THE USE OF EXPLOSIVES IN CONSTRUCTION

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PREFACE

Explosives are employed at one time or another in nearly all phases of construction work. The construction engineer should therefore have some understanding of the characteristics and employment of explosives. This report is intended to supplement my normal curriculum in preparing me to serve the United States Army Corps of Engineers in the field of construction.

Before a study of the calculation and placement of charges can be made, it is first necessary to have some knowledge of the types of commercial explosives available and their characteristics. Therefore, a chapter on the properties of commercial explosives precedes the primary chapter on charge calculation and placement. A chapter on the history of the use of explosives for construction purposes was included as a matter of interest.

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I would also like to express my appreciation to the following companies and explosive manufacturers for supplying

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CHAPTER I

INTRODUCTION

This report is written in fulfillment of the requirements for a Master's Degree in Civil Engineering at Oklahoma State University, 1963. This, however, is only one of the purposes instrumental in initiating this report. The degree could have been obtained without writing such a research report, but by choosing the method which I did, I have been given the opportunity to select a subject of great interest to me, conduct the research subject, and draw conclusions from the knowledge thus gained. This opportunity has been of greater advantage to me, perhaps, than to other students because my subject is rarely, if ever, taught in American colleges or universities. The topic I have selected is "The Use of Explosives in Construction."

Few people realize the significance of explosives. The quarry operator knows explosives are important commodities which he needs to bring down the tremendous quantities of rock required to keep his operations going. To certain engineers and builders, explosives are prime necessities in the construction of roads, canals, railroads, buildings - the vital requirements for healthy living and growth of a nation.

But how many student engineers know the basic fundamentals about the characteristics and uses of one of the engineer's greatest tools? What uses can be found for explosives? What will explosives do? How is an explosive selected and what is the most economical way to employ an explosive? These are the questions which I have strived to answer for myself in compiling this report.

The material used for this report came primarily from two sources: publications by the manufacturers of explosives and magazine articles written by the users of explosives. I have edited this material and compiled that which I felt most clearly answered my questions.

The first section of the report contains information concerning the use of explosives since the 17th Century in construction and closely related fields. Included also in chronological order are discoveries and inventions which in some way affected or changed the relationship of explosives to construction. Descriptions of some of the classic construction projects and the part played by explosives is discussed in this section. This serves to illustrate the wide variety of uses to which explosives may be applied. Also we profit by others' mistakes. To make an error made by another 100 years ago is needless when a brief study of available records would have prevented a mistake. History is important to the progress of the future.

The next section deals with the types of explosives presently used in the construction industry. A thorough knowledge of the types of explosives and their characteristics must be had before one can understand how to choose and employ an explosive on a project. Also, to understand the terms of an explosive manufacturer and to be able to order the desired explosive, a person must have some knowledge of the physical properties of explosives. Therefore, a brief discussion on this topic is included in the section. Also, the type and extent of packaging normally encountered is described. The sizes, both diameter and length, which are standard are important in selecting an explosive for a particular use so this, too, is included in this section.

The following section contains a discussion of the most frequently used methods of employing explosives for productive purposes by the construction industry. Included in the discussion of each use are the proper characteristics of the explosive to be used, a recommended brand name of explosive, the manner in which the explosive should be employed, and a description of an actual project in which this use of explosive was employed.

The final section contains a brief summary of the important facts which this research has revealed and my conclusions drawn from the course of my investigation.

CHAPTER II

HISTORY OF EXPLOSIVES AND CONSTRUCTION

Our modern day explosives had its crude beginning in the form of black powder. The actual inventor of black powder will probably never be known. Its first use has been attributed - by guess - to the Chinese, Indians, and Arabs. The first written record was made by an unknown scribe during the Sung Dynasty in ancient China prior to 1259 A.D. and read: "In the first year of the period of Kai-Khing the spear of the vehment fire was made. A handful of grains was placed in a long bamboo tube and set on fire."(1) However, it is believed that the Chinese had firecrackers as early as 1000 A.D. The 13th Century writings of Roger Bacon in England contain instructions for the preparation of black powder.

For the next three centuries, the 13th to the 16th, the use of black powder was confined solely to firearms. In 1613 it was suggested that the powder could be used in the mines of Saxony, but no record has been found of its use there. The first written records indicate that black powder was applied to the accomplishment of useful work in the mines of Hungary in 1627. Shortly afterwards, it was used in the tin mines of Cornwall, England.

The first black powder was manufactured in the United States in 1675 at Milton, Massachusetts. The first constructive use in the United States was in the copper mine at Simsbury, Connecticut, about 1705.

The first actual written reference to blasting for construction occurs in the records of the General Assembly of Connecticut in 1773. The Simsbury Mine was obtained for conversion into a prison and "by blasting rocks they had prepared a well-finished lodging room about fifteen feet by twelve feet in the caverns."[(2)] This became the infamous Newgate Prison of Revolutionary War fame.

The 18th Century and the first half of the 19th Century saw the discovery of a number of other explosives, but black powder remained the one in general use. Between 1790 and 1850 some thirty canals were dug in the United States using black powder for blasting. The most impressive of these were the Erie Canal and the Chesapeake and Ohio Canal. About 1820 the railroads began a rapid expansion, and blasting with black powder was responsible for clearing the right-of-ways. In 1820, also, commercial coal mining was begun, and it was destined to become the largest explosives-consuming industry in the country.

Safety Fuse

A noteworthy contribution to the explosives industry was made in 1831 by William Bickford. His invention of the safety fuse was a great advancement, for until that time the methods of igniting black powder had been uncertain and unsafe. In 1836 the first American-made safety fuse was placed on the market. This company, the Ensign-Bickford Co., still makes safety fuse and other blasting supplies today.

Nitroglycerin

In 1846 an Italian professor of industrial chemistry, Ascanio Sobrero, combined glycerin, a hand lotion created by Karl Wilheim Scheele, with a mixture of nitric and sulfuric acids and discovered the explosive which was to play a tremendous role in the advancement of civilization, nitroglycerin.[3] At this time little notice was given to nitroglycerin because at the same time as its discovery, a Swiss professor, Friedrich Schonbein, invented guncotton which received all of the acclaim from the users of explosives. About this same time Alfred Nobel, in Sweden, made the first reasonably safe and efficient blasting cap.

Dynamite

In 1866 Nobel mixed nitroglycerin with an absorbent so that, instead of a liquid which was difficult to handle and dangerous to transport, he had a solid substance sensitive to the action of a blasting cap but relatively insensitive to ordinary shock. His solid explosive was called dynamite. Prior to this time nitroglycerin was used in blasting hard rock in quarrying and road construction, but a series of fatal accidents in 1864 which claimed over a hundred lives, had caused nitroglycerin to be viewed as unsafe for construction purposes and shippers refused to accept it. It required several years before shippers would accept dynamite for shipment.

In 1870 a company in San Francisco manufactured dynamite for use in construction. This company was known as The Giant Powder Company and still produces much of the commercial explosives used today.

The first big construction job on which dynamite was used in America was the Musconnetcong Tunnel in Pennsylvania. This tunnel, a little less than a mile long, was started in the fall of 1872. As much as 17,000 pounds of dynamite were used each month, and the headings were advanced at the unheard rate of 135 feet per month.

In 1852 Congress had appropriated funds for the removal of rocks and reefs to form the East River Channel connecting Long Island Sound with Upper New York Bay. This work had been carried on slowly for many years but came to a climax on October 10, 1885, when a blast of 288,936 pounds of dynamite was fired to remove Flood Rock in the Hell Gate section of the river. This was the largest single explosion for construction purposes yet recorded.

Gelatin Explosives

In 1874 Alfred Nobel made another far reaching discovery when he dissolved collodion cotton in nitroglycerin. This resulted in a gelatinous mass which was much more powerful than his dynamite. This discovery was no accident. Nobel had become quite incensed over the fact that other dynamite manufacturers had infringed on the rights of his original discovery, and by improving on his product, were severely reducing the volume of sales from Nobel's own factory. Nobel was searching for a new product to increase the profit of his company when he discovered gelatin. It certainly cannot be said that Nobel was a pure scientist in every sense of the word. This product of Nobel's is essentially the blasting gelatin used today and was the forerunner of our gelatin dynamites.

Gelatin dynamite was used in quantity for the first time in driving the second Croton Tunnel or Aqueduct to supply New York City with water. This construction was begun in 1884 and completed in 1890 and was the first of the large American aqueducts. Gelatin proved in many cases to be quite advantageous over dynamite in many respects other than strength. These characteristics will be discussed in some detail in the next chapter.

Delay Blasting Cap

In 1895 H. Julius Smith, who had first made an electric blasting cap in 1876, patented a delay action blasting cap. The use of the delay blasting cap was to later prove a great asset in employing explosives in quarrying and excavation work.

New York Water Supply System(4)

In 1898 when the municipalities now within the bounds of New York City were consolidated, one of the pressing problems facing the city was that of providing a satisfactory water supply. The old city of New York was then obtaining its supply from the Croton aqueducts which were mentioned earlier. In 1905 the Board of Water Supply of the City of New York was established by the State Legislature and charged with the planning and construction of additions to the city's water supply system. This board initiated an enormous program. The following description of the work done will illustrate the accomplishments of the construction industry made possible by the use of explosives. The Catskill Aqueduct and the Shandaken Tunnel together are 110 miles long. The Delaware Aqueduct is 85 miles long, and City Tunnels Nos. 1 and 2 are 38 miles long which combined form a continuous pressure tunnel 105 miles in length - the longest in the world. These tunnels and aqueducts vary in diameter from 11 to 21 feet, and the major portion of them was driven through hard rock. Thirty-eight miles of the tunnel were blasted under city streets and buildings. In connection with these tunnels 110 shafts were sunk, varying in depth from 200 feet to 1,151 feet.

When the second Croton Aqueduct was constructed, a progress of 25 to 40 feet per week was made in a tunnel heading about 13 1/2 feet in finished diameter. On the Delaware Aqueduct the same size heading was excavated at a rate of 125 to 140 feet per week.

Few records were kept on the amount of explosives used on the completed projects, but the conservative estimate is more than 55 million pounds.

New York Subway System[5]

In 1900 the first subway of the Interborough Rapid Transit Co. in New York City was begun. The first section of this system was completed in 1904. Later other lines were constructed until now there is a system comprising 130.95 miles of underground subway in operation.

Essentially all of the way for this network has been blasted out of solid rock under existing streets and buildings, with little or no interruptions of regular traffic or business. This has necessitated the firing of small charges to prevent damage to nearby structures. This type of firing is called precision blasting. There are several new hand portable seismographs now on the market which aid considerably in controlling the shock waves of an explosion. Thousands of these small blasts were fired in NYC with pedestrians and occupants of buildings directly above wholly unaware of the blasts. This established a new first in the use of explosives and opened another door for improvement of construction methods.

Damming of the Saquenay River

Probably the most spectacular example of precision blasting of all time was carried out on July 23, 1930, as one phase of the ALCOA Power Company's Saquenay River project at Chute-a-Caron, Quebec, Canada. A power house had been constructed to serve it, and the main dam for the power house had been partially completed. But the river was too deep and too fast flowing for the construction of a cofferdam to divert the water through the channel so that the main dam could be finished. Some means had to be determined to turn aside this water flow. A unique scheme was suggested and adopted - to build a dam upright on one side of the river and drop it by blasting it into position across the stream in alignment with a concrete abutment on the opposite shore of the river.

Accordingly, a reinforced concrete block was built, measuring 92 feet in height, 45 feet in width, and up to 40 feet thick at the base. The base (side as constructed) was constructed irregular to conform to the shape of the river bottom. It weighed 11,000 tons.

On the appointed day, charges totaling 1,000 pounds of dynamite were loaded in this pier, and fired with totally satisfactory results. The huge column tipped and fell, without breaking, into 30 feet of swiftly flowing water and came to rest within <u>one inch</u> of the calculated location. Three days later the remaining flow of water was sealed off and construction of the main dam resumed.

Railroads and Tunnels

The expansion of the railroads consumed many tons of explosives, and many of the present tunneling techniques were developed by these railroad engineers. During the period of maximum expansion, the railroads were among the largest users of explosives. Railroad construction reached its peak in 1902 when 6,024 miles were built. Since that time until shortly after World War II, the railroads used large quantities of explosives for location of lines, terminal facilities, and cutoff projects (tunnels).

Two outstanding examples of this latter type of work were the Moffat Tunnel driven under the Continental Divide and the Cascade Tunnel driven under the Cascade Mountains.

The Moffat Tunnel, completed in 1926, was at the time, the longest tunnel in the Western Hemisphere, and the fifth longest in the world. About 8,000,000 pounds of dynamite were used in driving these two tunnels.

Panama Canal[6]

The Panama Canal has long been recognized as one of the world's greatest engineering feats. It is slightly over 47 miles long, including Gatum Lake created by Gatum Dam.

The French had excavated over 78,000,000 cubic yards of material prior to May 4, 1904, when the United States took over the work on the project. During the period of seven and one-half years in which the United States worked on the project, 232,000,000 cubic yards of material were excavated.

The Gaillard Cut proved to be the most formidable portion of this work. This cut was about nine miles long, 120 feet deep, 300 feet wide at the bottom, and at some points about one-third of a mile wide at the top. About 100 million yards of material was taken from this section.

Blasting was carried on incessantly. An average of 600 holes per day was fired for months at a time. More than 60 million pounds of dynamite were used by the U.S. Army Corps of Engineers. The canal was opened on August 15, 1914. Since that time, dynamite has been used on the canal more or less continually for maintenance and for deepening and widening certain sections. It is probable that more than 75 million pounds of dynamite have been used on this project to date.

In 1914 Germany's industrial scientific research system was strongly developed, and it revolved about coal tar dyes. Germany was ready for war in 1914. Her army of chemists and physicists had prepared her. A new explosive had been developed by these men which was so immune to shock that it could be handled safely under just about all conditions of war. It could be melted, poured into shells, and cast like iron or other solids. This new explosive was called trinitrotoluene - TNT - and later proved to be of considerable value to the construction industry.

Adams Tunnel

Just east of the Rocky Mountains in northeastern Colorado, and along the Cache la Poudre, and Big and Little Thompson and South Platte Rivers, there is an area of fertile soil capable of producing abundant crops when sufficient water is available. To aid this fertile area, engineers of the United States Bureau of Reclamation suggested a plan which became known as the Colorado-Big Thompson Project. The most important feature of this project was the driving of a tunnel under the continental divide, at one point 3,825 feet under a mountain peak, to divert water from the upper watershed of the Colorado River at Grand Lake on the western slope of the Rockies to the Big Thompson River on the eastern slope. This tunnel is now known as the Alva B. Adams Water Division Tunnel. It has a bore of 9 3/4 feet and a length of 13.03 miles.

About 2,480,000 pounds of dynamite were used in 2,535,000 feet, or 480 miles, of drill holes. A record excavation in one month was set when 1,634 feet were driven. When Reclamation engineers made the final inspection, they found an error of only 7/16 inch on line and 3/4 inch on grade.

Another far-reaching development in the construction industry was the introduction of "Nitramon" - ammonia nitrate explosives - by the DuPont company in 1935. This relatively inexpensive, non-sensitive explosive has completely remolded the excavation and quarrying functions of construction. This will be discussed in some detail in the next two sections.

World War II brought about the development of several new explosives, the most important of which is the plastic type. These newer explosives and their connection with construction will be discussed in the next two sections, also.

To give the reader some idea of the quantities of explosives which are sometimes used, reference is made to the Fontana Dam, built on the Little Tennessee River, near Fontana, N.C. It is 480 feet high, 375 feet thick at the base, and 2,333 feet long. A quarry site to produce aggregate for this dam set several records for the period up to 1945. On November 3, 1943, there was a blast of 27 nine-inch diameter churn drill holes averaging 330 feet deep, 20 feet apart, and 45 feet from the face. These holes were loaded with 188,328 pounds of cap nitramon. One hole which was 360 feet deep contained 8,943 pounds of explosives. On June 22, 1944, 51 similar holes with a 19-foot spacing, 190 feet deep were loaded with 208,583 pounds of Nitramon. This blast produced 630,000 tons of rock.

Another dam constructed by the TVA is located on the Holston River near Bristol, Tennessee. Essentially all of the rock for this dam was furnished by four large coyote tunnel blasts located below the natural surface of a nearby hill. The second of these blasts was fired on February 5, 1949. The coyote layout consisted of three adits and forty-four crosscuts, totaling 5,254 feet of tunnels. The charge consisted of 55,425 cans of Nitramon for a total of 1,362,985 pounds of explosives. About four miles of Primacord were used to connect the charges. The loading of the tunnel required seventeen working days. The blast produced in excess of 1,800,000 tons of broken rock.

The second largest blast of explosives on record for construction purposes was fired by the Morrison-Knudsen Company, Inc., on July 21, 1957. A blast of 1,790,000 pounds was fired at Promontory Point, Utah, and broke an estimated 3,000,000 tons of rock. This was for the Great Salt Lake Crossing Project for the Southern Pacific Railroad. The material used for this blast was a blasting agent of the ammonia - nitrate - fuel mixture type, heavily primed with TNT.

On April 5, 1958, the world's largest non-atomic blast was fired at Ripple Rock in Seymour Narrows, which lies about 100 miles north of Vancouver on the regular shipping route between Seattle and Alaska. Ripple Rock, a twin peak mountain, was only nine feet below the surface at low tide. More than 120 vessels have been lost by capsizing or running aground while trying to navigate the currents around the rock. At least 114 lives were lost in these mishaps. To remove this serious hazard to navigation, tunnels were driven from the shore, under the channel and up into the two peaks. Two million seven hundred fifty-six thousand pounds of DuPont "Nitramex" were loaded into the peaks. After the blast, the top of the rock was more than 50 feet below the surface at low tide which now enables the ships to negotiate the Seymour Narrows in safety.

CHAPTER III

TYPES OF EXPLOSIVES USED IN CONSTRUCTION

There are many types and grades of explosives presently available to the contractor, and more are becoming available each year. As a result of advancements in explosives and with the addition of versatile new developments in drilling equipment, blasting methods, and basic rock mechanics research, contractors are handling more jobs with less cost and better results than ever before.

The 60-gel man or powder monkey has been replaced by a contractor or engineer who sees a blasting job as part of a construction project as a whole. Two main factors influence the choice and use of explosives: results and costs. It is no longer necessary to rely on intuition or tradition in the selection of an explosive. The engineer can make his choice of an explosive at the estimating table long before the job begins.

The contractor may not pick the least expensive type or grade of explosive. The contractor's aim is to get the maximum results with the minimum cost per unit. He, therefore, has to be informed of the explosives available and their characteristics.

Contractors now want to haul out rock fast with scrapers instead of taking time to load trucks with a shovel. This trend towards shooting-to-pan calls for expecially close attention to how explosives are used and the characteristics of the explosive selected for a job. Fragmentation and control of rock throw are all important.

Contractors are asking explosives to work to much smaller tolerances. With pre-splitting techniques they cut sharp, complex faces for channels and tunnel portals. They excavate for bridge piers and soon will dig foundations for downtown buildings.

There are many types and grades of explosives used for industrial purposes today. All of these many types and grades fall into one of two general categories: low explosives or high explosives. An explosive is classified as low or high depending upon the speed at which the change of state from a solid to a gas takes place. It is important to realize the difference in reactions of a high and low explosive because they are vastly different. A low explosive, such as black powder, changes from a solid gaseous state relatively slowly. The action causing this change is called deflagration. A deflagrating explosive is one that burns over a relatively sustained period of time, and this action can be utilized to push or shove, rather than tear, the object against which it is placed. The principal use of the low explosive has been for powder trains such as time fuse, but more recently low explosives have come back into use in excavating work.

A high explosive, such as dynamite or TNT changes from a solid to a gaseous state almost instantaneously. The reaction causing this change is called detonation. A high explosive is detonated by a violent impulse from a blasting cap while low explosives may be set off by a flame. This sudden generation of gases and their extremely rapid expansion produces a shattering effect which can overcome great resistance. This is in considerable contrast to the low explosive which produces a relatively slow and regular explosive pressure. The velocity of detonation of a high explosive and the rate of deflagration of a low explosive is expressed in feet per second.

Our nation uses nearly one billion pounds of explosives in commercial enterprises each year. This does not include the large amount purchased by the military and foreign countries. Of this total amount, an average of 200 million pounds is used in the operation of quarries each year while another 200 million is used for purposes of construction. In 1961 the construction industry used 236 million pounds. Of this, 49% was ammonia nitrate explosives, 47% was dynamite, and the remaining 4% was special-purpose explosives such as TNT and plastics.

Dynamite(3)

There are numerous types of dynamite, and each type is divided into a series of grades. Each type and each grade are different from any other type and grade in one or more properties or characteristics. The principal properties which govern the selection of an explosive for use on a job are:

Strength - this refers to the energy content of an explosive which in turn determines the force and power the dynamite develops and the work it is capable of doing. The nitroglycerin or straight dynamites are rated in strength according to the percentage by weight of nitroglycerin which they contain; that is, dynamite referred to as 40% straight dynamite actually contains 40% of nitroglycerin by weight. An erroneous concept is that the actual blasting power developed by different strengths is in direct proportion to the percentage markings. For example, a 40% dynamite is twice as strong as 20% and that 60% is three times as strong as 20%. This is not true. This is because in increasing the amount of nitroglycerin in the dynamite it is necessary to decrease the other constituents which also add to the strength of the dynamite. These constituents will be discussed a little later.

Dynamites are sometimes graded according to their bulk or volume strength. This refers to the strength per cartridge of the explosive, and the bulk-strength figure indicates that one cartridge so marked has a strength comparable with one cartridge of straight dynamite at the same percentage and size. It should also be pointed out, however, that two dynamites of the same strength do not necessarily produce the same blasting action in the field. This is due to the fact that properties other than strength, particularly density and velocity, have a distinct influence on the performance.

Density - This is expressed as the number of 1 1/4-inch cartridges contained in a 50-pound case. This may vary from 85 to 205 cartridges per 50-pound case. The purpose of density variations is to enable the blaster to concentrate or distribute charges at will.

Sensitiveness - This is a measure of a dynamite's propagating ability both with regard to a column charge in a bore hole and between separate bore holes. It is important that dynamites be sensitive enough to insure detonation for the entire length of the hole or charge. However, dynamite must not be so sensitive that it will be exceptionally hazardous to handle. Sensitiveness is measured by the distance in inches over which one half of a 1 1/4-inch x 8-inch cartridge will propagate another 1/2 cartridge when both halves, with cut ends facing, are enclosed in a hollow paper tube and shot in the open.

Velocity - This is a measure in feet per second of the speed at which the detonation wave travels through a column of explosives. Dynamites range in velocity from 4000 fps to 23,000 fps. As the velocity is increased, the explosive usually produces greater shattering effect in hard materials.

Water Resistance - High explosives differ widely in their capacity to resist the effects of water. The gelatin dynamites are practically waterproof. Some of the high density ammonia dynamites have good water resistivity while the low density ammonia dynamites and permissables have little or no resistance to water. Dynamites which are penetrated by water, first have their efficiency impaired, and then on prolonged exposure to water may not detonate.

Freezing Resistance - All commercial dynamites supposedly will not freeze under ordinary exposure to the lowest atmospheric temperatures normally encountered in this country. However, dynamites which do become frozen must be thawed before being used because they become hazardous and unreliable if frozen. Thawed dynamite may lose some of its original strength.

Fumes - Gases resulting from the explosion of dynamite are principally carbon dioxide, nitrogen, and steam, which in the ordinary sense are nontoxic. In addition, poisonous gases may also be present. These gases, carbon monoxide and nitrogen oxides, are called fumes. Both the nature and the quantity of fumes vary among the different types and grades of dynamites. For open work, fumes are usually of no concern, but for underground work they require that considerable consideration be given to the choice of the explosive, amount of the explosive to be used, and to conditions of blasting and ventilation. Fumes should not be confused with smoke from a blast.

Packing - Dynamites are furnished in a wide variety of sizes. Usually these are divided into two classes: small cartridges are those under 4 inches in diameter and large cartridges are those over 4 inches in diameter. Among the small cartridges the most popular diameters are 1 1/8 inch and 1 1/4 inch. Diameters of 1 1/2, 1 3/4, and 2 inch are also frequently used. The most popular length is 8 inches, but there is a trend toward longer cartridges up to 24 inches.

In the large size category, diameters ranging up to 6 inches are most in demand. Lengths vary from 16 to 30 inches.

In selecting a dynamite for any specific purpose, and especially for underground work, many factors must be taken into account. The most important considerations involve the material to be blasted -- its denseness, hardness, toughness, friability, etc.-- the degree of fragmentation desired, whether the holes are wet or dry, the amount of ventilation in underground working places, and whether or not combustible gases or dust are present. Each blast presents some combinations of these conditions and hence a dynamite with proper combination of properties, and with the proper packing, should be chosen.

Dynamite is a general term given to a class of explosives in which the principal explosive ingredient is usually nitroglycerin. There are many distinct types of dynamite and each type has one or more grades, including special grades which are designated for special classes of work. There is no standard composition or set of ingredients for dynamite as there is for black powder or TNT. Even though nitroglycerin is the most common ingredient of dynamites, it may vary from 5 to 90 per cent by weight in different compositions. The more important ingredients of dynamite are: 1) synthetic nitrogen compounds such as Nitroglycerin or TNT, 2) oxidizing agents such as sodium or ammonia nitrates,

3) combustible ingredients, 4) freezing point depressants, and 5) antacids.

There are many manufacturers of explosives in the United States, but in discussing and researching the properties of dynamite only the three largest manufacturers were considered. The three companies whose products are discussed here are the DuPont, Hercules, and Atlas Companies. It should be noted that Atlas products west of the Mississippi River are carried with the brand name Giant Explosives.

For all practical purposes the dynamite used by the construction industry may be divided into nine distinct types. Each type has one or more series of grades, and most have in addition special grades which are normally used for one special type of work.

Straight or Nitroglycerin Dynamite - This is the standard against which all other dynamites are compared on a weight-for-weight basis. This type dynamite contains nitroglycerin as the only material which by itself is an explosive. These dynamites are characterized by high velocity which imparts a quick shattering action. They resist water very well, particularly in the higher strengths. Their fumes, however, make them unsuitable for use in underground or confined spaces. Straight dynamites are practically never used for general blasting because of relatively high cost, sensitiveness to shock and friction, and very high inflammability. Ditching dynamite is a straight 50% dynamite made especially for ditch blasting under wet conditions where the propagation method of blasting is applicable.

Red Cross Extra or Amodyn - This type is manufactured in grade strengths of 20% to 60%. It differs from straight dynamite in that a portion of the nitroglycerin is replaced by sufficient ammonium nitrate to maintain grade strength. Compared to the straight dynamites, the extra dynamites are, grade for grade, lower in velocity and water resistance. They are less sensitive to shock and friction, less inflammable, and considerably more economical. They have less shattering effect which is a definite advantage in certain types of work. Due to the use of special ingredients they are sufficiently waterproof for most practical purposes provided that they are used with the wrappers intact.

This Extra dynamite is probably the best known all-purpose explosive. It is widely used in quarry operations and on construction projects where the material to be blasted is of medium hardness. It is also used in stumping and boulder blasting. Because of its excellent fumes, it is well suited for underground work.

DuPont Extra, Hercomite, Apcodyn - This is a dynamite similar to the previous type except that these dynamites contain a relatively low percentage of nitroglycerin. The weight strength is obtained through the use of high proportions of ammonium nitrate. These dynamites are used extensively in blasting soft materials such as clay, limestone, gypsum, etc. This is a low-cost dynamite and should be considered whenever conditions appear to be favorable. This type carries as much strength as the straight dynamites but doesn't have the shattering effect. For example, military dynamite does not contain any nitroglycerin but is composed almost entirely of ammonium nitrate, yet it is rated as a higher strength than the straight dynamites.

Gelatin - The explosive base of gelatin dynamite is a jelly made by dissolving nitrocotton in nitroglycerin. Gelatinized nitroglycerin may vary in consistency from a thick, viscous liquid to a tough rubber-like substance. It is insoluble in water and tends to coat and waterproof other materials which it covers. Strengths vary from 20 to 90 per cent, and this type gelatin dynamite corresponds to the straight dynamites in the nongelatinous groups.

These explosives are dense, plastic, cohesive, and practically waterproof. They have excellent fumes in the 20 to 60 per cent strengths, but in the higher strengths their fumes are poor. Their plasticity makes it possible to load them solidly in bore holes in order to obtain maximum loading density. When confined in a borehole they develop high velocity of detonation and, consequently, a quick, shattering action. These two characteristics, combined with their high density, make them most effective in hard, tight work and in operations where a maximum shattering effect is required.

The gelatins are adapted to all varieties of work which is wet. The higher strengths are recommended for blasting very hard, tough rock as is sometimes encountered in tunnel driving. The gelatins do not enjoy wide use at the present time because of their high cost in comparison with more modern grades which can be substituted for most work with complete satisfaction.

High Velocity - High Pressure Gelatins - It is an inherent property of the conventional types of gelatin dynamites to detonate at two velocities. Unconfined they will usually explode at the rate of 7000 fps, whereas confined they will explode at 13,000 to 22,000 fps. However, high water pressures may cause them either to detonate at low velocity or fail entirely.

Because of this characteristic, this type of dynamite was developed which has the same strength as the regular gelatins but will retain its sensitiveness and high velocity under adverse conditions. Therefore, this type of gelatin is best when shooting under considerable hydrostatic head.

Special Gelatin - This is an ammonia gelatin, that is, one in which a portion of the nitroglycerin is replaced by ammonia nitrate. This type corresponds to the Red Cross Extra in the nongelatinous group. It is manufactured in grades from 25 to 85 per cent strength. These gelatins can replace the straight gelatins for most work and are more economical. They have good fumes in all grades. These special gelatins are widely used in quarrying and unconfined construction work.

Gelex, Gelamite, Gelodyn - This is a series of dynamites combining the economy of the low density extra dynamites with the water resistance and cohesiveness imparted by gelatinized nitroglycerin. In other words, it is a semigelatin that has certain gelatin characteristics which will enable it to replace gelatins and gelatin extras successfully in many instances and should result in an appreciable savings in explosive costs. This type dynamite is widely used as an all-purpose explosive for both quarrying and general construction.

Permissables - Explosives are designated "Permissable" when they have been tested and passed as safe for blasting in mines by the United States Bureau of Mines. An engineer might have need for this type of explosive when involved in underground work. However, a dynamite marked as Permissable does not mean that it can be used without reservation in an area where explosive gases may be present. When used in accordance with the seven rules prescribed by the Bureau of Mines, this type may be used with little likelihood of a gas or dust ignition. All explosives when fired give a flame which varies in volume, duration, and temperature. Black blasting powder gives the longest lasting flame. Some of the dynamites develop a flame which is shorter duration than that of black powder, but which is very much hotter. Permissable dynamites are especially designed to produce a flame of small volume, short duration and low temperature. Each major manufacturer of explosives has approximately 15 grades of permissables including the gelatin and semigelatin permissables. The grade selected would depend on moisture present, type material, degree of fracture desired, etc.

Permissable explosives, particularly the low and very low grades, have a tendency to absorb water or moisture readily and deteriorate very readily as a result. Therefore, good storage facilities must be provided.

Seismograph Types - The use of seismographs in the field of construction and civil engineering for subsoil investigation is becoming increasingly common. The powder manufacturers have met the need for the special type explosive used for this work. This explosive is special only in the sense that the containers are rigid which facilitates loading in partially blocked drill holes which are so often encountered in this prospecting work. All of the grades are so manufactured to withstand soil moisture which is normally encountered. Also there is a grade of this explosive for underwater prospecting.

This concludes the nine major types of dynamites which are most often encountered in construction. These types will be mentioned again in relation to a specific job under a given set of conditions.

Blasting Agents

The next type of explosive to be examined has the broad classification of "blasting agent." A blasting agent is an insensitive chemical composition or mixture, containing no nitroglycerin, which can be made to explode only when initiated with a high explosive primer. Under normal circumstances, the manufacturers claim that these blasting agents cannot be detonated by 1) the strongest commercial blasting cap, 2) Primacord, 3) flame, 4) shock, 5) friction, 6) the impact of ball ammunition. This is the reason why the name blasting agent and not high explosive is applied to the product.

The blasting agents are composed primarily of ammonium nitrate with a small percentage of other nitro-carbo-nitrates included. Blasting agents come in several forms: pre-packaged metal containers, burlap bags, cardboard containers, and asphalt laminated boxes. Some are employed intact in their containers while others, known as free running, are poured from their containers into the holes.

Ammonium nitrate continues to be a new explosive to a large number of contractors each year - or at least contractors are firing a larger amount each year. Figures compiled by the Construction Methods and Equipment magazine indicate that the percentage of ammonium nitrate used by the construction industry increased from 29% in 1959 to 49% in 1961.(7) This seems rather odd when, as pointed out earlier, the ANs (as ammonium nitrates are called) were sold commercially in 1935 and their ability to perform work efficiently and economically was demonstrated rather thoroughly by the TVA in the early 1940's. The figures for 1962 have not yet been compiled.

There are eight separate and specific types of AN explosives in general use by the construction industry. Each of these blasting agents is known by a brand name which is different for each product of the same type manufactured by the different producers. Therefore, it is pointed out that the following products listed are brand names and are called by some entirely different name if manufactured by a different company.

Nitramon - This AN comes in two grades: A and No. 2. These two grades differ in density, strength, and performance.

Grade A has a density of 1.27 to 1.48 and is comparable to 60% special gelatin in most work. Grade 2 has a density of 1.20 and is similar to 40% Red Cross Extra dynamite in performance. Both grades come in metal cans with diameters ranging from 4 1/2 inches to 9 inches in increments of 1/2-inch. Weights range from 13 1/2 to 85 pounds per can.

On one end of the can a bail is provided for handling and priming the hole. Nitramon gives its most outstanding results in rock of medium to soft hardness. It is recommended primarily for vertical holes but can be used in horizontal holes. It is not recommended for sprung holes.

Nitramon has proved ideal for coyote tunnel blasting. Here its safety features are especially attractive. Electric lights can be used safely for lighting while loading and headaches such as experienced with dynamite when working in enclosed places are not encountered.

Nitramex - As the use of Nitramon increased, it became clear that a stronger and denser grade was needed. This was especially true in hard rock formations. Therefore, Nitramex 2 and Nitramex 2H were developed. They have a density of 1.80, but other than strength the characteristics and packaging is the same as Nitramon.

Nitramon - S - This is a special packaged can of Nitramon used for seismic prospecting. It differs from normal Nitramon only in that the cans are stronger and have more resistance to water pressure. The cans are threaded at each end so that sections can be joined to form a long, rigid charge to facilitate loading the hole and to insure positive contact between the sections for detonation. They range in size from 2 inches to 2 1/2 inches in diameter and are 4 1/2 to 6 inches long. Each can weighs one pound.

Nitramon WW - This again is a special type of Nitramon for use in seismic prospecting at sea. It has a specific gravity of approximately 1.2 which allows it to sink readily in water, but it does not require excessive buoyant material if suspended charges are required.

Nitramon HH - HH means hot-hole. This type AN is designed for use where very high temperatures may be encountered in the hole as sometimes occurs in the coal mining industry. Special techniques are required with this type, and it should not be used in a "hot-hole" without special instructions.

Nitramite - This is a low-cost blasting agent with a density of 1.05 to 1.25. It is packed in heavy asphalt laminated shells which are, according to the manufacturer's claims, supposed to resist water for 8 to 36 hours. Except for wet work it will accomplish the same results as Nitramon at a more economical cost.

Akremite - This is a patented process whereby a granular free-flowing AN, generally fertilizer prills, is mixed with 1 to 12% of combustible material which is generally powdered coal or fuel oil. This mixture is packaged in bags of flexible waterproof plastic material which are capable of expanding and deforming without breaking to fill the hole completely.

Free Running Agents - It is often desirable for various reasons to load a bore hole with a granular free-flowing blasting agent rather than a rigid can of material. The main reason for using the free-flowing AN is that you get much better results in a crooked or partially blocked hole because with this material you can fill all available hole volume. Also the free-running material is more economical. There is no cost for packing and the right amount of explosive can be added to each hole with no loss due to packing. Even though the free-running AN is less dense than the packaged, this disadvantage is overcome by the larger volume in a hole being filled and by the lower costs for explosives. The net result is a substantial lowering of unit cost of material produced. The one point to remember in determining costs is that all blasting agents must be detonated with a high explosive primer.

To illustrate the physical characteristics and packaging of the ANs which are free running the following blasting agents which are most frequently used in the construction industry are described:

Pelletol 1 - This free-running blasting agent consists of slightly oval-shaped smooth pellets about 3/32 inches in diameter which can be poured easily through a 1/2-inch opening. The individual pellets have a density of 1.5 so they will sink easily in water. These pellets have unlimited resistance to water according to the manufacturer. The fumes from this AN are very poor, and its use should be limited in all cases to open work. Even with this precaution, personnel should be kept away from the blast area until the fumes and smoke have dissipated.

Nitramite FR - As the name indicates, this is a free running Nitramite which is often used by contractors for small-diameter hole blasting as frequently encountered in quarries and road work. It has no water resistance but can be used for top loading as is often done due to its low cost. Another frequent use of Nitramite FR is in coyote tunnel blasting. The 50-pound burlap bags of the explosive have been found to be easier loading than the cans as well as much more economical. The lesser density is of little significance in such volume blasting.

Nilite - This is also a non-waterproof, free running blasting agent composed of AN and oil. It has a density of 0.9. It is relatively inexpensive as compared to the other ANs, but it has limited use. It is used by contractors for blasting in dry stratified limestone, sandstone, shale, or other dry sedimentry deposits of medium hardness. Another disadvantage of this explosive is that it must be completely stemmed for satisfactory results. This poses a problem in coyote tunnel blasting.

Ammonium Nitrate - Fuel Oil - Following the introduction of "Akremite" by the DuPont Co. in 1955, a practice of mixing basically the same ingredients, ammonium nitrate and fuel oil, at the blasting location was started by a quick-thinking contractor and spread rapidly to practically all blasting operations where it offered a promise of economy. This mixture is called AN-FO after its constituents,Ammonium nitrate and fuel oil. This is a blaster's term and not a patented trade name.

The method is quite simple, and blasting performance in most instances will equal that of the more expensive manufactured or pre-mixed ANs. The ammonium nitrate used in the mixture is the common fertilizer prill. With the latest procedure the ammonium nitrate prills are simply poured into the holes with fuel oil added simultaneously or after a bag or two or prills have been emptied into the hole.

Some contractors mix the oil and prills on the surface before loading the holes. Mechanical mixing in either case is not necessary since the oil is dispersed through the prills in the borehole by the action of gravity.

The mixture proportions which seem to be favored by most contractors are 3 quarts of oil per 50-pound bag of prills; or about 6% oil by weight.

The one big advantage of the AN-FO mixtures is their reaction with water. Ammonium nitrate is soluble in water; therefore the AN-FO mixture is very hard to initiate when wet, and efficiency drops rapidly on exposure in a wet hole. Another limitation on its use is the size of the hole. The performance in holes below three inches in diameter is generally unsatisfactory or unreliable.

Because of its poor reaction to water, the fumes it creates, and because it has not been available in small cartridges, AN-FO has been used seldom in underground construction. However, it appears that the latter two disadvantages are rapidly being overcome and within the next two years, AN-FO is scheduled for tunnel driving duties. Atlas currently is developing test rounds for use on a tunnel that Tecon Corporation of Dallas will drive in Tennessee.

Air-jetting of AN-FO into tunnel blast holes appears to be the coming trend. It gives two advantages: prills are handled easier than by any manual method, and the air pressure loads the holes completely. Many powder companies now sell an air-jetting unit to speed placement of AN. Basically there are two kinds. One forces the prills in by direct air pressure and the other uses a semi-vacuum like a huge atomizer. Atlas calls theirs the Powder Monkey and DuPont has a Borehole Loader and a Mark II Supercharger.

There are several satisfactory methods used in priming the ANs. The most satisfactory results seem to be with the manufactured primers, but most contractors use dynamite or TNT to make primers. They are quickly manufactured on the job using Primacord and dynamite sticks or 1-pound blocks of TNT.

Slurries - Another "combination" explosive fast becoming accepted by the contractors is called a "slurry." It has been used for some time by ore and coal miners but only recently has been accepted for general use by the construction industry. A slurry is a mixture of 65% ammonium nitrate, 20% TNT, and 15% water. It has the consistency of a thick soup and is grey in color. It is heavier than water, and, therefore, it sinks and stays in wet holes.

The AN slurry combines into one material several advantages of free flowing AN and a high explosive; first, the slurry is unaffected by wet holes which do cause difficulties with the AN-FOs. Next, the slurry produces good breakage because of the presence of the TNT and the manner in which it is put into the hole. Third, slurries cost less than high explosives but give similar results. In a situation where the most practical dynamite would cost $.25 per cubic yard, a slurry would give the same results for $.15 per yard. Finally, slurries are as safe to handle as the AN agents.

Generally speaking, tunneling, precision drilling, demolition, etc., will still require the use of a high explosive, namely, dynamite. But the trend in excavation appears to be as follows: when holes are dry, AN-FO, which is the lowest cost of all practical construction explosives, will be used; when the holes are wet, slurries will be used. And when the holes are only partially wet - which is the general condition normally encountered - the contractor will use both AN-FO and a slurry.

Aerex - A new explosive which appears to have great possibilities in the construction industry but has yet to be proven economically is called Aerex, a trade name, and is manufactured by the Aerojet-General Corporation.

Aerex comes in two types: Aerex 1, a liquid; and Aerex 2, a powder. Both have only one grade at the present time, and it is reportedly more powerful than 60% straight dynamite. Both can be fired with a blasting cap and neither must be primed.

Both forms of the explosive arrive at the construction job as two separate components, Aerex A and Aerex B. Separately the components are not classified as an explosive and will not explode until they are mixed. They are combined in a ratio of 16% A to 84% B.

The manufacturer states that Aerex 1 - the liquid - is best for extremely wet conditions and for underwater jobs; Aerex 2, the powder, will propagate in boreholes as small as 1 inch in diameter, thus saving drilling and blasting costs. The explosive is expensive, presently costing $.50 per pound.

A contractor in California used Aerex at a dam job and cut his powder requirements from 1 pound per yard of AN-FO to 3/8 pound per yard of Aerex.

One method of employing this new explosive in underwater work which has been used is to place the Aerex in 6-inch diameter polyethylene sausages from 10 to 100 feet long. Divers place the charges around the submerged obstructions and they are detonated with 3-foot lengths of 50 grain Primacord.

Trinitrotoluene - This high explosive is commonly called by the abbreviation TNT. It is one of the least sensitive of the high explosives and also has the desirable characteristic of not being affected by water. It is commonly used by contractors for priming the less sensitive blasting agents, making slurries, and the demolition of structures.

The cost is rather high as compared to dynamite, so most contractors prefer to use dynamite whenever possible for economical reasons.

TNT is packaged in 1/2, 1, and 8-pound blocks. The 1/2 and 1-pound blocks come in cases of 50 pounds each, and the 8-pound blocks come 8 to each case.

The ends of the 1/2 and 1-pound blocks are fitted with cap wells for easier priming. TNT can be handled and formed much the same as dynamite, but it does not have the workability of dynamite.

Plastics - Plastic explosives were developed late in World War II and many improvements have been made since that time. Plastic is not used by contractors except for specialized jobs and then only in limited quantities. The main reason for the lack of popularity among contractors is the cost of these explosives.

Plastic is white in color (the earlier types were yellow), has a pleasant odor, and the fumes are fair. It retains its consistency of molding clay over a wide range of temperatures and has about the same sensitiveness as TNT.

Plastics can be used for cutting steel, concrete, or other dense materials. It has been used for removing jammed bolts, removing the heads of bolts, and other unusual and imaginative jobs.

TABLE I

Characteristics of Principal Explosives

Name	Velocity of Detonation (ft. per sec.)	Relative Effect As External Charge (TNT=100)	Intensity of Fumes	Resistance to Water
TNT	21,000	1.00	Poor	Excellent
Ammonium Nitrate	11,000	0.42	Poor	Poor
Plastic	26,000	1.34	Fair	Good
Straight Dynamite				
40%	15,000	0.65	Poor	Good
50%	18,000	0.79	Poor	Good
60%	19,000	0.83	Poor	Good
Ammonia Dynamite				
40%	9,000	0.41	Poor	Poor
50%	11,000	0.46	Poor	Poor
60%	12,000	0.53	Poor	Poor
Gelatin Dynamite				
40%	8,000	0.42	Fair	Good
50%	9,000	0.47	Fair	Excellent
60%	16,000	0.76	Fair	Excellent
Aerex	24,000	1.25	Good	Excellent

CHAPTER IV

USES OF EXPLOSIVES IN CONSTRUCTION

A great many types of construction projects involve the use of explosives; so many, in fact, that it would require considerable time and space to describe them all. Some applications are used only infrequently and will be omitted from this report. The uses of explosives for construction purposes can be placed into one of four categories: Grade construction, ditching, demolition, and tunneling. Grade construction may be further divided into clearing and grubbing, excavation, and fill settlement.

Clearing and Grubbing

Clearing and grubbing a section of land involves the removal of the cover, disposing of it, and removing stumps, roots, and boulders to a specified depth. Generally, the use of heavy equipment offers the fastest and most economical method to clear a piece of land. However, there are some instances where dynamite is the safest, most convenient, or most economical method for removal of stumps, rocks, or timber. Sometimes the use of explosives is the only practical means of accomplishing the job. Many stumps are too large and heavily rooted to be pulled out by machine.

On occasion suitable equipment is not available or cannot be used due to unfavorable ground conditions as in swamps or marsh lands. Then, too, when only a few stumps are present or they are widely scattered, it may not be economical to bring a dozer to a site for a few minutes work.

Most contractors have found that the greatest efficiency in large-scale stump removal usually results from a combination of explosive and mechanical power. When employing this method, the smaller stumps are pulled out with equipment, the intermediate sizes are blasted out, and the larger ones are first split into convenient sizes and then removed with a dozer. Of course, the use of this method would depend on the root system and the type trees involved.

Timber - Cutting - Charges - Timber may be cut by placing the charges in one of two methods, one internal and the other external. The external placement requires about twice as much explosives as the internal method, but it may be the least expensive, depending on the value of time.

TNT or 40% extra dynamite is most frequently used for external timber cutting charges. The amount necessary depends upon the hardness of the timber, and if a large number of trees are to be felled, the most economical size charges should be determined by trial shots. An initial charge of $P = 4/3C$ will fell most timber under ordinary circumstances. P is pounds of explosive and C is the circumference of the tree in feet.

External charges are placed as close as possible to the surface of the tree or timber to be cut. The explosive charge should be placed on the side of the tree in the direction in which it is desired for the tree to fall. In high winds or when the tree is leaning away from the desired direction of fall, it may be necessary to place a "kicker" charge, usually 1/2 pound, at a height of 3/4 the length of the tree on the side opposite the desired direction of fall. (See Fig. 1a).

Internal charges require holes to be drilled into the timber, thus this method is limited to the larger size trees. The two general procedures for placing the charges are shown in Fig. 1b. Again the correct size charge can be determined by trial but a charge equal to $P = D^2/250$ will insure cutting. P is the pounds of explosives and D is the diameter of the tree in inches, or the least cross-sectional dimension in inches of dressed timber.

Internal charges are placed in boreholes parallel with the greatest dimension of the timber cross-section. They should be tightly tamped with moist earth. If the charge is too large for one borehole, two boreholes are drilled close together. For round timber the holes are bored at right angles to each other. Both holes are primed and fired simultaneously.

<u>Stump Blasting</u> - Stumps are all classifed as either lateral rooted or tap rooted. Lateral rooted infers that all of the roots are near the ground and nearly parallel to it. The most common lateral rooted trees are cedar, fir, maple, and spruce. Tap rooted infers that the tree has one

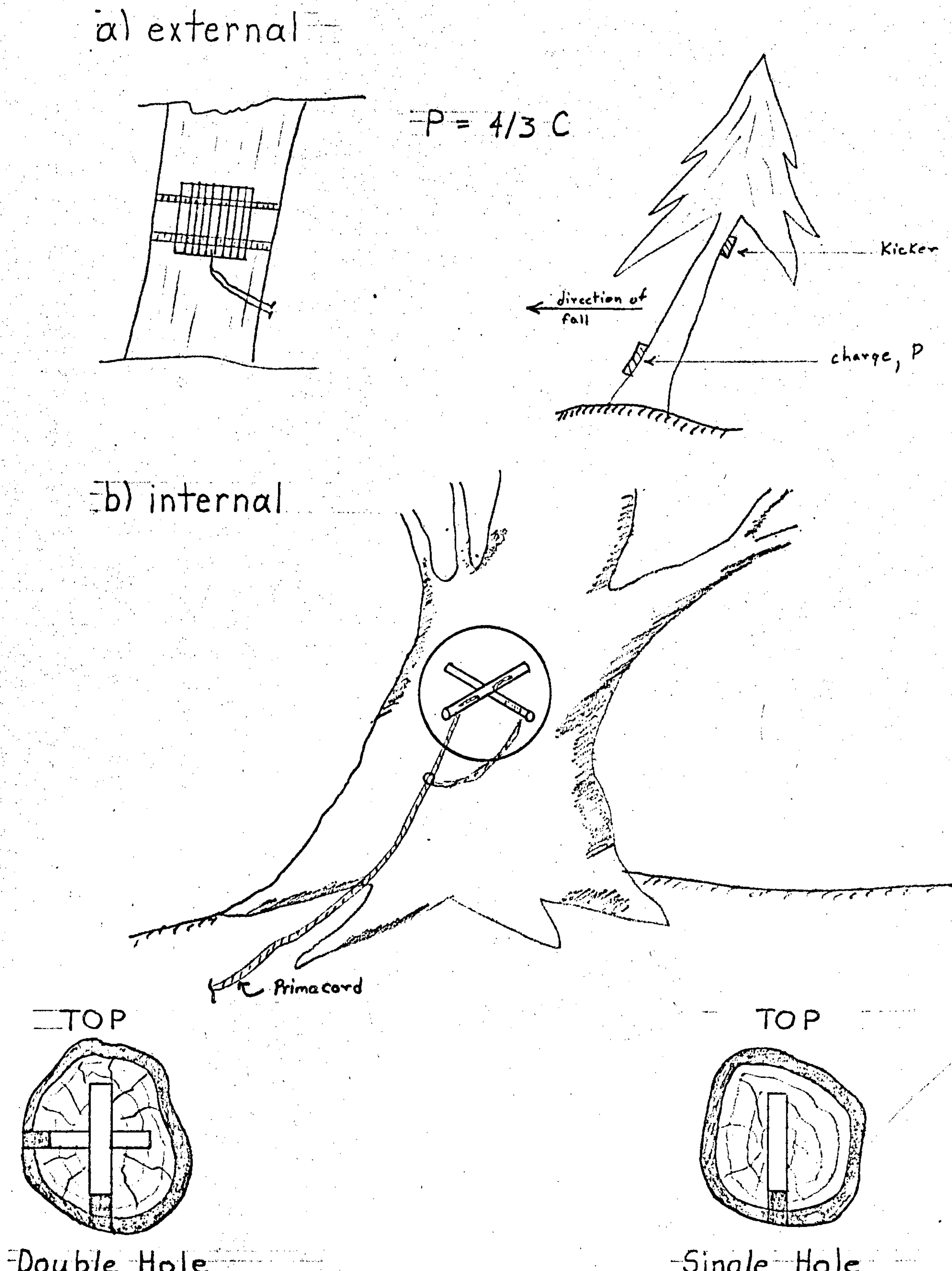


Fig. 1 Timber Cutting Charges

main root growing straight down. The best known examples of lateral rooted trees are red and yellow pine.

Many variables affect the size and placement of charges for stump removal. The size of the stump is stated as the diameter as measured at one foot above the ground surface. The condition of the stump must also be taken into consideration. Green stumps will usually require about twice as much dynamite as one that is old and dry. Results will also vary greatly in different kinds of soils. Heavy or dense soils such as clay or loam give the best results while sandy, loose, and dry soils give the poorest results. The type of explosive may vary for the various conditions, but generally a low velocity dynamite such as 20% ammonia dynamite gives the best results and is the most economical. DuPont makes a special dynamite for stumping called Logger's Powder which is about equivalent to a 40% extra dynamite. This special dynamite is more expensive than the regular, but it will take care of green stumps under the worst conditions.

Because so many variables are involved, it is impossible to predict the exact size charge which will remove a given size stump. All of the explosive manufacturers publish a chart which suggests quantities that have been found to be satisfactory under normal conditions. Experience and judgment will indicate whether the size charge should be increased or decreased for the given condition.

Table II, Recommended Charges, is published by the DuPont Company. This table is based on the use of 1 1/4 x 8-inch cartridges in firm, dense soil; if it is dry and

TABLE II

Recommended Charges

Diameter of stump one foot above ground	Number of Dynamite Cartridges Green	Dry	Partly Rotten
6"	2	1 1/2	1
12"	4	3	2
18"	6	4	3
24"	8	6	4
30"	10	7	5
36"	13	9	6
42"	16	12	8
48"	20	15	10

light, the charges will have to be increased. The recommended charges are also based on placement either under or along side the stump. In the case of a tap rooted stump, only about one-fifth of the recommended charge need be used if the charge can be placed in a hole bored in the root.

Figure 2 shows the typical charge placement for the conditions normally encountered, but these may be varied to suit individual conditions. For example, the roots are often much larger on one side of the stump than the other and the charge should be placed under the larger side rather than the center of the stump; stumps on hillsides should have the charges placed on the uphill side under the upper one-fourth of the root system.

Sometimes it is necessary to "spring" the hole in order to get the dynamite in the proper position. Sprung holes are

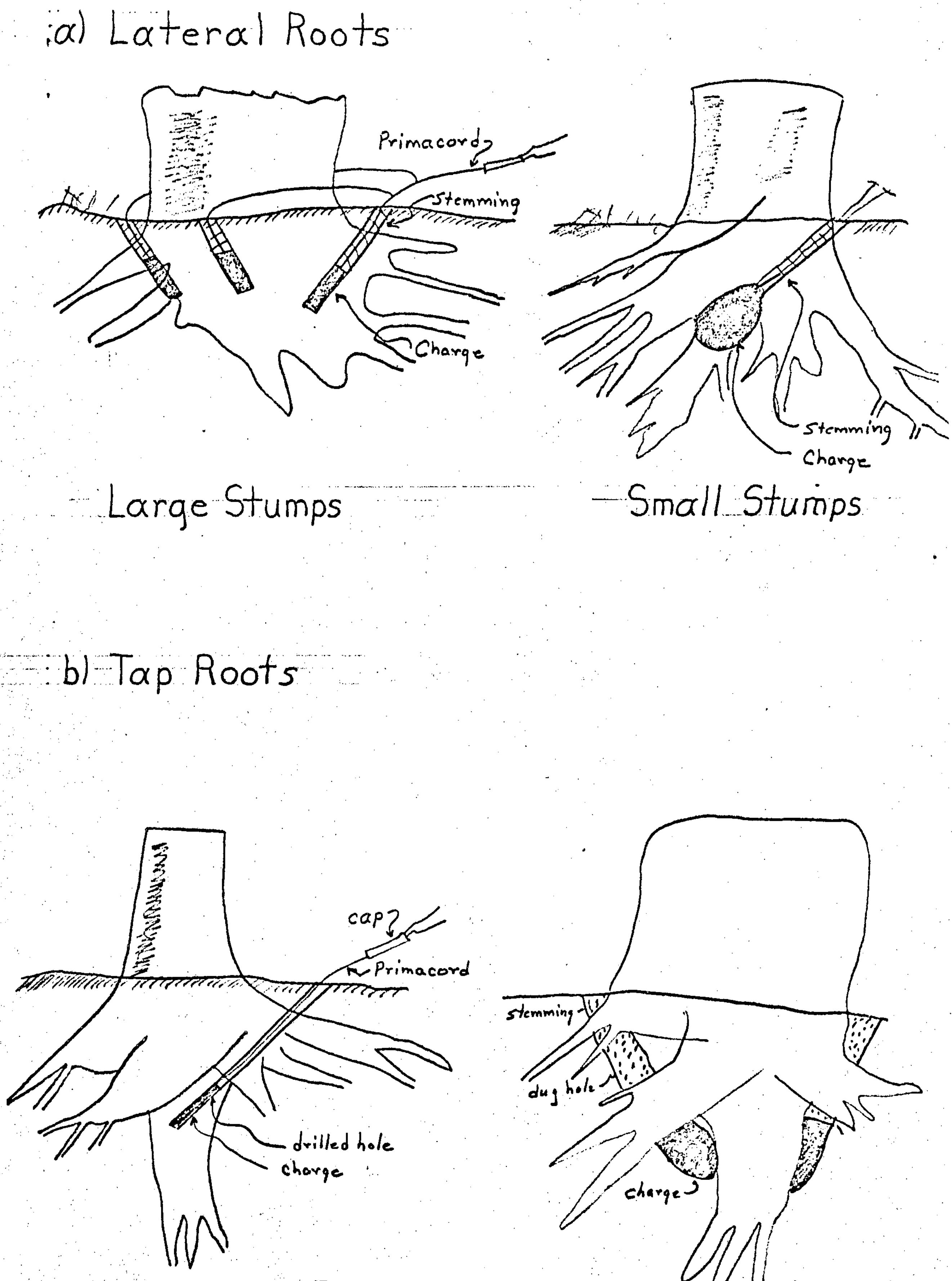


Fig. 2 Stump Blasting

made by placing a small charge in a drilled hole and detonating it in order to form a chamber at the bottom of the hole.

The best results in stump blasting are obtained when the charge is split and tamped solidly in the bottom of the hole. The efficiency is greatly increased by confinement so all charges should be adequately stemmed. The stemming material (wet soil is best) should be pushed down lightly for the first few inches, and then packed as hard as possible to the mouth of the hole.

Boulder Removal - Another use of explosives in clearing and grubbing is in the removal of boulders. There are two methods commonly used to blast and remove boulders: mudcapping and snakeholing. Another method not often used is called blockholing. To break the boulders into fragments for easier handling it is necessary to use a fast, powerful explosive such as TNT or straight or extra dynamite. If it is desired to remove the boulder without breaking it, a 40% ammonia dynamite could be used.

The snakeholing method is used primarily when the boulder is imbedded in the soil. It consists of digging or augering a hole under the rock which is large enough to permit enough explosives to be massed at a point against the rock. It is sometimes necessary to "spring" the hole to permit consentration of the explosives if the boulder is large enough to require a considerable charge. The explosive charge must be placed against the boulder if the boulder is to be broken as it is thrown out of the hole.

The amount of the charge is reduced due to the tamping effect of the ground and the rock. The amount of the charge will vary depending on the type of rock. Hard igneous rocks will require more explosives than a soft sedimentry rock such as shale. The recommended rule for determining the starting or initial charge is one to two 1 1/4 x 8-inch sticks of dynamite per foot of thickness of the rock.

The mudcapping method is recommended for use when the boulder is on the surface or only slightly imbedded. In this method the charge is placed on top of the rock and covered by 6 to 12 inches of mud. This mud serves as tamping and reduces the quantity of explosives required by about 1/4.

Because rock varies greatly in hardness, density, cleavage, etc., the size of a charge must be based on a trial blast or experience. The charges will vary from one to six sticks of dynamite (1 1/4 x 8-inch) depending on the type of rock. If the rock is very large, it may be necessary to place two charges to insure fracture into sizes which may be easily handled.

Blockholing Method - The blockholing method can be used when the boulder is on the surface or slightly imbedded in the earth. This method is time consuming and not frequently used. However, the amount of explosives required is considerably reduced. On the top of the boulder a hole is drilled deep and wide enough to hold the required amount of explosives. The charge is placed in the hole, tamped, and fired.

To give an example of the relative size of explosives required, a boulder of medium hardness and three feet in diameter would require two pounds of explosives by the mud-capping method, 3/4 pound by the snakeholing method, and 1/4 pound by the blockholing method.

Fill Settlement

A problem often encountered by contractors is the location of a highway, road, railroad, or structure through a swampy or marshy area. In such cases it is necessary to provide a solid foundation for the fill material, and the desired method in most cases is to remove the soft material so that the fill may rest on a solid foundation. One inexpensive method which has been used by some contractors in certain instances involves the use of explosives. Of course, the adaptability of this method depends upon a number of factors such as the thickness of the muck, job site location, etc. As in any sound engineering undertaking, a subsurface investigation should be made to determine the depth and nature of the soft material along, and in the vicinity of, the centerline.

Four general methods of fill settlement have been developed, namely: Toe-Shooting, Ditching, Underfill, and Relief Methods. The nature of the fill material will determine to some extent the method of fill settlement selected. Generally, coarse slag, crushed stone, or other dense, porous material with no fines makes the best material for this fill because of the absense of the compaction effort needed and time settlement which is avoided. Fills of the coarse material are ready for their hard surface in a comparatively short time.

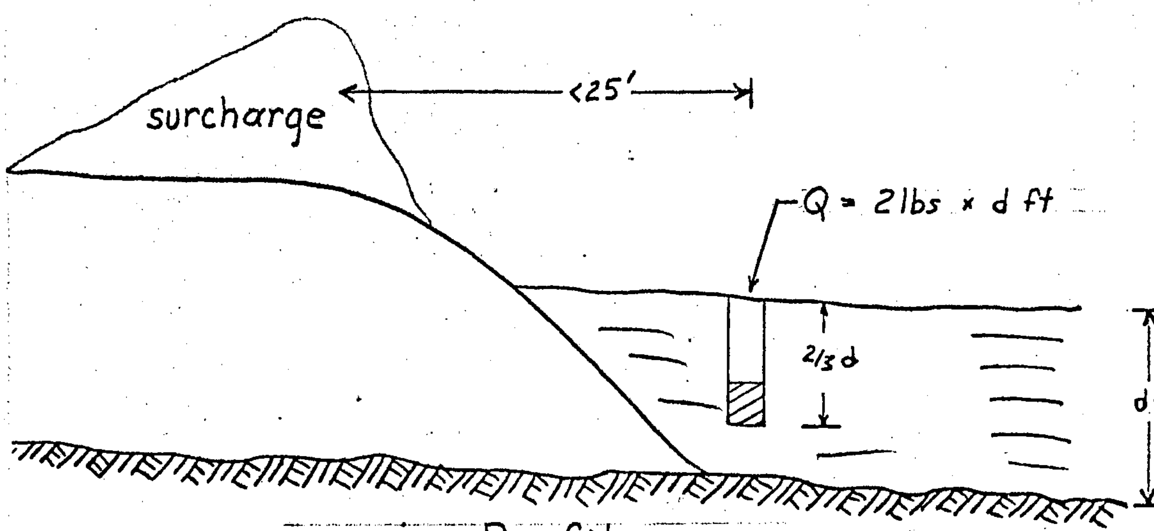
Toe-Shooting - This method consists of shooting the muck ahead of the advancing fill and has been the most widely used of any application of explosives to fill settlement.

The plan is to blast the muck ahead of the fill, which is usually done periodically about every 25 feet as the fill advances. The front of the fill is kept in the shape of a "V" and just before the blast a surcharge of fill is built up. Charges are loaded in the muck down to about two-thirds the depth and just in front of each side of the "V" point. The blast displaces the soft material and allows the fill to settle to the solid bottom underneath. The right amount of explosives and the distance apart for the blasts must be determined by trial blasts. The general rule is that the trials should be started with the blasts 10 feet apart and the explosive charge at 2 pounds of explosive per foot of depth of the muck. (See. Fig. 3a).

DuPont reports that the best results have been with 40% Special Gelatin placed in 2 to 3-inch diameter holes.

Underfill - The procedure for this method is to first place the required fill on top of the marsh. The underlying muck is then blasted by explosives which are loaded through casings that are driven through the fill and well down into the muck. Under normal conditions one stage of blasting will handle only 10 to 15 feet of unconsolidated material.

a) Toe - Shooting



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b) Underfill

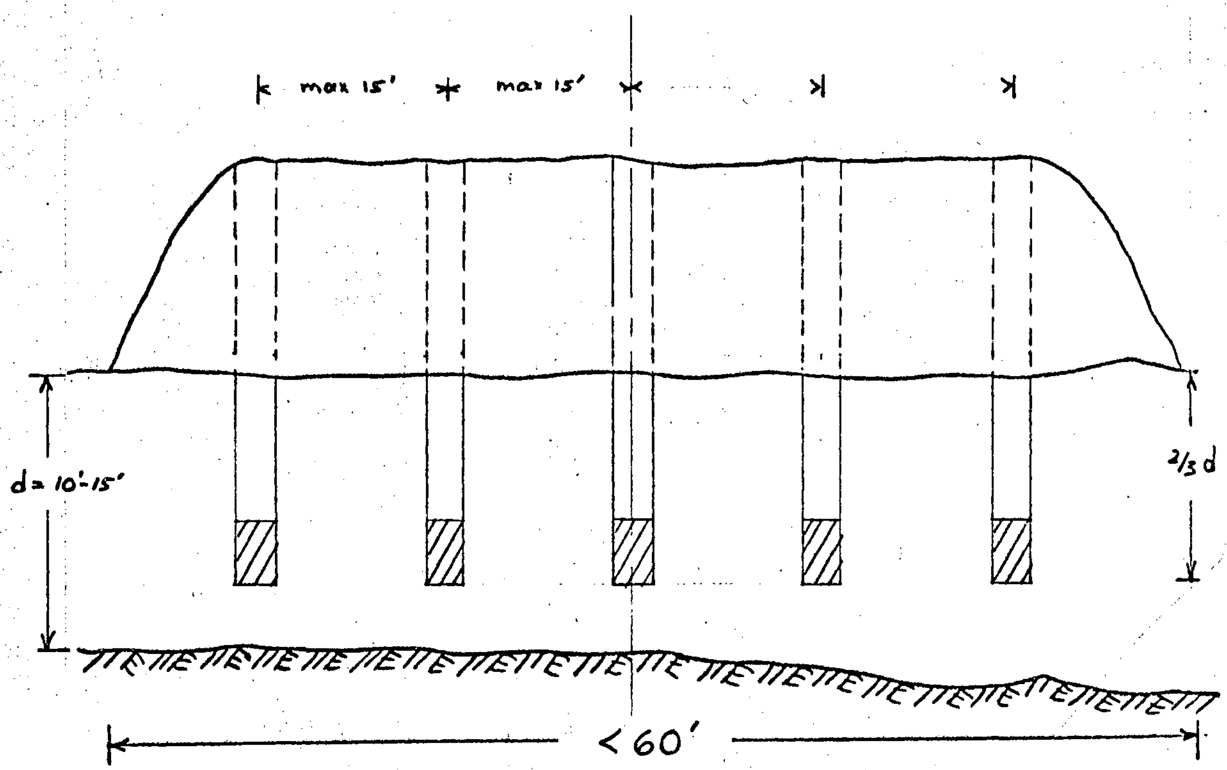


Fig. 3 Fill Settlement

When the muck is of greater depth than this, the process is repeated. This method is not recommended for widths of fill greater than 60 feet.

The function of the explosion is to liquify the muck and force it out laterally beyond the fill. The best results are encountered in materials which have a high sensitivity. Again, there is no set size of the blast, but test shots are necessary. The explosive charge should be as great as possible without displacing the overlying fill. Dynamites seem to have the best results in this method, and most contractors prefer a 40% Special Gelatin. (See. Fig. 3b).

Ditching - This method is used only in instances where the soft material is relatively shallow, not over 10 - 15 feet in depth. The method consists of blasting as large a ditch as possible along the centerline of the proposed project. Some contractors have reported successfully blasting ditches as great as 50 feet wide and 13 feet deep. However, this would be an exception and would depend on the nature of the material being blasted. The usual procedure is to shoot in short sections of 10 to 20 feet along the center line and then quickly pour in the fill before the muck can flow back into its original position.

The blasting of the ditch actually serves two purposes. It throws out as much material as possible from the path of the fill and it provides sufficient aggitation to the remainder to liquify that which is left so that the fill may push it aside and reach a firm foundation or base.

Relief - This method is often used for settlement of static locations as well as right of ways. It is most often used when the fill material is a cohesive material such as clay. The procedure is to place the fill into position over the muck. Then the explosives are loaded to a depth equal to the height of the fill plus two-thirds the depth of the muck but at a distance away from the fill, on either side of the fill, of ten feet. This causes a ditch to be blasted on either side of the fill. The weight of the fill then pushes out the underlying muck into the ditches. Sand or gravel fills will flow more or less readily into the blasted ditches while a cohesive soil such as clay sets up a bridging effect and acts as a compact solid body to force out the soft material.

Figure 3 shows the general method of placement of charges for the Toe-Shooting and the Underfill methods of fill settlement. The Ditching and Relief methods can be blasted by three different loading systems which are used in ditch blasting. These methods are the cross-section method, the relief method, and the posthole method. These methods of loading are discussed and illustrated under the section dealing with ditch blasting.

Another use of explosives closely related to fill settlement is the consolidation of the existing soil. Explosives compact the soil in this way: when a charge is set off in a loose, saturated, cohesionless material, the shock waves consolidate the soil particles and squeeze water out;

as the high pressure drives the soil particles together they gain improved bearing strength.

A recent publication describes a job in which 500 lbs. of Atlas 40% Giant Gelatin was used in consolidating a 200 x 500-foot site for a sewage plant in Charleston, W. Va.[8] The contractor had originally planned to use piles in the wet soil but then decided to densify the existing material with explosives. The contractor estimates that this method saved him 75% of the price of using piles.

The conditions were as follows: bed rock existed at a depth of 45 feet. The top 25 feet of soil had sufficient bearing strength to carry the design loads, but the lower 20 feet was submerged silty sand with very little shear resistance. Soil tests indicated that buildings on this material would settle drastically.

Test shots indicated that a three-hole pattern drilled on 40-foot centers and shot with a two-deck charge would work best. Each hole was loaded with two charges totaling 7.5 lbs. Each charge had a 75% Giant Gelatin primer and a 40% gel main load. Sixty-five holes in all were fired.

The lower of the two charges was placed 4 feet above bed rock and the upper charge was placed so that it sat 4 feet below the bottom of the firm soil. The charges were fired with millisecond delay electric caps, with five delays to each three-hole round. To keep the explosive force directed to the wet ground, upper charges were shot first. Delays 0 and 2 fired the first hole; delays 1 and 3 the second; and delays 4 and 5 the third hole.

After a shot, the density of the lower layer was checked by performing a standard penetration test in a bore hole. It must be remembered that the governing factors in the use of this method are the soil conditions. For example, if the upper layer in this case had been a dense sand, the blasting could possibly have been detrimental to its shearing resistance.

Another example of fill settlement with explosives which illustrates two of the methods discussed in this report was described in a popular magazine(9). The project consisted of placing a fill over a swamp which was 650 feet long and contained peat, a fibrous, spongy, organic material, to a depth of 20 to 40 feet.

Engineering studies indicated that it would be impossible to excavate in such material with mechanical equipment. Bids for the job were requested on the basis of two proposals: one utilizing explosives and the other sand drains. Bids based on the use of explosives were substantially cheaper.

A road had existed through the swamp for many years, and fill had been placed on the surface of the road many times to maintain the road above the level of the swamp and to grade. But gradually the fill would settle, and the surface of the road would be lowered below grade - about 15 feet in the center and east end and about five feet in the west end. Just prior to letting the bids, the grade of the surface of the road had sunk until it was nearly with the top of the swamp.

The contract plans called for relief ditches to be blasted on both sides of the roadway, after a fill of pervious material had been placed on the existing road. Each ditch was 630 feet long and of sufficient depth and width to facilitate the displacement of the peat when blasts were fired under the fill that had been placed on the roadway.

These relief ditches were blasted in a series of blasts about 75 feet long, each blast consisting of 6 to 9 holes each. The holes were 6 feet deep and 2 feet apart. Each hole was loaded with 60% straight dynamite, but only one hole in each series was primed. The existing soil was ideal for utilization of the progagation method of detonation. The resulting ditch was 7 feet deep, 7 feet wide at the bottom and 21 feet wide at the top. The total amount of explosives required to blow both ditches was 3,100 pounds.

Once the relief ditches were blasted, the final step was to blast under the fill to force the muck to flow into the ditches. This is not always necessary under different soil conditions. In some instances the weight of the fill alone will force the muck to flow into the ditches. In this case, holes were drilled through the new fill, old road, and about 10 feet into the muck. The holes were lined with 3-inch diameter pipe as they were drilled to keep the material from flowing into the hole. The holes were placed on 10-foot centers down the centerline of the fill. The holes were loaded with one stick of 2 x 24-inch 60% gelatin dynamite and "sprung." Then these spring holes were loaded with 75 to 175 pounds of gelatin dynamite depending on the depth of the muck at that spot.

The fill was settled; and, due to the porosity of the fill material, work was able to begin the following week on the surfacing.

DITCHING AND DRAINAGE

As a quick and economical agent for the excavation of trenches and drainage ditches in wet, marshy areas, dynamite has proved to be a great benefactor to both the farmer and the contractor. The same properties of dynamite which are beneficial to the contractor are valuable to the military for the strategical improvement of water-soaked areas which must be quickly developed into roads, airfields, weapons emplacements, etc. Propagated ditch blasting to drain swampy, marshy land is frequently employed, and it is a method of great potential usefulness to the military engineer.

Open ditches are necessary for mosquito and flood control, oil, gas, and water pipe lines, highway construction, fill settlement, land reclamation, stream correction and clearance, and many other purposes. Ditches may be dug quickly, easily, and economically by the use of dynamite in many types of soil, especially soils having a high water content. A number of specialized types of explosives are available to meet the requirements of ditch blasting, but their effective employment requires close adherence to the gradient, the right-of-way, the spacing and loading of holes, and to other factors based entirely on experience.

Ditching with dynamite has a number of advantages over hand or mechanical methods, some of which are of particular significance in decreasing delays and costs. Some of the advantages are: dynamite does the job in a minimum of time; handling of debris is eliminated; equipment and workmen can be utilized elsewhere. However, if conditions are such that the use of heavy equipment is practical, the resulting unit cost will probably be less than with dynamite.

Ditches may be blasted for any desired length. Cross-sectional dimensions that are considered within the realm of feasibility with this method range from 2 1/2 to 12 feet in depth and 4 to 40 feet in top width, depending on local soil conditions.

There are two distinct methods of blasting ditches; the propagation and the electric methods. Another method involving the use of Primacord is used in place of the electric method on occasion. The propagation method can be used to best advantage only in wet, dense soils. The electrical method can be used in wet or dry soils. In most instances, neither method is effective in loose, dry sand or gravel or in dry, hard packed clays or hardpans or in soil which is so fluid as to be unstable.

In wet soils, the propagation method is the quickest and most economical. It can be used even in the roughest swamps where the surface is covered with stumps and up to 2 feet of water is standing on the surface. In this method, a line of charges is placed, and only one hole is primed. The concussion from this one charge sets off the other charges by means of the detonation wave which travels through the soil by the conductance properties of the soil moisture.

When two lines of charges are used to obtain a wider ditch, one charge in each line should be primed to insure detonation.

The explosive used for the propagation method of firing should be a straight dynamite or one of the special ditching dynamites manufactured especially for ditching. This special purpose ditching dynamite is actually 50% straight dynamite. There are many tables and charts which indicate probable loads per hole and spacings between the holes, but it is important to remember that test shots are the <u>only</u> certain method of determining the best distribution of explosives.

As noted previously, the electric method permits blasting ditches in ground that is too dry or too heavy for the successful use of the propagation method. In this method an electric blasting cap must be placed in each charge. These caps are connected by means of the leg wires in a simple series, "leap-frog" series, or parallel circuit and exploded simultaneously by means of a blasting machine or other source of current such as a battery. These methods of firing are illustrated in Fig. 5. The capacity of the blasting machine must be taken into consideration when establishing the length of ditch to be blasted at one time. The voltage required to detonate a line of charges with an outside source can be determined by the application of Ohm's law, $E = IR$, where E is the voltage required, I is the current required to detonate a cap times the number of caps in the circuit, and R is the resistance in the circuit, which can be determined

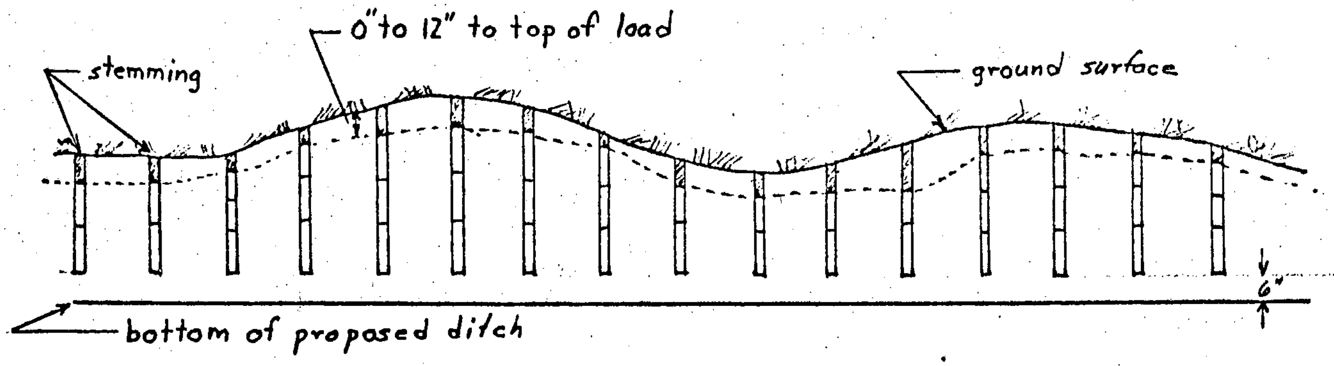


Fig. 4 Charge Placement

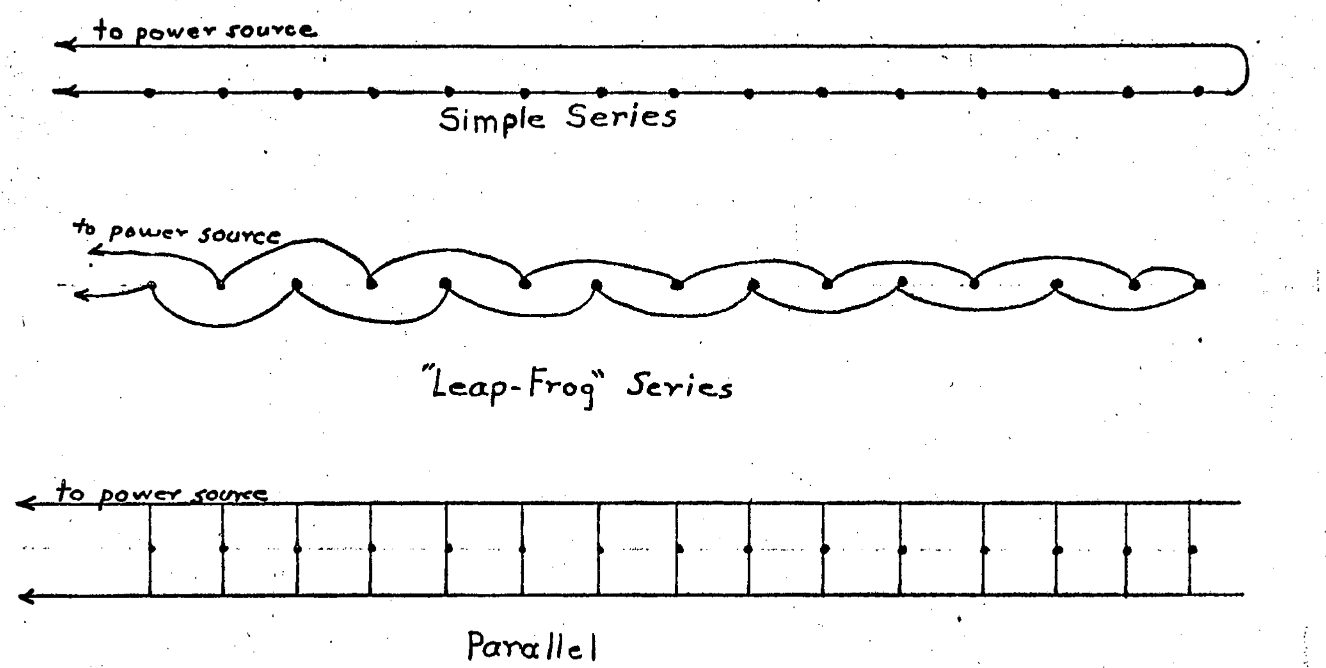


Fig. 5 Firing Circuits

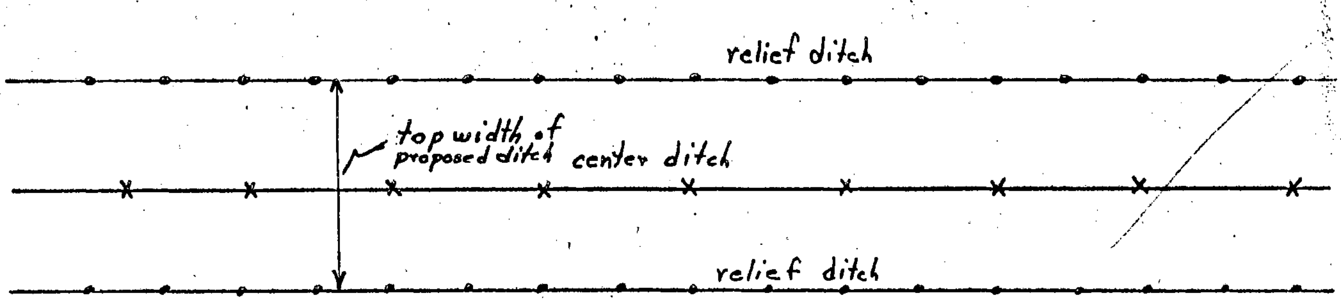


Fig. 6 Relief Method

by a galvonometer after the circuit is complete or it can be predetermined by using the manufacturer's data. One thing to remember in using electric caps is to use caps of the same size and produced by the same manufacturer in a circuit. This will reduce the number of misfires or partial detonation.

Almost any type of dynamite can be used with this method, but ditching dynamites seem to give a clearer more uniform ditch. The presense of water would eliminate the use of some types of dynamite.

It is evident that the propagation method greatly cuts the cost of ditching and should be used whenever the moisture content of the soil is sufficient to allow it.

There are several methods of placing the charges of dynamite when blasting a ditch, and the desired dimensions of the proposed ditch will determine the method to be used. The names of the methods, which describe the manner in which the dynamite is loaded, are: a) Single-Line Method, b) Cross-Section Method, c) Post-Hole Method, and d) Relief Method.

Single - Line Method - The Single-Line Method is a single line of charges spaced at equal intervals along the center line of a proposed ditch. The other methods use a single line of holes, but the Single-Line Method refers to column loaded holes, i.e. one stick on top of another. In dry soil the top of the last cartridge should be 12 inches or less beneath the surface. In very soft and wet soil the top of the last cartridge should not be more than 4 inches under the surface. Figure 5 shows the possible priming combinations and Table III shows the results expected under normal condition for the amount and distribution of charges as shown.

Cross-Section Method - This method is designed for wide, shallow ditches. A single line of holes is placed down the center line of the ditch as in the Single-Line Method. Then at every other hole a perpendicular row of charges is placed, the number depending upon the desired top width of the ditch. Loading data for the cross section is shown in Table IV. Variations in results may be expected due to different conditions, and test shots should be used to determine the best loading plan.

Post-Hole Method - To blast ditches over six feet in depth, the Post-Hole Method is used. These deep ditches require a relatively large charge in each hole. To accommodate these large charges, each hole is normally dug with a post-hole auger.

The charge is placed at a depth of 1/2 to 3/4 of the required depth of the ditch. This usually yields a ditch with the bottom width equal to the depth. It is sometimes necessary to spring the holes to enable them to hold the required amount of explosives. Ammonium nitrate explosives are sometimes used in the method instead of dynamite. The presence of water will often eliminate this type of explosive, however.

Relief Method - If the area in which the ditching is to take place is heavily sodded or rooted and if the surface is first broken by some means, the ditching charge can blow

TABLE III

Specifications for Single-Line Column Loads

Cartridges per hole	Depth to Top of Charge	Depth of Ditch	Top Width of Ditch	Distance Between Holes	Pounds per 100'
1/4	6 - 8"	1 1/2 - 2'	4 - 5'	12"	25
1	6 - 12"	2 1/2-3'	6'	15"	40
2	6 - 12"	3-3 1/2'	8'	18"	67
3	6 - 12"	4-4 1/2'	10'	21"	86
4	6 - 12"	5-5 1/2'	13'	24"	100
5	6 - 12"	6-6 1/2'	16'	24"	125

TABLE IV

Cross-Section Loading Method

Cartridges per Hole	1		2		3		4	
Distance Between Holes	15"		18"		21"		24"	
Distance Between Rows	30"		36"		42"		48"	
Depth of Ditch	2 1/2'		3 1/2'		4 1/2'		5 1/2'	
No. of Holes per Cross Row	Width	Dynamite per 100'	Width	Dynamite per 100'	Width	Dynamite per 100'	Width	Dynamite per 100'
3	11'	80 lb	11'	133 lb	13'	172 lb	17'	200 lb
5	14'	120	14'	200	17'	257	21'	300
7	16'	160	17'	267	20'	343	25'	400
9	19'	200	21'	333	24'	429	29'	500
11	--	---	24'	400	27'	514	33'	600

more material. In a single line ditch, two feet can sometimes be added to the width just by cutting along the desired edges of the ditch with a spade.

The relief method of ditch blasting is designed to break this rough surface by means of explosives. It requires the blowing of auxiliary or relief ditches to break the surface before the main ditching charge is fired. The wider the ditch in relation to its depth, the greater must be the relief charge. For best results, the charge in each relief ditch must not exceed 1/2 the main charge. The relief ditches are always loaded by the Single-Line Method, but the center may be loaded by any method. The required charges and spacing can be determined only by test shots and experience.

Loading Charges.- Holes are spaced uniformly with a tape at the distance required by experience. The dynamite should be loaded to a uniform depth with a marked or notched tamping stick. The line of the holes should be laid off with a string or wire to insure a straight ditch.

When ditching through woods, the timber and brush should be removed from the right of way. If trees and brush overhang the line of the ditch, they will catch large quantities of the material and cause it to fall back into the ditch.

When blasting in areas where stumps, logs, or boulders are present, these obstructions can be removed at the time the ditch is blasted. An additional charge of dynamite is placed under the obstruction and fired at the same time the ditch is blasted. Shooting the stumps out first will increase the cost and produce an unsatisfactory ditch.

Water standing on the surface must be considered in determining the size charge to be used. It is necessary to consider the water above the soil as though it were itself soil and load accordingly.

Theoretically, there is no limit to the length of a propagated ditch blast, but it has been found inadvisable to shoot more than 500 feet at a time. It also must be remembered to prime a new charge at each obstacle or at a change in grade of the ditch. The primed holes in a line are normally loaded a little heavy.

An example of ditching with dynamite was given in an issue of Explosives Engineer, and it described how blasting a series of ditches with dynamite converted 75 acres of marshland near Midvale, Ohio, to fertile, useful farm land.[9] For 25 years the farmers near this small Ohio farming town had been unable to utilize 75 acres which were covered with soft creekbottom muck, trees, and heavy brush. A ditch that had been dug through the section some years ago had become filled with sediment and overgrown with willows. The overflow of water in the area spread across the land on both sides of the old ditch.

Investigations developed that the original ditch had to be cleared, straightened, and deepened for a distance of about 3,000 feet, and new ditches totaling approximately 3,500 feet in length had to be provided. A decision was made to do the work by blasting with dynamite. The contract stipulated that the ditches were to be approximately 5 feet deep, 6 feet wide at the bottom, and 15 feet wide at the top.

Work began with the staking off of the center line of the old ditch. This was done by attaching twine to stakes and placing the stakes in the ground along the center line. By the use of a crow bar, holes averaging 3 feet deep, spaced on 1 1/4-foot centers, were punched into the soft mucky soil along the center line. Each hole was loaded with one cartridge of Ditching Dynamite, size 1 1/4 x 8 inch. When more depth and width of ditch were desired, two cartridges of dynamite were loaded into each hole. Additional dynamite cartridges were placed under trees, brush, and rocks encountered in the new and old ditch locations. The charges of dynamite placed in the holes were fired by the propagation method.

Completion of the project required the firing of numerous individual blasts. The heaviest blast comprised 216 holes, with each hole loaded with two cartridges. A total of 350 pounds of ditching dynamite was loaded and fired in this blast, including the cartridges placed under trees and heavy brush along the ditch line.

The original ditch was restored and new lateral ditches were made. The 75 useless acres were converted into rich, fertile soil with a minimum expenditure of money, effort, and time.

Excavation

The explosives requirements for the construction of roads and highways have increased tremendously in the past few years due to the tendency to design for the higher speed automobiles now being manufactured. Road beds are being widened, curves lengthened and eliminated, and the grades reduced thus creating the need for more excavation. Also, roads are being designed for the tremendous increase in traffic expected in the near future. Excavation of building foundations by explosives has also increased in recent years due to the development of blasting techniques and precision blasting. The use of millisecond (MS) delay caps has reduced vibrations and created such control of the blasted materials that blasting in heavily populated areas is becoming quite common.

Roads and Highways - In determining the location of the centerline and the grade line of a highway, an effort is made to keep the volume of excavation to a minimum consistent with the specifications for grades and curves. Generally, an attempt is made to balance the volume of cuts with the volume of fills within the limits of a reasonable haul of about 3,000 feet. Of course, this is not always possible or feasible so it is sometimes necessary to "borrow" material when the volume of fill is greater than the volume of the cut. On the other hand, it is sometimes necessary to "waste" excess cut material when the volume of fill is less than that of the cut. The former condition has little effect on the use of explosives but the latter condition can influence the type blasting and the quantity of explosives used as will be illustrated later.

Types of Cuts - Cuts are generally classified into two general categories: "thorough" and sidehill cuts. The different conditions which normally exist in each of these classifications require a different blasting technique. In a thorough cut, the excavation is made through a hill leaving a wall on both sides, and in a sidehill cut, the excavation is made in the side of a hill leaving a wall on one side only. In this latter type part of the section may be a fill in which the material from the cut may be utilized by blasting it down the hillside.

Blasting Methods - Whenever possible the material in an excavation is removed by shovels or tractor scrapers for reasons of economy. However, many cuts are necessary in rocky regions where it is necessary to blast to loosen the rock in order that it may be handled by the shovels or tractor scrapers.

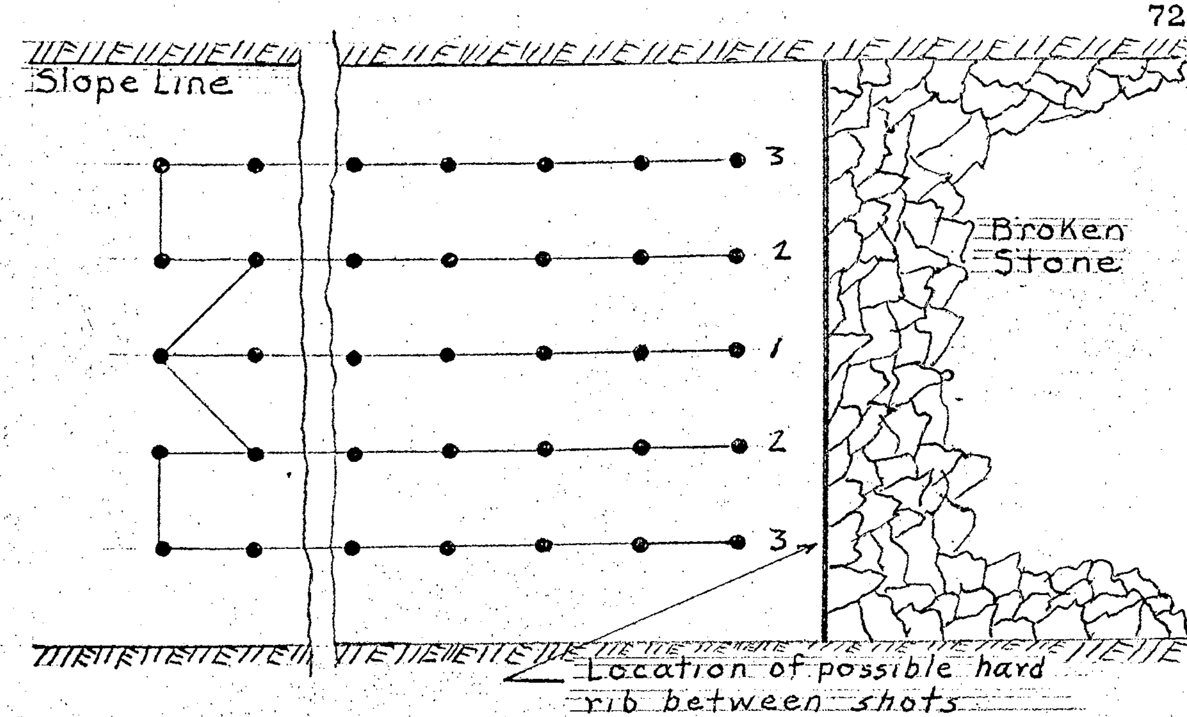
In determining the method of blasting, and particularly the depth of cut and area to be broken ahead of the shovel, the continuous operation of the loading and hauling equipment should receive first consideration. Whenever the depth of cut is in excess of 30 feet, it is usually more economical to blast in lifts or benches of 15 or 20 feet. This normally allows a shovel to operate near optimum depth of cut.

In some instances it may be more economical to excavate to final grade in a single operation. This is done by developing a face for large diameter borehole blasting. Individual shots generally consist of two or more rows of holes extending across the cut and fired into the shovel pit as needed in order to maintain continuous production.

Every effort should be made to provide maximum working area for the shovel so that an empty truck can be spotted before the loaded one pulls out. Also an attempt should be made in planning the blasting method so that the area is such that the angle of swing of the shovel is as small as possible. On sidehill cuts an attempt should be made to develop a long face parallel to the center line which will greatly improve the movement of hauling vehicles. With such an arrangement and when desired breakage can be obtained, the open face will cause the quantity of explosives required to be reduced.

The above method is occasionally used in deep thorough cuts also (100 to 300 feet wide at top). Here a long cut can be opened up along the center line or on either side, depending upon the slope of the surface. Then this face is worked as a quarry and pushed back laterally to the slope line. This method can be repeated on successive lifts until the cut becomes too narrow, or less than 100 feet. After that the thorough cut is worked in the normal manner.

The usual procedure with average size cuts is to let the shot extend to the full width of the cut and be of sufficient length to provide at least one day's shovel yardage. (Fig. 7).



Drilling Layout in a Thorough Cut
Fig. 7

From a blasting standpoint the shot should be as long as possible with the minimum length sufficient to supply one day's shovel yardage. Considerable delay and expense result in hooking up and firing and moving personnel and equipment out of the danger zone each time a blast is made.

It should be emphasized at this point that all conditions discussed here are considered to be normal conditions with no special problems existing due to the presence of structures, homes, etc. It is first necessary to understand the problems of everyday blasting before undertaking the special problems. This report will delve into special problems only when necessary to illustrate a blasting technique.

Drilling - An integral part of all blasting jobs is the drilling operation. The cost of drilling is a major part of the total costs of an excavation job. In the previous sections of this chapter the holes were all considered to be in soil and were inplaced with shovels, augers, or steel bars. However, the blasting of rock requires the use of highly complex and specialized drilling apparatus to create the holes for the placement of the explosives. This report will not go into this equipment other than to recognize the important role it assumes in blasting operations.

The most commonly used borehole diameters in excavation jobs range from 2 to 5 inches. Generally larger holes are used infrequently because the smaller and more closely spaced holes give the relatively fine breakage normally required on a job of this type. Holes up to 10 inches have been used on sidehill cuts where the cut material is wasted down the hill sides. These larger holes with the larger quantities of explosives thus eliminate the need for handling of blasted material.

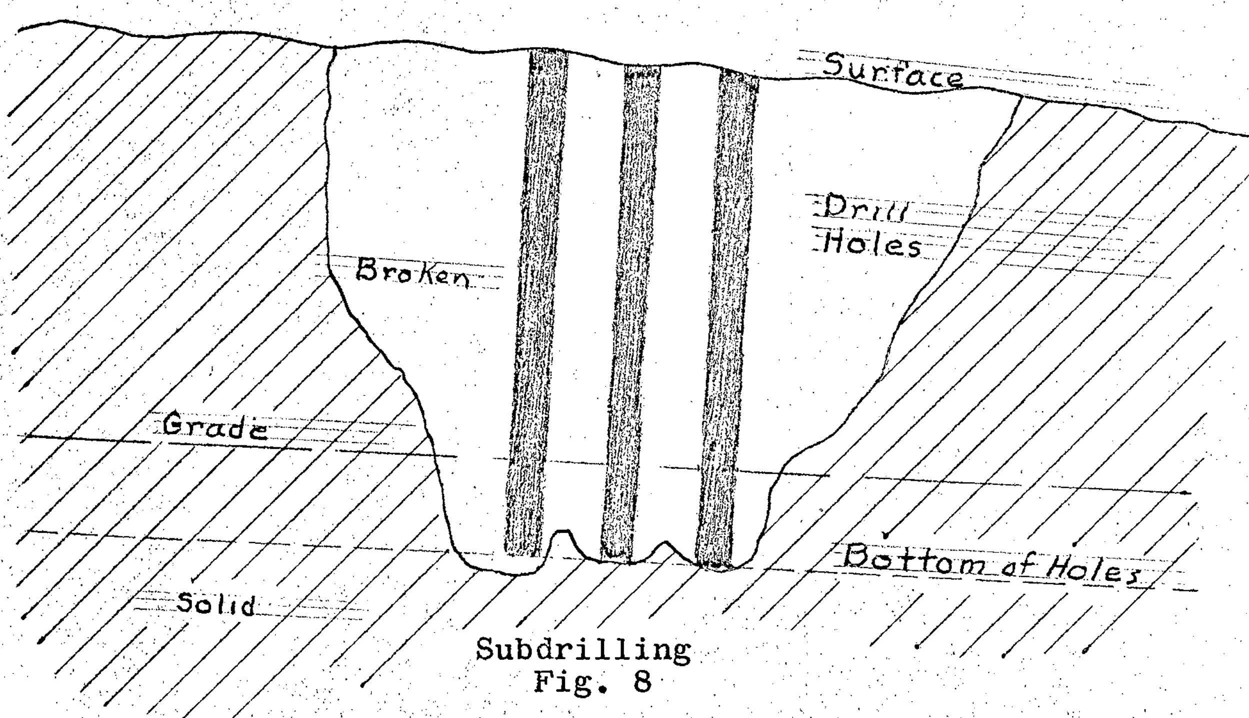
Generally, with the modern high-speed equipment now in use, low unit costs will permit small diameter holes spaced rather closely. This allows better distribution of explosives throughout the rock and thus produces better breakage.

Drill hole spacing in excavation work can vary from 4 x 4 feet up to 10 x 10 feet depending upon the type and quantity of explosives and the desired fracture. Spacing over 10 x 10 feet will usually not give the required fracture and still be economical.

Usually column loading the holes will give better distribution of the explosive effort and thus better results. Occasionally spring holes adjacent to a previous shot are used in order to break the bottom through the heavy burden that may be encountered and help eliminate the hard ridge that sometimes exists in this area (Fig. 7).

Normally, holes are subdrilled below shovel grade to a depth of about 10% of the hole depth to insure bottom breakage (Fig. 8). The amount of subdrilling necessary will depend upon the type of rock and should be adjusted as blasting progresses.

Explosives and Firing - To insure maximum effect, the explosive charge should fit the hole diameter as closely as possible. The more stemming that is placed on top of the charges, the smaller the amount of flying debris which will occur, but it may be necessary to load nearly the entire hole to obtain the necessary top breakage.



Subdrilling
Fig. 8

The types of explosives cover a wide range so it is impossible to state a preferred method of selecting an explosive. In small holes, dynamite is usually used while AN explosives are normally selected for large holes. The hardness of the rock, moisture present, location of the blast area, and the desired fracture will all affect the selection of an explosive.

In the previous examples of firing which were given for clearing and grubbing and for ditching, the charges were each primed with a cap (except for propagation firing) and all fired at the same time by a blasting machine or some other source of voltage. However, in some types of blasting encountered in excavation and tunneling, it is desirable to apply a firing circuit to a series of caps all at once but to have them fire at different times. This is accomplished by the use of a delay or millisecond delay (MS) caps. These contain, in addition to the standard devices of bridge wire, ignition agent, and priming and base charge, a delay fuse that is started burning by the ignition agent, and burns for a time proportional to its length before it reaches and fires the priming charge.

The difference between delay and millisecond delay caps and the advantages and disadvantages of each will be discussed in the section about blasting in tunneling.

The outstanding advantages of delay blasting over simultaneous blasting are improved fragmentation and decreased vibration. Delay detonation effectively separates the pressure fronts in rock and the bundles of energy which they deliver to the rock so that the shock front's work of breaking the rock is done as a series of closely spaced, but independent, events. The results are that the initial or first blast allows relief for the following blasts which increases fragmentation and reduces considerably the amount of energy that is carried to the surrounding territory by the rock. The greatest amount of energy that reaches surrounding ground and buildings for a delay blast is that released by the most explosive on any one of the delay intervals[10]. In addition, delay shooting aids in controlling the direction and amount of throw of the broken rock, and it minimizes backbreak. By sequence firing of rows of holes from the center of the cut toward the sides, shattering of slopes is greatly reduced as illustrated by Fig. 7.

To illustrate the basic principles in MS delay employment and to give an idea of the application of these principles to an actual construction project, the following example is given of a job described in an issue of <u>Construction Methods and Equipment</u>[11]:

Millisecond delay patterns and thoroughly confined charges were the key to succesaful blasting on a difficult stretch of the New York Thruway in Yonkers, New York. They reduced the dangers of ground vibrations, flying rock, and excessive noises.

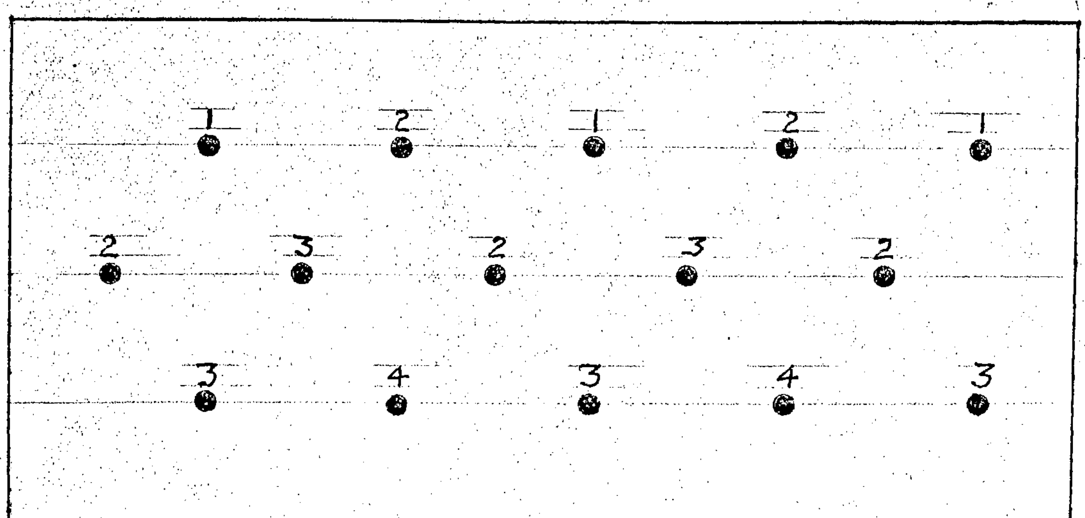
Rock lay in horizontal laminations, but in one section the layers of rock were nearly vertical. The maximum depth of cut was 40 feet. Blast holes ranging from 16 to 30 feet were loaded with either Atlas 40% Gelatin or Atlas Gelodyn No.

A basic millisecond delay pattern as shown in Fig. 9 was used throughout the job. Due to lower resistance, the throw of the rock was influenced towards the low numbered delays. In most cases the lower delays were spotted closest to the free face of the burden.

About 90% of the blasting was done in restricted locations. Holes were spaced on 4-foot centers, and only the bottoms of the holes were loaded. At least 10 feet of sand stemming was tamped on top of each charge. The primed cartridges were placed near the bottom of the holes. Initiation of each loaded hole at the point of greatest confinement made maximum use of energy. It produced good fragmentation while reducing flying rock and blast noise.

Generally, shots were fired across one-half of the right-of-way. Work progressed along the axis of highway with cuts made on alternate sides of the centerline. As one shot was loaded the next shot was drilled.

Besides protecting structures and utilities which were



Basic Pattern (Numbers refer to the order of firing)
Fig. 9

in the area, the contractor had to protect retaining walls which were constructed earlier on the job. (For job site layout, refer to Fig. 10). The bulk of the rock to be blasted lay not less than 1 nor more than 3 feet from the retaining walls, and at the intersection of McLean Avenue relocated utilities ran only 6 feet from the side of the cut. The circled letters in Fig. 10 indicate the order in which the sections were removed. In sections A and B, slight modifications in the basic pattern provided a longer delay period between rows closest to the retaining walls and produced a throw of rock away from this danger area. Along the back walls of sections A and B, longer delays between the last two rows of holes insured that breakback would not damage McLean Avenue.

Removal of sections A and B left only McLean Avenue in the path of the completed cut. This rock was removed in four stages. The center sections (C & D) were removed first, making it possible to shear the final sections (E & F) cleanly by providing three free faces for the final burden.

Sections E and F were shot with several blasts. Fig. 11 shows the pattern used to make the final shot in section E. It is again a modified-progressive pattern designed to throw towards the center of the right-of-way by providing a relatively long delay in the back row. This exaggerated delay insured that the last row would shoot to the free face, shearing the back wall cleanly. The final shot in section F was made in the same manner.

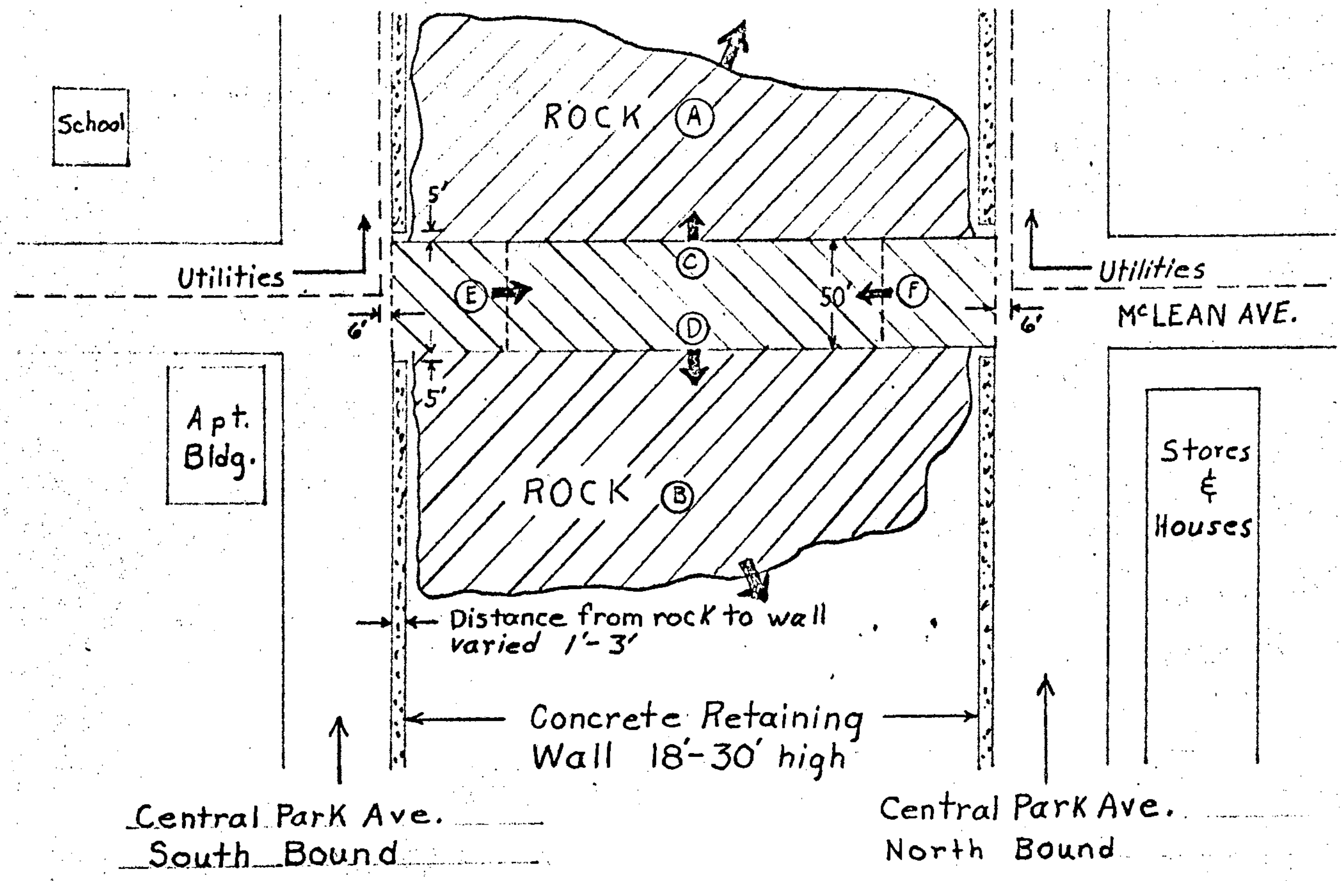


Fig 10 Difficult Blasting Problem

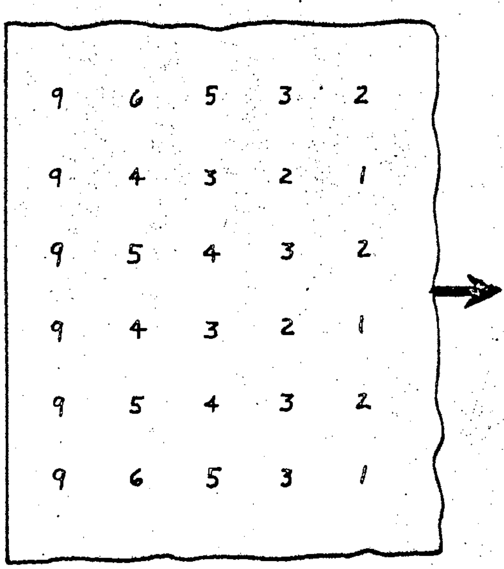


Fig 11 Typical Pattern Used - E & F

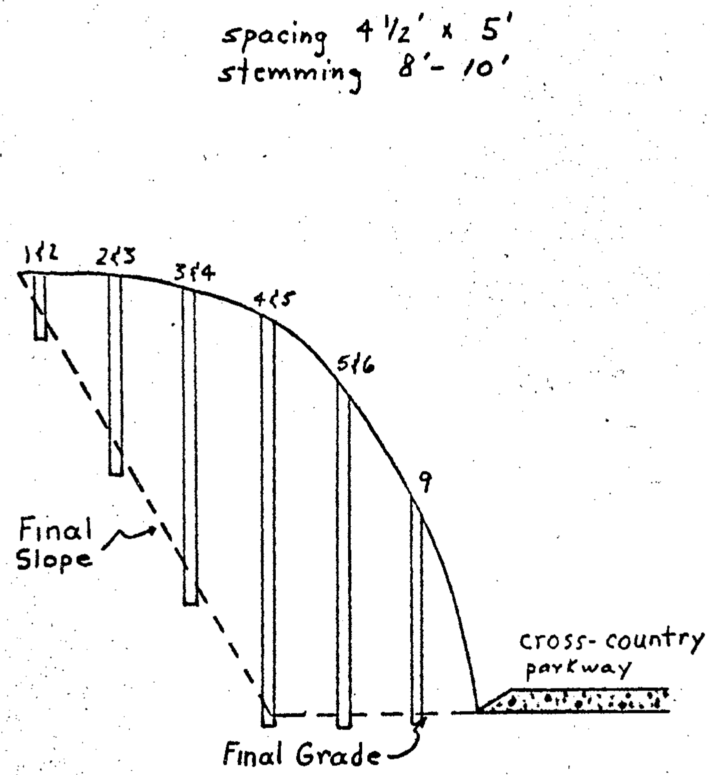


Fig 12 Up-Slope Shooting

In another area a cut had to be widened on each side of a heavily traveled parkway. The earlier shooting caps were placed in the up-slope holes, and the delay period was lengthened between the lower two rows of holes to insure an up-slope throw. Figure 12 shows the placement of charges and the delay arrangement. The basic alternate-progressive pattern was used except in the lowest row of holes. The shot provided excellent fragmentation and control of throw. It was reported by the author of this article that not one piece of rock fell on the parkway. This degree of accuracy is hard to visualize.

As mentioned previously, in one section the laminated rock lay vertically rather than horizontally, and paralleled the Thruway axis. Here the blasting pattern was rotated 90^{o}. Thus the line of least resistance followed by the staggered action of the delayed charges was through the rock perpendicular to the length of the vertical seams. The force of the blast worked on the rock rather than escaping through the seams to leave a muck pile of oversize boulders. Although a house was located about 10 feet away, it was undamaged. This method of employing delay blasting is applicable to many types of blasting other than excavation. It is also widely used in quarrying and in tunneling.

A new technique of blasting called "pre-splitting" is now being used which simplifies precision blasting and increases the accuracy of delay blasting as just described. Pre-splitting is a technique by which blasters split or crack a rock deposit along the line marking the edges of a cut prior to production blasting. This process first gained prominence in this country in late 1959 on the Niagara River Project.

The pre-split blast establishes a line of cleavage beyond which the force of later blasts, fired to break up the rock, cannot go. The net result is a sharp stable slope.

An actual project(12) on which the pre-splitting technique was used was the improvement of Southern Railway line in the Cumberland Mountains of Kentucky which was completed in November 1962. Some of the cuts were up to 200 feet deep and 74 feet wide at the bottom.

The powder crews used detonating fuse and 40% gelatin dynamite for pre-splitting. The procedure is to tie a stick of dynamite to the end of a section of fuse, lower it to the bottom of a hole and tamp in stemming. Then they alternate dynamite and stemming to the top of the hole. The most commonly used method for tying the dynamite to the fuse is to place three holes in the dynamite with a wooden stick or the punch end of a set of crimpers and lace the dynamite with the fuse or primer cord. Two other methods have been used in priming these pre-split holes. One method is to tape or fasten the dynamite cartridges to the fuse with masking tape or rubber bands at specified intervals. Another method which is time saving but much less certain of total detonation is to place the first cartridge as a primer, add stemming, then place the next cartridge on top of the stemming and then insure that the cartridge is in contact with the D-cord prior to placing the next layer of stemming.

The result of the firing of these small charges is an uneven fissure at the surface and cleanly cracked or broken webs between the holes farther down.

Once these pre-split holes have been fired the next step is to fire the main blasts for production. On the job for the railroad, a mixture of ammonium nitrate and diesel fuel was used. This AN/FO mixture was primed with 60% gelatin dynamite and millisecond delay caps. The holes were 9-inch, 6-inch, and 4 1/2-inch holes.

Prilled ammonium nitrate in bags was hauled to the site by truck. About 30 minutes before the holes were to be charged, workmen would open the bags and pour in the appropriate amount of fuel oil. The powder men made primers from the dynamite sticks by inserting the delay cap and placed one with the proper delay cap in each hole. Then the AN/FO mixture was added to a predetermined depth. Then more dynamite was added, and this procedure was repeated until the hole was filled. In a method of blasting such as this, the amount of dynamite used in the proportion depends upon the diameter of the holes, their spacing, and the type of rock to be broken.

Blasting caps with different delays are used in successive lines of holes to produce a controlled blast with good breakage and little throw of rock. All reports of contractors who have used this method which were examined indicated that the results were quite satisfactory but the costs per cubic yard of production were higher.

Demolition By Explosives

To most people the word "demolition" is synonymous with explosives. Actually, this is not true because demolition means the destruction of structures or materials by explosives, fire, water, mechanical means, or any other means. However, explosives are so often used for demolition purposes that such an erroneous assumption is only natural.

Investigation reveals that the use of explosives by the construction industry for demolition purposes may be classified into one of three categories: Masonry, brick, or concrete; reinforced concrete; and metal. Explosives are sometimes used for the rapid and economical destruction of soil and timber structures, but it is not felt that these uses need to be discussed in this chapter because the calculation and placement of charges is similar to those methods discussed under ditching and timber cutting.

The use of explosives for demolition work is much more scientific than for most purposes and requires blasters and engineers with experience. There is normally little opportunity to adjust the size and placement of charges as blasting progresses because most work is carried out with one blast or one series of blasts. Too large a charge may damage adjacent property and too small a charge may substantially weaken a structure thus creating hazardous conditions for further drilling and blasting. It is usually necessary for the engineer who determines the placement of charges to be familiar with the structural design of the structure to be demolished.

When properly employed, explosives offer a safe, economical, and rapid means of demolition as will be evidenced by the discussion of some actual projects.

Masonry, Brick, and Concrete - Old walls and building foundations may be economically removed by explosives providing the thickness is over 8 inches. Material or walls less than this size may generally be removed more practically by mechanical means.

Brick walls are generally easier to blast than concrete. The preferred method is to drill a row of holes near the bottom of the wall to a depth of about 3/4 of the thickness of the wall. The spacing will vary from about 3 to 4 feet for most walls and foundations. The size of the charge will range from 1/2 to 1 cartridge depending upon the age and condition of the wall. Any medium strength dynamite may be used, but gelatin is generally preferred because of its ease in handling in instances where whole sticks are not used. When walls or foundations over five feet in height are used it may be desirable or necessary to place an additional horizontal row of charges to break the wall into pieces which may be readily handled.

With concrete walls the same general procedure is followed as with brick, but the spacings range from 2 to 3 feet, and it will normally require 1 to 2 sticks of dynamite, depending on the thickness of the wall.

The holes should be primed with electric caps or with Primacord. If the location allows, the charges may all be fired simultaneously. However, it may be necessary to fire using delay caps or even fire the charges one at a time if there is danger to adjacent property. It is sometimes necessary to place heavy ties or timbers or even blasting mats around the blast to prevent flying debris.

Contractors have found through experience that the better the quality of the concrete the better and easier it blasts.

Contractors are frequently called upon to remove existing bridge piers which are generally stone masonry or a combination of masonry and concrete. If they are in an isolated location, each pier can usually be broken by a single blast. However, if the structure is in water, most contractors prefer to remove the dry portion first and then remove the underwater portion in a second blast.

Boreholes are spaced from 3 to 4 feet for best results, the spacing depending upon the diameter hole used. Loading ratios for dry work will vary from 0.50 to 0.75 pound of explosive per cubic yard of blasted material depending upon the age and condition of the structure. When blasting in populated areas or whenever vibrations or flyrock are a hazard, the loading ratio should be reduced to 0.25 to 0.33 pound per cubic yard and fired with a standard or MS delay.

The general belief of all contractors concerning underwater blasting of concrete is that heavier loading must be used than for dry blasting, and the loading ratios range from 1 pound to 1.25 pounds per cubic yard. This idea is based on the theory that water on the face of a target opposite the explosive draws off a large percentage of shock waves from the explosion. Even though the tamping effect of the water tends to increase the effectiveness of the explosive, the loss of power on the opposite side offsets this gain. The results of tests conducted by the Engineer Research and Development Laboratories in July, 1961, were released [13] in January, 1963. These tests, though not completely conclusive, seem to disprove the old theory and indicate that less explosives are actually required for underwater blasting. However, until more extensive tests are made it is advisable to continue with the proven loading ratios.

In congested areas it may be necessary to remove the pier in small blasts, or with MS delays, in order to minimize vibration. For delay blasting under water it may be necessary to use "Nitramon" or a comparable explosive because dynamite or gelatin would have a tendency to propagate.

Under normal conditions, a 40% Extra dynamite is satisfactory for dry work, and a 40% gelatin or Special gelatin is satisfactory for underwater work.

Reinforced Concrete - In most cases old piers, walls, or foundations are simply monolithic masonry or concrete structures without reinforcing, and blasting by the procedures previously described offer no particular problems. However, the demolition of reinforced concrete is usually more difficult. Somewhat heavier loading is required, and there is a greater hazard from flying material. The blasting is generally done progressively and may require the cutting or the cutting and removal of steel between blasts. The reinforcing steel will seldom, if ever, be cut by the initial charge so it is necessary to cut it with a torch by an explosive charge of dynamite, gelatin, or plastic.

The demolition of buildings usually requires the blasting of reinforced concrete columns or footings. The reinforcing steel is usually no problem here since the general procedure is to collapse the building by destroying key structural members and allow the weight of the building to demolish itself. Reinforcing may then have to be cut to facilitate debris removal.

Two buildings were demolished by explosives (14) in downtown Washington, D.C., in 1958. These apartment buildings were located on the corner of C and 22 Street N.W. The State Department Office Building was 100 feet from the blast, and the Federal Reserve Building was 150 feet away. Of major concern to the city were its water, gas, and steam lines which passed just 20 feet from the site.

The manner in which the charges were placed and the use of a millisecond delay system made the blast possible under the existing conditions. The general procedure was to destroy the reinforced columns in the basement and on the first floor in such a manner and sequence as to cause the building to collapse inward.

The charges were small, consisting of 1/2 pound of dynamite each. Holes were drilled in the columns and spaced about 9 inches apart. This close spacing was necessary due to the presence of the reinforcing steel.

The firing of each charge was controlled by a MS cap. By controlling the firing at each point within the structure, each building was made to fall in toward its center, with the walls folding down on top of each other like the collapsing sides of a house of cards. Thus employed, the dynamite alone is not the working force; the dynamite kicks away the building's underpinnings and the mass collapses, the weight of the building doing the work.

The entire collapse took 17 seconds, and the placing of the charges required only a few days. The vibrations of the collapsing building were measured with a seismograph, and it was found that the ground vibrations were not as great as those caused by a passing train. The utility lines, about which the city was concerned, were uninjured. The total cost of the job was $95,000, which was $55,000 under the lowest bid price for conventional demolition.

The engineering publications are full of stories involving examples of economical demolition by explosives. The majority of the experienced blasting contractors prefer to use a 60% gelatin placed in charges not exceeding 1/2 pound and fired in a predetermined sequence by millisecond delays. This delay can be instigated by one of two methods. The most commonly used method is by electric caps connected in series. Another method involves the use of Primacord which is manufactured by the Ensign-Bickford Co. and Primacord M/S Connectors manufactured by the DuPont Company. These connectors are delay devices designed for surface delay firing with a Primacord trunkline system and are the proper amount of explosives to use: $P = 3/8\ A$ where P is pounds of TNT required and A is the cross-sectional area in square inches of the steel member to be cut. For gelatin the amount should be increased by about 20% and for plastics it can be reduced by an equal amount.

High Carbon Steel - This grade of steel is usually used for such parts as metal working dies and rolls.

Alloy Steels - Such items as gears, shafts, and tools are normally made from alloy steel. Cables and chains are usually made from this or high carbon steel. The proper size charge for these two grades of steel as well as for reinforcing bars may be determined by $P = D^2$, where P is pounds of TNT and D is the diameter in inches of the section to be cut.

Placement of Charges - The size and type of a steel section dictate the placement of explosive charges. Some elongated sections may be cut by placing the explosive on one side of the section completely along the desired line of rupture. More explosive should be placed against the thicker portion of the cross-section than against the thinner portions. In some steel trusses, the individual members are fabricated from two or more primary sections such as angle irons or bars separated by spacer washers or gusset plates. Generally, the charge on such sections has to be distributed on opposite sides of the member to produce a shearing action (Fig. 13). Heavier H-beams, wide flange beams, and columns may also require auxiliary charges placed on the outside of the flanges. Care should

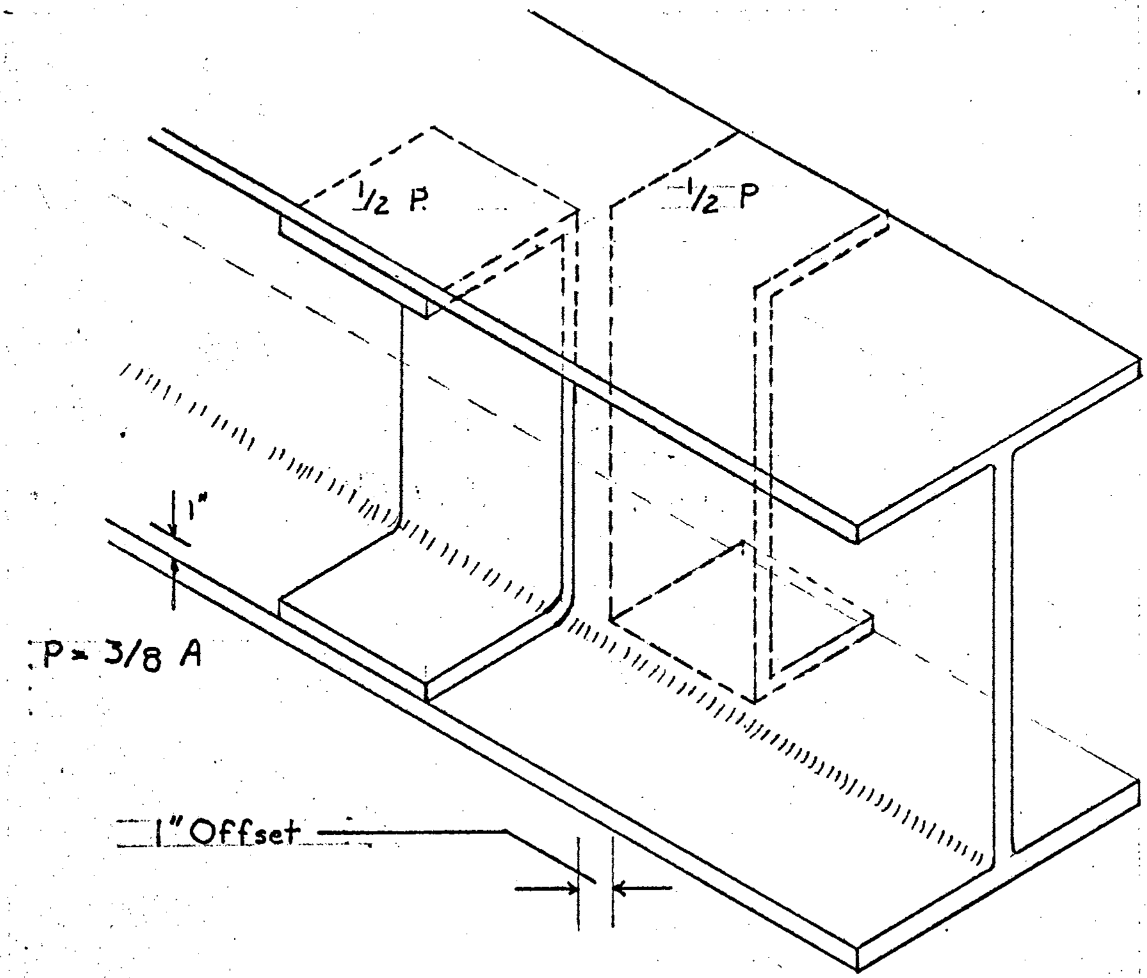


Fig. 13 Charge Placement

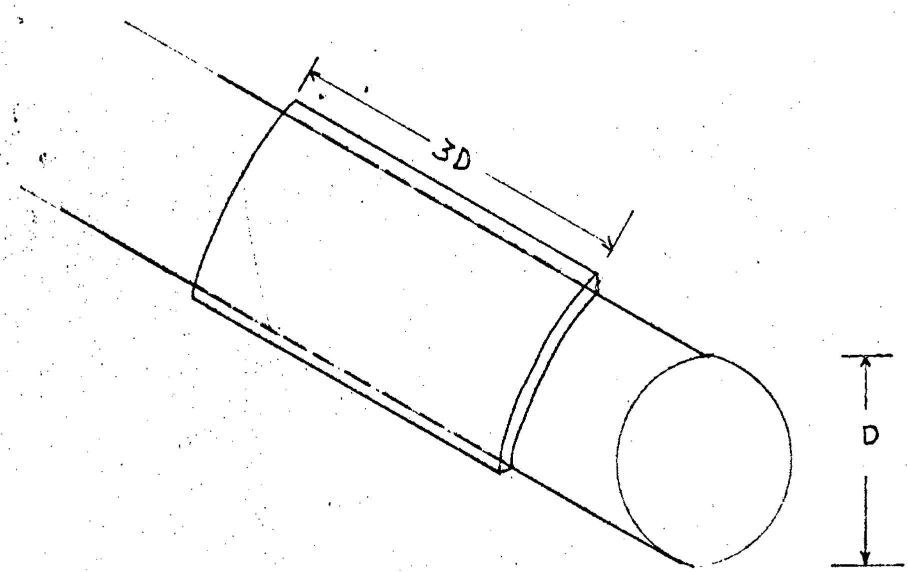


Fig. 14 Rods, Chains, & Cables

be taken to insure that the charges are not directly opposite each other because they will tend to neutralize one another.

When cutting steel rods, chains, and cables (Fig. 14), either gelatin or plastic should be used. The charge should be placed on only one side of the member to be cut, the width of the charge slightly less than 1/2 the circumference. The length of the charge should be at least three times the thickness of the member. The charge should be at least 1 inch thick and detonated from one end rather than the middle in order to produce a major cross fracture at the opposite end. This relatively new technique is based on the utilization of the collision of shock waves with their reflexions to amplify the cutting power of the explosion. When the explosive is initiated at one end, the shock waves from the explosive produce shock waves in the steel as they travel through the explosive. These waves intersect at a point near the end of the charge. The interaction of these shock waves produces a fracture in the steel perpendicular to its surface.

Tunnels

A large percentage of the explosives used in the construction industry is used in tunneling operations. There are many aspects to a tunneling operation such as the method of drilling, the method of driving the tunnel, the type of cut and round used, the mucking procedure, the ventilation system, the method of firing, etc. Due to the nature of this report, it will be necessary to discuss certain of the above-mentioned topics, but an effort will be made to discuss these topics only to the extent to which they influence the blasting procedure.

Tunnels vary in size according to their purpose. Those used for water supply, sewer, and utility purposes may be as small as 4 feet in diameter, while water diversion, railroad, and vehicular tunnels may be as great as 60 feet in diameter.

Wet drilling to reduce rock dust is required by law in practically every state. For tunnels 10 feet or less in diameter, the drilling and mucking equipment are small and compact. For larger tunnels, portable "jumbos" mounting a number of drills are used to expedite drilling and to provide platforms for loading the blast holes and connecting the firing circuit. These platforms are usually made to fold against the jumbo frame when not in use, and space is provided on the jumbo for all of the drilling equipment. Heavy-duty, high-speed mucking equipment is employed to load out the broken rock.

In high-speed tunneling, labor is one of the largest single cost items, and it must be used as effectively as possible. Therefore, every effort is made to have as efficient an operation as possible and to avoid all possible delays in the cycle. This will involve selecting the most economical depth of round as will be shown later.

Since the rate of advance depends upon good fragmentation and breakage of a complete round for every blast, relatively high strength dynamites are generally used. Other explosive requirements are good plasticity and cohesiveness for easy tamping, high loading density, and good fume properties. The grades of dynamite most commonly used are Gelex or its equivalent and 40% to 60% Special Gelatin. The Special Gelatin is used mostly where severe water conditions are encountered. It also gives the best results in very hard rock such as granite. To speed up loading and tamping, the dynamite cartridges should have as large a diameter as possible. The most commonly used length cartridge in tunneling is 24 inch.

Cuts and Rounds - Cuts and rounds are fundamental and applicable not only to tunneling but to any form of "tight" blasting where only one free face is available. The cut is an opening in the solid ground which serves to develop a second free face to which the cut of the round may break. Making the cut is usually the first and most difficult step in driving any heading. The cut is the most important part of the blast since the remainder of the hole cannot break effectively unless the cut comes out completely.

A round is the term used to indicate the physical arrangement such as the drilling pattern, the firing circuit and the depth of the holes for advancing the tunnel a given distance. Rounds are named for the type of cut that is used to open them. Rounds may consist of any combination of the following: cut holes, relief holes, breast or enlarger holes, and trim holes including "lifters."

Types of Cuts - There are three different types of cuts: the angled cut, in which holes are drilled at an angle to the face to provide as much freedom of movement as possible for the broken rock; the burn-cut in which two or more closely spaced holes are drilled straight into the face to provide a space into which the loaded holes can break; and a combination of the angled and burn cuts. All of the various V-cuts, pyramid cuts, and draw cuts fall into the first group.

Until recently angled cuts have been the most widely used type of cut, but with vast and rapid improvements in drilling equipment, the burn cut has become the most frequently used cut, particularly in the smaller headings.

Angled Cuts - The angled cuts have several disadvantages. They will not consistently break rounds of greater depth than the minimum dimension of the heading. Another disadvantage is that the rock enclosed by the holes of an angled cut may be thrown out in large pieces that may cause considerable damage unless holes known as "baby cuts" are used to break these pieces apart. Some advantages of the angled cuts are that they will usually require fewer holes than the burn cuts and the dynamite consumption per cubic yard of material broken will usually be lower where angled cuts are used.

The V or wedge cut is the most commonly used angle cut. Each V consists of two holes drilled from points as far apart as possible on the face to meet or nearly meet at the bottoms of the holes (Fig. 15). The cut may consist of one or several V's drilled parallel to each other. V cuts are drilled either horizontal or vertical depending upon the stratification of the rock and dimensions of the tunnel.

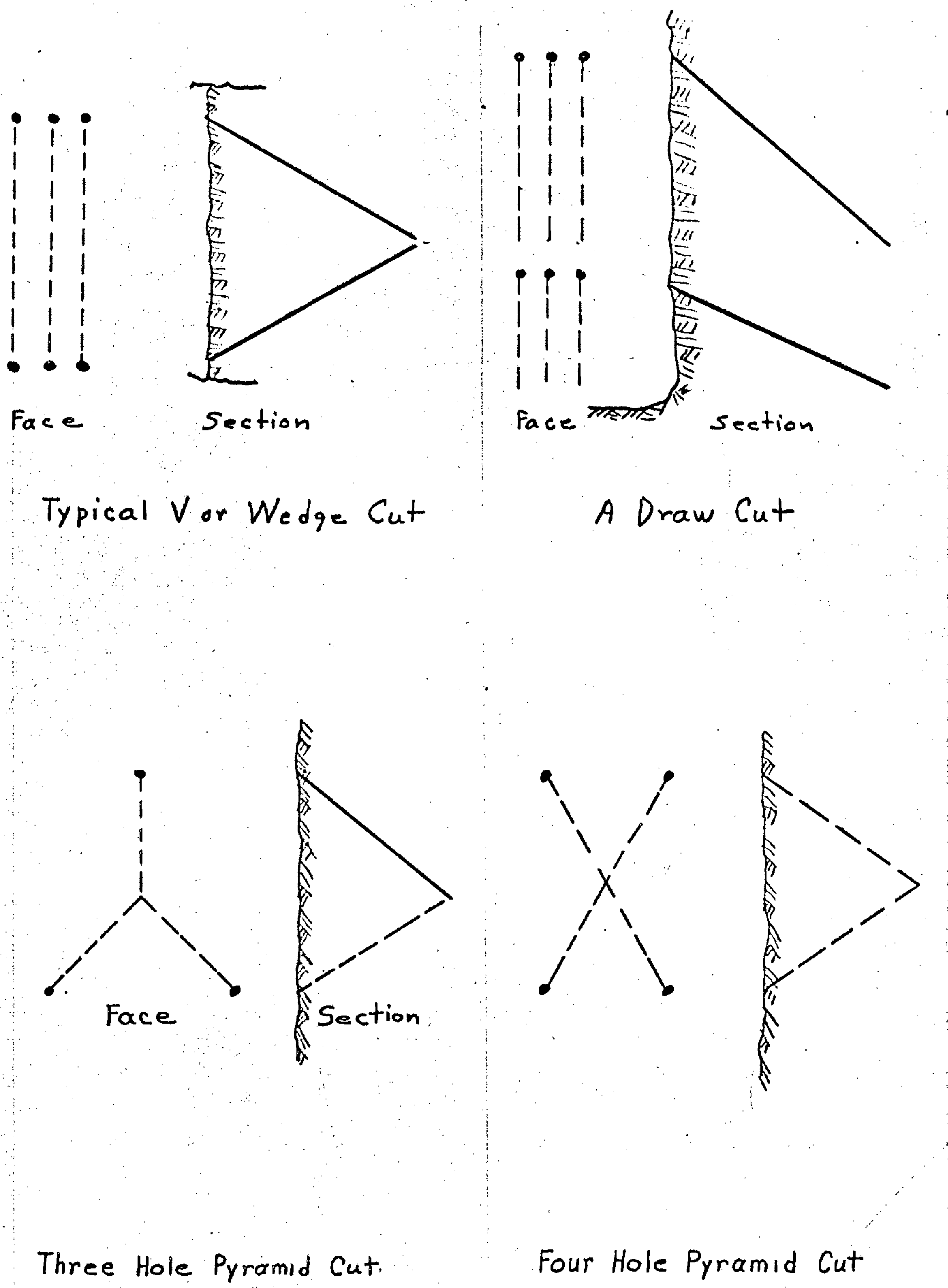


Fig 15 Angled Cuts

A modification of the V cut, known as the draw cut, is often used in small headings when drilling is done with unmounted drills (Fig. 15).

Another type of angled cut frequently used when the rock is very hard and breakage is not satisfactory with the V cut is the pyramid cut. It consists of three to six holes drilled to meet in a common apex near the center of the face (Fig. 15).

Burn Cuts - The advance per round which is possible with the burn cut is frequently much greater than that with an angled cut. While burn cuts may require a few more holes and slightly more dynamite per foot of advance than angled cuts, it is often possible to reduce the over-all cost of advance by increasing the footage per shift as will be later illustrated by an actual project.

Fundamentally all of the many variations of the burn cut utilize the same principle. Unlike the angled cuts which are designed to breach out a wedge of material, burn cuts are designed to shatter the rock in a roughly cylinderical opening. This property makes the burn cut particularly applicable to heavily timbered tunnels. Burn cuts consist of holes drilled parallel to each other and to the center line of the drift. Figure 16 shows the more commonly used arrangements. The usual practice is to leave one or more holes unloaded in order to provide open space into which the open holes may break. The general practice is to drill the unloaded holes considerably larger than the primed ones.

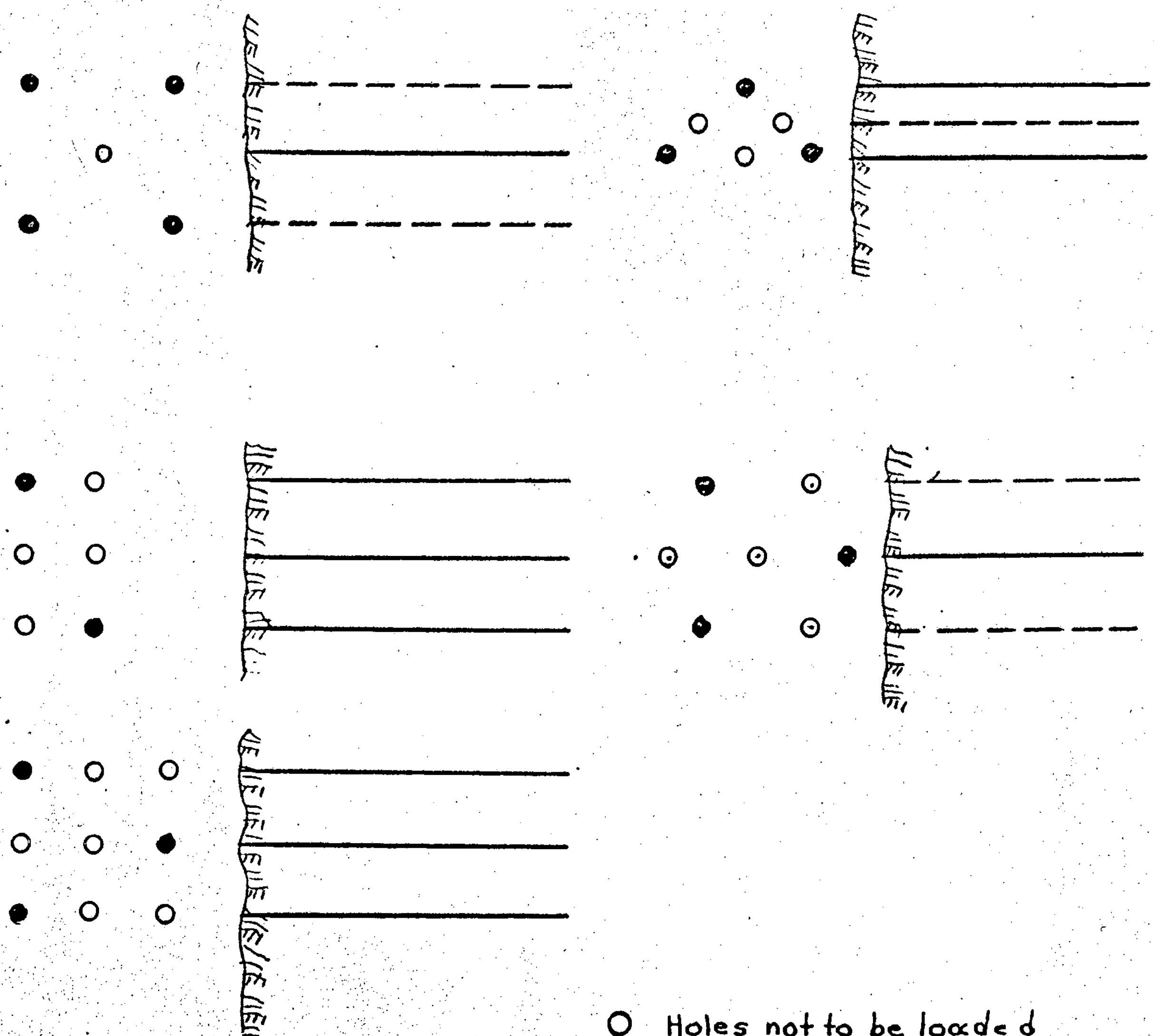


Fig 16 Burn Cuts

The best results are obtained by using a delay firing pattern on the cut as will be shown later.

Combination Cuts - Combination cuts are sometimes necessary in extremely hard, tough rock. One combination cut sometimes used is the spiral burn which consists of a series of 4 or 5 holes drilled parallel to one or two large unloaded holes. The first of the series has a burden of only 3 or 4 inches with the burden of each succeeding hole in the spiral pattern gradually increasing by 2 or 3 inches until the required opening is obtained. These spiral burn holes are generally fired in sequence with delays beginning at the center.

Other combination cuts for hard ground may include pyramids with enclosed V and burn cuts, V cuts with enclosed short pyramids or burns with enveloping V's.

Two of the contractors working on New York City's 44-mile West Delaware Tunnel[15] set new tunneling records using burn cuts in the drilling pattern. This tunneling operation took place in 1959. There had been some doubt about the use of burn cuts on large tunneling jobs by the contractors until the method was proven satisfactory on this job. These contractors felt too much reliance was placed on one larger drill; if it broke down the job would be delayed for some time.

However, the use of burn holes on this particular job removed the doubts of most of the contractors, and it is now a generally accepted procedure to use the burn hole cut even on the very large tunnels.

As Fig. 17 shows, twin 5-inch diameter burn holes were used in the drill pattern in one heading and a single 8-inch hole was used in another heading (Fig. 18). The headings were each under contract to separate contractors.

The burn holes as used by both contractors provided relief for the loaded 1 3/4-inch diameter horizontal blast holes in the rest of the pattern. The burn holes were not loaded.

Angled cuts were also tried and a comparison made of the results before the drilling pattern was confirmed. The burn holes produced more muck per blast, the muck was more consentrated to allow faster mucking, and there was less overbreak when using the burn holes. The disadvantages were that more explosives were required per foot of advance and the requirement of securing and maintaining the larger drill.

The blasting was accomplished by short-period delayed-action electric blasting caps (0-9).

Rounds - As previously mentioned, rounds are usually called V cut rounds or burn cut rounds. The type of cut used, the length of round, and the number of holes per round depend upon the size of the heading and the hardness of the material to be broken.

The usual practice in drilling rounds is to drill the cut so that it will break about six inches deeper than the rest of the round. This makes it easier for the remainder of the holes to break to the bottom. In driving a heading

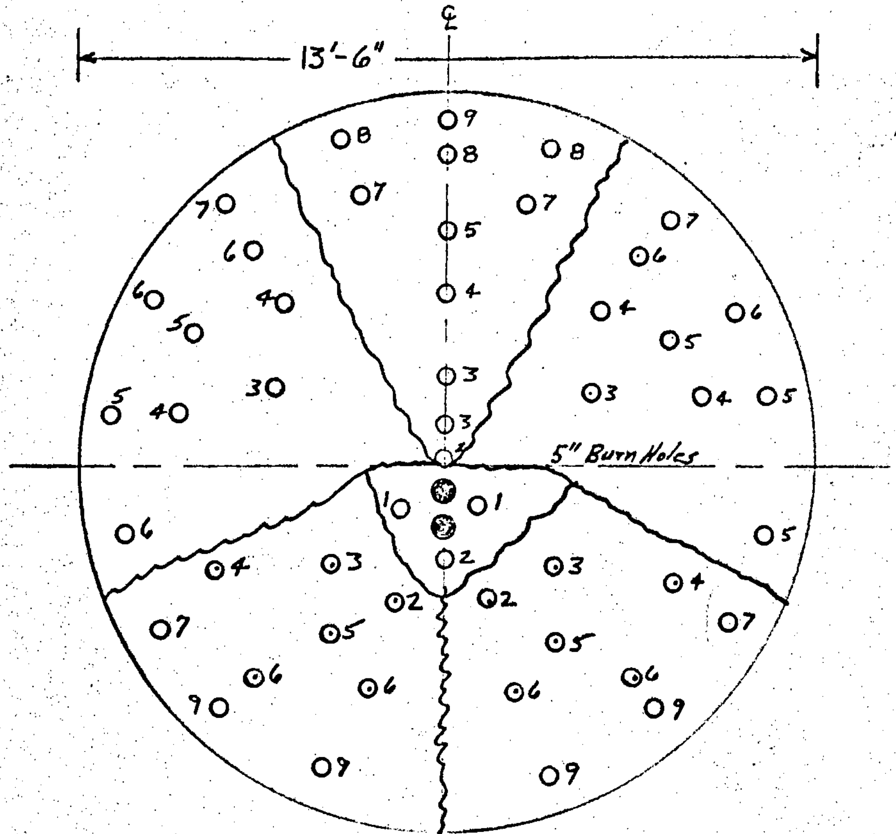


Fig 17 5 Inch Burn Holes

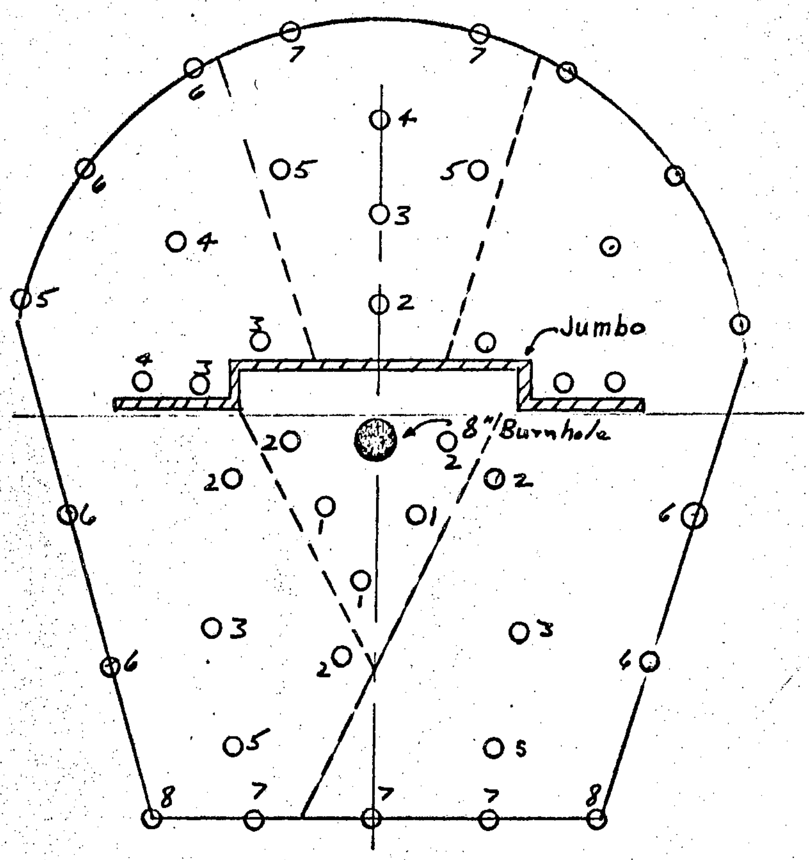


Fig 18 8 Inch Burn Hole

it may be necessary to change the drilling pattern several times within a few feet because of the different rock formations encountered.

In any round increasing the depth means a longer drilling cycle and more difficult breakage. Deeper drilling may involve more holes and more explosives per cubic yard of rock excavated. The most efficient cycle should be determined. For example, a given set of conditions may allow eight 8-foot rounds per 24 hours in contrast to only six 10-foot rounds in the same period of time.

Most tunnels are bid on a "payline" basis. This makes it economical and thereby mandatory that the round be designed and drilled to keep overbreak to a minimum. At times, it may even require a different size or grade of dynamite or a special loading procedure for the trim holes as compared to those used in the rest of the holes.

Tunnel Driving Methods [16] - There are several methods for driving tunnels presently recognized by the construction industry. The method selected will depend upon the size of the opening, the physical characteristics of the rock, the equipment available, and the extent of shoring or timbering required. The most commonly used methods of attack are: 1) Full face, 2) Top heading and bench, 3) Pilot tunnel, and 4) Pioneer tunnel or drift. The top heading and bench method was, at one time, almost standard for driving large tunnels. The development of the modern drills and jumbos caused a wide-spread acceptance of the full face method.

Full-face method - This method uses a round to pull the full cross sectional area of the face in one blast. This has been the method used for small tunnels, and it is now being used almost extensively for large or small tunnels unless extremely hard ground conditions prohibit its use. The depth of the round will normally fall in the range of 10 to 15 feet but may be considerably shorter when rock conditions are bad. In this method, the entire bore is drilled using the predetermined drilling pattern, the holes are loaded, and the round fired. The charges may be fired electrically or by a Primacord priming system. Regardless of the firing system used, a delay system is normally used.

Top Heading and Bench Method - This method is now used primarily for driving in weak ground or in very large tunnels. This method consists of driving a heading at the top of the tunnel that takes in a portion of the finished height and its full width (Fig. 19). The lower portion is then removed in one or more benches with either vertical or horizontal holes. When vertical holes are used, multiple rows are usually fired in sequence with MS delays.

The top heading may be driven with a round using any of the previously discussed cuts. Normally, the heading is completed and may even be lined before the bottom is removed.

Pilot and Pioneer Tunnel Methods - These methods are used in driving very large or long tunnels. Since the blasting technique is similar to the methods already discussed, these methods will be discussed no further.

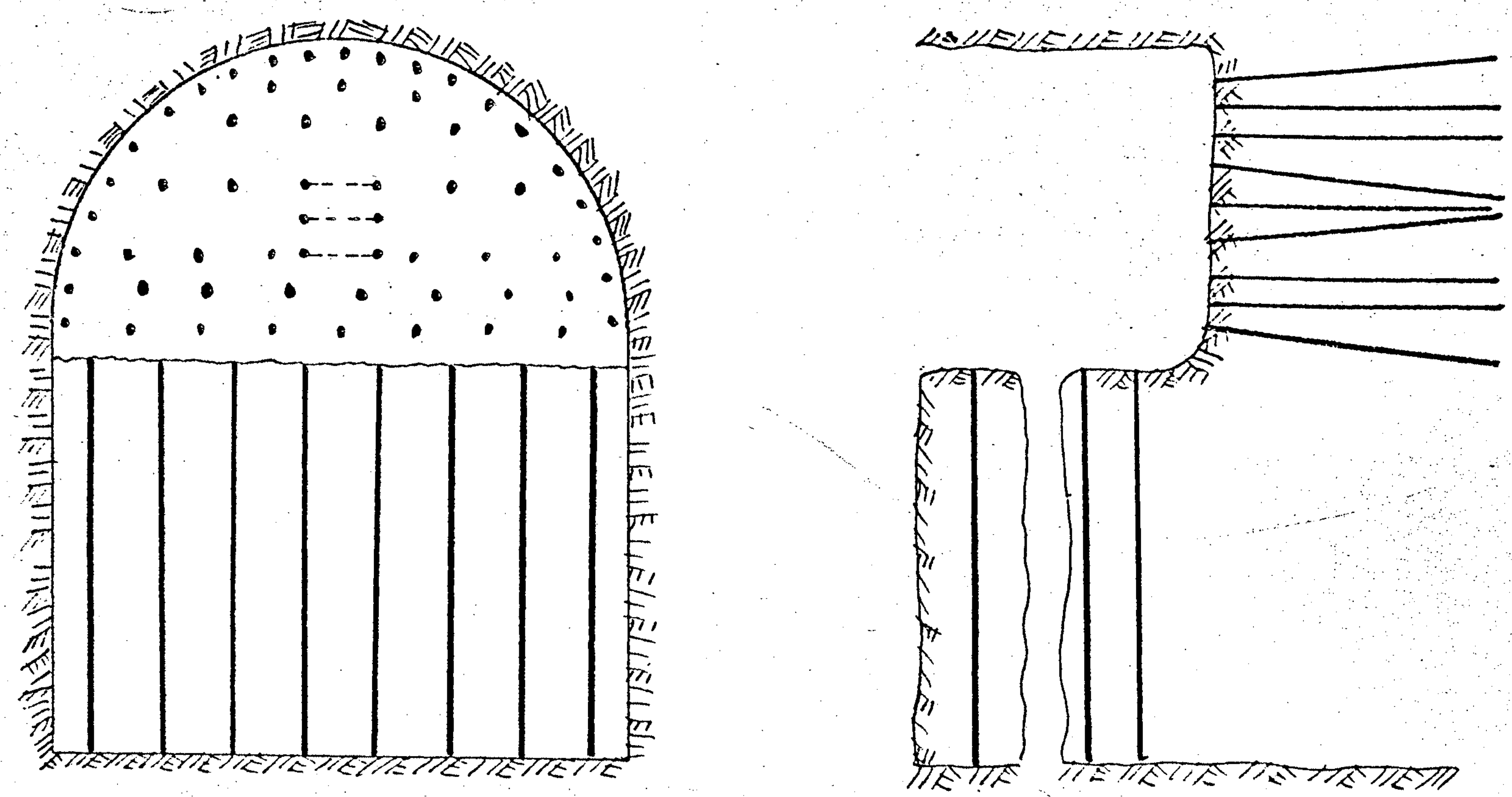


Fig 19. Top Heading and Bench Round

Loading and Firing - To obtain the desired loading density, cartridges should be perforated or split. Normally the primer is loaded as the first cartridge in the hole with the cap pointing toward the collar. Extreme care must be taken in tamping for obvious reasons.

Practically all firing in tunnel construction is done electrically. Primacord [17] is seldom used in development of headings except in rounds where a number of cut holes must be fired simultaneously. The firing is usually done with regular delay blasting caps, MS delays, or a combination of both.

Even though the millisecond delays were developed 16 years ago, their acceptance for tunnel work was slow. Whereas millisecond blasting is standard procedure in open excavation, tunnel drivers preferred the standard delay electric caps with a half-second interval. An on-the-job comparison of the results of the two types was made on the Chicago Water Tunnel job and reported in an issue of Civil Engineering[18].

At the beginning of the operation, both millisecond delay and standard delay electric blasting caps were used in experimental rounds. Experience proved conclusively that short-delay, millisecond caps provided the following definite advantages: 1) a loose muck pile, easier to dig; 2) better fragmentation; 3) fewer noxious fumes; 4) lower powder factor and 5) fewer vibrations.

The primary objection to MS delay caps in tunnel driving has been its tendency to throw rock excessively, resulting in scattered, slow-to-dig piles. This is due to its more nearly simultaneous action as compared to the longer interval of standard delays. This was overcome on the Chicago Tunnel by skipping a delay period between adjacent holes which lengthened the time interval between their detonation.

The resulting pile is still strung out more than that normally resulting from standard delays, but it is loose and well broken, thus it is mucked more quickly.

The "smoke time" was reduced by 30 percent. This was due to the smaller quantity of explosives required and a more efficient utilization of explosive energy.

It was discovered that a lower powder factor provided better results with MS caps. About 5 pounds of explosives per cubic yard of inplace rock was required with the standard delay, but a powder factor of less than 4 pounds per cubic yard was obtained with MS delay caps.

The secret of the successful millisecond delay blasting pattern is the use of an entire series of delays in order to skip delay periods between adjacent holes when necessary. This tends to stretch out the initiation sequence.

As shown in Fig. 20, the blasting pattern in the 16-foot tunnel employed a large diameter hole in the center of the heading. This 14-inch diameter hole was drilled the full depth of the round and left empty to provide relief in the center of the cut. The engineer on the job estimated that this one large hole takes the place of or provides the same results as 9 small-diameter, conventional holes.

The holes are 1 5/8 inches in diameter and 11 feet deep. Millisecond caps with the intervals shown in the

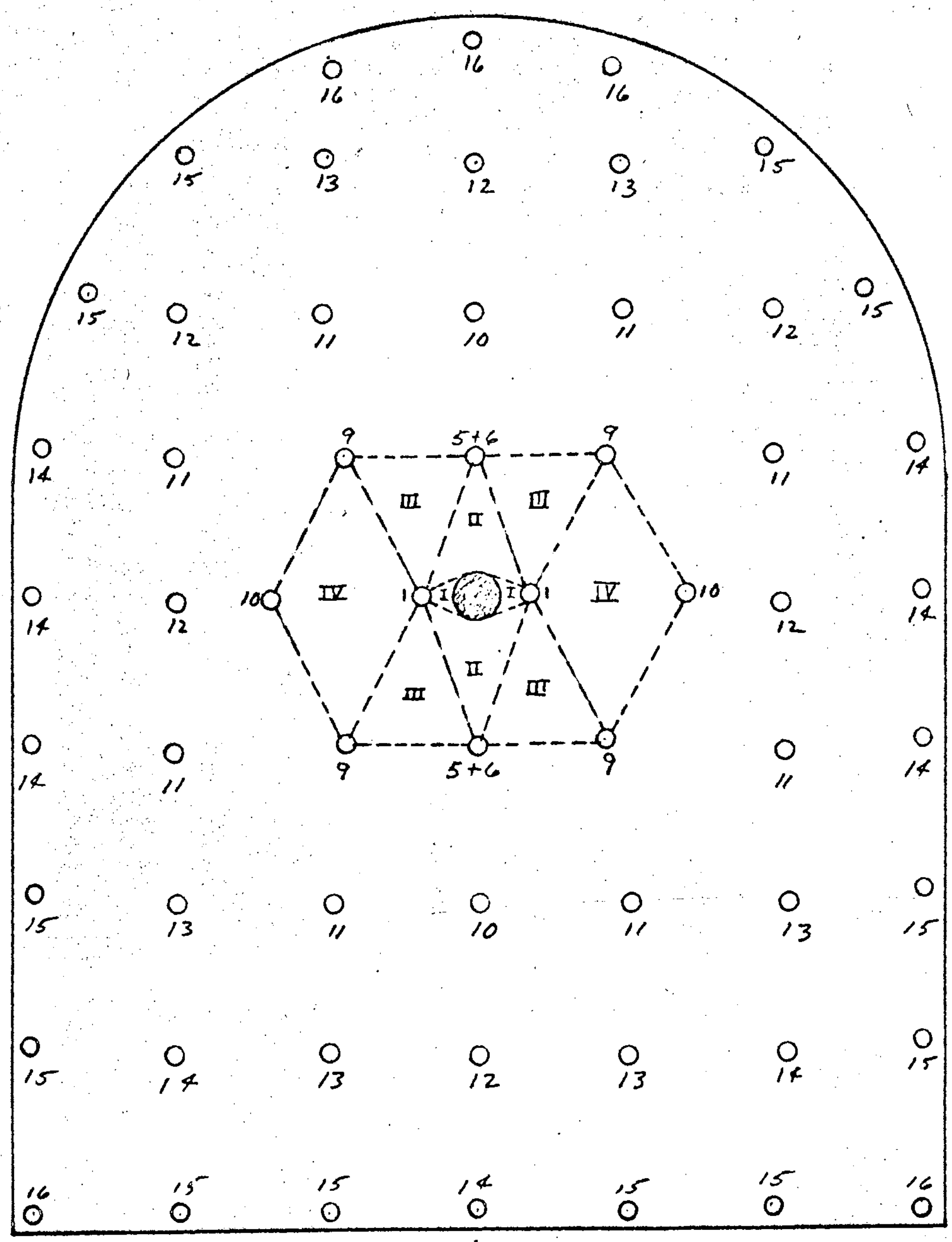


Fig. 20 Blasting Pattern For Chicago Water Tunnel

figure are used. This figure also shows the delay periods which are skipped between successive holes radiating from the center of the cut.

Holes nearest the center of the cut are primed to fire first and the detonation radiates progressively outward. In Fig. 20 the roman numerals indicate the sequence in which the critical, tight center wedges come out to provide relief for successive rings or holes.

A blasting technique new to this country is being used to tunnel the underground combat operations center of the North American Air Defense Command at Colorado Springs, Colorado [19]. Being used is the technique of smooth blasting which was pioneered by the Swedish and refined by the Canadians. The objective is not only surface smoothness but to break loose the rock that must be removed without setting up secondary stresses or creating planes of weakness in the rock left standing.

The European method of smooth blasting had to be adopted to American standards and conditions since the rock properties differ and American laws prohibit the use of dynamite with the qualities of the dynamite used by the Swedes due to fume consentration.

Thus far, an absolutely satisfactory technique has not been adopted, but experiments are continuing. In the experimentation, there are two control factors. One is that all blasting shall be to a free face. The other is to attempt to get a tension failure rather than a shear failure around the tunnel's periphery.

Dynamite is being string-loaded without tamping into holes 1 3/4 inches in diameter. The arrangement provides an air cushion that will give a solid push with less shatter.

A low energy dynamite promises the best results. Being used on this job is an explosive with a relatively low detonating velocity of 6,700 feet per second. This is compared to the 6,000 feet per second of the Swedish dynamite. A point of interest here is that the Swedish still use a dynamite which has the same formula as Nobel's original dynamite. This lower velocity dynamite tends to lessen shatter.

CHAPTER V

CONCLUSIONS

The purpose of this report has been to enable the writer to determine the extent of the use of explosives by the construction industry and to investigate the procedures for the employment of explosives for constructive purposes as used by contractors.

The actual inventor of black powder is not known, but it is thought to have been invented prior to 1000 A.D. Between the time of its conception and the 17th century, no known use was made of this original explosive for constructive purposes. Some advancement was made in the following two centuries in the application of the energy of explosions to the accomplishment of useful work.

The middle of the 19th century saw the actual beginning of the rise of explosives as a major tool of construction. The invention of guncotton and nitroglycerin in 1846 and Nobel's invention of dynamite in 1866 were the sparks which started explosives on the path to prominence as one of the foremost tools of construction.

From 1870 through the present, the number of tremendous engineering projects made possible by explosives has continually grown. Such wonders as the Panama Canal, The

New York Subway System, and the great U.S. canals and tunnels were made possible by the successful application of explosives for construction purposes.

There are several types of explosives used by the construction industry today, but 96% of the total amount consumed is divided between dynamite and ammonia nitrate explosives.

Dynamite is the explosive developed by Nobel in 1866. From this original formula more than 200 separate grades and types have been developed, each with individual properties and blast characteristics. For practical purposes the different types of dynamite, including gelatin, used in the construction industry are nine in number. Each of these nine types is subdivided into grades which are expressed as percentages. For example, straight dynamite is graded from 20% to 80%. This percent represents the percentage of nitroglycerin by weight in the dynamite. All other types of dynamite are also graded by a percent, but this percentage means that one stick of the given type is equivalent in power to a stick of equal size and the same percentage of straight dynamite.

Dynamite is used in all phases of construction blasting; if not as the primary explosive, then as a primer or booster.

In excavation and quarrying the ammonia nitrates have overtaken the dynamites in total quantities consumed. This is the result of economy, the safety in handling, and the ease in handling of the ANs. In 1961, 49% of the total amount of explosives consumed by the construction industry was an ammonia nitrate derivative.

New methods of employment such as mixing the AN with fuel oil or into slurries have aided the recent acceptance and use of the nitrates. It is predicted that within five years, 75% of the explosives consumed by the construction industry will be some form of nitrate.

There are several other forms of explosives used by the construction industry, but these are used only to a limited extent. For example, black powder is used in safety fuse and Petn is used in Primacord. TNT still enjoys some use as a primer for the less sensitive explosives and is sometimes used in demolition work.

A new explosive called "Aerex" appears to have many of the desirable characteristics of a construction explosive, but it will be some time before it can be produced at a sufficiently low cost to compete economically with ammonium nitrate or dynamite.

The common uses of explosive for construction purposes can be placed into one of four categories: grade construction, ditching, demolition, and tunneling. Grade construction is further divided into clearing and grubbing and excavation.

It has proven economical to use explosives for clearing and grubbing only when it is impossible to use mechanical equipment due to job site location or soil conditions or when the extent of work to be done is so small that the costs of bringing in equipment would be excessive.

Boulders are often removed by blasting. Two methods are used: one is called mudcapping and the other snakeholing.

The amount of the explosive charge varies from 1 to 2 sticks of dynamite per foot of rock diameter.

Fill settlement with explosives is fast and economical only under certain soil conditions. Coarse, cohesionless fill material will give better results when using explosives for fill settlement. Four methods of fill settlement utilizing explosives are in general use. They are the Toe-Shooting Method, the Ditching Method, the Underfill Method, and the Relief Method.

One of the more widely used applications of explosives for construction purposes is the blasting of ditches. Ditches may be blasted quickly, economically, and in rough terrain by dynamite. The costs are even more economical where the soil is quite damp thus allowing the use of the propagation method of firing. Ditches ranging from 2 to 12 feet deep and from 4 to 40 feet wide at the top can be blasted with tremendous savings over mechanical methods of excavation. Normally a 50% straight dynamite or a special ditching dynamite will give the best results.

The use of explosives for excavation has made many great engineering feats possible, and the introduction and use of millisecond delay blasting caps has created new opportunities for explosives in the excavation field. By controlling vibrations and throw of blasted material, it is possible to blast in areas where previously slow, expensive means of excavation were used. Pre-splitting techniques make the excavation of building foundations feasible and less expensive.

Tunneling has long employed explosives for construction purposes. New advancements in drilling equipment and ventilation apparatus have reduced the round time and increased driving rates. This new drilling equipment has also caused the full face method of advancement to be used almost exclusively, even in driving the larger tunnels. The use of millisecond delay blasting has only recently been accepted for application in tunnel blasting. The key to the successful use of this delay system is to use a full delay system and skip intervals between holes.

The Swedish method of smooth bore blasting is now being developed for use in this country. Successful applications of this method meeting American standards and conditions could save contractors money and reduce the injury rate.

Demolition by explosives is a subject for which there is very little written reference material. There appear to be no definite solutions for any given problem. The accepted procedure is to blast with as small a charge as possible and to try to control the blast in such a manner that there is little throw of material. Normally charges are no larger than 1/2 pound, and charges are spaced no more than 12 inches apart. The delay system is set so that the blast develops toward the free face. In blasting metal, certain formulas are available which will give the size charge necessary to cut the metal. TNT or gelatin is normally used when cutting metal.

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