fig. 20.
Sand Pump.

LUBRICATION.—When starting up new air drills use a lubricant consisting of one pint of cylinder oil to one-fourth pound of flake graphite, applying one tablespoonful of lubricant for each 5-foot hole during the first ten shifts drilled. After this use a good grade of drill oil, one tablespoonful for each 10-foot hole drilled. Do not use a heavy grade of oil with air drills, as such oil freezes readily and retards the machine.

RUNNING WITH STEAM.

SETTING UP AND STARTING.—Whatever the mounting, it must be firmly secured. If the drill is mounted on a tripod or quarry bar set the mounting in the desired position and then "spot" a small hole in the rock with a hand drill for each leg, and place the weights on the legs. Where the rock is so soft that the jar of the machine causes the legs to cut into the stone, and thereby throws the drill out of line with the hole, it is necessary to put a wooden block under each leg. An iron plate, with a hole in it for the leg, should be screwed on each block. Where compressed air is used the drill will start at once, but with steam it will take a few minutes for the machine to become equally heated.

Do not strike the steam chest or any other part of the drill, or loosen any bolt or side rod, for when the steam chest or cylinder becomes sufficiently heated the drill will start. Start the drill slowly and on a short stroke, as noted above.

LUBRICATION.—The general instructions for putting in upper (or dry) and down (or wet) holes with air drills apply also to those run by steam.

When starting a steam machine which has been shut down some time do not oil until the water is all out of it, then oil often and in small quantities through the oiler which is furnished with each machine. Also oil the drill through the hole in the top head. Use a good grade of cylinder oil when running with steam.

GENERAL SUGGESTIONS.

In soft ground in both wet and dry holes the drill may cut into the rock faster than it can throw the cuttings out of the hole, causing mudding or clogging. In these cases always throttle the air to reduce the hardness of the blow and use the longest possible stroke.

When the drill strikes a cavity or seam in the rock crank the machine down to a short stroke, until the bit has started in the next ledge. Do not keep the machine running if the piston stops rotating, or if the drill stops cutting. If a tripod leg has worked low, causing the steel to bind in the hole, straighten it up. If a column arm is too high let it down, or vice versa.

Keep the drill steel running freely in the hole by making such changes in the position of the drill on its mounting as may be required, making these changes as soon as the steel begins to bind. Do not wait until the hole has become crooked. Avoid running with crooked steels or shanks. Have the steel tight in the chuck or it will rapidly wear the chuck bushing, which causes the drill to run out of center, and results in excessive friction and wearing of the bit on the sides of the hole.

ADJUSTMENTS.—In starting a new drill care should be taken that all adjustments on the drill are tight and secure, and they should be kept so at all times. The exhaust pipe should be screwed in with a wrench and made tight. Otherwise it will jar loose, wearing or stripping the threads so that when next screwed tight it may partially choke the exhaust passage. The steam-chest plugs, or buffers, should be screwed in as far as they will go and the check nuts which hold them in place then made tight. After running for a few hours, slack off the check nuts and tighten the plugs again. These buffers do not form any means of adjustment, but merely afford access to the valve.

CHAPTER VI.

ROCK DRILL BITS OR STEELS.

ROCK DRILL STEELS.—Too much emphasis cannot be placed on the importance of using suitable drill steels with rock drills. The bits must be properly formed, sharpened and tempered for the work in hand, and must be of the right gauge, or the drilling machine cannot operate to advantage.

A typical rock drill steel is shown in perspective in Fig 21. Other drill steels differ from this only in the length of the ribs or wings, the angle of the cutting edge and the angles at which the wings cross each other.

Experience in the manufacture and use of drilling machines shows that it will prove economical to secure the best blacksmith obtainable to care for the drill steels. If bits of the right temper, shape and sharpness are always on hand the drills will be able to work constantly to the best advantage, whereas delays to the drills mean losses in efficiency to the whole plant.

For general mining and quarrying purposes the ordinary cross-bit is recommended. The proportions of the bit, as to length and thickness of the wings or ribs, are indicated in the accompanying illustrations. Figs. 22 and 23 are bits for hard, non-gritty rock, and are alike except for the different angles shown on the cutting edges. Fig. 22 shows about the highest angle to which the cutting edge can be made without danger of breaking. The angle shown on the cutting edge in Fig. 23 is one of many which may be used under different conditions without any other change in the bit. In cutting hard and medium hard rock, sharp drills and a wide-open throttle may be used to good advantage, and the hole will not ordinarily clog with mud, as the amount of rock loosened by each blow is so little that it is at once mixed into slush by the water in the hole. The sharp rebound of the drill when striking hard rock, together with the positive recovery of the machine, quickly gets rid of this slush. If the same bits and drill are run on an open throttle in soft or even medium-soft ground the hole soon becomes clogged. The reason for this is that while the hole remains the

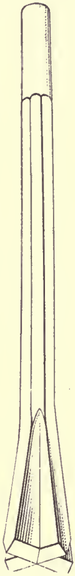


Fig. 21. Perspective View of Rock Drill Steel

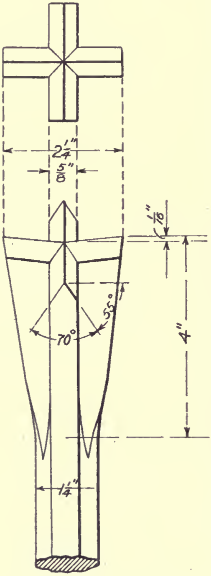


Fig. 22. Drill Steel for Hard Rock.

same diameter and the amount of water for mudding purposes is, therefore, the same, the steel chips out three or four times as much dust at each blow as it does in hard rock. The rate of cutting should, therefore, be reduced in order to keep the drill working at maximum efficiency. The speed may be regulated by throttling the air or steam, but this reduces the rapidity of action of the drill, so that it does not always mix into slush the dust caused, even at the slower speed. The recoil of the steel from soft rock is also considerably less. In soft rock duller bits should be used, like that shown in Fig. 23. The angle of the cutting edge may be even duller than this, sometimes almost square on the end, in order to

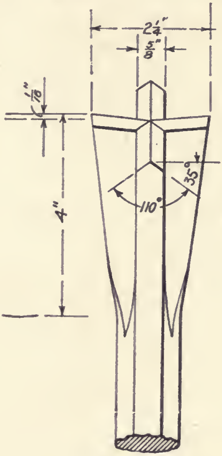


Fig. 23.
Drill Steel for Soft Rock.

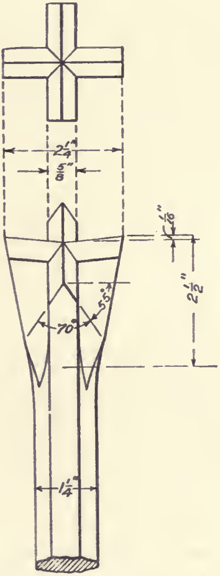


Fig. 24.
Length of Rib on Drill for Soft Rock.

secure good results. In connection with the above subject it is well to bear in mind the length of the wings or ribs for different kinds of work. Figs. 22 and 23 show extreme lengths for very hard rock, intended to give strength and hold the gauge as long as it is necessary. Figs. 24 and 25 show shorter ribs, which give the bit more clearance and make it more desirable for general purposes. Under ordinary conditions its ability to mix mud is much greater than that of the long bit like Fig. 22. For drilling dry holes in tunnel headings or elsewhere, the bit with short ribs has less tendency to allow the hole to draw up. The wings are five-eighths of an inch thick, for the size shown in Figs. 22 to 25, and should never be less than that for this size of bit and steel. They should be the same thickness throughout to allow free return of the cuttings. If gauge less than 2¼ inches is desired make the bit correspondingly shorter.

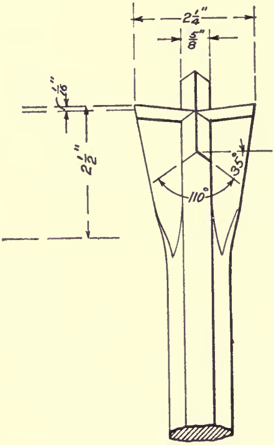


Fig. 25.
Cutting Edge on Drill Steel for Soft Rock.

In seamy ground the bit shown in Fig. 26 will occasionally work satisfactorily when a cross bit would not prevent a "rifled" hole, since the "x" bit strikes only half as often as the "+" bit in a given spot. Flat or chisel bits are not recommended, since their reaming qualities are poor, and while cutting faster than the + bit under some conditions they are very hard on the machine. It is important to keep the wings square at the corners, as this permits the gauge of the hole to be properly maintained. Do not use a set of steels after the gauge has begun to wear. The time and trouble taken in securing fresh steel amount to little in comparison with the delay caused by trying to work down a hole with steel that is constantly sticking, to say nothing of the wear and tear on the machine. Blacksmiths should take pains to furnish bits made exactly to the required gauge. A little neglect in this particular causes much trouble and loss of time with the drill.

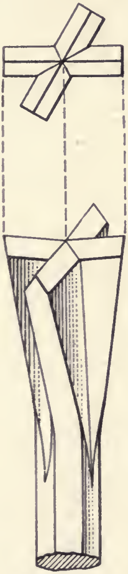


Fig. 26.
X Bit Drill Steel

On any rock on which the cutting edges are not dulled upon the first hole a system should be devised by the foreman or superintendent to determine how much each bit will do without too much "hammer help." The improvement will be very pronounced.

SIZE AND WEIGHTS OF DRILL STEELS.—In Table III will be found the number of drill steels used

TABLE III.

Weights and Specifications of Drill Steels.

For Drill "UA"—2 inches—Feed 12 Inches

(Size of Shank, ¾ in. 3⅜ in.)

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Sizes of Steel Inches	Weight in Pounds
Starter	1½	1 ft. 0 in.	⅞	3½
2d length	1⅜	2 ft. 0 in.	⅞	5
3d length	1¼	3 ft. 0 in.	¾	6
4th length	1⅛	4 ft. 0 in.	¾	7½
5th length	1	5 ft. 0 in.	¾	9

For Drill "US"—2¼ Inches—Feed 15 Inches

(Size of Shank, ⅞ in. x 4 in.)

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Size of Steel Inches	Weight in Pounds
Starter	1¾	1 ft. 3 in.	1	5
2d length	1⅝	2 ft. 6 in.	1	9
3d length	1½	3 ft. 9 in.	⅞	10
4th length	1⅜	5 ft. 0 in.	⅞	13
5th length	1¼	6 ft. 3 in.	⅞	16

For Drill "UR"—2¼ Inches—Feed 20 Inches

(Size of Shank, ⅞ in. x 4¼ in.)

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Size of Steel Inches	Weight in Pounds
Starter	1¾	1 ft. 8 in.	1	7
2d length	1⅝	3 ft. 4 in.	1	11
3d length	1½	5 ft. 0 in.	⅞	13
4th length	1⅜	6 ft. 8 in.	⅞	17
5th length	1¼	8 ft. 4 in.	⅞	21

TABLE III.—Continued.
Weights and Specifications of Drill Steels.

For Drills "UC" and "UC11—2¾ Inches—Feed 24 Inches

(Size of Shank, 1 in. x 4½ in.)

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Sizes of Steel Inches	Weight in Pounds
Starter	2⅛	2 ft. 0 in.	1⅛	10
2d length	2	4 ft. 0 in.	1⅛	18
3d length	1⅞	6 ft. 0 in.	1	20
4th length	1¾	8 ft. 0 in.	1	30
5th length	1⅝	10 ft. 0 in.	1	35
6th length	1½	12 ft. 0 in.	1	35

For Drill "UD"—3 Inches—Feed 24 Inches

For Drills "UE2" and "UE11"—3⅛ Inches—Feed 24 Inches

For Drills "UF2" and "UF11"—3¼ Inches—Feed 24 Inches

(Size of Shank, 1⅛ in. x 4⅞ in.

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Sizes of Steel Inches	Weight in Pounds
Starter	2½	2 ft. 0 in.	1¼	11
2d length	2⅜	4 ft. 0 in.	1¼	19
3d length	2¼	6 ft. 0 in.	1⅛	23
4th length	2⅛	8 ft. 0 in.	1⅛	31
5th length	2	10 ft. 0 in.	1⅛	39
6th length	1⅞	12 ft. 0 in.	1⅛	47
7th length	1¾	14 ft. 0 in.	1⅛	55
8th length	1⅝	16 ft. 0 in.	1⅛	63
9th length	1½	18 ft. 0 in.	1⅛	71
10th length	1⅜	20 ft. 0 in.	1⅛	79

TABLE III.—Continued.
Weights and Specifications of Drill Steels.

For Drills "UH" and "UH11"—3⅝ Inches—Feed 30 Inches

(Size of Shank, 1¼ in. x 5½ in.)

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Size of Steel Inches	Weight in Pounds
Starter	3	2 ft. 6 in.	1⅜	18
2d length	2⅞	5 ft. 0 in.	1⅜	32
3d length	2¾	7 ft. 0 in.	1¼	37
4th length	2⅝	10 ft. 0 in.	1¼	48
5th length	2½	12 ft. 6 in.	1¼	59
6th length	2⅜	15 ft. 0 in.	1¼	70
7th length	2¼	17 ft. 6 in.	1¼	81
8th length	2⅛	20 ft. 0 in.	1¼	92
9th length	2	22 ft. 6 in.	1¼	103
10th length	1⅞	25 ft. 0 in.	1¼	114
11th length	1¾	27 ft. 6 in.	1¼	125

For Drill "UH"—3⅝ Inches—Feed 24 Inches

(Size of Shank, 1¼ in x 5½ in.)

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Size of Steel Inches	Weight in Pounds
Starter	3	2 ft. 0 in.	1⅜	15
2d length	2⅞	4 ft. 0 in.	1⅜	25
3d length	2¾	6 ft. 0 in.	1¼	31
4th length	2⅝	8 ft. 0 in.	1¼	41
5th length	2½	10 ft. 0 in.	1¼	50
6th length	2⅜	12 ft. 0 in.	1¼	57
7th length	2¼	14 ft. 0 in.	1¼	63
8th length	2⅛	16 ft. 0 in.	1¼	76
9th length	2	18 ft. 0 in.	1¼	82
10th length	1⅞	20 ft. 0 in.	1¼	92

TABLE III.—Continued.
Weights and Specifications of Drill Steels.

For Drill "UK"—4¼ Inches—Feed 30 Inches
(Size of Shank, 1½ in. x 6 in.)

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Size of Steel Inches	Weight in Pounds
Starter	3⅝	2 ft. 6 in.	1⅝	27
2d length . .	3½	5 ft. 0 in.	1⅝	47
3d length . .	3⅜	7 ft. 6 in.	1⅝	66
4th length .	3¼	10 ft. 0 in.	1½	74
5th length .	3⅛	12 ft. 6 in.	1½	90
6th length .	3	15 ft. 0 in.	1½	107
7th length .	2⅞	17 ft. 6 in.	1½	123
8th length .	2¾	20 ft. 0 in.	1½	140
9th length .	2⅝	22 ft. 6 in.	1½	156
10th length .	2½	25 ft. 0 in.	1½	174
11th length .	2⅜	27 ft. 6 in.	1½	190
12th length .	2¼	30 ft. 0 in.	1½	206
13th length .	2⅛	32 ft. 6 in.	1½	222
14th length .	2	35 ft. 0 in.	1½	238

For Drill "UL"—5 Inches—Feed 30 Inches
(Size of Shank, 1¾ in. x 6⅝ in.)

Name of Each Part	Regular Size of Gauge Inches	Length Steel Will Cut	Size of Steel Inches	Weight in Pounds
Starter . . .	4	2 ft. 0 in.	1⅝	22
2d length .	3⅞	4 ft. 6 in.	1⅝	39
3d length . .	3¾	7 ft. 0 in.	1½	42
4th length .	3⅝	9 ft. 6 in.	1½	65
5th length .	3½	12 ft. 0 in.	1½	81
6th length .	3⅜	14 ft. 6 in.	1½	98
7th length .	3¼	17 ft. 0 in.	1½	114
8th length .	3⅛	19 ft. 6 in.	1½	131
9th length .	3	22 ft. 0 in.	1½	148
10th length .	2⅞	24 ft. 6 in.	1½	165
11th length .	2¾	27 ft. 0 in.	1½	182
12th length .	2⅝	29 ft. 6 in.	1½	200
13th length	2½	32 ft. 0 in.	1½	217
14th length	2⅜	34 ft. 6 in.	1½	234
15th length .	2¼	37 ft. 0 in.	1½	251
16th length .	2	39 ft. 6 in.	1½	268

with Sullivan machines of various sizes, the lengths, weights, etc. The letters at the top of each table refer to the size of the rock drill, so that full information can be had by referring back to Table II. For instance, the "UA" size, by referring to Table II, will be found to have a cylinder 2 inches in diameter with 4½-inch stroke and length of feed of 12 inches, together with all necessary data as to sizes of steam or air inlets and outlets, and all other information about the machine.

In column two the regular size of gauge in inches refers to the size of the cutting head in end of the bit.

It will be noticed that the size of the gauge, or, in other words, the size of the drill head, decreases in size with each length added. For instance, in the last size of drill listed in this table, the machine starts off with a drill that will make a hole four inches in diameter, and each time the drill is changed and lengthened the size of the bit is decreased one-eighth inch in diameter, so that at a depth of 39 feet 6 inches it is drilling a hole only 2 inches in diameter. The object of thus decreasing the size of drill at each change of the drill steels is to prevent the drill from binding, as would be the case if the attempt were made to use a steel with the same size bit throughout the entire depth of the hole.

It might be well to state here that for ordinary building construction it will seldom be necessary to use a machine that will drill deeper than 8 feet

4 inches. For large engineering works the large size drills may be used, but for ordinary operations the smaller sizes will be found to give satisfactory results.

Drills 30 feet in length and over are generally made in two parts for convenience in shipping and handling, but can be had in one piece when so desired.

BLACKSMITHS' TOOLS FOR FORGING DRILL STEELS.

The special tools required by a blacksmith for keeping the drill steels in condition are shown in the following eight illustrations: Fig. 27 is a swage for forming the wings of the drill steel, Fig. 28 is a "sow" for gauging the wings, Fig. 29 is a cross-shaped "dolly" for shaping the cutting end of the drill steels, Fig. 30 is an X-shaped dolly for the same purpose, Fig. 31 is a flatter, Fig. 32 is a spreader, Fig. 33 is a drill shank swage for anvil and Fig. 34 is a similar swage for a hammer.

AIR REQUIRED FOR DRILLING MACHINES.

The type of air compressor used to furnish air for the machine drills will depend to a great extent upon whether the work is of a permanent or temporary nature. For rock drilling in quarries naturally a power plant will be required, and a stationary air compressor, permanently mounted

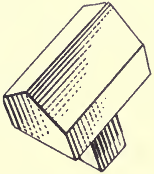


Fig. 27.
Swage.

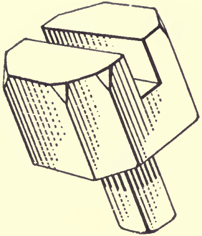


Fig. 28.
Sow.

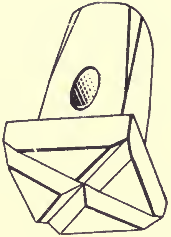


Fig. 29.
Cross-Shaped Dolly.

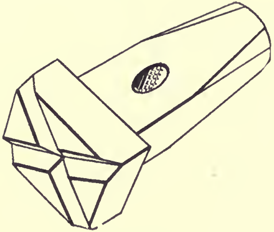


Fig. 30.
X-Shaped Dolly.

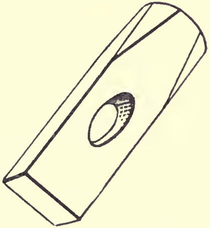


Fig. 31.
Flatter.

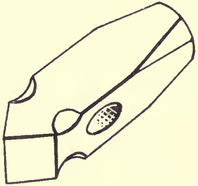


Fig. 32.
Spreader.

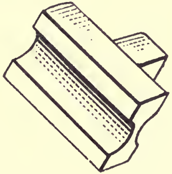


Fig. 33.
Swage for Anvil.

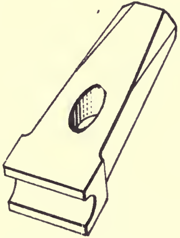


Fig. 34.
Swage for Hammer.

on a solid base, would be preferable. For temporary work in building construction, unless the operation is a particularly large one, a portable boiler when steam is to be used, or a boiler, engine and air compressor when air is to be used, will be found the more convenient.

The size of the compressor required will depend upon the number of drills that are to be operated, which in turn determine the amount of free air, that is, atmospheric air, which must be compressed to the required pressure. Seventy-five pounds is a common pressure to supply air to the drills, and in Table IV can be found the number of cubic feet of free air required to run from one to forty drills.

Allowance has been made in the table for the difference between piston displacement and actual delivery, so that no further deduction need be made from the compressor capacities stated in catalogue. The figures represent the requirements of drills under ordinary working conditions. When a practice is made of drilling deep holes, or where special conditions render the work unusually severe, more air will be necessary. It is, therefore, wise in purchasing an air compressor to allow for such contingencies, and many contractors, quarrymen and mine managers of experience invariably install a compressor capable of furnishing 20 or 25 per cent. more air than their machines require.

TABLE IV.

Air Required to Run Rock Drills.

No. of Machines	AMOUNT FREE AIR PER MINUTE									
	ROCK DRILLS (AIR PRESSURE, 75 POUNDS PER SQUARE INCH AT OCEAN LEVEL)									
	UA	US	UB	UC UC11	UD	UE2 UE11	UF2 UF11	UH, UH11 UH2	UK	UL
	2 Inches*	2¼ Inches	2½ Inches	2¾ Inches	3 Inches	3⅛ Inches	3¼ Inches	3⅝ Inches	4¼ Inches	5 Inches
1	55	70	84	100	112	123	135	149	180	214
2	110	140	168	200	224	246	270	298	360	428
3	149	189	227	270	303	332	365	403	486	578
4	187	238	286	340	381	419	460	506	612	728
5	226	287	344	410	460	505	554	611	739	878
6	264	336	404	480	538	590	648	715	864	1,029
7	297	378	454	540	605	665	730	805	973	1,157
8	330	420	504	600	672	738	810	894	1,080	1,284
9	358	455	546	650	728	800	878	968	1,170	1,392
10	385	490	588	700	784	861	945	1,043	1,260	1,498
12	446	567	681	810	907	995	1,095	1,209	1,460	1,735
15	539	686	824	980	1,100	1,206	1,324	1,460	1,765	2,100
20	676	861	1,035	1,230	1,378	1,514	1,660	1,833	2,215	2,633
25	803	1,022	1,228	1,460	1,636	1,796	1,970	2,176	2,628	3,125
30	935	1,190	1,430	1,700	1,904	2,090	2,295	2,533	3,060	3,640
40	1,190	1,512	1,815	2,160	2,420	2,660	2,920	3,220	3,890	4,625

*Diameter of cylinder.

The figures given in Table IV are for air at 75 pounds pressure at sea level. The modern tendency in rock drill practice is toward higher pressures, and the present standard is near 90 pounds. For estimating the air consumption of drills at any required pressure or altitude the factors of multiplication given in Table V will be found convenient.

These tables are used in the following manner. Suppose, for instance, instead of 75 pounds pressure, the drill is to operate under a pressure of only 60 pounds, and at sea level. In column 2, Table IV, it will be seen that a single drill requires 55 cubic feet of free air to operate at 75 pounds of pressure. According to the factors for various altitudes and pressures given in Table V, however, it would require only .83 per cent. of 55, or, $.83 \times 55 = 45.65$ cubic feet of air per minute.

Suppose, however, that instead of being at sea level the rock drill was to be used in excavating on the top or side of a mountain at an elevation of 6,000 feet above the level of the sea. In that case, instead of a factor of .83 it will require 1.03 times as much air to operate the drill under a pressure of 60 pounds as it would to operate the same drill at sea level under a pressure of 75 pounds. At sea level and at 75 pounds pressure the drill requires 55 cubic feet of free air, therefore at an altitude of 6,000 feet and under 60 pounds pressure it would require $55 \times 1.03 = 56.65$ cubic feet of free air per minute.

TABLE V.

Factors of Multiplication for Various Altitudes and Pressures

Air Pressure at Machine Pounds	ALTITUDE ABOVE SEA LEVEL IN FEET									
	0	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
60	.83	.89	.92	.96	1.00	1.03	1.07	1.11	1.15	1.19
65	.85	.92	.95	.98	1.02	1.05	1.08	1.12	1.17	1.22
70	.96	1.02	1.04	1.08	1.12	1.17	1.21	1.25	1.30	1.34
75	1.00	1.07	1.11	1.15	1.20	1.24	1.29	1.32	1.37	1.42
80	1.06	1.13	1.17	1.22	1.27	1.31	1.37	1.41	1.46	1.52
85	1.12	1.19	1.24	1.28	1.34	1.38	1.44	1.48	1.54	1.60
90	1.17	1.25	1.29	1.34	1.38	1.45	1.51	1.55	1.61	1.67
100	1.28	1.37	1.42	1.47	1.54	1.59	1.66	1.71	1.77	1.83
110	1.39	1.49	1.54	1.60	1.67	1.72	1.79	1.85	1.92	1.99
120	1.51	1.62	1.67	1.73	1.81	1.87	1.94	2.01	2.08	2.16

Take another example. Instead of running the rock drill with air at 75 pounds pressure, suppose 100 pounds pressure be used. In that case 1.28 times as much free air would be required as when the machine is operated under the lower pressure of 75 pounds per square inch—$1.28 \times 75 = 96$ cubic feet of free air per minute. When the power plant and compressor are located at considerable distance from the workings, an additional allowance of say 15 per cent. should be made for the loss of head due to friction of the pipes, and the loss of volume due to condensation or contraction. Compressing air heats it so that it expands and occupies more space than it would if compressed without heat; and this air when in the storage tank and being conducted through pipes to the several machines, in cold climates or during cold weather, has its temperature reduced and shrinks or contracts correspondingly in volume, condensing, perhaps, to a less volume, relatively, than when in the free state.

It is false economy to try to operate with an inadequate supply of air, so to remedy this state of affairs it is well to have a compressor with a capacity of from 25% to 40% greater than that actually required. This makes the plant more elastic likewise, enabling more machines to be run at one time than was originally planned, a condition which is sometimes necessary.

On large machines, like stone channelers, it has been found economical to use re-heaters for heating the air before it is used in the machine. The re-heaters not only increase the volume of air, thereby increasing the supply to the machine, but it also keeps the moisture in the air from freezing in the exhaust ports, an occurrence which is liable if the air is not heated, for the air on expansion, when released from the cylinders of the channeler has a refrigerating effect, just the opposite of the heating effect due to compression. It is the cooling effect of expansion which causes the exhaust ports of machines operated by compressed air to freeze, and, of course, the higher the pressure of the air, the greater the cooling effect of expansion.

CHAPTER VII.

HAMMER DRILLS.

IN blasting work, a charge of explosive generally throws out or breaks down blocks of rock too large and heavy for removal. When such is the case, "pop" holes must be drilled in them, and the rocks broken up into convenient sizes for handling by blasting them with small charges of explosives. Hand drilling was formerly employed for this purpose, but machine hammer drills, operated by one man, and using compressed air, are now generally used.

Hammer drills are handy not alone for breaking up boulders and large rock fragments, but will be found convenient for cutting hitches in rock walls to receive timbers, and for trimming the walls, roof or floor of tunnels, shafts or cellar excavations. They can likewise be used to good advantage in excavating rock in narrow sewer or water trenches, where light weight, compactness and rapidity of setting up go a long way toward reducing the cost of the work.

Hammer drills are made in two sizes. The small size weighs 25 pounds and is for drilling holes up to 3 feet in depth, and large enough for 7/8-inch powder. The large drill weighs 35 pounds and will drill holes 3 feet deep and large enough for 1¼-inch powder.

The characteristic feature of the hammer drill is that the cutting edge of the steel rests against the rock all the time, and is forced into it by the repeated blows of the piston, which is independent or detached from the drill steel, and is driven rapidly back and forth in the cylinder.

The weights, dimensions and capacity of Sullivan hammer drills can be found in Table VI.

TABLE VI.

Capacities of Hammer Drills.

Class of Drill	DB-15	DB-19
Depths to which holes may be drilled (inches)	36	60
Maximum diameter of holes (inches) .	1½	2
Weight of drill in pounds	25	35
Size of hose required (inches) . .	7-16	½
Size of shanks, inches (shank is hexagonal) . . .	7/8x3	1x3½

For the classes of work for which they are used the hammer drill has important advantages in its light weight, the ease and rapidity with which it can be set up and handled, its high drilling speed and economy of power.

These machines or tools are so light they can be handled readily by one man, and as no tripod, column or other mounting is required no time is lost in setting up or in removing the drills from one point to another.

They are so light and compact that they can be carried wherever a man can go, and in narrow trench work the openings need be driven only wide enough to permit a man to enter. Holes may be drilled at any point, at any angle, or in any direction.

Some idea of the capacity of these hammer drills may be obtained from past performances. In oolitic limestone of varying hardness, very irregular, full of mud pockets and often covered with water, twelve of the smaller hammer drills each averaged forty holes 18 inches deep per shift of 10 hours. The best record was 100 holes 18 inches deep or 150 feet of drilling, while 36 holes 3½ feet deep were drilled by one tool in seven hours. Hammer drills are now being used to a considerable extent in mine work for drifting, owing to the time saved after a shot. The driller can put in his upper holes from the top of the muck pile while the mucker is at work loading out the heaps. The lifters are then put in last after the muck has all been removed. The great advantage in using hammer drills for work of this class lies in the fact that no time is lost in mucking for the "set-up" as in the case of piston drills, or in mounting the drills afterwards on the bars or columns.

"Plug" and "foot hole" drills of the hammer type are made in two sizes for drilling "plug" and "foot holes."

The smaller hammer is for drilling holes up to 6 inches in depth, and the larger one for holes up to 12 inches in depth. A hammer drill of this type, which differs but slightly from those just described, is shown in Fig. 35. This tool employs solid steels or bits, while the larger size uses hollow drill steels. The solid steel, shown in the illustration, is rotated by a hand wrench shown sticking out to the left of the drill steel, and the hole is kept free from dust by exhaust air from the drill, which is directed into it by the blower hose shown, connecting the exhaust port to the flange, near the end of the drill steel. When starting a hole the valve is opened, exhausting into the atmosphere, to avoid the annoyance of flying stone dust. After the hole is started a small amount of exhaust air is allowed to flow into the hole. As the hole is deepened more and more exhaust air is deflected into the

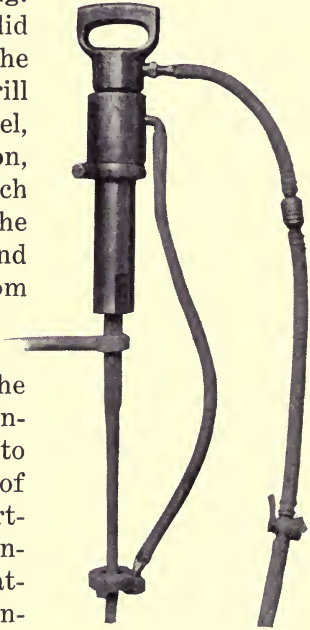


Fig. 35.
Hammer Drill.

opening, all being used in this way if desired. This will keep the bit free from dust and dirt, even in broken, wet and seaming ground.

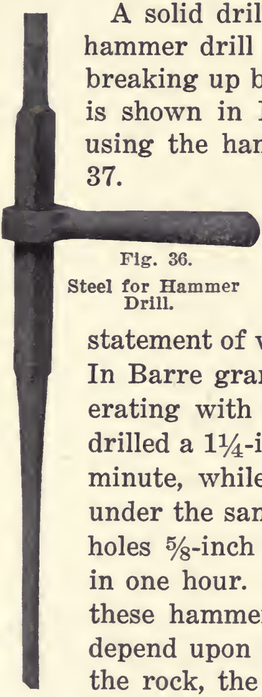


Fig. 36.
Steel for Hammer Drill.

A solid drill steel, such as is used in a hammer drill for drilling "pop" holes for breaking up boulders and rock fragments, is shown in Fig. 36, and the method of using the hammer drill is shown in Fig. 37.

Some idea of the capacities of the "plug" and "foot hole" drills can be gained from the following statement of what they have accomplished. In Barre granite the "foot hole" drill operating with air pressure of 100 pounds drilled a 1¼-inch hole 6 inches deep in one minute, while the "plug" drill, operating under the same conditions, has put in 160 holes ⅝-inch diameter and 3 inches deep in one hour. Of course, the work one of these hammer drills will accomplish will depend upon the character and quality of the rock, the skill of the workman handling it, and the air pressure supplied at the valve. The foregoing statement of what they have already accomplished, however, ought to serve as a guide to what they can do, keeping in mind, of course, the fact that rock varies so that it is seldom the same in any two cases, and the difference in quality, fissures, etc., must be taken into consideration.

Fig. 37.
Method of Using Hammer Drill.

CHAPTER VIII.

STONE CHANNELERS.

⁂

NO work on rock excavating would be complete without some reference to stone channelers for engineering and architectural works. For over forty years machines of this kind have been used in quarry work, and for many years engineers have considered channeling machines indispensable when rock has to be cut away for canals, locks, wheel pits, railroad cuts or similar excavations. More recently still they have been used in architectural works, the new Pennsylvania Station in New York City and the sub-grade terminal yards of the New York Central Railroad at Forty-second street being notable examples.

The channeling machine has advantages of economy and utility for certain classes of work which put them in a class by themselves. For instance, the smooth, straight, solid walls cut by a channeler are better in many ways than the jagged wall left after drilling and blasting.

The channeler cuts exactly to the surveyed line of the work, a matter which is difficult to accomplish when the wall is made by drilling and blasting. In the latter case too much rock is removed at some points and the cavities so formed must be filled with concrete or masonry. At other points projections are left which must be trimmed off to the survey line. A further advantage lies in the fact that the cut made by a channeler affords an additional free face for the powder used in blasting to act against, thereby making the blasting easier and reducing the amount of explosive needed.

The wall left by the channeler and the rock back of the channeled face remain as solid as the rock strata themselves, since they are not weakened or shattered by explosives.

Under many conditions a blasted wall needs to be sloped away from the line of excavation, in order to prevent slides, thereby making necessary a large amount of extra blasting. Oftentimes rock-blasted walls must have retaining walls to prevent rock falls or slips, and they are greatly affected by weather, water freezing in the crevices caused by the shattering effect of the explosive and heaving the loose particles out of place. Channeled walls, on the other hand, are but little affected by weather and will stand without deterioration for an indefinite length of time.

Finally, in thickly built-up districts, where it is necessary to excavate rock close to the foundations of existing structures, channeling around the sides of the excavation close to the buildings is desirable, as it completely isolates the rock in-

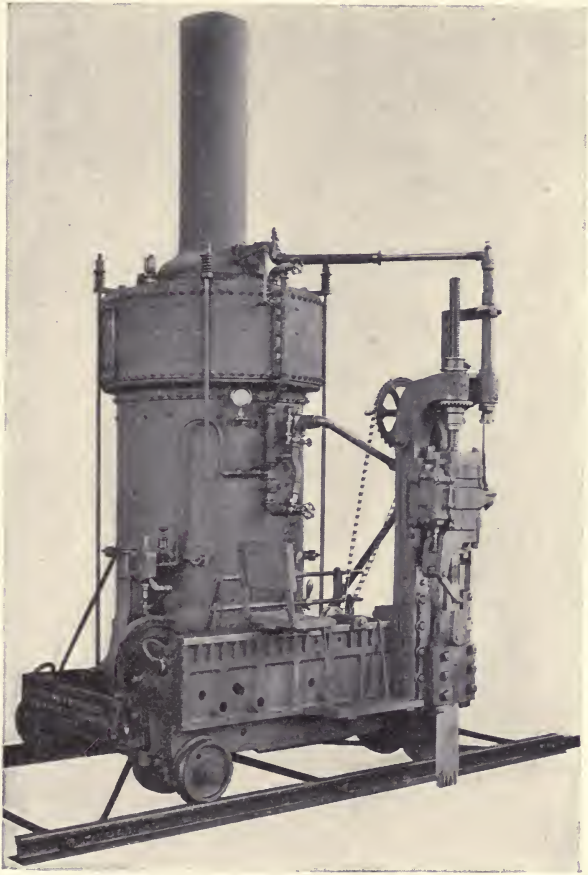


Fig. 38.
Simplex Channeling Machine.

side of the cellar space, which can then be drilled and blasted without damaging the foundations of the near-by buildings.

The usefulness of channelers is limited to the softer kinds of rock, and cannot successfully be used for channeling trap rock, granite or hard gneiss. They can be successfully and economically employed, though, on marble, sandstone, limestone, slate, soapstone and for the softer gneisses, such as that underlying New York City, also the softer porphyries and granites.

SIMPLEX CHANNELING MACHINES.—A Sullivan direct-acting simplex channeling machine, mounted on a movable truck, together with a boiler for furnishing steam, is shown in Fig. 38. The truck runs on steel rails, which keep the machine in alignment for the channel it is cutting, and at the same time permits it to be easily moved from one position to another. The channel-cutting drill steels are shown extending below the level of the rails. These drill steels are in groups of five, working so close together that the holes they make run together into one continuous slot.

After the gang drills have cut a groove to the required depth the machine is moved along so that the next set of holes will form a continuation of the slot already made. The cutting or chopping engine which operates the drill steels is raised or lowered on its standard by means of a feed screw, in a manner similar to that employed for the ordinary tripod-mounted rock drill. Machines of this

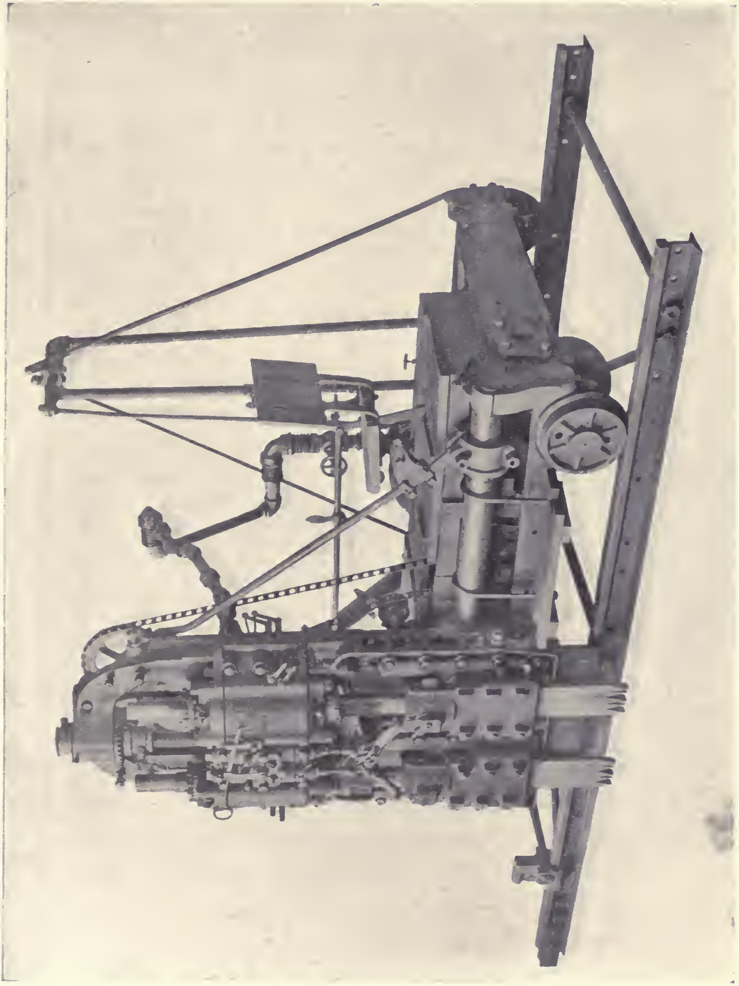


Fig. 39.
Duplex Channeling Machine.

type can be used to cut not only vertically, but likewise at any angle up to 23 degrees.

DUPLEX CHANNELING MACHINES.—A duplex channeling machine of the same make as the simplex machine is shown in Fig. 39. With this channeler two sets of gang drills are used, so that double the amount of groove is being cut at one time that is possible with a simplex machine. Further, this channeler is designed to cut grooves at various angles, and although shown in the illustration set up ready to channel a vertical groove, by adjusting the mounting frame on the round bar seen in the foreground the chisels can be tilted to any desired angle up to 39 degrees, and by means of special braces can be adjusted to cut angles as high as 90 degrees from the vertical. In other words, the machine has a range of from vertical, or straight down, to a horizontal position.

Duplex channeling machines can be had with or without air reheaters. The one shown in the illustration is without a reheater, although there are conditions under which it is of great advantage to have the air reheated before delivering it to the engine.

DRILL STEELS FOR CHANNELING MACHINES.—The drill steels used for channeling are considerably different from those used in ordinary rock drilling machines, and, in fact, differ from one another according to the character of the rock they are to be used upon. A five-piece gang of

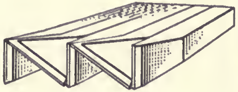


Fig. 40.
Channeler Steels for Marble.

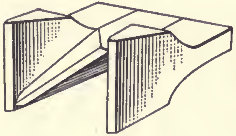


Fig. 41.
Three-Piece Gang Drill Steels for Channeler.

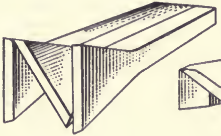


Fig. 42.
Gang Drill Steels for Channeling Slate.

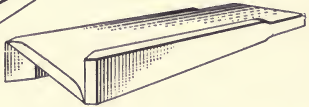


Fig. 43.
Z-Shaped Channeling Steel for Broken or Fissured Rock.

steels suitable for working marble is shown in Fig. 40. The illustration shows clearly the way the drills are sharpened and set in relation to one another.

A three-piece gang of drill steels for a channeling machine working in crystallized and other limestone is shown in Fig. 41.

A gang drill of three pieces for channeling slate is shown in Fig. 42, which also illustrates the way the steels are set in relation to one another.

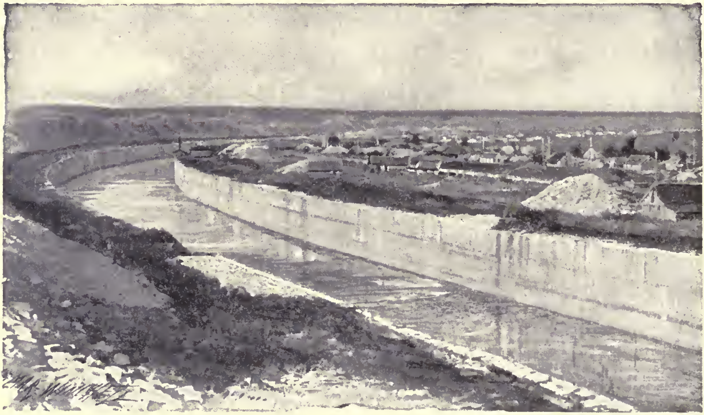


Fig. 44.
Channeled Walls of Chicago Drainage Canal.

In Fig. 43 we have a solid Z-shaped bit, or drill steel, which has been adopted by the manufacturers and is recommended by them for engineering and architectural works, particularly where the cuttings are deep and the rock is broken or fissured.

Fig. 45.
Quarrying Dimension Stones with Channeler.

ILLUSTRATIONS OF CHANNELED WORK.—Some idea of the appearance of channeled walls can be obtained from the accompanying illustration, Fig. 44, which shows a curve in the Chicago drainage channel, which was channeled out of the solid Joliet limestone.

No other illustration perhaps would convey such a good understanding of what can be accomplished by a channeling machine as this solid bank of rock rising perpendicularly from the water and presenting smooth walls, free from pockets or projections to impede the flow of water.

Another view which shows how dimension rocks can be taken out of a quarry for building purposes is shown in Fig. 45. Two channeling machines may be seen in the background making the vertical cuts, while the free face of the bench of rock shows the smooth surface of the cut, made by the channeling bits.

The sizes, weights and specifications of Sullivan stone channels can be found in Table VII.

AIR REHEATERS.—When channelers are to be operated by air power the use of a reheater is strongly advised. A saving of from 15 to 25 per cent. in power may be attained by reheating the compressed air before it is used in the channeler engine, and freezing at the exhaust is also prevented by this means.

SPECIFICATION OF STEEL FOR CHANNELING MACHINES.—As has already been pointed out, the type of drill steels varies with the work it is to

TABLE VII.

Specifications of Stone Channelers.

Size	TYPE	Diameter of Cylinder, Inches	Height of Machine		Length along Track		Width		Gauge of Track, Inside Measurement		Distance, Center of Cut to Wall, Inches	Distance Between Centers of Cuts when Machine is Turned on Track		FreeAirConsumption at 100 lbs Pressure, Cu. Ft. per Min.	Weight in Pounds		
			ft.	in.	ft.	in.	ft.	in.	ft.	in.		ft.	in.		Machine only	Equipment only	Total
Y-8	Rigid head with boiler	8	9	11	6	6	6	10	4	11	7	6	8		13,270	6,050	19,320
Y-8	Rigid head without boiler	8	8	3	6	6	6	10	4	11	7	6	8	400	*13,900	5,830	19,730
Y-8	Double head without boiler	8	8	3	6	6	6	10	4	11	7	6	8	750	16,500	6,800	23,300
Y	Rigid head with boiler	7	9	11	6	6	6	9	4	11	6	6	6		12,235	6,050	18,285
Y	Rigid head without boiler	7	7	6	6	6	6	9	4	11	6	6	6	300	*12,860	5,830	18,690
Y	Double head without boiler	7	7	6	6	6	6	9	4	11	6	6	6	550	10,230	6,800	17,030
6½	‡Rigid head with boiler	6½	9	11	6	6	6	10	4	11	9	6	3		10,520	5,435	15,955
6½	‡Rigid head without boiler	6½	6	3	6	6	6	7	4	11	9	6	3	230	6,520	5,215	11,735
Z	Swivel head with boiler	7	9	11	6	6	6	9	4	11	6	6	6		13,000	6,050	19,050
Z	Swivel head without boiler	7	7	6	6	6	8	5	4	11	6	6	6	300	9,000	5,830	14,830
Z	Double head without boiler	7	7	6	6	6	6	5	4	11	6	6	6	550	11,210	6,800	18,010
VW	Swivel head duplex with boiler	6½	10	3	6	6	6	2	4	11	8	6	6		13,900	8,600	22,500
VW	Swivel head duplex without boiler	6½	6	7	6	6	6	7	4	11	8	6	6	500	8,900	8,575	17,475
6½	Swivel head with boiler	6½	9	11	6	6	6	9	4	11	6	6	6		11,000	5,430	16,430
6½	Swivel head without boiler	6½	6	8	6	6	6	5	4	11	6	6	6	230	7,200	5,215	12,415
6½	Double head without boiler	6½	6	8	6	6	6	5	4	11	6	6	6	410	8,900	6,080	14,980
VX	Swivel head without boiler: ‡Standard on bar to cut from vertical to horizontal	4½	5	10	4	3	4	5	3	3	4½	....		190	2,600	3,140	5,740
	‡Standard removed from bar and hung at either end of frame for undercutting	4½	2	6	variable				3	3	Height of bench, 8½ in.			190	2,600	3,340	5,940

Machines with boiler are measured to the top of the smoke bonnet without the stack; machines without boiler, to the top of the standard, when vertical.
Includes three balance weights, sent unless otherwise ordered (weight 4,635 pounds).
These channelers are not equipped with the power hoist
Without reheating.

do and the machine with which it will be used. In Table VIII will be found full information on the subject, pointing out the kind of drill steel, length, dimensions, number used in a gang and other information for different kinds of work.

CAPACITIES OF CHANNELING MACHINES.—For large engineering and architectural works channelers are made which will successfully cut to a depth of 16 feet. For ordinary practice, however, a depth of from 9 to 12 feet is about all that will be required. After taking out rock to the 9, 12 or 16-foot level the channeler can be lowered to the next bench and another depth channeled.

The cutting speed of channeling machines varies within wide limits, depending upon the hardness of the stone, freedom from fissures or other irregularities, and to a considerable extent the skill of the operator. Instead of giving averages of various machines it is considered better to give the actual performances of the several machines listed in Table VII, as furnished by the manufacturer, so that the actual capacity of any of the machines listed can be judged. The class letters, Z, Y, etc., refer to the sizes and specifications of channeling machines.

At Brandon, Vt., a "6½" channeler has averaged 1,485 feet per month, and a "Z" 1,677 feet for twelve consecutive months. This is the hardest marble in the State. At West Rutland a "6½" channeler has cut 2,652, 2,649, 2,287 and 2,449 square feet in four consecutive months, or about 100 feet per ten-hour day.

TABLE VIII.

Specifications of Channeling Machine Steels.

Size of Machine	Kind of Work	Length of Run or Distance Drilled Without Changing Steel	Kind of Gang	Regular Equipment		
				Two * Gangs Each of Following Lengths		Dimensions of Steel, Inches
		Inches		ft.	in.	
Y-8 Y Z	Usual Quarry and Contract Work, Hard Limestone	18	3-piece gang	2 4	10 4	First two gangs, 1 x 2¼
			5-piece gang	5 7	10 4	Last two gangs, 1 x 1⅜
Y-8 Y Z	N. Y. Sandstones, Marble, Hard Sandstone	18	5-piece gang	2 4 5 7	10 4 10 4	Each piece 1 x 1⅛
Y-8 Y	Soft Limestone	24	3-piece gang	3 5	4 4	Each piece 1 x 2¼
			5-piece gang	7	4	Each piece 1 x 1⅜
Y-8 Y Z	Broken Rock, Contract Work	18	Z Solid	2 4 5 7	10 4 10 4	1 x 6
Y Y-8	Ohio Sandstone	18	3-piece gang	2 4 5 7	10 4 10 4	Each piece 1 x 2¼
6½ VW	Limestone, Slate, Marble and Soapstone	18	5-piece gang	2 4 5 7	10 4 10 4	Five pieces 1 x 1¼
VX	Work of all Classes	18	3-piece gang	2 4 5 7 8 10	6 0 6 0 6 0	Each piece 1 x 1¼

The double-head machine will cut from 40 to 50 per cent. more than this. In Georgia marble 220 square feet have been channeled in 7½ hours with a double-head "6½" channeler. In the Tennessee district, where single-head channels are the standard, 80 feet per day is considered a fair average for a season's channeling, taking into account delays and other loss of time. A good day's work will often run as high as 115 or even 140 feet per day.

In the Indiana Bedford oolitic limestone the "Class Y" channeler will cut from 200 to 350 square feet in opening up a quarry, when the stone is rough and uneven. In developed quarries the improved machines will cut from 400 to 700 feet, depending on the length of runs and the evenness of the stone. In the Carthage, Mo., district, where the stone is much harder, 125 to 150 feet is the limit of the "Y" machine's capacity, when operating with 140 pounds boiler pressure. In Joliet limestone a record of forty consecutive shifts, made with one "Y" channeler, on the turbine-wheel pits for the drainage-canal power house, in 1905, showed an average per ten-hour shift of 210 feet, with a high run of 382 feet in twelve hours.

In the Batesville, Ark., field, where the crystallized limestone is hard and close grained, the "Z" machine, with boiler attached, makes an average of 130 feet per day, and has cut as high as 250 feet on a test run. The "Z" in the tough sandstone found at the "Soo," using a "Z" bit, and putting in cuts from 9 to 12 feet deep, averaged from 60 to 75 feet under usual conditions, but when given long runs was able to make 150 feet in a day. In channeling gneiss, which is practically a soft granite formation, in New York City, the "Y-S" channeler, with air reheater, averaged from 60 to 75 feet per day of eight hours.

The "VX" machine, in channeling Vermont or Pennsylvania slate, operating on a steam pressure of 100 pounds, will cut, month in and month out, 60 to 75 feet per day, and under favorable conditions will run as high as 100 to 125 feet. The soft soapstone in which the "6½" and "VX" channelers are used in Virginia is cut at the rate of 150 to 250 feet with the "VX," and from 175 to 350 feet with the "6½" machine, depending upon the hardness of the veins. In engineering and architectural works, to judge the comparative cost of channeling along the outer boundry of an excavation, and removing the rock along the same line of survey by means of rock drills and blasting, the cost of a retaining wall, when necessary, must be added to the cost of removing the rock by blasting. A retaining wall, or other means, must often be employed to face the rough surface of a cut made by explosives, while no such work is necessary along a channeled wall.

Where a wall has been channeled, the undisturbed rock alongside of the cut is as strong and firm as before channeling. When explosives are used, on the other hand, for a distance back from the face of the wall the rock is more or less shattered, the extent of the shattering depending to a great extent on the care with which the work was done, and the skill of the rock-men.

At its best a blasted wall presents a rough, jagged surface, which for some purposes is objectionable and possesses economic disadvantages. For instance, flumes, mill races, canals, and channels of all kinds will conduct a greater amount of water, size for size, under the same head, when the walls are channeled, for they then present less frictional resistance to the flow of water through them.

Again, with a channeling machine rock can be excavated right to the surveyed line, and the cut is as smooth as the surface of a masonry wall. To work right to the line with drilling machine and explosives is not so easy a task, and when completed, if well done, is perhaps no cheaper than the channeled wall.

* * *

PART III.

EXPLOSIVES USED IN BLASTING

CHAPTER IX.

POWDER.

THERE are many different kinds of explosives used for different purposes, such as mining, army and navy, hunting, quarrying and in engineering works. For mining where there is danger of gas, flameless or safety explosives are used. For army and navy uses smokeless powders are used, while the various explosives so employed are sub-divided into different grades and classes. For the purpose of rock excavating, however, the consideration of explosives can be confined to blasting powders and dynamites, those being the two kinds of explosives commonly used.

HIGH EXPLOSIVES AND LOW EXPLOSIVES.—Explosives are classified in practice as high explosives and low explosives, and this classification separates the materials into blasting powder and dynamite.

Blasting powder is classed as a "low explosive" because it is exploded by a spark, flame or other means of generating a sufficiently high temperature, whereas "high explosives" are detonated by the powerful shock of a blasting cap or electric fuse. Low explosives, or blasting powders, are slower in action than high explosives of the dynamite group, and, consequently, are less likely to shatter the material blasted.

COMPOSITION OF BLASTING POWDERS.—All powders of the nitrate group, whether gunpowder or blasting powder, are frequently referred to as black powder. Gunpowder, the most familiar type of powder, consists of an intimate mechanical mixture of potassium nitrate, charcoal and sulphur in the following proportions by weight:

	Parts
Potassium nitrate	75
Charcoal	15
Suphur	10
Total	100

Ordinary blasting powder contains the same constituents as gunpowder, but in different proportions.

The composition of blasting powder averages as follows, different manufacturers using slightly different proportions:

	Parts	Parts	Parts
Potassium or sodium nitrate ..	65	76	66
Sulphur	20	14	11
Charcoal	15	10	23
	—	—	—
Totals	100	100	100

There are two grades of blasting powders made, which are classed by the DuPont Company as "A" and "B." The "A" powders are made of saltpetre and the "B" powders of nitrate of soda. Both are made in several standard granulations, or sizes of grains, as shown in Fig. 46, which illustrates the several granulations of "A" powders, listed, according to their letters, C, F, FF, etc. The lower the letter in the alphabet the coarser the grain of the powder, and the greater the num-

Fig. 46.
Group of "A" Powders.

ber of letters used to designate a grade the finer is the powder.

The various granulations of "B" powder can be seen in Fig. 47.

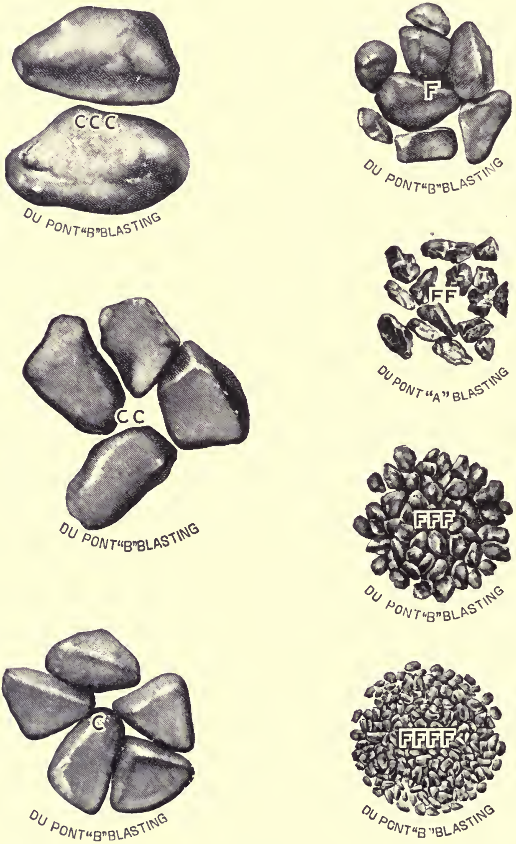


Fig. 47.
Group of "B" Powders.

An important fact about powders to bear in mind is that the finer the granulations the quicker the powder will act, consequently the more shattering the effect on the material blasted. "A" powders and "B" powders are both made either glazed (polished) or unglazed. Glazed or polished blasting powder withstands dampness or moisture better than unglazed, and will run more freely, therefore more of it can be put in a bore hole or pocket of given size. On the other hand, glazed blasting powder gives off a little more smoke than unglazed powder. Blasting powder will not give the best results unless the drill hole in which it is charged is carefully and compactly tamped to a depth sufficient to prevent a blowout. Furthermore, it is quickly affected by moisture, both in storage and in use, and care must always be taken to keep it dry. It cannot be used to advantage in wet works.

"A," or saltpetre, blasting powder is somewhat stronger and quicker in action than "B" blasting powder. It also withstands moisture better. It is used principally in marble or other dimension stone quarries, where conditions are such that "B," or nitrate of soda, blasting powder would not be sufficiently strong to give satisfactory results, and where high explosives would shatter the material too much.

"B," or nitrate of soda, blasting powder is very slow in action and is used in coal mines where gas and coal dust are not met with in sufficient quantities to cause dangerous explosions. It is so slow in its action that it lifts and pushes the coal out in large lumps and breaks it up but little if properly used. Granulations from FF to CCC are generally used in coal blasting, although FFF is sometimes necessary for hard coal.

The finer granulations of blasting powder, also a mixed granulation known as "railroad powder," is commonly used for engineering, architectural and other open-cut work, where the material is not particularly hard. "Railroad" blasting powder is a mixture of all the granulations of B powder from F or FF to FFF inclusive, for which reason it is possible to get a greater weight of it in a given space, as the smaller grades fill the spaces between the larger grains. This makes a mixed powder especially valuable in large blasts, where it is desired to shake down a large amount of material for removal by means of steam shovels.

PROPERTIES OF BLASTING POWDERS.—As black powder is a deflagrating, not a detonating, explosive, its quickness depends upon its rate of burning. By a deflagrating explosive is meant an explosive that does its work by an extremely quick burning of its ingredients to form gases, in differentiation from those explosives known as "high explosives," which are instantaneously converted into gases by means of a blasting cap or electric fuse. The "B" blasting powders are slower in their action than the corresponding sizes of "A" blasting powders, consequently do not seem to be so "strong." The "B" blasting powders are recommended wherever a particularly slow powder is required, such as blasting coal, particularly bituminous coal, earth, soft or rotten rock, etc.

Although both grades of black powder are ruined by contact with water the "A" blasting powders are less susceptible to the moisture of the atmosphere than the "B" blasting powders. If necessarily exposed to damp air, or stored in a damp place, the "A" blasting powders will retain their qualities for a considerably longer time, and should, therefore, be used in tropical climates where the air is heavily charged with moisture, or wherever the powder in storage or in use is to be exposed to unusual climatic conditions.

As has already been mentioned, black powder is a deflagrating explosive, and its quickness can be varied by changing its rate of burning. A certain number of large grains present less surface for ignition than an equal weight of smaller grains; thus the smaller-grained black powders burn faster and are quicker in their action than larger-grained powder of the same quality.

For blasting in any soft material, such as rotten or soft stone, where the material is wanted broken down in large fragments, a coarse-grained powder should be used. Where the material is hard, or where it is to be broken up fine, a fine-grained powder should be used. In either case an equal amount of material will be removed, but in the latter instance the rock will be shattered into finer fragments.

Hard-pressed powders and glazed powders

burn slower than soft-pressed powders of the same grade or unglazed powders. Also hard pressed and glazed powders are not affected by moisture as readily as soft-pressed or unglazed powders. Again, on account of the greater density of the hard-pressed grades of black powder, and on account of the smooth polish on glazed powders, these grades will pack closer in bore holes and cartridges, consequently give a greater explosive force, bulk for bulk, than the soft-pressed powders or the unglazed powders. Therefore, in the selection of a suitable powder for any particular work these several properties must be taken into consideration.

INITIAL FORCE OF EXPLOSIONS.—The potassium nitrate in a powder furnishes the oxygen for the combustion of the carbon and sulphur, which results in the production of a large volume of heated gas. It is the pressure of this large volume of gas which disrupts the rock in which it is liberated, consequently the greater the volume of the gas produced and the tighter it is confined the greater is the rending or shattering force.

After a blast has taken place the solid residue remaining occupies about one-third of the original volume or space, while powder exploded under conditions similar to those in practice yields from 175 to 200 volumes of gas at ordinary temperature and atmosphere pressure. The solid products resulting from the explosion occupying slightly more than one-third of the original volume of the explosive, and the gaseous products somewhat less than two-thirds, gives the relative volume of gases with respect to the actual volume of the hole they occupy as from 260 to 300 volumes. But we have been assuming that the expansion of the gas took place at ordinary temperature. As a matter of fact, however, there would be a great increase in temperature due to the explosion, and the volume of gas resulting would be many times more than 300, depending upon the nature of the explosive used.

The temperature of combustion for most of the explosives varies from 5,000 degrees Fahrenheit to 6,000 degrees Fahrenheit. In blasting coal with black powder the temperature of explosion does not much exceed 2,000 degrees Fahrenheit, owing to the slow combustion of the powder and the yielding nature of the coal, which shatters before the maximum pressure can be reached. This gives in coal blasting an expansion of about five times the gas produced, due to the heat of the explosion.

If, then, the relative volume of gas produced in powder blasting is 300 volumes, and the expansion due to heat equals five times, the blasting volume, pent up in that part of a drill hole originally occupied by the charge of powder, would be $300\times5=1{,}500$ volumes of gas.

High explosives, on the other hand, produce When exploded about 1,300 volumes of gas at ordinary temperature, or about 16,000 volumes at the temperature of combustion, giving a volume ten times greater than that of powder. This is possible on account of the quicker action of high explosives, which evolves the gases and raises them in temperature before fissures in the rock have time to open.

Powder used in rock blasting, on account of the greater resistance of the rock, will create a greater volume than in coal blasting. In practice it can be assumed that under ordinary conditions low explosives are capable of 1,500 expansions in blasting coal, about 2,000 in blasting rock, while high explosives are capable of about 16,000 expansions under similar conditions.

The initial force of an explosion, or the pressure exerted at the instant the explosion takes place, is proportional to the number of expansions of which the explosives are capable, and is equal to the atmospheric pressure multiplied by the number of expansions.

Example: With the atmospheric pressure 14.7 pounds per square inch, and blasting powder developing 2,000 expansions in rock blasting, what will be the initial force of an explosion in tons per square inch?

Solution: $\frac{2{,}000}{14.7 \times 2{,}000}$ =14.7 tons per sq. in.

MECHANICAL WORK OF AN EXPLOSION.—Theoretically, as pointed out in the preceding paragraph, the mechanical work of which an explosive is capable is estimated by multiplying the volume of gas produced in the explosion by the pressure of the atmosphere. In practice, however, the theoretical amount of work can never be realized. Further, the factors or conditions affecting the force of an explosion are so varied that seldom can exactly similar results be obtained from blasts fired apparently under similar conditions.

The stored energy of an explosive is only partly converted into mechanical work in blasting, some of the heat of combustion being lost by conduction in the material enclosing the explosive. In case the drill hole is damp or wet or the rock cold it will decrease the available heat produced by the discharge and the power of the explosive. Further. slips, joints, cleavage planes and loose tamping affect the blast, as do also the texture and structure of the rock, so that the work to be done by a blast cannot be calculated definitely beforehand.

AMOUNT OF EXPLOSIVE REQUIRED.—As the object of blasting is merely to shatter and dislodge the rock so that it can be easily removed, only enough explosive should be used to do the work. When fragments are thrown more than a few yards by a blast, it is generally evidence that too large a charge of explosive was used. Unfortunately, there is no rule that will apply in every case as to the amount of powder necessary to use in blasting. There is, however, a method and formula by means of which the approximate amount of explosive to be used may be judged, and the effect produced by such a charge will serve as a guide to the quarryman in determining whether to increase or decrease the amount.

In starting work on a new operation select a homogeneous rock bench about 2 feet wide and 3 feet high, and in the bench, far enough apart so they will not affect one another by opening up seams when blasted, drill several holes 3 feet deep, and of the standard diameter corresponding to the depth.

The holes are to be drilled 2 feet back from the face of the bench, thus giving a line of least resistance of 2 feet, to a depth of 3 feet, which is the right proportion.

Charge these several holes with different weights of the explosive to be used, beginning with a quantity too small to affect rupture, and increasing by regular amounts to a charge which will be more than sufficient. Explode all these charges separately, one at a time, and select as a coefficient for the formula the amount of explosive producing the desired effect.

The coefficient for future work where the line of least resistance varies can then be found by means of the following rule:

Rule.—To find the coefficient for rock blasting divide the effective charge of explosion used in the trial holes by the cube of the line of least resistance. The quotient will be the coefficient to be used in determining the amount of powder to be used.

Expressed as a formula:

$$\frac{P}{R^3} = C$$

In which

P =weight of powder in pounds and decimals of pounds.

R^3=cube of line of least resistance in feet and decimals of a foot.

C =coefficient for use in determining amount of powder required.

Example.—What is the coefficient required for determining the amount of powder to be used, in subsequent blasts with greater lines of least resistance, when in the trial blasts, with a line of least resistance of 2 feet, the powder used was 1-3 pound?

Solution.—Substituting in the formula the values given,

1-3 pound=.33 pounds, and $2^3=2\times2\times2=8$; then

$$\frac{P}{R^3}=\frac{.33}{8}=.04125$$

Having determined the coefficient, it may be used to find the charge of explosive required by the following rule:

Rule.—To find the charge of explosive required for blasting rock, multiply the cube of the line of least resistance in feet by the coefficient determined by trial blasts.

Expressed as a formula:

$$R^3 \times C = B$$

in which

R^3= cube of line of least resistance.

C = coefficient obtained as explained above.

B = charge of explosive required.

Example.—What weight of powder will be required to blast rock in which the line of least resistance is 8 feet, and the coefficient .04125?

Solution.—$R^3 = 8 \times 8 \times 8 = 512$. Coefficient = .04125. Substituting these volumes in the formula:

$R^3 C = 512 \times .04125 = 21.12$ pounds of powder. (Answer.)

In the foregoing example it must be remembered all the qualities were assumed, so that the result obtained in the answer does not necessarily represent the quantity that would be found in the application of the rule and formula in practice. The example is given and worked out to show how the rule and formula are applied. The main thing is to find the right coefficient, for naturally this will vary with the kind and quality of the rock, a larger charge being required for granite than would be needed for limestone or sandstone, while at the same time a smaller charge would be required for a soft granite than for a hard one, which would occasion different coefficients for these various materials.

The quantity of explosive determined in the foregoing manner is for rock with two free faces. In blasting where three free faces are exposed only two-thirds of the calculated charge need be used. In blasting where four faces are exposed only one-half the calculated amount need be employed. When five faces only two-fifths the amount, and when all six sides, as in the case of large blocks, are exposed only one-quarter of the calculated charge will be required.

When the quantity of explosive to use has been determined the size of drill hole that will hold the amount, while at the same time occupying in the bore hole a depth or distance equal to only twelve times the diameter, can be found in Table IX. This table was compiled from the formula

$$C = .3396gd^3$$

in which

C = weight of charge of explosive in pounds.
g = specified gravity of explosive.
d = diameter of hole in inches.

TABLE IX.

Size of Drill Holes for Different Weights of Explosives.

Name of Explosive	Specified Gravity of Explosive G	Diameter of Holes in Inches					
		¾	⅞	1	1⅛	1¼	1⅜
Blasting powder	1 000	.143	.228	.340	.480	.664	.880
Carbonite	1 120	.160	.258	380	.541	.742	.988
Ardeer powder	1 160	.166	.264	.394	561	.769	1.024
Blasting gelatine	1.550	.222	352	526	.749	1.027	1.367
Gelatine dynamite	1.550	.222	.352	.526	.749	1 027	1.367
Dynamite	1.600	.229	.363	543	773	1 060	1 060

Name of Explosive	Specified Gravity of Explosive G	Diameter of Holes in Inches						
		1½	1⅝	1¾	1⅞	2	2¼	2½
Blasting powder	1.000	1 148	1.459	1.822	2.240	2 720	3 872	5.312
Carbonite	1.120	1.280	1.630	2 036	2.505	3.040	4.328	5.936
Ardeer powder	1 160	1.330	1.690	2 160	2 597	3.151	4 488	6.152
Blasting gelatine	1.550	1.775	2 256	2.819	3 467	4.211	5.991	8.218
Gelatine dynamite	1.550	1.775	2.256	2 819	3.467	4.211	5 991	8 218
Dynamite	1 600	1 833	2.329	2 910	3 579	4 347	6.184	8.480

*Daw.

It will be observed that a 2-inch drill hole will hold only 2.720 pounds of blasting powder when properly charged, but that by changing from 2 inch to 2½ inch that charge can be almost doubled. The table does not give the size of hole for larger drill than 2½ inches, which corresponds to a charge of blasting powder of 5.3 pounds. This is a sufficiently large charge for ordinary building practice, although in large engineering works away from habitations as high as twenty pounds in a bore hole are used, and from 18 to 20 of such charges fired simultaneously. In works of that size it is found that in soft rock like limestone about two cubic yards of rock can be excavated for each lineal foot of hole drilled, and that each ¾ pounds of powder brings down about one cubic yard of rock.

When a blast is fired the workmen can judge whether or not there has been enough, too much or the right amount of explosive used. If the right amount of explosive is used there will be a deep boom and the rock will not be thrown with great force for any distance nor will it be badly shattered. If there was too much powder used there will be a sharp report and the blast will throw the rock a considerable distance, shattering it badly. If not enough explosive is used, of course, the rock will not be broken down in the right-sized fragments, as it should be. If too small a charge is used to break the rock the tamping will be blown out from the drill hole, just as a bullet is shot from a gun.

CHAPTER X.

CHARGING DRILL HOLES WITH POWDER.

CARTRIDGES AND TAMPING MATERIAL.—In open-cut work where the drill holes are dry and slope downward from the mouth, blasting powder can be poured into the hole and tamped. If the hole is sloped upward, however, the powder cannot be poured in loose, but must first be enclosed in cartridges, which are usually cylinders of Manila paper, and these cartridges can be tamped into the drill hole. In damp holes, likewise, the powder should be confined in cartridges to prevent it from losing its effectiveness by becoming damp or wet. Bore holes underground should never be loaded with loose powder on account of the danger of dust from the powder coming in contact with lights and carrying the flames to the main body of powder, thus causing an explosion.

The cartridges for use in blasting can be made by rolling paper around a wooden cartridge bar of a slightly smaller diameter than the drill hole. The loose edges of the paper are stuck down by means of miner's soap, one end of the paper is folded over to close the end of the cartridge, and the stick when removed leaves a paper cylinder. When the cylinder is filled with powder, the cartridge is completed by folding down the other end.

A uniform and compact tamping is essential with the use of black powder. For tamping black powder the material used should be free from small pieces of stone or other hard substances which might produce sparks or damage the fuse, consequently stone dust and coal dust are not considered suitable tamping, although for want of better materials they are sometimes used. The best material for tamping is moist clay. In holes having anything but a downward slant the tamping material is best wrapped in short paper cartridges. When loose powder is used a wad of paper should be tamped between the powder and the wet clay.

In tamping, if the hole is dry, the cartridges may be tamped hard enough to break the paper so the powder will pack close and fill all crevices—for the closer the powder is packed in the hole the greater will be the effect produced by the blast. If the hole is drilled in seamy rock a ball of clay may first be put into the hole and a bar driven into it to spread out and fill the seams and crevices. If these crevices are not filled the gases formed by the explosion will escape through them and part of the force of the blast will be lost. In wet drill holes the cartridges should be well coated with miner's soap and the filling not tamped hard enough to break the paper.

DEPTH OF TAMPING.—In deep drill holes it is never necessary to tamp the hole full, only sufficient tamping being necessary to prevent a blowout or to prevent yielding before the full force of the explosion is reached. With dynamite and other high explosives which develop their full power instantaneously, less tamping is required than with powder, for the reason that with the high explosives the shock is delivered on the sides of the chamber with sufficient force to burst the rock before it has time to affect the tamping. With high explosives very light tampings are sometimes used, as, for instance, filling the drill hole with water or filling the hole a few inches with sand or fine dirt, while for powder blasting considerable tamping must be used, the depth of tamping depending on the diameter of hole. For 1-inch holes the very least tamping that will hold is 17 inches; in a 2-inch hole, 18 inches of tamping; and in a 3-inch hole not less than 20 inches of tamping. These values are the minimum, it must be remembered, and in actual practice not less than 2 feet should be used for any size, while even deeper tampings will prove safer.

METHOD OF CHARGING A DRILL HOLE.—In Fig. 48 is shown how a drill hole is charged with powder, tamped and made ready to fire with a fuse. The fuse, it will be noticed, is extended to the center of the powder cartridge and where it leaves the top end of the cartridge is offset to one side of the drill hole to make way for the tamping. The tamping bar has a groove at one side so it will not cut or strip the fuse, or needle when a

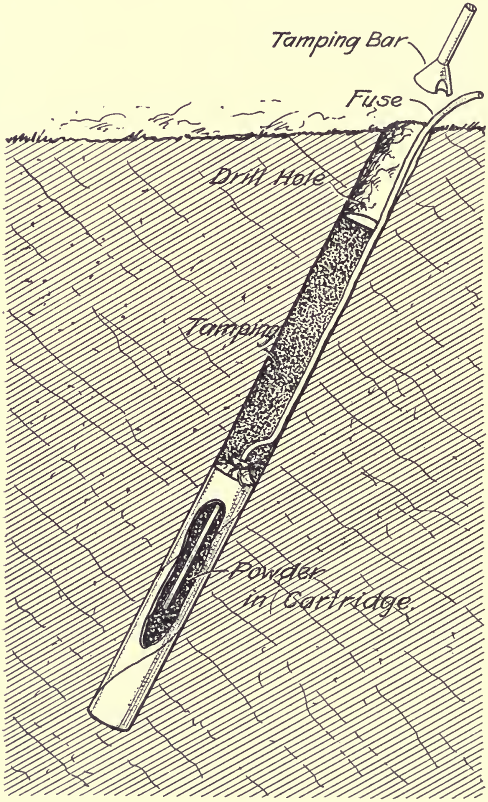


Fig. 48.
Method of Charging Drill Hole.

squib needle is used, and at the same time will tamp the filling well around the fuse or needle. Tamping rods having metal parts should never be used on account of the danger of striking sparks when tamping. When loose powder is poured in the hole it is of the greatest importance to use a wooden tamping rod, as an iron rod coming in contact with stone or pyrites is liable to spark and cause a premature explosion. Whenever a metal tamping rod is used, it should be either copper or brass, never iron or steel.

In filling the drill hole the tamping is put in and tamped little by little, the first few inches being rammed hard and the remainder only packed sufficiently tight to keep its shape and leave open the needle hole when a squibbing needle is used.

SQUIBBING.—Charging with a needle and firing by means of a squib is practised rather extensively, particularly in mines, but the operation is rather dangerous and requires careful manipulation. In this method a rod of metal called a needle, about ¼ inch in diameter and pointed at one end, is placed along the side of the bore hole, the powder placed in position, pressed down, the hole tamped and the needle carefully withdrawn. When the powder is in a cartridge, the cartridge is first inserted in the bore hole and the needle then placed in position, with the point piercing the cartridge a few inches. The withdrawal of the needle then leaves a channel down one side of the tamping and into the center of the powder in the cartridge, into which the squib is inserted.

A squib is a small paper tube or straw that is filled with a quick powder and has a slow match attached to one end. The burning of the slow match gives the workman time to get away after lighting it and before the flame reaches the powder. When this quick powder in the paper tube is fired it shoots like a rocket back into the blasting powder through the hole in the tamping left by the withdrawal of the needle.

In squib firing a metal needle is required, but this metal should be copper or some alloy like brass. It should never be of iron or steel for the same reason given for not using a steel or iron tamping rod.

USES FOR POWDERS AND DYNAMITES.—Black powders are generally favored for use in coal mines, building-stone quarries or other places where the material is to be taken out without too much shattering. Also for blasting in soft materials where all classes of high explosives are too quick in their action to utilize their entire strength. The great advantage of powder in these classes of work is that it exerts a strong push upon the material to be removed, not a quick, sharp, shattering blow, characteristic of high explosives.

It must be remembered, however, that dynamite is now made in nine or ten different grades, some slow acting, others quick acting, some full strength, others of less strength, so that dynamite can be used for almost every purpose that black powder is suitable for, and for many purposes for which powder would be unfit.

TESTS OF BLASTING POWDER.—The only tests of gunpowder that need be made by workmen or the superintendent on the premises are some simple ones to determine whether or not the powder is dry and in good, usable condition. If the powder has absorbed moisture enough to make it wet or damp, it should not be used until dried. One way to test for moisture is to rub the grains of powder on a piece of clean white paper. If the paper becomes blackened the powder is moist, while if not discolored no moisture is present.

Another method is the ignition test. If a small quantity of good, dry powder is ignited on a sheet of dry paper it will flash up instantly without burning the paper or discoloring it to any great extent. Burning of the paper usually indicates the presence of moisture. Black spots left on the paper after flashing the powder indicate an excess of charcoal or an imperfect mixing of the ingredients, usually the former, as with the machinery used in making powder the ingredients are well mixed together. Yellow spots on the paper indicate an excess of sulphur in the powder.

These tests at their best, while simple and easily made, give only a rough approximate idea of the quality or condition of the powder. At all events, if sufficient heat must be applied to the powder in testing to ignite the paper, it is pretty conclusive evidence that the powder is damp and not fit for use without drying.

DRYING BLASTING POWDER.—Don't use wet blasting powder. If the powder is only damp it can be dried, thereby making it suitable for use. The only way to dry damp blasting powder is to spread it out in the hot sun on a dry day and in a protected place where the wind cannot blow it away. The powder must be spread out in a thin layer and on a platform raised from the ground so it cannot absorb moisture as it is given off.

Powder should never be dried on a stove or near a fire, whether in the powder keg or loose, as there is liable to be a flash or explosion if it becomes overheated. The best way is to avoid the use of blasting powder if there is danger of it becoming damp or wet, and use a suitable grade of dynamite.

HANDLING BLASTING POWDER UNDERGROUND.—Too great care cannot be exercised in the handling of blasting powder underground in tunnels or shafts. Underground bore holes should never be loaded with powder unless the powder is made up into cartridges. The cartridges had better be made up in daylight on the surface and carried down in that way. Under no condition should a light, unless a safety lamp, be permitted near an open keg of powder, and if necessary to make up powder cartridges underground the light should be kept well away from the powder and to the windward side of it. If the light were on the "lee" side of the keg, powder dust from the loading might communicate with the light, thereby carrying the flame to the main body of the powder and exploding it. This is the reason that loose powder should not be used for charging bore holes underground. Trails of powder spilled on the ground or powder dust in the air might lead to a premature blast or an explosion of the powder in the keg.

TAMPING BAGS.—No bore hole can be properly charged with loose powder unless the bore hole points down. In tunnel driving and other inside and outside work, however, many of the drill holes point upward, and to properly charge them with powder the powder must first be made up in the form of a cartridge. In tamping bore holes that point upward it is likewise practically impossible to get loose material to stay in the hole as it should, and in practice tamping bags are made to hold the tamping material. Tamping bags and cartridges are made in the same way and same size and may be made by the workman himself as previously explained, or can be had with other blasting supplies.

The size, weight and other information about stock tamping bags can be found in Table X.

Blasting powder weighs approximately the same as water, which is 29.2 cubic inches to the pound. For convenience in calculating, 30 cubic

TABLE X.

Size, Number and Weights of Tamping Bags.

Size Number	Size in Inches	Number in Bale	Shipping Weight per Bale	Approximate Weight One Powder Bag Will Hold
A	1 x 8	5 M	32 Pounds	3 Ounces
B	1¼ x 8	5 M	33 "	5 "
C	1¼ x 10	5 M	35 "	6½ "
D	1¼ x 12	5 M	40 "	7¾ "
E	1½ x 8	5 M	35 "	7½ "
F	1½ x 10	5 M	40 "	9½ "
G	1½ x 12	5 M	57 "	11 "
H	1½ x 16	5 M	105 "	15 "

inches of powder is often assumed as weighing a pound. This gives to a cubic inch of powder an approximate weight of .53 ounces. These figures are, of course, only approximate, as the weight of powder in bulk depends on the size of the grains and how closely the grains are packed. The individual grains themselves likewise differ in weight, varying in specific gravity from 1.5 to 1.85.

CHAPTER XI.

HIGH EXPLOSIVES.

DYNAMITE.

NITROGLYCERINE.—There are a number of high explosives used for different purposes, but so far as ordinary rock blasting is concerned dynamite and blasting gelatine are the only ones that need be considered in detail. It will be well, however, to explain the nature of nitroglycerine, as this will help to a better understanding of the nature of dynamite, while gun cotton will also be considered as one of the active principles in all blasting gelatines.

Nitroglycerine is a mixture of nitric acid, sulphuric acid and glycerine. The glycerine used is the pure glycerine of commerce, a heavy, oily liquid resembling syrup and known as the sweet principle of oils. It is obtained by the decomposition of vegetable or animal fats or fixed oils. In the manufacture of nitroglycerine three parts of strong nitric acid are mixed with five parts of concentrated sulphuric acid, and after this mixture, which has become heated by the process, cools off, 1 to 1.15 parts of glycerine are slowly and gradually added, the mixture being stirred all the while. In the manufacture of nitroglycerine in dynamite mills, compressed air is generally used for mixing the ingredients, and every precaution is taken to prevent the mixture from heating.

After the nitroglycerine has been mixed it is poured into five or six times its bulk of cold water, where it sinks to the bottom as a heavy, oily liquid of a yellowish tint. The color is due to impurities in the ingredients, absolutely pure nitroglycerine being clear and transparent.

PROPERTIES OF NITROGLYCERINE.—At ordinary temperature nitroglycerine is an oily liquid, and must be confined in a bottle or like receptacle. It does not mix well with warm water, and seems to be unaffected by cold water, which makes solid explosives made of this mixture suitable for use in damp places and under water.

Nitroglycerine has a sweet, pungent taste, is an active poison, and produces in those unaccustomed to handle it nausea, faintness and severe headaches. Persons of a nervous temperament are more easily affected than others, but become accustomed to handling it without noticeable effect when made up into dynamite or like compounds.

In the liquid state, when confined, nitroglycerine is very sensitive and a slight concussion or jar is liable to explode it. This unstability makes nitroglycerine dangerous to store and handle, consequently it is not used extensively in liquid condition.

When frozen, nitroglycerine is less sensitive to concussion than when in the liquid state, but it is still dangerous to handle and the process of thawing is both difficult and dangerous. The explosive, furthermore, loses some of its force after freezing, so that all told little if anything is gained by keeping it in the solid condition. Freshly made nitroglycerine freezes at 55 degrees F., while purified nitroglycerine freezes to a white, crystalline mass at 36 degrees F.

The firing point of nitroglycerine is 356 degrees Fahrenheit, a comparatively low temperature, equal only to that of steam under a pressure of 132 pounds per square inch, but it decomposes at a lower heat. When unconfined, nitroglycerine will burn, but a spark will not explode it, a concussion or detonation being necessary to produce an explosion.

Outside of shooting oil wells, blowing safes and for a few purposes like that nitroglycerine is not extensively used in its free state. Its interest to us here lies in the fact that it is the active agent in all forms of dynamite, really is still nitroglycerine when made into dynamite, but is thus made comparatively safe to store and handle.

DYNAMITE.—Dynamite is simply nitroglycerine absorbed by some absorbent material called a dope. If the dope is merely an absorbent for the nitroglycerine and does not add anything to the explosive character of the mixture it is said to be inactive. If, on the other hand, the dope is of such a material or composition that when the explosion takes place the dope also ignites or explodes, thereby adding to the force of the initial explosion, the dope is said to be active. Strictly speaking, the term dynamite is applied only to those nitroglycerine explosives which have an inactive dope, and special trade names are given to those mixtures in which the dope is active. Ordinary dynamite, also dynamites with active bases, possess the advantages over nitroglycerine not only that they are less sensitive and can therefore be more easily and safely handled, but they can further be made in various degrees of strength and put up in packages for convenient handling.

DYNAMITE WITH AN INACTIVE BASE.—Dynamites with inactive bases have been made with such inert dopes as infusorial earth, magnesium carbonate, sawdust and charcoal. Of all the foregoing materials infusorial earth makes the best dope, as this earth is very porous and when carefully prepared will absorb 75 per cent. of nitroglycerine. In America, however, very little dynamite is made with infusorial earth, charcoal or any of the other dopes enumerated above, for the reason that cheaper dopes of equal safety can be had in the form of wood pulp. The wood pulp is usually mixed with sodium nitrate, which furnishes oxygen for burning the wood pulp when the dynamite is exploded. When a silicious dope like infusorial earth is used, on the other hand, it is inert, acts merely as an absorbent, and leaves a residue when the dynamite is exploded. Dynamite having an inactive base and containing less than 30 per cent. of nitroglycerine cannot be exploded.

DYNAMITE WITH AN ACTIVE BASE.—As ordinary dynamite cannot be exploded when it contains less than 30 per cent. of nitroglycerine, that is the lowest possible amount that can be used, and the force of the explosion cannot be regulated below that limit. The force of an explosion from that minimum limit upward, however, can be regulated by varying the amount of nitroglycerine the dynamite contains. That is the reason ordinary dynamite is not suitable for blasting coal, rock for building purposes, or for other purposes where shattering is not desired, while at the same time special dynamites with active bases can sometimes be used for those purposes to good advantage.

If, instead of the inactive base, some combustible or explosive substance be used as an absorbing dope and the proportion of nitroglycerine can be reduced below 30 per cent., it will explode, and the force of the explosion will be less than that from the weakest common dynamite. On the other hand, by retaining the same percentages of nitroglycerine and using an active base the force of an explosion can be increased beyond that which the nitroglycerine alone produces.

STRENGTH OF DYNAMITE.—The strength of all high explosives is based on their execution, comparing them with ordinary dynamite of known percentage. For instance, much of the dynamite now sold has an active base, but is classed as an ordinary dynamite so far as strength is concerned. It is rated as 40, 50 and 60 per cent. dynamite, but this does not mean it contains that percentage of nitroglycerine, but that it has an explosive force equal to 40, 50 or 60 per cent. common dynamite. Common dynamite, which is the standard of comparison, is rated according to the amount of nitroglycerine it actually contains, and a 40 per cent. common dynamite means that it possesses 40 per cent. of nitroglycerine.

The strength, or disruptive force, of special dynamites is due to the active ingredients forming the base as well as to the nitroglycerine. These ingredients differ in the fumes they evolve, water-resisting properties and resistance to freezing—consequently it is necessary to use different grades for different works, a non-gas-forming dynamite for tunnel or shaft work, a frost-resisting brand for outdoor work and cold weather, and a dynamite that will not be damaged by water for blasting in wet places.

APPEARANCE OF DYNAMITE.—Dynamite looks something like fine sawdust slightly dampened, but varying in color from black, brown, yellow, gray to almost white, depending on the ingredients used for the dope. For use in blasting, dynamite is made up into cartridges as shown in Figure 49. The cartridge wrappers are made of cylinders of paraffined brown paper, carefully folded down or crimped at the ends so that none of the contents can run out.

Fig. 49.
Cartridge of Dynamite.

SIZE OF DYNAMITE CARTRIDGES.—Dynamite cartridges are made of such diameters that they will enter their complementary bore holes, if of standard size, without forcing them. They are made in sizes from ⅞ inch to 2 inches in diameter, and in length of 8 inches. The standard stock sizes and approximate weights of dynamite cartridges can be found in Table XI.

TABLE XI.

Sizes and Weights of Dynamite Cartridges.

Diameter of Cartridge	Length of Cartridge	Approximate Weight of Dynamite
⅞ Inches	8 Inches	2 Ounces
1 "	8 "	4 "
1⅛ "	8 "	5 "
1¼ "	8 "	6 "
1½ "	8 "	9 "
1¾ "	8 "	12 "
2 "	8 "	1 Pound

Dynamite is shipped in twenty-five and fifty-pound wooden boxes, lined with paraffined paper and packed with sawdust.

PROPERTIES OF DYNAMITE.—Dynamite is rather plastic, which favors its being charged in a drill hole. In spite of the fact that glycerine is an oil, dynamite is not what would be called greasy. The specific gravity of dynamite depends some on its dope. Ordinarily, the specific gravity is about 1.15, which being heavier than water favors it when used for submarine blasting. Dynamite has the physical qualities of nitro-glycerine so far as explosive power is concerned, and is equally poisonous to those unaccustomed to handle it. Like nitroglycerine, dynamite has a firing point of 356 degrees Fahrenheit, at which temperature it will either burn or explode. If free from gas or pressure it will burn, but if jarred, even when loose and unconfined, may explode.

Ordinary dynamite freezes at a temperature of about 43 degrees Fahrenheit and becomes insensitive at from 45 to 50 degrees Fahrenheit. When completely frozen dynamite is hard and rigid. This condition is easily recognized, but it requires a careful examination to determine whether or not it is only partly frozen or chilled. Dynamite will not do good work if chilled, and when solidly frozen it is difficult or impossible to explode it, or if it does explode the detonation at best is only partial. Care should be taken, therefore, to see that the explosive is thoroughly thawed in cold weather before using. It is dangerous to cut, break or ram a frozen dynamite cartridge, as part of the cartridge might be in a thawed condition and the nitroglycerine crystals explode.

The sensitiveness of dynamite to blows or shocks increases very rapidly with rise of temperature, as would be expected, as that is a condition common to nitroglycerine, from which it is made.

In the foregoing paragraphs the properties of ordinary dynamite are pointed out. It will be well for the quarryman to remember, however, that there are special makes of high explosives which differ greatly in behavior from ordinary dynamite, while having the same explosive force. Monobel and Judson powder R. R. P., for instance, freeze at the same temperature as dynamite, but if a suitable detonator be used they can be properly exploded even when frozen. The Arctic brand of dynamite, on the other hand, does not freeze at all, and the Red Cross grades do not freeze until water freezes, at a temperature of 32 degrees Fahrenheit. It would follow from the foregoing that high explosives differ widely in their character, and it is of the greatest importance to select a grade best adapted for the work to be done. Besides the different conditions under which various grades of dynamite can be used, each kind of high explosive, except blasting gelatine, is made in different strengths, and each strength is put up in cartridges of various diameters, suitable for the different sizes of drill holes. When engaged in rock excavating, whether mining, quarrying, tunneling or removing rock in construction work, the superintendent in charge will do well to secure from the various manufacturers of explosives their catalogues and descriptive matter about the various brands of explosives they make, and the purposes for which they are best suited. Manufacturers of explosives, as well as independent experimenters, are constantly at work trying out new formulas, and as soon as the demand arises for an explosive of any quality, the demand is soon filled.

CHAPTER XII.

METHODS OF THAWING DYNAMITE.

THAWING FROZEN DYNAMITE.—Frozen dynamite will thaw out completely in a very short time if it is subjected to a dry temperature of 80 degrees Fahrenheit and the cartridges so arranged that the heat can reach them on all sides. Care should be exercised in this process, however, to keep the temperature from rising higher than necessary, for every degree through which the dynamite is heated brings it that much nearer its firing point and makes it so much more dangerous to handle. It is a dangerous practice to thaw frozen dynamite by passing it through the flame of a candle, heating it in an oven or holding it on a shovel before the open fire, for, while dynamite will frequently burn in the open and when unconfined, it very often explodes.

Convenience, safety and economy are all promoted by having a suitable thawing kettle or as many of them as are needed on an operation, for blasting cannot be properly conducted in cold weather without some appliance for thawing the explosives and keeping them thawed until they are loaded into the bore holes. A thawing kettle, specially designed for thawing dynamite cartridges, is shown in Fig. 50. It is simply what is known in the kitchen as a double boiler, only much larger, being made in two sizes, having capacities respectively of 22 and 60 pounds of the explosive. The space between the inner and outer kettles is filled with hot water or with cold water and placed on a stove or on a fire to heat, and when the water has been raised to the right temperature the kettle is packed in sawdust, the dynamite cartridges placed in the inner compartment and a cloth of some kind or other non-heat conducting material placed over the top to keep in the heat.

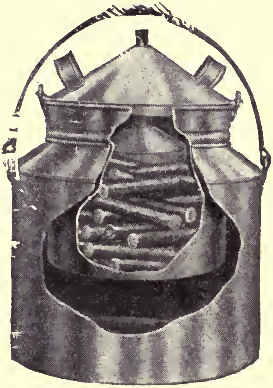


Fig. 50.
Kettle for Thawing Dynamite.

The temperature to heat the water is a question which must be considered when using a thawing kettle. It must be remembered that a temperature of 80 degrees is all that is required to thaw dynamite and keep it in that condition, while the firing point is 356 degrees, or only 144 degrees above the temperature of boiling water in an open vessel. It must be still further remembered that the higher the temperature of the dynamite the more unstable it is and the more likely to be detonated by a slight shock. It is well, therefore, to aim not to heat the cartridges to a higher temperature than 100 degrees Fahrenheit. If a full charge of 22 or 60 pounds of dynamite is to be placed in a kettle and the dynamite is frozen, the water may be raised to the boiling point, because the heat required to raise the temperature of the dynamite will lower the temperature of the water until they will both be around 100 degrees Fahrenheit. If only a small amount of dynamite is to be thawed, on the other hand, or the dynamite to go into the kettle is not frozen, merely chilled, or being placed there to keep from freezing, then the water should be heated only sufficient to perform the work it has to do without raising the temperature of the dynamite to a dangerous degree.

Dynamite should never be thawed by exposing it to steam or soaking it in hot water, as it will lose some of its strength and the nitroglycerine removed becomes a source of danger. For this reason the water in a thawing kettle should never be reheated by placing it over a fire or on a stove, as nitroglycerine from the dynamite in the thawing compartment might have been extracted and leaked through to the water compartment. When necessary to replenish the heat in a thawing kettle, add warm water from another vessel. In the absence of a thawing kettle, burying dynamite in a water-tight box in fresh manure which is giving off heat is a safe and effective way to either thaw or keep in a plastic state dynamite cartridges. The method requires considerable time, however; a suitable manure pile is not always available and it would seem more logical to get a thawing kettle than a special water-tight box.

THAWING BOXES.—Fresh manure is a thawing agent which is inexpensive, convenient, safe and

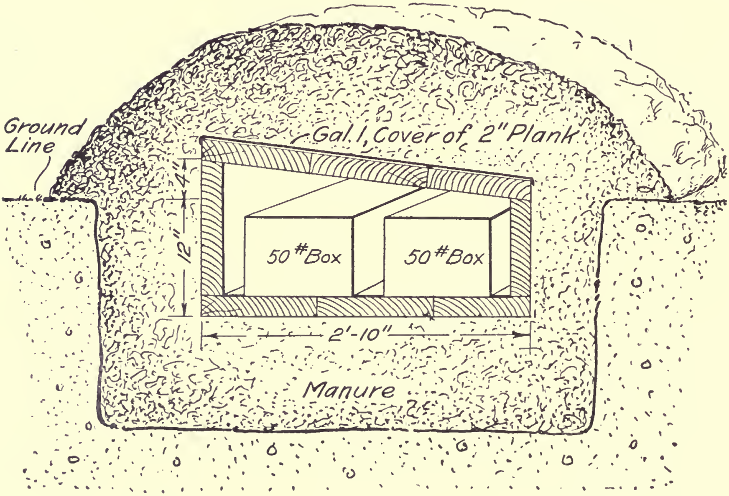


Fig. 51.
Thawing Box for Dynamite.

usually readily obtainable on all large blasting operations where horses form part of the working force or equipment. Manure is efficient, however, only when it is fresh and will give off heat. It is useless to take old manure in which no heat is being given off by the fermentation taking place. Time is another element in the thawing of dynamite by means of manure, for it must be thawed in large quantities, and the larger the quantity the longer it will take. The dynamite cartridges must not be allowed to come in contact with the manure, as the moisture would draw more or less nitrogen from the absorbent. It must be buried in the manure, therefore, either in closed cases or in specially designed boxes or magazines having walls lined with manure. A box for thawing dynamite is shown in Fig. 51, which will give an idea of how to construct a thawing box for manure. If there is a big heap of manure available, it may be buried in the manure heap. If, on the other hand, manure is not so plentiful, a hole or pit can be dug in the ground a sufficient depth to permit a good, deep lining of manure. The box is then placed in the pit on top of the manure lining, and the sides banked up to the level of the ground. The dynamite cartridges in the cases, the tops of which should be removed before placing them in the thawing box, may now be placed in position, and the cover placed, then the whole heaped up with manure. In the course of time, a nice even temperature will be generated inside of the thawing box, and all of the dynamite will be thoroughly thawed.

It is advisable to take the covers off the cases before placing them in the thawing boxes, so that sticks or cartridges of dynamite can be taken out by simply removing the cover of the box, and without jarring or otherwise disturbing the dynamite. Removing the cover further gives more of a chance for the heat to reach the interior of the case.

The thawing box shown in the illustration is made for just two cases of dynamite. They can be made any size desired, however, just as well as for two cases. The walls of the box are made of 2-inch planks, one side higher than the other, to give a pitch to the cover. This pitch, together with a layer of galvanized iron, sheds all moisture from the box and keeps the contents dry. A double-wall manure box may be used instead of a single-wall box when desirable, the other box or wall serving as the pit shown in the illustration.

A thawing box 22 by 34 inches will be found large enough to hold two fifty-pound boxes of dynamite, and will leave room all around them for the heat to reach all sides. At the same time the extra room will facilitate handling boxes or cases when placing them in the thawing box or taking them out.

Whether in storage or in a thawing box or house, dynamite cartridges ought to be placed so they will lay on their sides, not stand on their ends, for if standing on their ends the nitroglycerine is liable to ooze from the dope and collect in the bottom of the receptacle.

THAWING HOUSES WITH MANURE-FILLED WALLS.—In Fig. 52 is shown the construction of a dynamite-thawing house with manure-filled walls. It is 8 by 10 feet outside dimensions, and is 7 feet 6 inches high inside.

The house has walls 18 inches thick, filled with fresh manure, and possesses a storage capacity

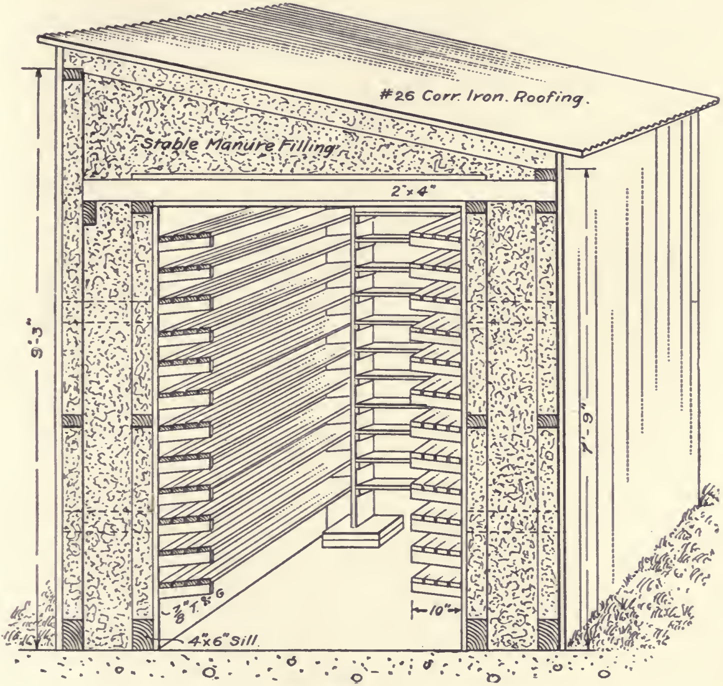


Fig. 52.
Thawing House for Dynamite.

of from 800 to 1,200 pounds of dynamite, taken out of the cases and placed in a single layer on the slatted shelves. This thawing house depends for its heat entirely upon the stable manure which fills the walls. The length of time required to thaw the stored dynamite, and the thickness of the walls, are variable quantities and depend to a great extent upon the severity of the climate and the age of the manure.

With good, active manure giving off a large quantity of heat, eighteen inches of manure will be found sufficient for any ordinary locality. A thawing house of this size and character is adapted to work requiring a large quantity of explosive, but running through a period of one winter only, or a few months of cold weather. However, by removing some of the top boards from the walls and replacing the old manure with a lot of fresh manure each winter, such a thawing house can be used indefinitely.

The class of materials used in construction can be changed to suit any local conditions. For instance, the illustration shows the roof covered with galvanized sheet iron. It may be more convenient in some cases, however, to cover the roof with tar paper or some other prepared roofing material, while in some places the climatic conditions or the short time for which the house is to be used will permit the omission of any other covering than the sheathing.

On the other hand, in some places it may be advisable to cover the walls as well as the roof with sheet metal or other like material.

This thawing house possesses one bad feature. It is so arranged that it is necessary to enter to get dynamite or place it on the shelves.

As the house is both warm and convenient, there will, therefore, be a probability of using it as a place in which to make up the primers for the blasts, unless regulations to the contrary are emphatically enforced.

STEAM THAWING HOUSE.—Permanent houses for thawing dynamite are preferably heated with exhaust steam or hot water. So far as the method of construction is concerned, there is no difference between the construction of a steam-heated thawing house and one heated with hot water, except that when exhaust steam is used the supply is obtained from the engine, or pump house, while when the thawing house is to be heated with hot water, a special heater house will be required, unless the boiler house already on the premises happens to be so located that it can be used.

Exhaust steam is usually the most convenient and inexpensive heat that can be used, for at the majority of permanent works where explosives are used there is an engine or pump, the exhaust steam from which can be used at practically no cost for the heat required in the coils of the thawing house.

Live steam is dangerous to use, because of the high temperatures of steam under pressure. Eighty pounds is a comparatively low pressure for steam driving an engine or pump, but at that comparatively low pressure steam has a temperature of about 324 degrees Fahrenheit, while the dynamite has a firing point of only 356 degrees Fahrenheit. At a pressure of only 131 pounds per square inch, a pressure commonly carried in power plants, the temperature of the steam is 356 degrees Fahrenheit, the firing point of dynamite. It will be seen, therefore, how necessary it is not to have live steam for thawing purposes, for if some of the workmen were to carelessly, ignorantly or recklessly attempt to thaw out sticks of dynamite on the steam coils, as they sometimes do, there would in all probability be an explosion if steam of sufficient high pressure were being used.

It is well to keep a thermometer on the back wall of the thawing house, in what ought to be the hottest part of the interior, and have a double glass window in front of this thermometer, so the temperature of the interior can be determined without opening the door and admitting cold air. A damper should also be placed in the ventilation flue to permit the regulation of the air circulating through the house.

A thawing house suitable for the use of either exhaust steam or hot water is shown in Fig. 53. In this case, however, a heater house is incorporated, showing the method of connecting up the water heater with the heater coils.

It will be noticed that the house cannot be entered. On the contrary, the dynamite is placed on and taken from wooden trays or drawers which slide in and fill the compartments where they are located. It follows that it is impossible to use such a house as a place for priming cartridges or doing other work of a like dangerous character.

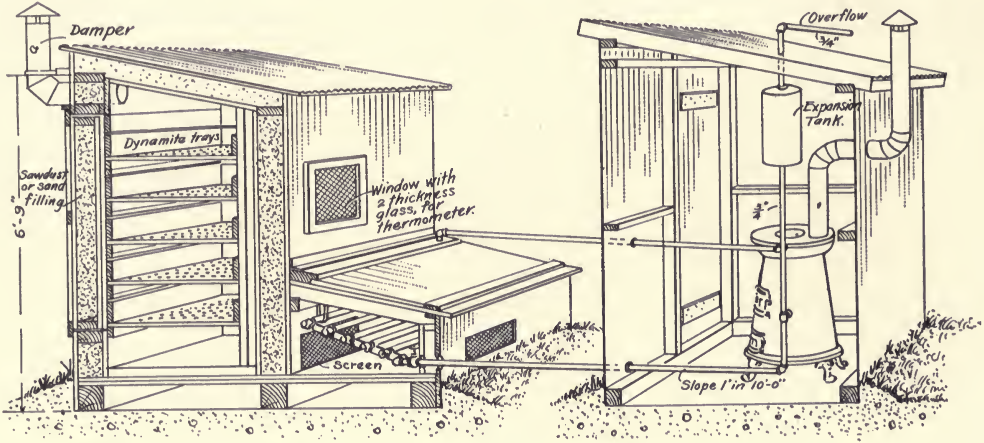


Fig. 53.
Steam or Water Heated Thawing House.

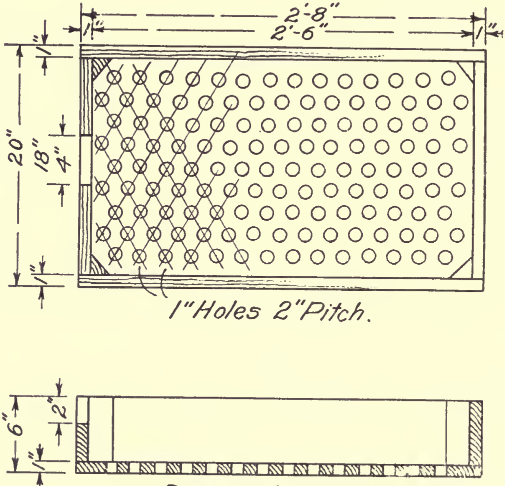
It ought to be needless to add that the thawing house should always be kept locked and that only one person should have possession or custody of the key to the lock.

The heating coils for a thawing house must never be placed in that portion of the building where the trays are located, but must be installed in a little lean-to attached to the thawing house, and from where the heat from the coils can spread to the tray racks. It is well to so construct the lean-to that air will circulate freely through, in at the bottom from the dynamite trays, up through the heater coils, and out again at the top into the thawing room. The amount of heating surface required in the steam or hot water coils will have to be worked out in each case. It will depend upon the size of the building, the way it is built, and the climate where the thawing house is to be located. In severe climates, also where there is a variable climate, it will be well to have the coils in sections and controlled from the outside, so that sections can be thrown into service, or cut out as occasion requires. The aim is to keep the interior of the thawing house and its contents at a uniform temperature of about 80 degrees Fahrenheit.

The walls of the house must be carefully looked after, as they must be well insulated. Either sand or sawdust may be used for this purpose when the thawing house is in a protected place, out of danger of rifle shot. When there is a possibility of the building being used as a target for rifle practise by careless persons, however, it is better to use sand for the filling material, the same as in magazines for the storage of dynamite. The precaution to use coarse, dry sand, but not coarse gravel, should be observed here the same as in the case of storage magazines, and for the same reason.

The size of house to build will depend upon the quantity of dynamite that is to be thawed. The size is regulated to a great extent by the size of trays. The trays are made 18 by 30 inches inside measurement, by 5 inches deep, and are designed to hold 50 pounds of dynamite each. Ten inches space in height is allowed for each of the trays, and a tier of five trays allowed to each compartment. Two such tiers would make a thawing house holding 500 pounds of dynamite, and if a larger building is required, it can be increased in units of 250 pounds each, making at the same time a corresponding increase in the size of the steam or hot water coils.

A dynamite tray for a thawing house is shown in Fig. 54. The bottom of the tray is either slatted or perforated, to allow the circulation of air. When hot water is the heating medium used, the heater house must be situated at a sufficiently low level, so that there will be a rise of at least 1 inch in 10 feet in the pipe from the top of the heater to the hot water coils in the leant-to of the thawing house. If this grade is lacking there will be no circulation of hot water, but steam will form in the heater and make a rattling, snapping sound. For safety sake the system must never be a closed one, but must be open and provided with an expansion tank to prevent the pressure ever rising above that due to the head of water. If the water were confined in a closed circuit, pressure would be generated, and as the temperature of boiling water and steam are the same under



Dynamite Tray.

Fig. 54.

equal pressures, the water in a closed hot-water system could be made as hot and, therefore, as dangerous as steam in a direct steam system using high pressure. There would likewise be the additional danger of a boiler explosion, with the possible detonation of the dynamite. With an open system of hot water heating, on the other hand, the temperature of the water can never rise above 212 degrees in the heater, and would be much less than that at the coils, so that the danger of overheating is thus minimized by using an atmospheric system of hot water heating.

Distance of the heater house from the thawing house is another condition that requires consideration. A distance of from 30 to 50 feet has been found the most satisfactory. Too close proximity of the heater house to the thawing house, that is, a distance of less than 30 feet, adds to the fire risk, while too great a distance, that is, further than 50 feet, increases the cost of construction and diminishes the economy of operation. The aim should be, then, to strike the happy medium between the two extremes.

The exposed piping, of course, must be well insulated, or a frozen pipe and interrupted service will result. The best of pipe covering is none too good for this purpose, and non-combustible covering material would be preferable to combustible materials.

At permanent works, an inexpensive way to keep dynamite from freezing is to store it in a stone, concrete or brick vault below the surface of the ground, and well below the frost line. The roof can be tightly roofed over and banked with earth or manure.

Perhaps no better advice could be given in this chapter on dynamite than to incorporate the rules to be observed in handling dynamite, sent out with each shipment of high explosives by the DuPont Powder Company:

Never under any circumstances forget that it is an explosive, and must be treated as such.

Do not store blasting caps or electric fuses near dynamite. They are easily exploded, but by themselves do only local damage. If they are in the vicinity of dynamite they might set it off and cause great loss.

Do not carry or transport blasting caps or electric fuses together with dynamite.

Never expose dynamite to the direct rays of the sun, a fire or hot stove. Never roast, toast or bake it in any way.

Never put it on or in a stove or oven, on hot steam pipes or on any hot metal.

Never fire into dynamite with a rifle or pistol, either in or out of a magazine.

When a shot misses, never dig it out. Take plenty of time before investigating.

Never use a metal tamping rod. Wood is the only safe material.

Never attempt to use frozen dynamite. Thaw it first.

Never store dynamite in a wet or damp place.

Never leave it in a field where stock can get at it. Cattle like the taste of dynamite, but it would probably make them sick.

All explosive material should be kept in a suitable dry place, under lock and key, and where children or irresponsible persons cannot get at it.

GUNCOTTON AND BLASTING GELATINE.

GUNCOTTON.—Guncotton is a highly explosive compound prepared by treating cotton or other cellulose materials with strong nitric and sulphuric acids. Ordinary cotton of commerce is the cellulose material most commonly used for this purpose.

Guncotton is highly inflammable, burning without ash, but quietly unless under compression, when it will explode. It is largely used as an ingredient in smokeless powder, but as an explosive it has been largely superseded by dynamite. When dry, guncotton is very sensitive and easily exploded, but when wet with from 15 to 30 per cent. of water it is insensitive to all ordinary shocks. While in this condition, however, it may be caused to detonate by detonating dry guncotton in contact with it. The dry guncotton can be detonated in a number of ways, but the surest and most convenient is by means of a fuse of fulminate of mercury or a detonator of the same material in a rubber sack in contact with the dry guncotton.

Guncotton differs but little in appearance from ordinary cotton, but it is harsher to the touch and less flexible. It is insoluble in hot or cold water, but it is readily soluble in many other liquids, notably a mixture of ether and alcohol. Guncotton by itself is not much used for rock blasting, but it forms the base of a number of powerful powders, among which are "Tonite," consisting of guncotton 52.5 per cent. and barium nitrate 47.5; and "Potentite," consisting of 66.2 per cent. of guncotton and 33.8 per cent. of potassium nitrate. Blasting gelatines are also made from guncotton mixed with some solvent.

The explosive force of guncotton has been found to be more than fifty times that of equal weights of gunpowder.

BLASTING GELATINE.—Blasting gelatine is a compound of guncotton and nitroglycerine in which, strange to say, the qualities of both explosives are so far modified that the resulting blasting gelatine, while retaining nearly all of the explosive force of its true constituents, is made less sensitive than either. It is probably the safest of the high explosives, with the exception of wet guncotton. Blasting gelatine is a yellowish brown, jellylike mass, having a specific gravity of 1.6. It does not absorb water, nor is it affected by water, being only slightly affected at the surface when immersed in water. This property makes it more suitable than dynamite for use in wet places, for under the action of water the nitroglycerine in dynamite has a tendency to exude.

When unconfined, blasting gelatine burns with a hissing sound, but will not explode. When confined it explodes at a tempreature of 399 degrees Fahrenheit, which is 43 degrees above the firing point of either nitroglycerine or dynamite. It freezes at a temperature of 35 to 40 degrees Fahrenheit, and when frozen is far more sensitive than when unfrozen, which makes it unsuitable for extremely cold climates but rather suitable for warm ones.

Closely allied to blasting gelatine are gelatine dynamites, which are formed by absorbing blasting gelatine in an active base in a similar manner to making ordinary dynamite by absorbing nitroglycerine with a dope. Many of the dynamites of commerce are really gelatine dynamites, they generally being packed, shipped, classed and otherwise treated as dynamites. Different grades of gelatine dynamites are made with a view of providing a suitable explosive for every known condition. Among the advantages claimed for this kind of high explosives are that the gases produced are less injurious, therefore in tunnel driving the drill runners and muckers can return to their work with less loss of time and be in better physical condition during the rest of their shift. Gelatine dynamite is heavier, bulk for bulk, than ordinary dynamite and consequently can be more easily loaded in water. Being heavier allows a shorter charge to be used, thereby saving the extra depth of drill hole. It is less affected by water, which makes it more suitable for submarine work and wet work, and being plastic it will stick in upward drilled holes and not be jarred out by other shots.

Among the gelatine dynamite group are the following well-known commercial brands: Hercules gelatine, Atlas gelatine, Repawno gelatine, Giant gelatine, Ætna gelatine and Forate. All the explosives of the dynamite group, that is the high explosives such as guncotton, blasting gelatine and gelatine dynamites, are handled and stored like dynamite, and are generally classed as such. Guncotton should be excepted from this list to a certain extent, for instead of keeping guncotton dry, it is kept wet, as it is less liable to detonation while in that condition. It is well for the quarryman and miner to know the differences between the various explosives, their peculiarities and properties, as this knowledge makes more safe, or less dangerous, the handling of them.

CHAPTER XIII.

DETONATORS FOR EXPLODING CHARGES.

FULMINATE OF MERCURY.—Fulminate of mercury, one of the most sensitive and violent explosives known, and therefore one of the most dangerous, is not used as a blasting agent but merely as a detonator for exploding charges of other explosives. Fulminate of mercury is in fact never handled except in very small quantities. It is, however, almost indispensable in work with other explosives, because the shock resulting from its detonation has some peculiar characteristics, not fully understood, by reason of which it can detonate any high explosive with which it is in contact. Moreover, the flame from its detonation ignites and so explodes blasting powder. Fulminate of mercury explodes when heated to 305 degrees Fahrenheit.

DETONATORS OR BLASTING CAPS.—The most common example of the use of fulminate of mercury is in the percussion caps for ordinary shotgun shells, cartridges for rifles or revolvers, and such purposes. In rock blasting the blasting cap shown in Fig. 55 is likewise charged with this sensitive explosive, which is used in connection with safety fuse to detonate high explosives. These caps are readily affected by moisture, and must be kept perfectly dry until used. They are put up in lots of 100 in tin boxes, and these tin boxes are packed in wooden cases containing respectively 500, 1,000, 2,000, 3,000 and 5,000 blasting caps. In Table XII can be found the trade name, marking and sizes of DuPont blasting caps.

Fig. 55.
Blasting Cap.

TABLE XII.

Sizes of Blasting Caps.

Name and Number of Caps	Silver Medal No. 3	Gold Medal No. 4	Du Pont No. 5	Du Pont No. 6	Du Pont No. 7	Du Pont No. 8
Color of Box	Silver	Gold	Blue	Red	Brown	Green
Length of Caps	1″	1″	1¼″	1¾″	1¾″	1¾″

Blasting caps must be kept perfectly dry, and it is well not to take the detonators into a wet or damp working until they are actually needed, as they deteriorate rapidly underground or in a damp place. For example, according to some experiments made in Leadville a number of years ago, fresh caps which gave complete detonation, when kept underground for twenty-four hours gave incomplete detonation; after forty-eight hours underground, they gave incomplete detonation without red fumes. After seventy-two hours underground, one of the caps exploded without detonation, and finally, after being underground one hundred and forty-four hours, or six days, practically a work week, the caps refused to explode.

The strength of the blasting caps should likewise be considered, for it is poor economy besides increasing the danger to use weak detonators. A strong blasting cap will not only bring down from 10 per cent. to 25 per cent. more material when used to detonate a charge of explosive than where weakened caps are used, but there is less danger of a strong cap missing fire and a missed shot is not only a financial loss but a source of danger. In the table of sizes of blasting caps the numbers 3, 4, 5, 6, 7 and 8 refer to the strength of the caps —the higher the number, the higher the strength. As different manufacturers use different amounts of fulminate of mercury in the caps, only the approximate strengths can be given. What are known as single-strength and double-strength caps are not used in the United States. Triple-strength caps, the weakest used here, contain from 4½ to 5 grains of fulminate of mercury. Quadruple strength contains from 6 to 7 grains; quintuple strength, 8 to 9 grains; the next size, 10 to 11 grains; then come 12 to 15 grains, 19, 23 and 31 grains respectively.

MEANS OF FIRING EXPLOSIVES.

FIRING WITH FUSES.—Blasting powders may be fired by means of squibs, fuses or safety fuses with blasting caps, for blasting power explodes upon being ignited, and any safe means that will cause ignition may be used. High explosives, on the other hand, must be detonated, and for this purpose a safety fuse with blasting cap or an electric fuse or detonator must be used. Fuses defer the time of explosion to allow the quarryman to reach a place of safety before the blast takes place. Once the fuse has been lighted, however, he has no further control over the time of explosion than that provided for in the length and make of fuse used. With electric firing, on the contrary, everything can be put in readiness and the time of firing deferred to suit the operator's convenience, a simple pulling up or pushing down of the handle of the blasting machine causing the explosion. It will be seen that in electric blasting, therefore, the time of the blast is completely under the operator's control, which makes this the safest means of firing explosives.

DESCRIPTION OF A FUSE.—A fuse is a tube, generally flexible, filled with an inflammable compound, or, what is more commonly the case in blasting, a cord or tape inflammable itself, or impregnated with an inflammable substance, usually slow burning and intended to convey fire to an explosive or combustible mass, but so slowly as to allow the escape of the person lighting it. While fuses are generally made slow burning for rock blasting, there are also made quick-acting fuses, some of them almost instantaneous in their action. It is well, therefore, to test a fuse before using it by noting the rate of burning of a short piece. The rate of burning of ordinary fuses varies from 18 inches to 4 feet per minute. For most purposes a fuse with a rate of 2 feet per minute will be found the most satisfactory.

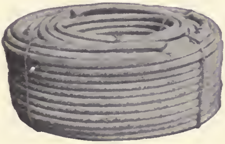


Fig. 56.
Coil of Fuse.

Fuses are shipped in coils as shown in Fig. 56. They are put up in cases of 500 feet, 1,000 feet, 2,000 feet, 3,000 feet, 4,000 feet, 5,000 feet, 6,000 feet, and in barrels of 8,000 feet. It might seem needless to say that fuses should be stored in a cool, dry place, and out of contact with oil. The interior of the place of storage should further be kept free from sudden changes of temperature. Fuses are made in a number of grades, depending upon the character of work for which they will be used. In Table XIII will be found the several grades put out by the DuPont Company and the uses for which they are intended.

While certain grades of fuses can be depended upon for very wet work, or even work under water, they cannot be relied upon to give satisfactory results in submarine work or under any depth of water. Blasting in this kind of work should always be done by electricity, as in submarine work the pressure might force water into the cartridge or fuse, saturating them and rendering them useless.

TABLE XIII.

Name and Use of Fuses.

Dry Work or Damp Work	Wet Work	Very Wet Work or Work Under Water
Single Tape	Double Tape Crescent Reliable	Triple Tape Stag

Firing with Fuse and Cap.—As was previously pointed out, blasting powder can be fired by means of a fuse without the aid of a cap, but for dynamite or other high explosive some form of detonator must be used, which in turn may be fired by a fuse. To prepare the cap and fuse for use, the fuse is cut off square across, never at an angle, so fire cannot sputter out the side and ignite the explosive before the cap has a chance to detonate, and so the cap can be given a good hold

Fig. 57.
Fuse Attached to Blasting Cap.

when crimped onto the fuse. The cap is next crimped onto the fuse as shown in Fig. 57, by means of a pair of special crimping pliers or cap crimpers. This crimping should never be done by means of the teeth or by pounding the cap with an iron bar, and care should be taken to crimp the cap near the open end so that the fulminate in the other end of the cap will not be disturbed, for if the fulminate should happen to be tightly pinched an explosion might result.

When the fuse is properly capped, next fold back the paper from one end of the dynamite cartridge and with a sharp stick like a lead pencil but of just the right size for the cap to slip into the opening made, gently make a hole in the top of the dynamite and in this hole push the blasting cap, as shown in Fig. 58, then tie the paper to the fuse, as shown in the illustration. Instead of making the hole parallel with the axis of the dynamite catridge it can be made slanting to one side, so the fuse will be along one side of the bore hole and out of the way of the tamping. Some rock-men extend the hole down to the center of the cartridge so that the detonation will take place in the center of the dynamite. It is a question, however, whether anything is gained by that method, while carrying the fuse through a couple of inches of the explosive is liable to ignite it, thereby causing

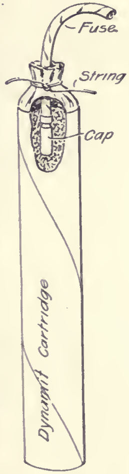


Fig. 58. Blasting Cap in Dynamite Cartridge.

deflagration of the cartridge instead of detonation. In short cartridges it would seem that the top method of priming was the best, the only objection being that the fuse is more or less in the way and apt to be bent or injured by the tamping.

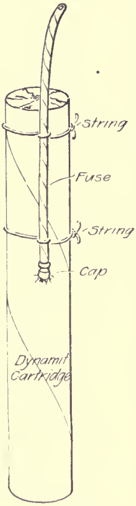


Fig. 59.
Fuse Attached to side of Cartridge.

In long cartridges, 18 inches and thereabouts in length, if it is deemed advisable to place the cap near the center of the dynamite, the best way is to run the fuse down the outside of the cartridge and insert the cap through a hole on the side which points *downward,* as shown in Fig. 59. The fuse must *then* be bound in place with strings, as shown in the illustration, to prevent the cap being pulled out or otherwise displaced when placing the cartridge in the bore hole and tamping the drill hole for the blast.

All that is then necessary is to cut off the fuse, allowing a sufficient length of time for the operator to get to a place of safety before the explosion takes place. If a two-foot fuse is being used, that is, a fuse that burns two feet per minute, and it will take two minutes to reach a point or place of safety, a fuse *at least* four feet long over all should be used, while under some conditions, such as a difficult place to get away from, a greater length would prove safer. There is no advantage gained by placing the blasting cap at the center of the dynamite cartridge, because the instant detonation takes place the shock is communicated to the entire mass, so that wherever the cap is all parts of the dynamite are equally affected.

Some rock-men and miners when placing a blasting cap in the side of a cartridge make the hole pointing upward, then bend the fuse back again upon itself to point toward the mouth of the drill hole. Such a practice is bad and should be discouraged, for the sharp bend might pull the fuse free from the cap, or if it does not, the sharp bend in the fuse might be sufficient to cause a break in the train of powder or choke the fuse, so the fuse will snuff out and a misfire result.

Lighting the Fuse.—When all is ready for firing the shots, the quarryman has but little time at his disposal after he has lighted the first fuse, and it is important that each fuse takes the flame as he passes along. If an ordinary fuse be merely cut off and a match or lighter applied, the powder will not always ignite immediately and the lighter might have to leave before all the fuses are lighted. In order to make sure that all the fuses take fire, special flaming pieces are often provided. In Fig. 60 is shown one method of priming fuses for ignition. The end of the fuse in this case is split for a short distance and a wedge of giant powder introduced into the split.

Fig. 60.
Fuse Primed for Lighting.

When giant powder is ignited in the open it burns with a bright, fierce flame, so that a small piece lighted in the end of a fuse is almost sure to ignite it.

Another method is shown in Fig. 61. A piece of candle wick dipped in kerosense or alcohol is twisted about the end of the fuse, so that all that is necessary is to walk along the line of drill holes applying the flame of a torch to each candle wick in turn. The kerosene soaked wick will immediately burst into flame, and the flame from the burning wick will ignite the fuse.

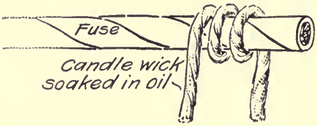


Fig. 61.
Lampwick Primer for Fuse.

As it is desirable to count the shots when blasting by fuse to see that they have all gone off, the fuses ought to be made of different lengths so that one shot will follow another when they are all lighted at the same time. Having the shots follow one another instead of exploding simultaneously does not give as great disruptive force, but it is safer for the workmen. Besides, it is almost impossible to so time all the fuses in a battery that the explosions will all take place together. Electric blasting is the only method which will accomplish this.

CHAPTER XIV.

FIRING BLASTS BY ELECTRICITY.

Advantages of Blasting by Electricity.—Blasting by electricity is now conceded to be the safest, most economical, most effective and by far the most convenient way of firing explosives, surpassing any other for safety and certainty of action. By electric firing the entire strength of the explosive is developed at the same instant, less explosive being thus required where these are a number of drill holes than when each hole is fired separately, as is more than likely to be the case when fuses are used.

By electric blasting all holes are exploded simultaneously, and if all connections are properly made there is no possibility of a second explosion. If a misfire occurs by reason of improper connections, such missed hole will not hang fire and explode unexpectedly as sometimes occurs when blasting with safety fuses. Electric blasting consequently eliminates this dangerous feature in connection with blasting operations.

Electric Fuses.—In electric blasting the electric fuse takes the place of the blasting cap, and is used in connection with a maganeto, or "blasting machine," and copper wire instead of a safety fuse. An electric fuse is shown in section in Fig. 62. The shell (a) is of copper and has a bead or corrugation thrown out or pressed from the inside to form a locking device to hold the sulphur cement (b) more firmly in place than it would be held in a smooth cylinder or cap. The explosive, which consists mainly of fulminate of mercury, is contained in the chamber (c), which is sealed by the sulphur cement which likewise holds the fuse wires firmly in place.

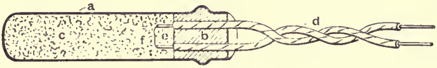


Fig. 62.
Section of Electric Fuse.

The copper fuse wires (d) are covered with insulating material sufficient for all ordinary purposes, and the bare ends of the copper wire project through at (e) into the charge of fulminate of mercury, where they are joined together by the short platinum wire or bridge (f). It is the heating of this platinum wire to redness when an electric current is passed through it that causes the detonation to explode the dynamite cartridge. Fuses are made with leading wires of from four to thirty feet in length. If longer wires are needed they may be spliced with the usual twisted splice with which all electric wires are joined, then insulated with insulating tape.

Electric fuses are made of different strengths, and for different purposes, such as for dry blasting and for submarine work. Illustration of an electric fuse is shown in Fig. 63. This fuse for submarine work, it will be observed, is covered with gutta percha to keep it from being affected by the water, and the connecting wires leading down to it must likewise be of waterproof quality. For ordinary work the gutta percha covering is not needed and is omitted. In rock excavating the fuses should be ordered with wires long enough to allow at least eight inches to project outside the drill holes to be connected to the connecting wires. The connecting wires should never be of smaller size than the connecting wires to the electric fuses.

Fig. 63.
Waterproof Fuse for Submarine Work.

PLACING THE ELECTRIC FUSE.—The electric fuse is best placed in the center of the charge, and in placing the electric fuse a hole is usually made in the side of the cartridge as explained for a cap and fuse in Fig. 59, and the electric fuse inserted in this cavity, pointing downward.

The wires from the electric fuse are then bound to the cartridge with string to hold the fuse in place, the free ends being kept above the mouth of the drill hole for connecting to the leading wires from a magneto. Instead of placing the electric fuse in the center of the charge, some rock-men place it in the end of the cartridge as explained for blasting with fuse, but they then turn the cartridge upside down and bind the wires to the cartridge, as shown in Fig. 64, so that the fuse is at the bottom of the charge when loaded in the bore hole.

Care should be taken when tamping a bore hole that the electric wires are not broken or the insulating materially injured, so the current can short circuit, or there might be a misfire. In the handling of the electric fuse care is necessary, also, not to break the sulphur cement, disarrange the wires in the fuse, or break the fine platinum wire or bridge. Breaking the cement will leave a free passage to any water which might be in the hole, so that the fuse will become spoiled and a misfire result.

The platinum bridge of an electric fuse is of necessity very small and delicate in order to keep down the cost, and at the same time be capable of being heated red hot by the small current of electricity generally used for this purpose. If this bridge or wire be subjected to any great strain it is liable to become broken, thereby destroying the fuse.

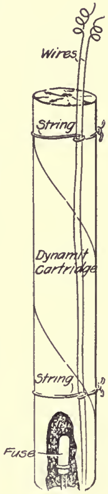


Fig. 64. Electric Fuse Attached to Cartridge.

Sharp bending of the electric wires might also lead to a misfire. Damaging the insulation so the current can short circuit will have this effect, and the wires need not touch to cause this damage, for if they be bare there might be sufficient moisture present to rob that particular cap of part of its current, and the result will be the fuse will miss fire.

Two Electric Fuses in One Drill Hole.—Two electric fuses are often used in deep drill holes where there is a large charge of explosive, so that the cartridge at the two ends can be touched off simultaneously. When such is the case the electric wires to the fuses should be connected in series, as shown in Fig. 65. One of the wires from the lower fuse is connected to one of the wires from the upper fuse, and the two remaining free wires are then brought to the surface of the ground, and the entire charge then treated as one so far as subsequent wiring is concerned. In considering the capacity of a blasting machine, however, each double-fused drill hole or charge must be rated as two distinct charges, for it takes just as much electric current to touch off two fuses in a single bore hole as it would to touch off two fuses in separate drill holes.

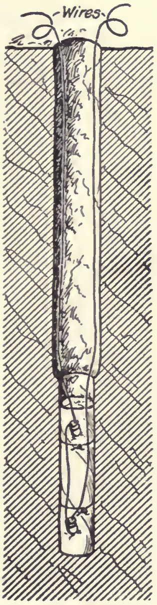


Fig. 65
Two Electric Fuses in One Drill Hole.

Wiring for Multiple Blasts.—The manner of wiring for an electric blast when a number of charges are to be exploded at once is shown diagrammatically in Fig. 66. Starting at one end of the row of drill holes, one pole of the blasting machine is connected to one fuse wire of the nearest hole. The other fuse wire is connected by means of special connecting wire to one of the fuse wires in the next nearest hole. The free wire in this hole is in turn connected to one of the fuse wires in the next succeeding drill hole, and so on until the last hole is reached, when the remaining fuse wire is connected by means of a leading wire to the other pole of the blasting machine. It will be seen that by this method of wiring, the electric current must pass successively through every fuse in the lot, thereby insuring them all being detonated. In the illustration the blasting machine or

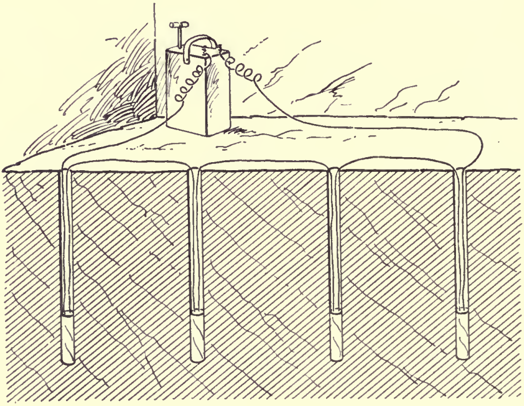


Fig. 66.
Two Wire Circuit for Multiple Blasts.

magneto is shown in the background. This is merely to show the entire apparatus complete, however. In practice the blasting machine would be located in some sheltered place out of range of the rock broken out by the blast, and about 250 feet away.

The wiring shown in the illustration is for a two-pole or two-wire blasting machine. Where a great number of blasts are to be fired at the same time, however, three-wire machines are frequently used. The manner of wiring for a three-wire machine is shown in Fig. 67. The series of drill holes, 1, 1, 1 form one circuit and the series 2, 2, 2 another circuit, which could be fired separately by bringing separate return leaders to the

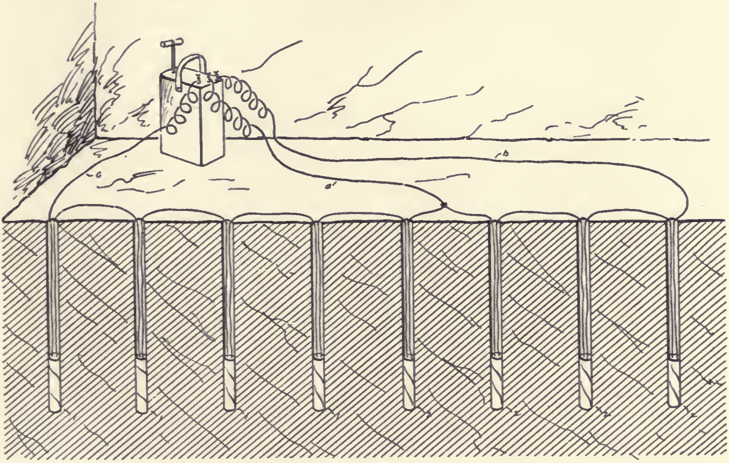
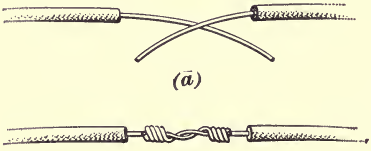


Fig. 67.
Three Wire Circuit for Multiple Blasting.

middle binding post of the blasting machine or may be connected up in one big circuit, as shown in the illustration, by connecting the return wire, *a,* to the connecting wires at the middle of the battery of drill holes. The wires, *a-b,* form one loop of the circuit, and the wires, *a-c,* the other loop of the circuit, and if only the bore holes 1, 1 were to be fired the wires would be connected up in the loop, *a-c,* without being joined to the other half of the system, while if the bore holes 2, 2 were to be fired separately the wires, *a-b,* would be used, but they would be disconnected from all contact with wire *c.* When a three-post blasting machine is used, the size of the leading wires need not be so large as for two-wire work, and almost 50 per cent. more fuses can be fired with the machine than could be fired with a two-wire blasting machine of equal size.


(a)

(b)

Fig. 68.
Joint for Electric Wires.

CONNECTIONS FOR ELECTRIC WIRES.—The method of making a straight splice or joint in copper electric wires is shown in Fig. 68. The insulation is removed from the ends of the two pieces to be joined for a distance of about 2½ inches back and the wires scraped with a knife to brighten them if they have become dulled or tarnished. The ends are next brought together and twisted either with fingers or pliers into the connections shown in the illustration. When a branch joint is to be made, the insulation is scraped off the branch wire in the manner explained and on the main wire the insulation is removed for a distance of two inches where the connection is to be made. The end of the branch wire is next wound tightly around the main wire and the connection is made. It is very important that the wires when joined together be perfectly clean and bright, and that they be twisted together tight and firm. If the joints are not well made or if any one of them is defective it will affect the whole circuit, perhaps causing all the holes to misfire.

The bare wire at joints should never be allowed to touch the ground, particularly if it be wet, or a ground current might result. This can be avoided by putting dry stones under the wires at the sides of the joints to keep them off the ground. Insulating tape may likewise be used for this purpose, but in ordinary rock blasting in fairly dry places insulating the joint will hardly be necessary.

TWO-POST BLASTING MACHINE.—Two-post dynamo-electric, or magneto-electric, blasting machines of small size, occupying less than one-half a cubic foot of space and weighing less than twenty-two pounds, are the kind most commonly used for small work, such as ordinary rock blasting, and on account of their reliability they are very suitable for the purpose.

The interior and outside views of a two-post blasting machine may be seen in Fig. 69. In this

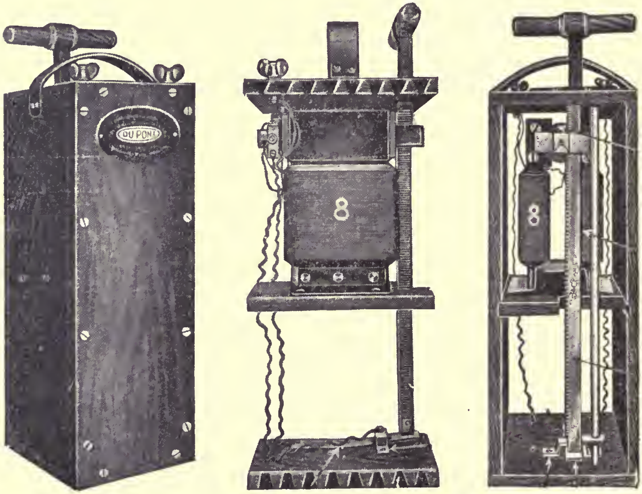


Fig. 69.
Two-Post Blasting Machines.

apparatus there is a magnet, and an armature which by revolving between the poles of the principal magnet generates the electric current which explodes the charges. Also there is a loose pinion which has teeth to engage with the rack bar. By clutching the spindle of the armature on the down stroke it generates the current of electricity, and when it reaches the end of its stroke breaks the contact between the small platinum bearings at the bottom, thus causing the whole charge or current of electricity to pass through the firing circuit composed of the leading wire, connecting wire and electric fuses.

THREE-POST BLASTING MACHINES.—The interior and exterior of a three-post blasting machine, such as is used with three-wire circuits, is shown in Fig. 70. The object attained by the use of the third or middle post is that when a large number of electric fuses are in circuit there will be less liability of failure of some of those near the middle of the circuit, if the big circuit is

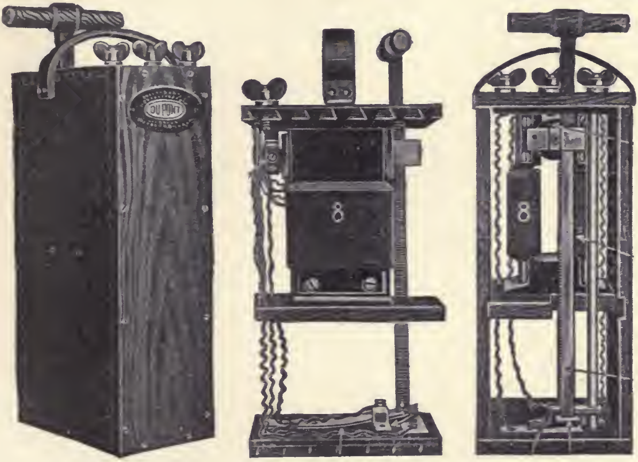


Fig. 70.
Three-Post Blasting Machines.

really broken up into smaller loop or circuits, and a common return brought back to the blasting machine.

In firing in one circuit a moderate number of electric fuses, only two leading wires need be used, but one of these must be connected with the middle post and the other may be connected with either of the side posts.

The three-post machine requires more care in the handling and connecting up than a two-post machine, and for ordinary blasting operations the two-post machine will generally be found satisfactory.

THE CAPACITY OF A BLASTING MACHINE.—Blasting machines are generally rated according to the number of fuses or "holes" they will fire. For instance, a machine rated at from one to ten holes means that the machine has sufficient power or will generate sufficient current to detonate the electric fuses in from one to ten holes at once. The difference between holes and charges must be clearly understood, however. Sometimes it is desirable, as when using deep holes with large charges, to place more than one electric fuse in each hole. When this is done it must be remembered that each fuse is to be considered as a charge or hole. It cannot be expected that a ten-hole machine will explode two or more electric fuses in each of the ten holes, for it will not do so. The rating of the machines is on the assumption that only one fuse will be in each hole. For each additional fuse put in a bore hole, one hole must be omitted or deducted from the capacity of the machine.

"PULL-UP" AND "PUSH-DOWN" BLASTING MACHINES.—The blasting machines described in this chapter are what are known as "push-down" machines. That is, the machines are operated by a downward stroke of the handle bar. The only essential difference between this and a "pull-up" machine is that in the latter the upward stroke is the effective motion.

FIRING WITH A BLASTING MACHINE.—After the drill holes have been loaded all the fuse wires project from eight inches to a couple of feet above ground. These wires are connected up in series, as previously explained, the joints supported on stones so the bare wires will not be in contact with the earth, and the free-end wires are then connected to the blasting machine. The wires which connect the fuse wires together are called the *connecting wires,* while the wires which connect the free-end fuse wires to the blasting machine are known as the *leading wires.* The leading wires are first connected to the respective fuse wires and the free ends are carried back to where the blasting machine will be used, but the ends of the leading wires are not attached to the binding posts of the machine until everything is in readiness for blasting. These connections are then made, the operator lifts the handle of the magneto to its full height, pushes it down slowly for the first half inch or so, and then with all his force, until the rack attached to the handle reaches the bottom of the box and sends the current through the outer circuit to the fuses.

When operating the blasting machine the handle or rack bar should never be churned up and down, but should simply be given the one vigorous downward push for the "push-down" machine, or a similar upward pull for the "pull-up" machine.

TESTING A BLASTING MACHINE.—A blasting machine should always be kept in good condition, clean, and never abused or played with. Its strength should be tested from time to time to see that sufficient power can be generated to fire the fuses. A simple way to test a blasting machine is by means of an ordinary incandescent electric lamp. A lamp and socket properly wired must first be tested to see that they are in good condition, the wires are then attached to the binding posts of the machine—to one side post and the center post in the case of a three-post machine—as when firing a blast, and, if the machine is in good condition, the lamp will show when the machine is operated a bright, incandescent light or white flash if the current be strong. If the light in the lamp cannot be made strong or bright it is evident that the current generated is weak and might not fire a fuse. If the lamp does not show any light the machine is out of order, and a blast cannot be fired with it until repaired. Most of the misfires blamed on poor fuses are as a matter of fact lack of current from the machine.

Another way to test a blasting machine is to connect in series above ground the full number of good electric fuses which the machine should be able to explode if it were in good condition. Next connect these electric fuses in a regular circuit to the machine, placing the machine at a safe distance so as not to be damaged by the explosion of the fuses. If the blasting machine, when properly operated, then fails to explode all the electric fuses in the series, it is because the current produced by the machine is weak and the machine needs repairing.

The blasting machine when not in use should not be left carelessly lying around the workings, but should be kept in the office or some other dry room until wanted. Never overload a blasting machine. It is better to divide the holes up into two blasts.

When all the electric fuses connected to a machine do not fire, in nine cases out of ten the fault is with the blasting machine or its manipulation, not with the fuses. Tests have repeatedly shown that when some of the holes in a circuit explode and some fail the cause is an insufficient amount of electricity. Generally this is caused by the blasting machine being in bad condition, or by the operator giving only a comparatively light push to the handle.

SOME PRECAUTIONS IN BLASTING.—In handling explosives and in preparing for a blast too great care cannot be exercised to prevent accidents. It is a poor policy to use a short fuse to hasten an explosion or with the idea that it is economical to do so, as the blast might be set off before the operator has time to seek cover. It is likewise dangerous to attempt to withdraw a wire from an electric fuse. An explosion of the fuse might result.

Never fire a charge to chamber a hole, then immediately reload it, as the hole will be hot and might cause a premature explosion. When everything is ready for the blast, do not fire the shot before everybody is well beyond the danger zone and protected from flying debris. Protect the supply of explosives also from danger from this source.

In case of a misfire or an apparent misfire, do not be in a hurry to seek an explanation of the cause. Take plenty of time before approaching the misfire. It might be only a delayed explosion. In case the charge has missed fire, don't bore, drill or pick out the misfire shot. Drill and charge another hole at least two feet from the missed hole and fire this charge.

CHAPTER XV.

HANDLING AND STORING EXPLOSIVES.

Laws Regulating Storage and Handling of Explosives.—In most States the handling and storage of explosives is regulated by law, and before commencing operations in any locality the one responsible for the handling and storage of the explosives should familiarize himself with the requirements of the laws, and then comply with them. Failure to do so will lead to heavy damages in civil suits, and perhaps prison sentence should an accidental explosion occur and cause loss of life, injury, or damage.

The Interstate Commerce Commission have formulated regulations for the transportation of explosives, as have likewise the American Railway Association. These instructions are contained in a little 140-page book which can be had for the asking by applying to any freight agent. It is to the interest of everybody handling and transporting or shipping explosives, therefore, to secure a copy and be guided by the rules and regulations there laid down.

Handling and Storing of Blasting Powder.—Blasting powder can be handled with a high degree of safety, still it is advisable to remember at all times that it is an explosive, and that recklessness in its handling should neither be practised nor tolerated. When loading powders on cars, wagons, or other vehicles for transportation they should be so packed that they will remain firmly in place and not slide or move about while in transit. Kegs should likewise be protected from snow, rain, direct rays of the sun, or extremes of any kind.

The site for a magazine for the storage of blasting powder should be such that the possibility of damage due to an accidental explosion will be reduced to the minimum. The location should be as dry as possible, and should consequently never be constructed against rock or earthen banks where moisture could trickle in or dampness penetrate. The ground around and beneath the magazine should be well drained and graded, and ample space allowed underneath the floor to provide for free circulation of air on all sides of the building. The magazine itself should have provision made for ventilating the interior, with means for closing the ventilators during stormy weather.

In storing the powder the kegs should be placed on end, bungs down, to prevent the possible entrance of moisture to the powder. The floor of the powder magazine should be kept scrupulously clean, for loose powder on the floor is liable to form a train to carry flame from a light to the powder kegs.

Fuses or caps should never be stored in a powder magazine or in a high-explosive magazine, as they are more easily detonated than high explosives, and if detonated close to dynamite might cause it to explode. If lightning rods are placed on the magazine the rods should have a ground connection to water, otherwise they are worse than useless.

No iron tools should be used in the magazine, and the floor nails should be driven into the floor so their heads will not project. In case a keg becomes broken or powder is spilled on the floor, a wooden scoop and broom brush should be used to clean it up, never a steel shovel. It is dangerous to walk on loose powder in a magazine with shoe nails projecting from the soles of shoes, as they might fire the powder. For this reason the floor of a powder magazine should be kept perfectly free from loose powder.

MAGAZINES FOR THE STORAGE OF DYNAMITE.—Permanent magazines for the storage of high explosives are preferably made of bricks, stones, concrete or some other equally fireproof and bulletproof materials. The magazines should be located in isolated spots, and surrounded, if possible, with high banks. Brush, weeds and high grass ought to be kept trimmed back a sufficient distance to insure safety in case of fire in the underbrush and dead grass near by. As in the case of powder storage, the dynamite magazine must be well ventilated and at the same time so ventilated that rain or snow cannot drift in during stormy weather. The temperature in the magazine should be regulated to about 80 degrees Fahrenheit. The higher the temperature of the explosive the more uncertain and unstable it becomes, so that temperatures above 100 degrees Fahrenheit become correspondingly dangerous. Besides, the nitrogen, although it has a high boil-

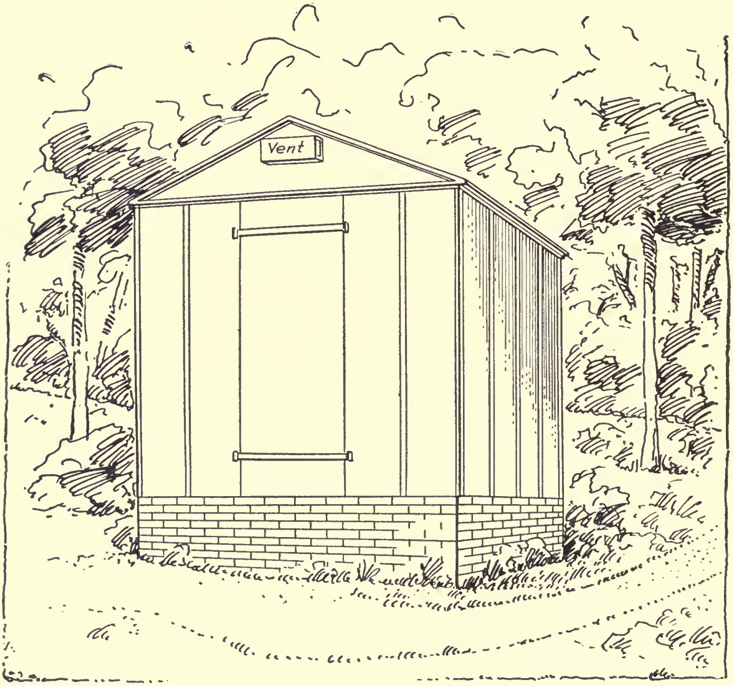


Fig. 71.
Portable Dynamite Magazine.

ing point, evaporates sensibly at a temperature a little above 100 degrees, and thereby loses much of its strength.

It is not necessary to build portable magazines or magazines for temporary use out of bricks, stone or concrete, but they ought to be made bulletproof and fireproof, or at least fire-retarding, if not actually fireproof. A portable or temporary dynamite magazine is shown in perspective in Fig. 71. This building is mounted on a brick foundation and is encased on the outside with No. 24 or No. 26 sheet metal, which may be either black or galvanized. When the cost of brick foundations must be eliminated, the magazine may be set on posts spaced from 4 to 6 feet centers, sunk in the ground below frost level, and capped with a 6x6 or larger sill. The outside of the posts must then be boarded like the rest of the building, clear to the ground, and covered with sheet metal in the same way, so that fire cannot creep under the building and set fire to the magazine from beneath.

The details of construction of a portable magazine can be seen in Fig. 72. The studding are boarded on the outside with matched, or tongue and groove, sheathing, and the outer surface, both sides and roof, covered with a layer of No. 24 or No. 26 sheet metal. This does not make a fireproof construction, but it is fire retardant, as the sheet metal will not burn, although it will transmit enough heat to the wood within to cause that to take fire. The boards beneath the sheet metal will burn very slowly, however, owing to the fact that but little air or oxygen can reach them, and without air the boards will char, forming charcoal.

To make the walls bulletproof, the inside of the building is lined with boards, the same as the outside, and the space between the inner and the outer boards is filled from sill to plate with good, coarse, dry sand. Instead of using sand the magazine can be bulletproofed by laying one course of bricks in cement mortar inside the magazine, or filling the spaces between the studding with bricks laid in cement mortar. As a rule, however, the sand will be found preferable, although coarse gravel is never to be used, on account of the missiles that would be thrown in case of an explosion.

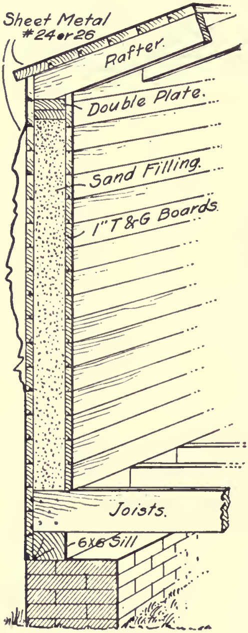


Fig. 72.
Detail of Portable Magazine.

The thickness of the walls of sand required to make a magazine bulletproof will depend pretty much upon the character of firearms used in the locality. In places where smokeless powder is used in high-power rifles, such as the Government Springfield, 11 inches of sand are absolutely necessary to bulletproof the magazine. When the 30-30

Winchester, or equivalent, is the strongest rifle in common local use, 8 inches of dry coarse sand filling is sufficient. When shotguns and rifles not heavier than 32 calibre are the firearms ordinarily used, 6 inches of sand filling will bulletproof the magazine. Nothing less than 6 inches of sand filling, however, should be used.

INDEX