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NTRP 4-04.2.12
AFMAN 10-903
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QUARRY OPERATIONS

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HEADQUARTERS, DEPARTMENT OF THE ARMY

Foreword

This publication has been prepared under our direction for use by our respective commands and other commands as appropriate.

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Norfolk, VA

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Air Force Civil Engineer Center
Tyndall Air Force Base, FL

Quarry Operations

Contents

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***This publication supersedes Field Manual 3-34.465, 15 April 2005, and FM 3-34.468, 19 December 2003.**

Figures

Tables

Preface

Note: **DOD and service directives outlining restrictions and procedures for general demolition or explosive ordnance disposal (EOD) procedures do not apply to the specialized techniques described in this manual.**

Construction in the theater of operations is normally limited to roads, airfields, and structures necessary for military operations. This manual emphasizes the aspects of pit and quarry layout, design, and operation. It outlines the methods and procedures used in the exploration and operation of pits and quarries. It provides information on the equipment required for operating pits and quarries and for supplying crushed mineral products. This manual does not cover the operation of the stated types of equipment. This manual is not intended to replace the blasting procedures outlined in individual service publications on general demolition or EOD procedures.

This TM supplies doctrinal tenets and technical facts concerning the layout, design, and operation of pits and quarries for military construction. It provides guidance for solving problems related to excavating rock using blasting techniques. It also discusses various types of explosives used in quarry operations.

This publication applies to engineers, both active and reserve military and civilian from the United States Active Army, the Army National Guard (ARNG)/the Army National Guard of the United States (ARNGUS), and the United States Army Reserve (USAR), United States Navy (USN), and United States Air Force (USAF).

The content of this manual does not explain or define explosive and geological terms in detail.

The Army proponent of this publication is the United States Army Engineer School. The preparing agency is the Manuever Support Center of Excellence (MSCoE) Capabilities Development and Integration Directorate (CDID); Concepts, Organizations, and Doctrine Development Division (CODDD); Doctrine Branch. Send comments and recommendations on a Department of the Army (DA) Form 2028 (Recommended Changes to Publications and Blank Forms) to Commander, MSCoE, ATTN: ATZT-CDC, 14000 MSCoE Loop, Suite 270, Fort Leonard Wood, Missouri 65473-8929; by e-mail to usarmy.leonardwood.mscoe.mbx.cdidcodddengdoc@mail.mil; or submit an electronic DA Form 2028.

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DANGER, WARNINGS, AND CAUTIONS

For Army:

The following definitions apply to danger, warning, and caution notes used in this manual:

Danger: Alerts users to the possibility of immediate death or permanent injury. Although damage to equipment may occur, the major concern is the probability of death or permanent injury if the warning is ignored.

Warning: Alerts users to the possibility of immediate personal injury or damage to equipment

Caution: Alerts users to the possibility of personal injury or damage to equipment that may result from long term failure to follow correct procedures

For Navy and Air Force:

The following definitions apply to warning and caution notes used in this manual:

Warning: An operating procedure, practice, or condition that may result in injury or death if not carefully observed or followed.

Caution: An operating procedure, practice, or condition that may result in damage to equipment if not carefully observed or followed.

Unless this publication states otherwise, masculine nouns and pronouns do not refer exclusively to men.

A listing of preferred metric units for general use is contained in Federal Standard 376B <http://www.usaid.gov/policy/ads/300/fstd376b.pdf>.

ACKNOWLEDGMENT

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Course materials: Mining 307, *Principles of Explosives Engineering (Basic Blasting Course)* and Mining 350, *Blasting Design and Technology (Advanced Blasting Course)*, provided by Professor Paul Worsey, Department of Mining Engineering, Missouri University of Science and Technology, Rolla, Missouri.

Chapter 1
Geology

The crust of the earth is made of rock which, in turn, is composed of minerals. The rock type implies information on many properties that serve as a guide in determining the engineering characteristics of a site. Rocks are mineral aggregates, naturally occurring, and inorganically formed substances.

ANALYSIS AND PROPERTIES OF COMMON ROCK

1-1. Within this manual a *quarry* is to be considered a facility that produces rock for construction operations. In general, the term *rock* refers to consolidated substances of the earth's crust that cannot be excavated without blasting or cutting. Geologists classify rocks into three groups (igneous, sedimentary, and metamorphic).

IGNEOUS ROCKS

1-2. Igneous rocks are rocks formed by the cooling and solidification of magma. The following are types of igneous rocks:

- **Extrusive.** Extrusive igneous rocks are found when the magma is thrown out from the volcanoes or pushed slowly up through the cracks in the earth's crust. As the molten rock reaches the surface, it usually spreads out and cools rapidly, which may result in small fragments. Recently extruded lavas may contain long hollow tubes or tunnels.
- **Intrusive.** Intrusive igneous rocks are formed from deeply buried magmas that cool very slowly within the crust of the earth, thus forming larger crystals. The following are the main types of intrusive masses:
  - **Stocks.** Stocks are smaller masses of a few square kilometers in surface.
  - **Sills.** Sills are tabular masses intruded between rock layers.
  - **Dikes.** Dikes fill cracks or fractures, cutting across such layered structures.

Note. All intrusive rock masses do not fit neatly into the above types. Many times, they must be determined by detailed mapping or core drilling.

Common Igneous Rocks and Their Properties

1-3. The following are the types of igneous rocks and their properties:

- **Granite.** Granite is an intrusive igneous rock with an even texture. Light-colored, coarse- to medium-grain rock may be granite. Granite is gray, pink, or red, with a crushing strength ranging from 15,000 to 30,000 pounds per square inch. Granite is found in all parts of the world and forms a large part of the continental masses. Unweathered granite is strong and durable rock that is suitable for bridge piers, seawalls, and building foundations. The chief disadvantage of granite is that when it is heated and chilled, the quartz and feldspar grains expand or contract at different rates, sometimes causing the rock surface to crumble or peel.
- **Diorites.** Diorites are a family of rocks that resemble dark granite and are most often found in sills, dikes, and small stocks. Unweathered diorites are strong and durable and have an average compressive strength of 28,000 pounds per square inch.
- **Gabbro.** Gabbro is a dark gray, green, or black granular rock similar in appearance to diorites. Like granite, gabbro is found in batholiths, but it also forms small stocks, dikes, sills, and volcanic necks. Gabbro, which is a durable construction material, has a high degree of

compressive strength (average is 26,000 per square inch) and low absorbability. Gabbro is chiefly used for road materials.

- **Felsites.** Felsites are a group of very dense, fine-grained extrusive igneous rocks. They have dull, stony textures and are composed of quartz and feldspars. Colors range from light or medium gray to pink, brown, yellow, bud purplish, and light green. Weathering causes felsite to become brown, rusty and crumble, eventually breaking down completely to become clay. Felsites are generally used as concrete aggregate.
- **Basalts.** Basalts are a group of very dense, fine-grained igneous rocks. Colors range from black to dark gray to green to purplish. Basalts contain a great deal of lime, magnesium, and iron. They are a fine-grained equivalent of gabbro and are closely related to the andesites.

Engineering Properties of Igneous Rocks

1-4. Intrusive rocks, when fresh and unweathered, have high crushing and shearing strengths and, unless fractured too small, are satisfactory for engineering construction operations. They often provide an excellent source of concrete aggregates and other types of construction materials. Extrusive igneous rocks require extensive examination before their engineering characteristics can be determined. Many lavas are as satisfactory as intrusive rock, but the pyroclastic material may be unreliable.

SEDIMENTARY ROCKS

1-5. Most sedimentary rocks result from direct or indirect weathering. They consist of hardened or cemented layers of sand, clay, and lime. The following are the types of sedimentary rock:

- **Chemical sediments.** Chemical sediments are formed by material that has been transported in solution and later precipitated. Limestone and dolomite are the most widespread of the chemically precipitated rocks, and the dense varieties of these carbonate rocks have high crushing and shearing strength. Their principal defects are solution cavities formed during past geologic time. Other chemically precipitated sediments (chert, flint, rock salt, anhydrite, coquina, caliche, and soft coral) are unsatisfactory for most engineering purposes due to their solubility, chemical reactivity, or low physical strength.
- **Clastic sediments.** Clastic sediments are formed by mechanical transportation (wind, water, glacial action) and deposition. Clastic sediments are formed from fragments of other rock and transported from the original sources. These sediments may be cemented to form firm rock by a variety of materials, the most important being oxides, carbonates, and silica.

Common Sedimentary Rocks and Their Properties

1-6. The following are common sedimentary rocks and their properties:

- **Limestone.** Rocks that contain more than 50 percent calcium carbonate in the form of calcite are considered limestone. When pure, limestone is white or colored, but usually colored gray to black by carbon or stained buff, yellow, red, or brown by iron oxides. As a building stone, it is used in inner and outer walls and in floors and foundations, bridges, and a variety of other structures. Crushed limestone is used in the manufacture of portland cement.
- **Dolomite.** Although similar in appearance and use to limestone, dolomite is a calcium magnesium carbonate of varying proportions.
- **Chert and flint.** Siliceous sediments are usually found in limestone and shale. They are very hard and difficult to drill. Chert can be used as a satisfactory road material.
- **Rock salt and anhydrite.** Rock salt and anhydrite are very abundant, soluble in water, and very soft. Rock salt deposits are of no value as a construction material.
- **Conglomerates.** Conglomerates are composed of cemented gravel of varying sizes. Breccia (conglomerates composed of cemented angular fragments) may be used for road material if properly graded or crushed to size. It is usually susceptible to rapid weathering and consequent weakness.

- **Till.** Till consists of a heterogeneous group of materials that have been deposited by glaciers. Till is an excellent source of material for earth dams and embankments, but is usually not suitable for concrete and bituminous aggregates.
- **Sandstone.** Sandstone consists of small grains (1/16 to 2 millimeters) that have been cemented together to form rock. The color of sandstone depends on the nature of the cement. Iron oxides give the red, yellow, and brown shades. Sandstone that splits easily into even slabs is known as *flagstone*. Flagstone is commonly used as a decorative building material.
- **Siltstone.** Siltstone is similar to sandstone, but composed mainly of cemented particles that are between 1/256 and 1/16 millimeter in diameter.
- **Clays and shales.** Clays and shales are made up of clay minerals, various oxides, silica, fine particles of ordinary minerals, and a greater or lesser amount of colloidal and organic material.

Engineering Properties of Sedimentary Rocks

1-7. The shearing resistance, crushing strength, and hardness of clastic sediments depends, for the most part, on the degree of consolidation and cementation.

METAMORPHIC ROCKS

1-8. Methamorphic rocks are the result of metamorphism in igneous and sedimentary rock. The following are the types of metamorphism:

- **Igneous.** Igneous metamorphism is caused by direct contact with hot igneous rocks and the water, steam, and other gasses that come from them.
- **Dynamic.** Dynamic metamorphism is caused by the movement of the crust and the action of water, providing that the resulting rock changes go further than compaction and cementation.

Common Metamorphic Rocks and Their Properties

1-9. The following are the types of metamorphic rocks and their properties:

- **Gneiss.** Gneiss is a banded rock of granite composition, containing quartz, feldspar, and mica. Their banded structure enables the rock to be split into parallel surfaces (more or less) allowing its use in the construction of tough walls and some road surfaces.
- **Schists.** Schist has a much finer texture than gneiss and has a well-marked cleavage. Unlike gneisses, schist bands are mineralogically alike, causing treacherous rock slips in quarries, rock cuts, and tunnels if unsupported on steep or vertical faces.
- **Slate.** Slate is a fine-grained, hard, and dense rock that was formed by the metamorphism of shale. It splits easily into thin layers that cut across bedding planes. The most important feature of slate is its cleavage, which makes it valuable for roofing. Although not recommended, it can be used as a road material if absolutely necessary.
- **Quartzite.** For the most part, quartzite is metamorphosed sandstone. The grains of feldspar, hematite, chlorite, muscovite, and other minerals are present as impurities and give the rock a pink, brown, or red brick color. Although similar in appearance to grainy limestones, quartzites are much harder. Quartzite is not used as building stone due to shattering during jointing; but when crushed, it becomes an excellent material for concrete work, railroad ballast, and road work.
- **Marble.** Marble is the result of the metamorphism of limestone and dolomite. When crushed and used as an aggregate, marble has the same value as limestone.

Engineering Properties of Metamorphic Rocks

1-10. It is impossible to generalize the engineering properties of metamorphosed rocks. Most gneisses are hard and tough and have high crushing and shearing strengths. Most schists are highly anisotropic, and attention should be given to their cleavage orientation. Also, many schists are very soft and unusable for high unit loading.

COMMON ROCK IDENTIFICATION

1-11. The following are ways to identify common rocks:

- **Mohs' hardness scale.** Rocks that fall between 5 and 7 on the Mohs' hardness scale (table 1-1) are most suitable for construction use. Below 5 on the scale is too soft, and above 7 is too hard to crush. This scale does not indicate an exact hardness. The number 9 is not three times as hard as the number 3. It only means that minerals can scratch all minerals beneath it on the scale and can be scratched by all the minerals above it. Two minerals of the same number will scratch each other.

Table 1-1. Mohs' scale

Mineral	*Relative Hardness*	*Equivalent Objects*
Diamond	10	
Corundum	9	
Topaz	8	
Quartz	7	Porcelain (7)
Feldspar	6	Steel file (6.5)
Apatite	5	Window glass (5.5) Knife blade or nail (5)
Fluorite	4	
Calcite	3	Copper coin (3.5)
Gypsum	2	Fingernail (2)
Talc	1	

- **Expedient scale.** In the absence of the Mohs' scale, a hardness test can be done in the field using the expedient scale. This is a simple test; if a file scratches the rock, the rock is below 6.5 hardness. If the rock scratches the file, the rock is above 6.5 hardness. If the rock scratches a knife blade or glass, but not the file, the rock hardness is between 5.5 and 6.5.
- **Taste test.** Most minerals that are readily soluble in water have a distinctive taste. Halite, for example, can be identified quite easily because of its salty taste. A good rule of thumb: if it tastes salty, it is not good for construction and will erode quickly.
- **Color.** The color of a mineral is not always a dependable guide since some minerals, quartz for example, occur in a bewildering array of colors without a perceptible change in composition. A few minerals are reasonably constant in their color, and color can be considered an identifying property.
- **Tenacity.** Tenacity is the term used to describe the behavior of a mineral when an attempt is made to break, hammer, cut, bend, or crush it. A mineral is—
  - Brittle if it breaks or powders easily.
  - Malleable if it flattens under the hammer.
  - Tough if it resists being torn apart under a blow or great strain.
  - Flexible if it bends and remains bent after the pressure is released.
  - Elastic if when bent it recovers its original position upon release of pressure.
- **Acid test.** The acid test (hydrochloric being the most common) is used most effectively in the identification of carbonates. Acid plus a carbonate will produce an effervescent reaction.
- **Durability.** Durability is the resistance of the material to slaking or disintegration due to alternating cycles of wetting and drying or freezing and thawing. Estimate durability in the field by observing the effects of weathering on natural exposures of rock.
- **Crushed shape.** Crushed shape refers to the irregular, bulky, blocky, and elongate fragments made when rock breaks. Irregular and blocky broken rocks provide the best aggregates for construction because their particles compact well and interlock to resist displacement and to distribute loads. They are of nearly equal strength in all directions. Elongated pieces (slabs;

distributed loads, plates, or sheets; flakes, or chips) (figure 1-1) are weak in their thin dimensions and do not compact, interlock, or distribute loads.

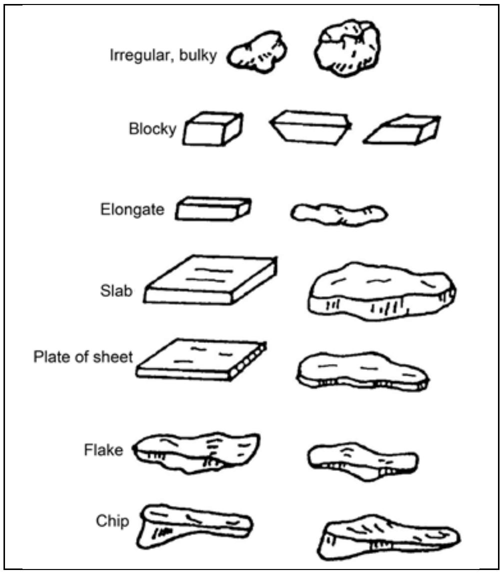


Figure 1-1. Crushed shape of rock

- **Chemical stability.** Chemical stability is the resistance of the material to a reaction with the alkali material in portland cements. Rock types contain impure forms of silica that react with alkalies in cement to form a gel. The gel absorbs water and expands, which causes cracks or disintegration in the hardened concrete. Estimate this potential alkali aggregate reaction in the field by identifying the rock and comparing it to known reactive types or by investigating structures in which the aggregate has previously been used.
- **Surface character.** Surface character is the bonding characteristics of the surface of the broken rock. Excessively smooth, slick, nonabsorbent aggregate surfaces bond poorly with cementing materials and shift readily under loads. Excessively rough, jagged, or absorbent surfaces are likewise undesired because they resist compaction or placement and require excessive amounts of cementing material. In addition, if the absorption ability of the aggregate is greater than about 1 percent, the water that is likely to be trapped in the pores will cause destruction of the aggregate particles during freeze-thaw cycles.
- **Density.** Density is the material weight per unit volume. Estimate density in the field by hoisting a rock sample. Density reflects one excavation and hauling costs and may influence the selection of rocks (riprap, jetty stone, lightweight aggregate) for special requirements. Among rocks of the same type, density is often a good indicator of the toughness and durability to be expected (tables 1-2, 1-3, 1-4, 1-5, and 1-6, pages 1-6 through 1-8).
- **Slaking.** Slaking is the crumbling of an aggregate into visible particles when water or other liquids destroy the bond between its mineral grains and cause expansion of air inside the pores. Hard clay lumps and shale are generally deleterious particles in aggregate, partly because they slake when immersed in water for short periods of time. Aggregate should not slake in water or other liquids that are present in a pavement system.
- **Deleterious materials.** Deleterious materials are materials that will make the aggregate unsuitable. These can include organic matter, soft or weak rock, clay, chert (which will display disruptive expansion), and chemically reactive rock. There are methods available to somewhat remove deleterious material. It is preferred to have minimal or no deleterious material in the supply.

Table 1-2. Field-estimating rock density

Description	*Density (Gram/Centimeter^3)*
Very dense	≥3.0
Dense	≥2.8 to <3.0
Moderately dense	≥2.6 to <2.8
Low density	≥2.4 to <2.6
Very low density	<2.4

Table 1-3. Aggregate suitability based on physical properties

Use of Aggregate	*Toughness*	*Hardness*	*Durability*	*Crushed Shape*	*Chemical Stability*	*Surface Character*
Portland cement	Good	Fair	Good	*Good	Good	Good
Bituminous surfaces	Good	Good	Good	Good	Any	Good
Base course	Good	Good	Good	Good	Any	Good
*The preferred shape for portland cement aggregate is an irregular, bulky shape.						

Table 1-4. Use of aggregate for military construction

Classification	*Rock Type*	*Use of Aggregate*		*Use as a Base Course or Subcourse*
		Concrete	*Asphalt*	
Igneous	Granite Gabbro-diorite Basalt Felsite	Fair–good Excellent Excellent *Poor	**Fair–good Excellent Excellent Fair	Good Excellent Excellent Fair–good
Sedimentary	Conglomerate (Breccia) Sandstone Shale Limestone Dolomite Chert	Poor Poor–fair Poor Fair–good Good *Poor	Poor Poor–fair Poor Good — *Poor	Poor Fair–good Poor Good — Poor–fair
Metamorphic	Gneiss Schist Slate Quartzite Marble	Good Poor–fair Poor Good Fair	Good Poor–fair Poor Fair–good Fair	Good Poor–fair Poor Fair–good Fair
*Reacts (alkali aggregate). **Antistripping agents should be used.				

Table 1-5. Pit and quarry classifications

Type	*Material*	*Primary Use*	*Operation*
Borrow pit	Soil, sand, and gravel	Subgrades, base course, or fill	Medium and light mechanical
Gravel pit	Gravel, coarse sand, and clay	Base course, surfacing, or fill	Medium and light mechanical
Alluvial pit	Clean gravel and sand	Aggregate for concrete and mixes	Heavy mechanical crushing, screening, and washing
Dump pit	Mine spoil, slag, and overburden	Recycling, surfacing, or aggregate	Heavy mechanical crushing, screening, and washing
Hard-rock quarry	Aggregate	Base course, surfacing, or aggregate for concrete and mixes	Heavy mechanical crushing, screening, and washing; drilling; and blasting
Medium-rock quarry	Aggregate	Base course, surfacing, or fill	Heavy mechanical crushing, screening, and washing and drilling and blasting
Soft-rock quarry	Cement material	Base course and surfacing of roads and airfields	Medium and light mechanical

Table 1-6. Engineering properties of rocks

Classification	Rock Type	Toughness	Hardness	Durability	Crushed Shape	Chemical Stability	Surface Character	Density (gr/cm3)	Pounds/ Cubic Foot	Tons/Cubic Yard	Cubic Feet/Ton
Igneous	Granite	Good - very good (1.2 - 2.1)	Good	Good	Good	Excellent	Good - fair	2.65	165.0	2.23	11.80
	Gabbro-diorite	Excellent(1.6 - 2.1)	Excellent	Excellent	Good	Excellent	Excellent	2.96-2.92	183.5	2.48	10.60
	Basalt	Excellent (2.3)	Excellent	Excellent	Fair	Excellent	Excellent	2.86-2.96	178.0	2.41	11.10
	Felsite	Excellent (2.0)	Good	Good	Fair	Questionable	Fair	2.66	166.0	2.24	—
	Obsidian	Poor (—)	Good	Good	Very poor	Questionable	Very poor	2.3-2.4	—	—	—
	Pumice	Very poor (—)	Very poor	Poor	Good	Questionable	Poor	<1.0	—	—	—
	Scoria	Poor (—)	Poor	Poor	Good	Good	Poor	Variable	—	—	—
Sedimentary	Tuff	Poor (—)	Poor	Poor	Good	Questionable	Good	Variable	—	—	—
	Conglomerate (breccia)	Poor (1.0)	Poor	Poor	Fair	Variable	Good	2.68-2.57	163.5	2.21	—
	Sandstone	Variable (1.0)	Variable	Variable	Good	Good	Good	2.54	159.0	2.14	13.20
	Shale	Poor (1.0)	Poor	Poor	Poor	Questionable	Fair - good	1.8-2.5	134.0	182	11.40
	Limestone or dolomite	Good (1.0)	Good	Fair - good	Good	Good	Good	2.66-2.70	167.5	2.26	11.90
	Chert	Good (1.5)	Excellent	Poor	Poor	Poor	Fair	2.50	156.0	2.11	—
Metamorphic	Gneiss	Good (1.0)	Good	Good	Good - fair	Excellent	Good	2.74	171.0	2.31	11.90
	Schist	Good (—)	Good	Fair	Poor - fair	Excellent	Poor - fair	2.85	178.0	2.40	11.90
	Slate	Good (1.2)	Good	Fair	Poor	Excellent	Good	2.72	—	—	11.40
	Quartzite	Excellent (1.9)	Excellent	Excellent	Fair	Excellent	Good - fair	2.69	168.0	2.27	12.10
	Marble	Good (1.0)	Fair	Good	Good	Good	Good	2.63	164.0	2.22	—

Chapter 2
Site Selection

Preliminary and field reconnaissances are important aspects of site selection. Information collected before going to the field may save time by limiting field investigations to those areas that are most likely to yield the best mineral material. Time and effort given to the preliminary phase are dictated by tactical considerations. However, collect as much data as possible when locating the best site for pit and quarry material. Contact local and state environmental agencies early in the site reconnaissance effort to identify potential environmental considerations in the specific area of operations.

INFORMATION SOURCES

2-1. There is a wealth of information contained in intelligence reports. Satellite imagery and high- and low-altitude photography will assist in locating soil types, rock formations, and locations of existing pits and quarries. It is essential to obtain as much information as possible on landforms, soil types and thicknesses, bedrock types and structures, and groundwater conditions (potential environmental impacts and concerns). If time and resources permit, develop long-range plans before entering an area.

2-2. Geologic maps are good aids for locating pits and quarries. They often contain information on existing pits and quarries and mining districts. Geologic maps may provide information on surface geology and may indicate the angles of strike and dip. Preliminary haul road locations, elevations, vegetation, drainage, and surface limitations may also be gained through geologic maps. Although geologic maps are generally available for most areas of the world, they may not be readily available in all areas.

2-3. Perhaps the greatest aid comes from using satellite imagery (a geographic information system). A geographic information system offers flexibility and speed because it is geographically referenced data and computer-based. A geographic information system-identified location of natural outcrops and surface features allows the complex analyses and manipulation of information.

2-4. Topographic maps are the most common source for preliminary information and planning. They may also be used with other sources of information (a geographic information system, geologic maps). Topographic maps indicate existing pit and quarry locations, streams, roads, railway beds, cuts, cliffs, routes of communication, and other important tactical information. The close inspection and interpretation of topographic patterns (steepness of slopes, stream patterns) often provide clues to the relative nature of rocks, depth of weathering, soil, and drainage.

2-5. When gathering information, do not overlook the benefits of local inhabitants, particularly surveyors, engineers, miners, and contractors. They may provide useful information about the local geology or engineering problems that may be encountered. The local courthouse, library, and drilling and mining records also provide useful information. Coordinate with Army and civilian environmental offices to ensure that there are no environmental concerns for the proposed pit or quarry location. These offices can help in determining the location of wetlands, identifying endangered species or habitats of the area, and answering questions about other protected areas. The U.S. Geological Survey is an additional source of useful information.

ROCK STRUCTURE

2-6. The rock structure is referred to in the following terms:

- **Strike and dip.** Strike and dip are the orientation of planar features and are determined by the attitude of the rock. Strike is the trend of the line of intersection formed between the horizontal plane and the bedding plane being measured. The dip is the inclination of the bedding plane (the acute angle between the bedding plane and a horizontal plane). It is a vertical angle measured at right angles from the strike line (figures 2-1 and 2-2).

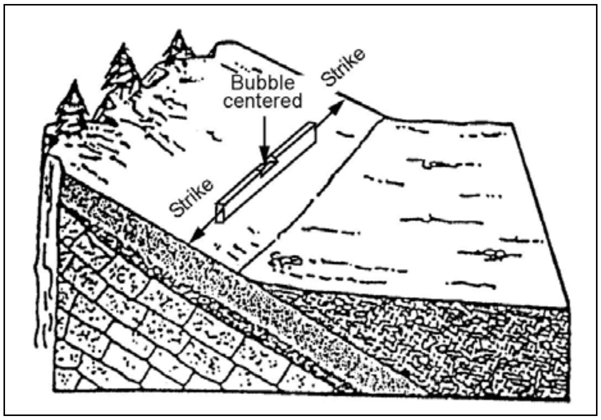


Figure 2-1. Strike

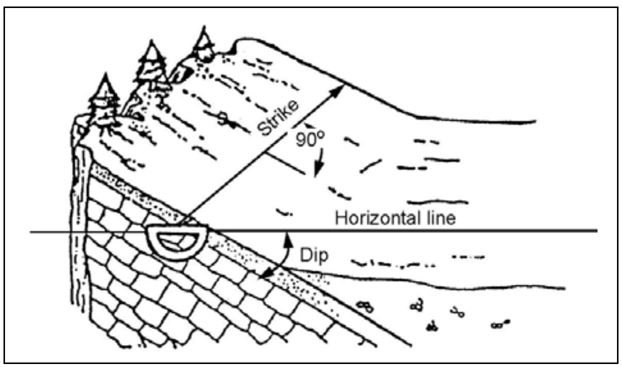


Figure 2-2. Dip

- **Folds.** Folds are undulating surface expressions of the forces of bending and crumpling. Folding is the most common type of deformation. The following are basic types of folds (figures 2-3 and 2-4):
  - Homocline.
  - Monocline.
  - Anticline.
  - Syncline.
  - Plunging.
  - Dome.
  - Basin.
- **Faults.** Faults are fractures that cause the displacement of the rock parallel to the fracture plane. Faults are commonly recognized on rock outcrop surfaces by the relative displacement of strata on opposite sides of the fault plane. Faults are identifiable on aerial photographs by long linear traces on the ground surface and by the offset of linear features (strata, streams, fences, roads) (figure 2-5).

- **Joints.** Joints are rock masses that fracture in such a way that there is little or no displacement parallel to the fractured surface. Joints influence the way the rock mass behaves when subjected to the stresses of construction. Strike and dip are used to measure the attitude of joints. Joints may result from a number of processes, including deformation, expansion, and contraction (figure 2-6, page 2-4).

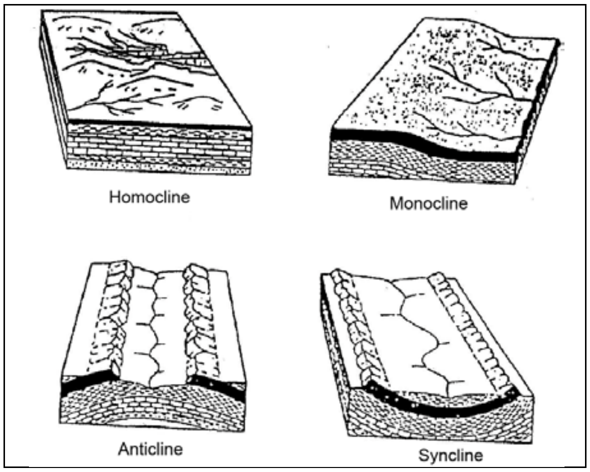


Figure 2-3. Common types of folds

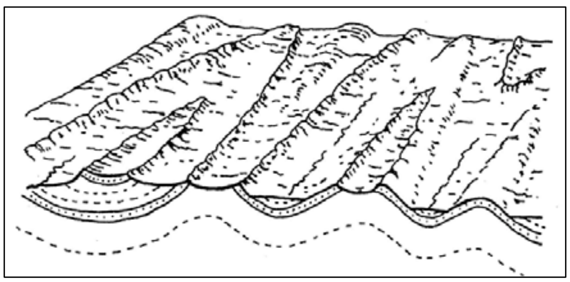


Figure 2-4. Topographic expression of plunging folds

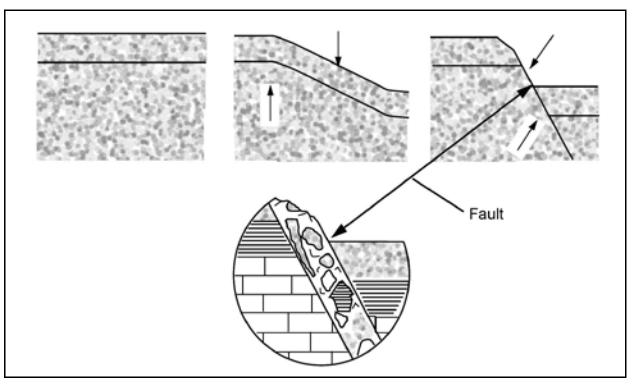


Figure 2-5. Faulting and fault zone

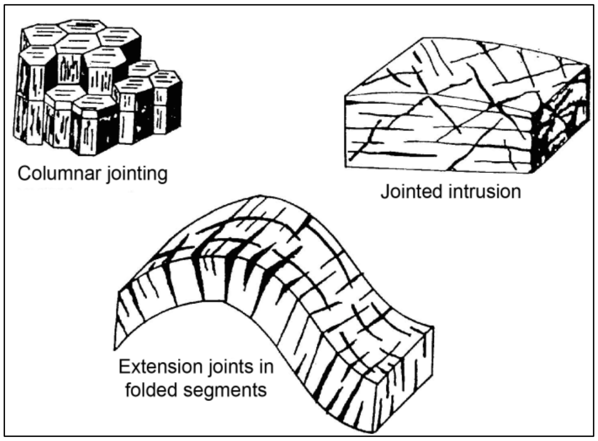


Figure 2-6. Jointing in sedimentary and igneous rocks

Field Reconnaissance

2-7. A field reconnaissance follows the preliminary phase of geologic and map research and investigation. A field reconnaissance may involve one or more trips to the field to *ground truth* potential pit and quarry sites. Detailed records on overlays adaptable to geographic information system, geologic, or topographic maps are maintained during this phase. During a field reconnaissance, it is important to obtain as much information as possible about landforms, soil types, overburden thickness, bedrock, groundwater and surface-water conditions, and the volume of construction materials. Other factors that may influence the site selection should also be noted. The observation and application of topographic formations, attitudes of outcrops, faults, and outcrop patterns to the maps on hand will assist in locating the best sites. Appendix A contains map symbols and outcropping patterns.

2-8. After intelligence regarding potential pit and quarry sites has been gathered, the sites are prioritized for final investigations. The prioritizations are known, probable, and possible sites:

- *Known sites* are those pits and quarries currently or previously used and meeting the necessary criteria.
- *Probable sites* are those sites that contain desirable construction materials as indicated during the field reconnaissance.
- *Possible sites* are those sites that were located from sources other than an actual field investigation. Available data suggests that these possible sites may contain suitable construction materials.

On-Site Testing

2-9. On-site testing is a critical part of field reconnaissance. Although it can be time consuming, it should be used as the tactical situation permits. Use information gained during an on-site test to evaluate pit and quarry sites.

Boring

2-10. Boring is the process of drilling, cutting, sinking, or enlarging a vertical hole through the earth’s surface deep enough to provide the desired information. Boring is accomplished mechanically or by hand. The hole may be made with a cylindrical cutting bar that has an attached boring tool. The boring tool has an attached bit that enlarges the hole as the tool descends. The residue (shavings or chips) is sampled as it rises from the hole. In soft rock, boring may also be accomplished using a water jet to force water through a hollow drill rod with an attached drill bit. The water forces the residue to the surface where it is gathered for sampling and testing.

Probing

2-11. Probing involves driving a steel rod through the ground's surface while observing the penetration resistance. This can be performed mechanically or by hand. The steel rod is sometimes pointed or has a driving point attached. Probing is an acceptable method for determining the presence or absence of bedrock. However, penetration refusal may erroneously be interpreted as bedrock when the probing rod may have actually encountered cobble or a boulder. The depth of the probe is also limited due to the probing rod size (diameter and length) and whether mechanical or hand methods are used.

Drilling

2-12. Drilling involves the cutting and recovery of core samples. It is similar to boring except that drilling forces residue into a tube that is brought to the surface. Core drilling allows the encountered strata to be sampled, tested, and observed. A jackhammer can be used for shallow drilling. The resistance to penetration and the color of cuttings from the hole are observed, sampled, and tested.

Excavating

2-13. Excavating is an expedient method of site testing. Test pits and trenches are mechanically excavated vertically from the ground. Excavations expose the subsurface materials, allowing in-place examination. Pits are generally smaller and shallower and are used primarily with soil determinations. Pits and trenches are reliable methods for determining the occurrence, composition, distribution, structure, and stability of materials in deep alluvial deposits.

QUALITY AND QUANTITY REQUIREMENTS

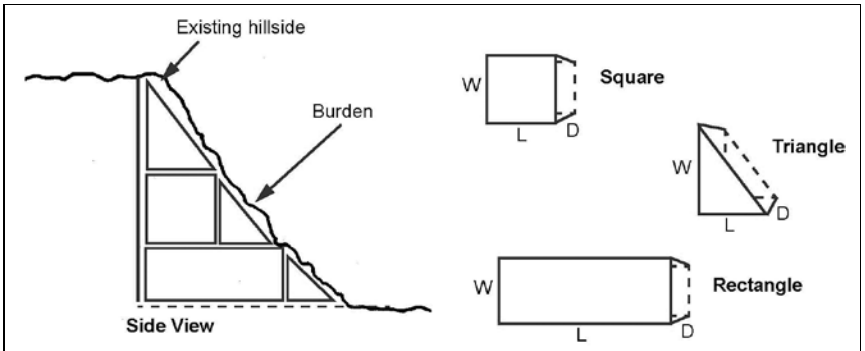
2-14. The intended use of the mineral material is the primary determining factor governing its quality. Chapter 1 listed mineral properties and tests for making quality judgments concerning the use of rock materials as construction aggregate (FM 5-410).

2-15. The quantity of material available at a site is estimated to include a safety margin. Unforeseen difficulties (such as the deterioration of quality or the presence of water) may reduce the estimated output. Estimate the volume of a site by selecting a reference plane (usually the quarry floor or the pit bottom). Compute the volume directly, or divide the area into segments and add the volume of each segment. Measure the deposit thickness at right angles to the reference plane. Do not include unsuitable or unusable materials, waste, or overburden in the volume calculations.

2-16. Pit material is generally calculated in cubic yards, while quarry material is calculated in tons per cubic yard. It is important to remember that in-place pit or quarry material is compacted. When it is removed or broken from the deposit, it will swell, causing it to have a greater volume than before excavation. Estimate the quantity of rock in a quarry by multiplying the average depth of the face by the working area and then deducting the overlying waste rock and overburden. (See table 1-3, page 1-6, for the weight of rocks as identified by the Army Institute for Professional Development, FM 5-410, and FM 5-34.) Use the following formula to calculate cubic yards (figure 2-7, page 2-6):

$$V = \frac{R(LWD) + S(LWS) + T\left(\frac{LWD}{2}\right)}{27}$$

where—
D = depth of excavation (feet)
L = length of side (feet)
R = number of rectangles
S = number of squares
T = number of triangles
V = volume (cubic yards)
W = width of sides (feet)



Legend:

D	depth
L	length
W	width

Figure 2-7. Cubic yards calculation

2-17. Select pit and quarry sites based on the quality and quantity of the desired mineral material. Other selection criteria may include the location, ease of operation, and available equipment and personnel. Use an existing site when possible. The quality and quantity of material for existing pits and quarries are easily determined. Existing sites are generally located near good haul roads with an access already in place. This greatly reduces the amount of work required to begin supplying usable material. Locating pit and quarry sites close to the construction site and having good access routes are desirable. Quarry haulage is ordinarily completed by truck; however, railway or water transportation is sometimes used for large operations.

Note. Rock properties can vary significantly within the same rock grouping.

FACTORS AFFECTING OPERATIONS

2-18. A determination of the quantity of the quarry material is important. Such a determination considers the type of material found, the in-place and broken pounds per cubic foot, cubic feet per ton, and tons per cubic yard. (See table 2-1 for the weight of rocks.)

Table 2-1. Weight of rocks

Material	*Pounds Per Foot*		*Feet Per Ton*		*Tons Per Yard*		
	In Place	*Broken*	*In Place*	*Broken*	*In Place*	*Broken*	*Swell*
Andesite	181	97	11.1	20.6	2.44	1.31	1.75
Basal	181	97	11.1	20.6	2.44	1.31	1.75
Diabase	187	94	10.6	21.3	2.52	1.27	1.75
Diorite	187	94	10.6	21.3	2.52	1.27	1.75
Gneiss	168	96	11.9	20.8	2.27	1.30	1.75
Granite	170	97	11.8	20.6	2.30	1.31	1.74
Limestone	168	96	11.9	20.8	2.27	1.30	1.75
Porphry	170	97	11.8	20.6	2.30	1.31	1.74
Rhyolite	150	86	13.4	23.3	2.02	1.16	1.75
Quartzite	165	94	12.1	21.3	2.23	1.27	1.74
Sandstone	151	86	13.2	23.3	2.04	1.16	1.76
Schist	168	91	11.9	22.0	2.27	1.23	1.75
Shale	175	95	11.4	21.1	2.36	1.28	1.85
Slate	175	95	11.4	21.1	2.36	1.28	1.85

2-19. The following factors affect site selection and operations:

- **Groundwater and surface water.** Use test pits or auger borings to determine the approximate amount of groundwater and the depth of the water table. These findings may be determining factors in site selection. Seepage or rainwater may fill or partially fill existing pits. In most cases, this water can successfully be drained or pumped. However, take care to avoid pump damage caused by rock and soil particles. The feasibility of removing standing water may first need to be ascertained. Quarries are worked in dry conditions unless impractical or impossible (such as operations involving coral reefs). Consider extensive drainage projects (diverting a stream, draining a lake) only in extreme cases when an emergency operation is necessary and when other sites are unavailable. Contact post, local, and state environmental offices before altering existent drainage patterns or beginning an extensive drainage project.
- **Overburden.** Sites containing quality materials with the least overburden are the most desirable. Stripping the overburden can be as large an operation as excavating the material itself. If the overburden exceeds one-third of the depth of the usable material, it may not be prudent to excavate. Also consider the requirements for clearing vegetation.
- **Utilities.** Certain utilities are desirable to increase operation efficiency. Electricity for lighting is essential for efficient, safe operations. Electricity of the correct voltage and frequency (hertz) will provide a more reliable source of power for the crushing and screening plant and be a logistical benefit. Consider the power requirements for the utilities when planning for pit and quarry operations. Clean water is essential for cleaning and maintaining equipment. Water is also critical when aggregate is to be washed for concrete and bituminous uses.
- **Security.** Pit and quarry equipment is susceptible to enemy operations. Major items of equipment that are destroyed at the site may close down the entire operation. Many items essential to the operation are also vulnerable to pilferage and vandalism. Therefore, security is necessary to prevent potential problems.
- **Training.** Capability, experience, and previous training of assigned personnel is often an overlooked factor of site selection. Special training programs may be needed to prevent damage to equipment and to maintain the flow of material and are required to operate in a safe, efficient manner.
- **Environment.** When selecting a site, ensure that there are no archaeological sites in the area and that the vegetation and animals living on the land are not protected or endangered. Check area maps to determine if the site is located on a designated wetland area. If an environmental question is left unresolved, check with the post or local environmental office.

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Chapter 3
Pit Operations

A pit is a site where unconsolidated earth or rock particles suitable for engineer construction can be obtained in quantity. Pits are categorized according to the type of material produced and the manner of operation used in their production. The principles of pit layout and development take into account if the pit is worked wet or dry, if it is on a slope or on level terrain, and what type of earthmoving equipment is used. Pit operations in this chapter are discussed without reference to the particular category of the pit being operated.

CATEGORIES

3-1. Pits fall into the following categories:

- **Borrow pit.** A borrow pit is a site where material suitable for fill, surfacing, or blending can be removed with earthmoving equipment. Borrow pits should be worked dry.
- **Gravel pit.** A gravel pit is a source of coarse-grained soil, consisting predominantly of gravel-sized particles. Pit-run gravel is used extensively for surfacing secondary roads; as a base course for pavement in roads, taxiways, and runways; and as aggregate in concrete and bituminous construction. The types of gravel pits are as follows:
  - **Alluvial gravel pit.** Alluvial gravel pits are named for the origin of the deposit. The gravel or sandy gravel obtained from alluvial pits is often very clean and free of clay and humus, making it particularly desirable. This type of pit may be worked wet or dry.
  - **Bank or hill gravel pit.** Bank or hill gravel pits produce clayey gravel or clayey, sandy gravel. This type of material is desirable for surfacing because of its binding qualities.
  - **Miscellaneous gravel pits.** Miscellaneous gravel pits are sometimes referred to as dumps. These pits may consist of mine tailings, slag, cinder, or similar material. This type of material is used as aggregate, for surfacing, and for fill and railroad ballast (occasionally).

PREPARATION

3-2. Pit preparation includes developing a standing operating procedure (SOP), clearing and stripping, removing overburden, providing drainage, constructing access roads, and installing equipment and utilities.

3-3. Before beginning the excavation, determine the limit of the area to be developed. Choose the best excavation methods and the proper equipment. Locate structures and equipment, and plan for traffic supervision. If the area is heavily vegetated, the first step is clearing and grubbing the site. If cover and concealment are important, remove no more trees than necessary. Stockpile timber for use in the construction phase. Excavate and remove large boulders.

OVERBURDEN

3-4. Stripping is a process used for removing overburden from pits. Dump the spoil in a suitable location to avoid double handling. Raise the spoil banks evenly so that they may be negotiated without difficulty by excavation equipment. Use the same equipment for stripping and excavating. Use bulldozers to remove topsoil, humus, and other light overburden away from pits up to a distance of about 300 feet. Use scrapers to move topsoil to distances beyond 300 feet. Other equipment (front-end loaders, hydraulic excavators) may be used to strip overburden. Each piece of equipment has its limitations and benefits. Consider the available equipment when developing the pit.

DRAINAGE

3-5. Draining water away from or out of pits is much the same as for quarry operations. If water cannot be drained by gravity, then sump operations will be necessary. Consider erosion control as a normal part of the drainage plan. Check with local environmental offices on regulations affecting the operation.

ACCESS

3-6. Roads to and from the pit should be graded and compacted to reduce rolling resistance for tracked and wheeled vehicles. Dust should be controlled in dry weather by applying water, geotextiles, asphalt, or road oil. Do not use waste oil.

EQUIPMENT

3-7. The equipment to be used is largely determined by the material to be removed and the material end use. In the case of alluvial gravel, the choice of equipment also depends on whether the pit is worked wet or dry and whether the aggregate material requires washing. Another consideration is where the pit will be constructed—on flat ground or on a bank or hillside. Equipment should also be on hand to maintain the pit in proper operational order.

EXCAVATION

3-8. Motorized scrapers are the most efficient equipment available for moving large quantities of pit material. Plan to use pusher tractors as needed. If scrapers assisted by pusher tractors will not pick up a large enough load of consolidated gravel or soft rock in about 100 to 150 feet, use a rooter or ripper to increase loading efficiency. If the material is too consolidated for efficient rooter or ripper operation, it may be necessary to blast. Excavation includes the removal of material from its natural bed and transportation to the construction site. Remove material from the floor of the pit in successive layers over the entire width of the zone being worked. To coordinate stripping, excavating, and maintaining scraper-operated sites, divide the pit into zones at right angles to ground contours. Figure 3-1 shows the layout and development of a typical scraper pit.

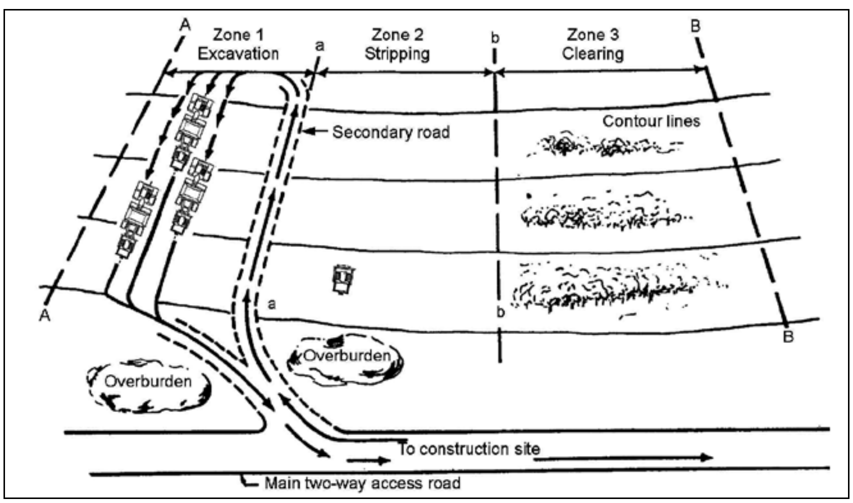

Figure 3-1. Layout and development of a scraper pit

3-9. Use trucks with a hydraulic excavator, front-end loader, or both for excavating pits consisting of above-water gravel deposits. This equipment is used when a smaller amount of material is required and the hauling distances are greater than for borrow pits. A hydraulic excavator is well adapted to hillside deposits having slopes too great for the practical operation of earthmoving equipment. Maintain a working face of about 5 feet when excavating horizontal deposits with a hydraulic excavator. The maximum safe bench height should be equal to or less than the boom length. For unstable conditions, it should be less. The excavator and truck combination is best for hauling distances of 3,500 feet or more. Efficient excavator and truck operations require that the—

- Number of trucks is sufficient.
- Tops of the truck sides are not higher than the top of the tracks on the excavator.
- Excavator swing distance is as short as possible.
- Spotting trucks are on the swing and digging sides of the excavator.
- Excavator is swung over the rear of the truck instead of over the cab (for safety).
- Excavator is level.
- Haul roads and work areas are in good shape.
- Supervision given to equipment servicing and maintenance is constant.

3-10. Excavate hillside deposits, beginning at the top, by successively cutting parallel to the contour lines using a hydraulic excavator or front-end loader in benches (figure 3-2). The trucks will back into the cut made by the excavator for efficient operation. A dozer can be used to level the path that the excavator will follow. The excavator can do the leveling, but it will cause a loss of excavator productivity. When the top bench is finished, move down the hillside and begin again. The trucks can use the first cut as a road. When the excavator is advanced into the hill to a point where the maximum working face height is reached, bulldoze a second road above the cut and start a new bench. When the second face reaches a maximum height, start a third bench, and so on. Always keep the floors of the benches sloping slightly away from the face to provide drainage.

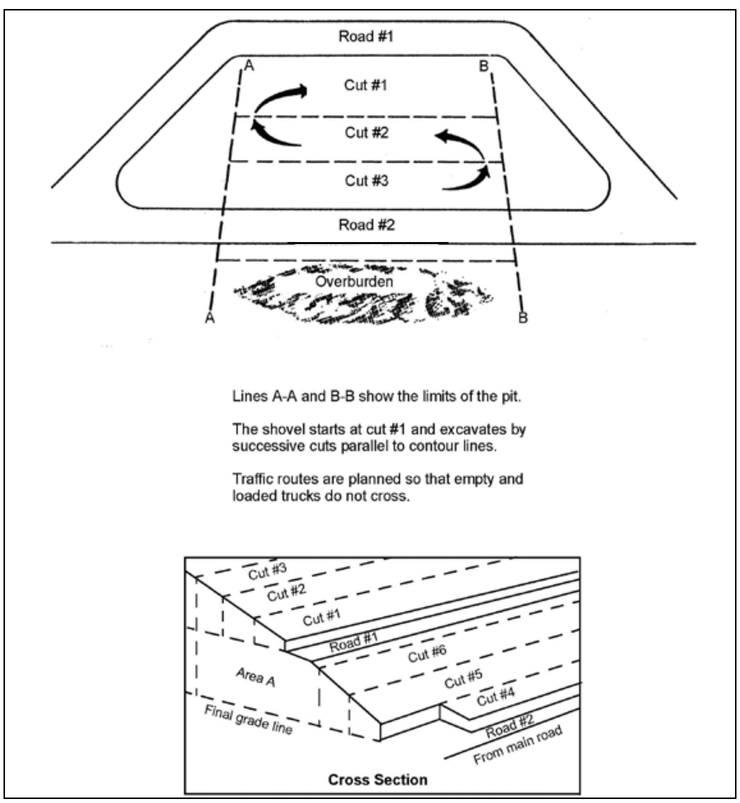

Figure 3-2. Layout and development of a hillside pit

3-11. In level terrain where drainage is not a problem, it is sometimes necessary to excavate material from deposits below the surrounding ground level. Where deposits are sufficiently large, develop pits by using the circular-bench method (figure 3-3). Excavate the entire top level, and then continue with the same procedure, advancing one layer at a time until reaching the desired depth. If digging on a downgrade of 10 percent or less, a hydraulic excavator can be used until a working face is obtained. Trucks are spotted in the first cut for loading while the excavator is making the second cut and so on. The excavator continues to dig deeper with each successive cut until the desired maximum height of the working face is reached. As the pit widens from successive cuts, it assumes a circular shape. Traffic control may be looped within the pit or made to flow one way through the pit (depending on the situation).

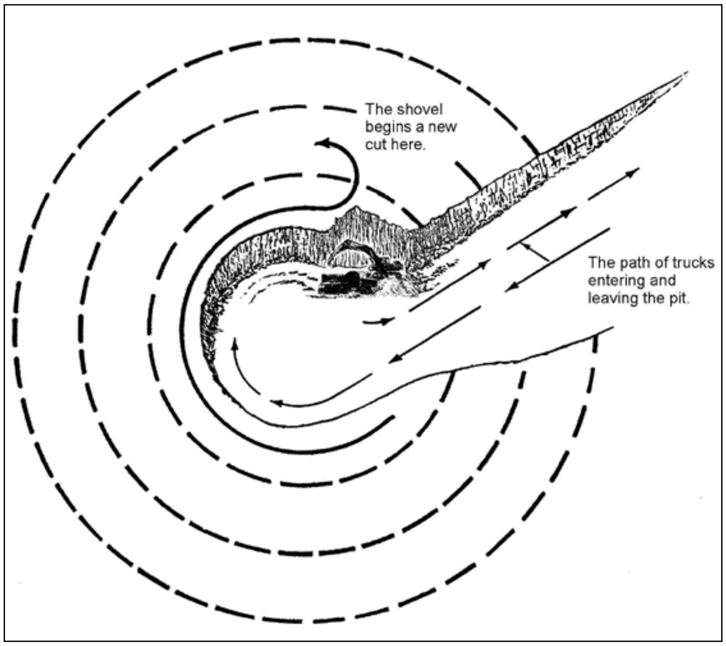

Figure 3-3. Layout and development of a subsurface pit using the circular-bench method

3-12. On material sites (such as those along old streambeds), circular pit development is not practical because of stream width. However, a similar method of operation involving straight-line benches may be used (figure 3-4). Use a hydraulic excavator or a bulldozer to dig the first cut to a depth sufficient to provide a desirable height of working face. Continue the cut at this level, loading trucks in the cut. Reverse the direction of the hydraulic excavator, making a second cut beside the first. Level the first cut for truck travel. Make each succeeding excavation in parallel, straight cuts. If the deposit is deep enough, a second or third level may be developed. Excavations often become deep and narrow, so exercise caution to avoid endangering personnel and equipment due to cave-ins and slides.

3-13. A dragline excavation is best for loose materials below the track level of the machine. A dragline is the most practical piece of equipment for underwater digging and is well adapted for submerged gravel pit operations. Draglines are typically used to recover sand, gravel, or coral from streambeds, lake bottoms, and beaches. They are also used to stockpile material for other loading equipment. Draglines are slower and less accurate than power shovels, so they are not generally used to load trucks (figure 3-5).

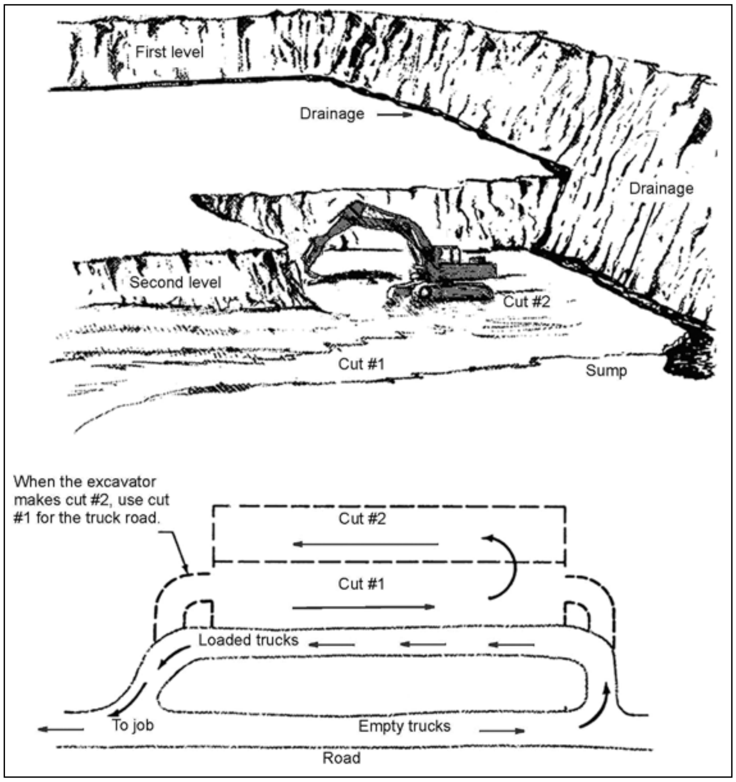

Figure 3-4. Layout and development of a subsurface pit using the straight-bench method

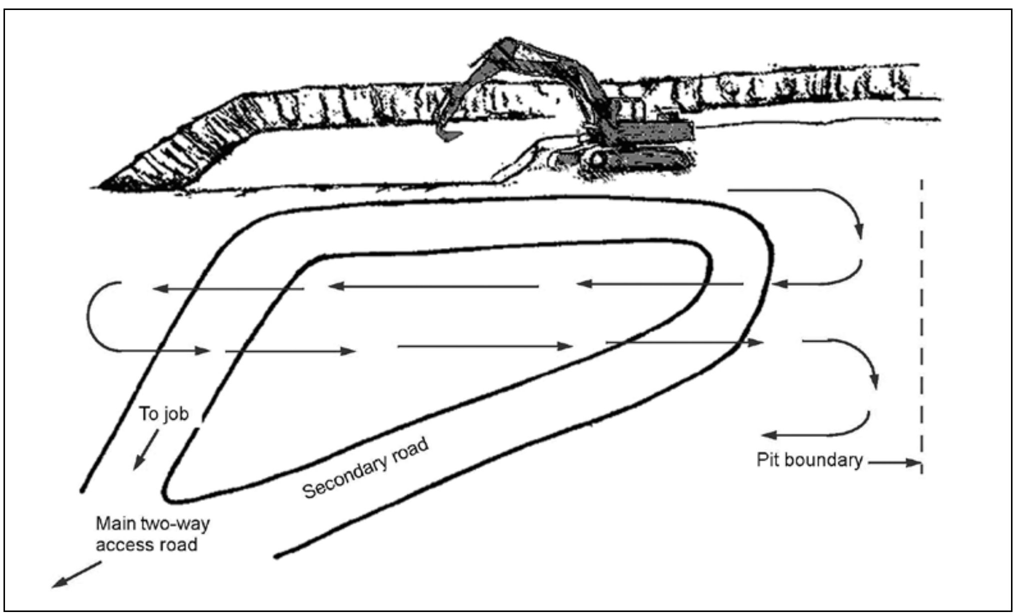

Figure 3-5. Layout and development of a subsurface pit using a hydraulic excavator

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Chapter 4

Quarry Layout

In many cases, a quarry site cannot be planned without simultaneously considering its development. The quarry development consists of preliminary and continuing work to achieve the desired layout.

PREPARATION

4-1. Quarry layout consists of preplanning the location, dimensions, and arrangement of the quarry and its supporting roads and facilities. The following factors must be considered:

- Mission.
- Structural geology of the rock source.
- Amount of overburden.
- Equipment (design for the largest equipment expected and additional equipment that could be brought onto the site).
- Access.
- Drainage.
- Traffic flow and the type of equipment required to design haul roads.
- Short- and long-term development.
- Explosives safety storage distances between explosives storage and blasting operations.

4-2. The objectives of preplanning are to ensure that—

- Adequate space is provided for future activities within and around the site.
- The flow of materials will be safe and efficient.
- Unnecessary work is avoided and the product is provided as soon as possible.
- Unnecessary equipment is not brought to the site (for example, a jaw crusher is not brought to an alluvial deposit).
- Additional equipment that may be needed to meet production requirements is identified and requested.
- Personnel and equipment are equal to the task, with special consideration given to the characteristics and limitations of the equipment to be used at the site.

4-3. The intended use of the quarry will dictate the type to develop. The following are the basic types of quarries:

- **Hillside quarry.** A hillside quarry is constructed in rock that is part of the structural geology of a hill. These quarries have the advantage of natural drainage and gravity affecting the material flow from the quarry face (figure 4-1, page 4-2). The disadvantages of a hillside quarry are the removal of overburden, the grade or steepness of haul roads, highly visible operations, noise radiating from the site, the susceptibility to severe weather, and the necessity of bench operations.
- **Subsurface quarry.** A subsurface quarry is one that is opened below the level of the surrounding terrain. A disadvantage of this type of quarry is the removal of material below grade and the disposition of the material above grade. This applies to overburden and construction aggregate. Another disadvantage is that this type of quarry will not drain naturally (figure 4-2, page 4-2). Advantages include being masked from view, containing noise, and providing some protection from severe weather.

- **Terrain quarry.** A terrain quarry is a temporary operation in which the existing terrain is lowered or leveled (such as the excavation of a roadway through a rock formation).

Figure 4-1. Hillside quarry with spiral access

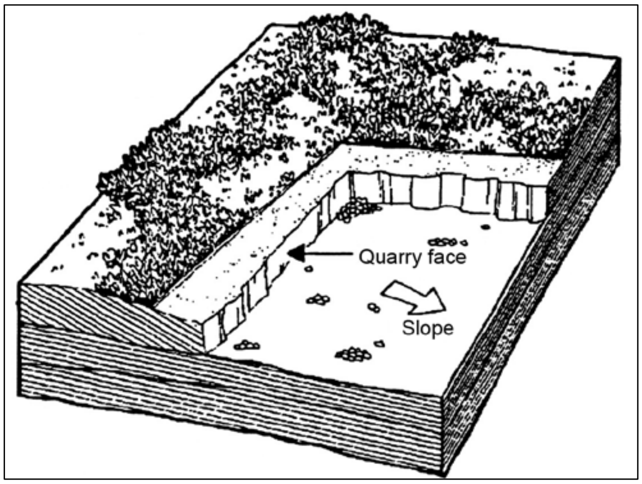


Figure 4-2. Quarry face on slightly inclined strata showing underlying stratum used as quarry floor and slope away from quarry face

QUARRY FACE DIRECTION

4-4. Before determining the layout of the quarry, it is necessary to determine the direction of the quarry face. The following are types of quarry faces:

- **Steeply inclined and folded strata.** The quarry face must be oriented perpendicular to the strike in these types of strata as shown in figure 4-3. If the rock is worked in this manner, a vertical or near vertical face will result. If the face is oriented parallel to the strike, an overhanging or sloping face with an extended toe will result. These conditions are hazardous and inefficient (figure 4-3).
- **Level and slightly inclined stratum and massive rock formations.** Where conditions of level stratum or massive rock formations exist, the direction of the quarry face may be determined by other factors. If the strata at the proposed quarry site are slightly inclined, the quarry face should be worked up the grade so that the floor of the quarry will slope away from the face (figure 4-4).

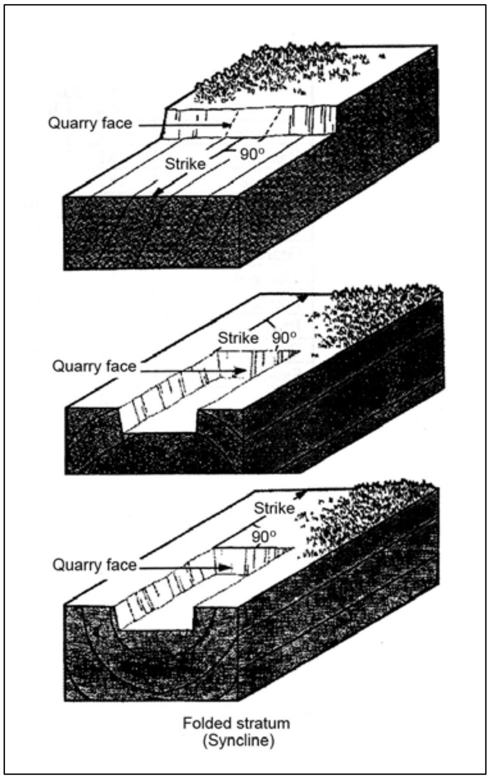


Figure 4-3. Direction of the quarry face

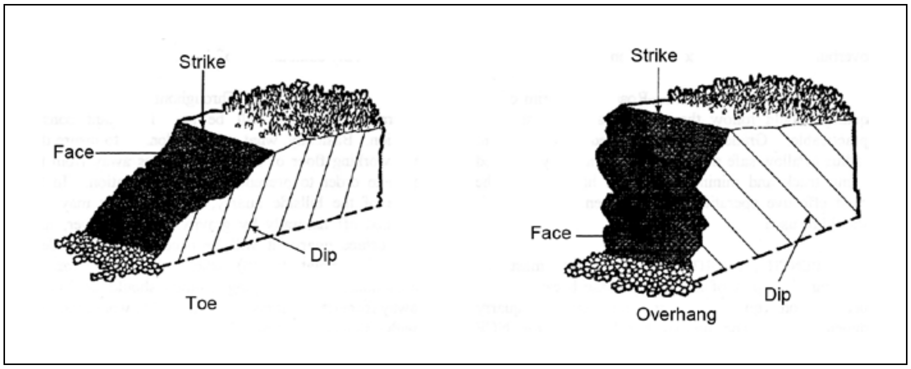


Figure 4-4. Disadvantage of the opening face parallel to the strike

STRIKE AND DIP

4-5. As previously discussed, strike and dip are important factors to consider before determining the quarry layout. It is necessary to determine the site strike and dip, especially the mineral material to be excavated (figures 4-5, 4-6, and 4-7, page 4-4).

4-6. *Strike* is the direction of the line of intersection of an inclined layer of rock with a horizontal plane. *Dip* is the maximum angular departure of an inclined bed from the horizontal plane. Dip is expressed in degrees and is always measured at right angles to the line of strike.

4-7. Determine the strike of an inclined bed by placing a level flush against the bed and adjusting its position until the bubble is centered. Draw a line parallel to the long axis of the level. This is the strike. To measure the dip, draw an inclined line perpendicular to the strike and measure its inclination from the horizontal plane (figures 4-3, 4-4, 4-5, 4-6, and 4-7).

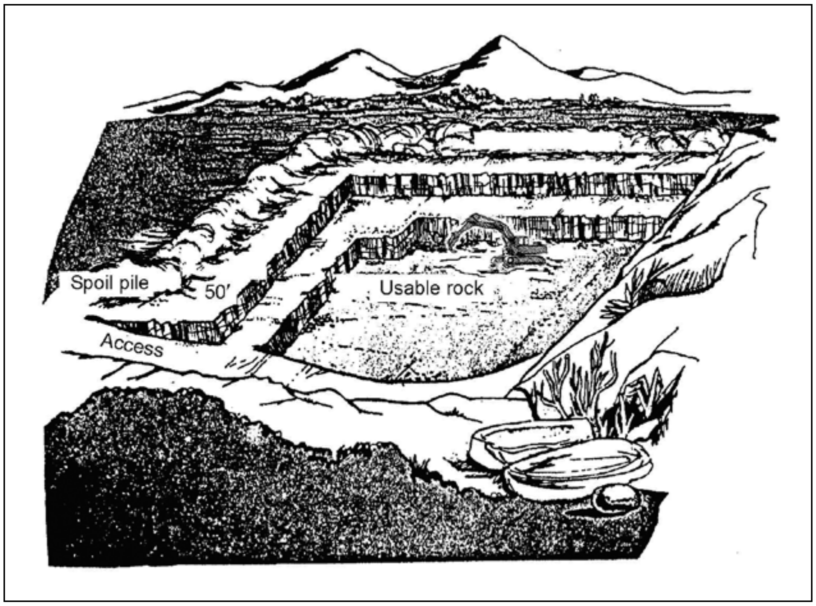
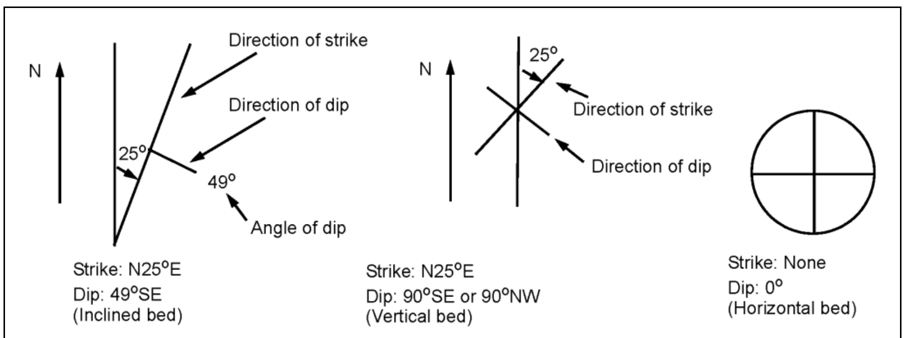


Figure 4-5. Subsurface quarry



Legend:

E	east
N	north
NW	northwest
SE	southeast

Figure 4-6. Strike and dip symbols

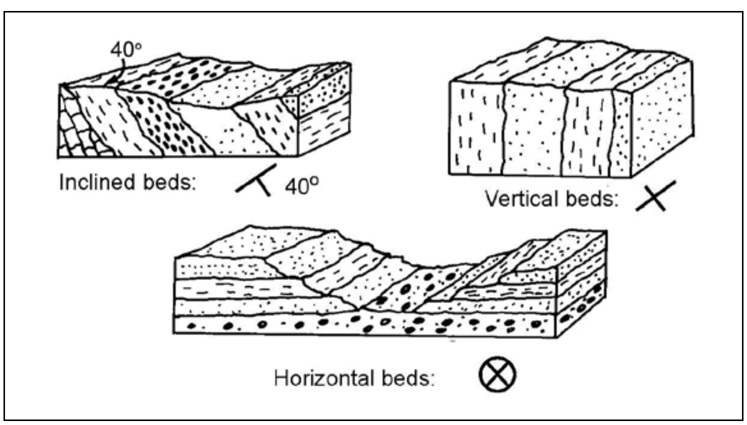
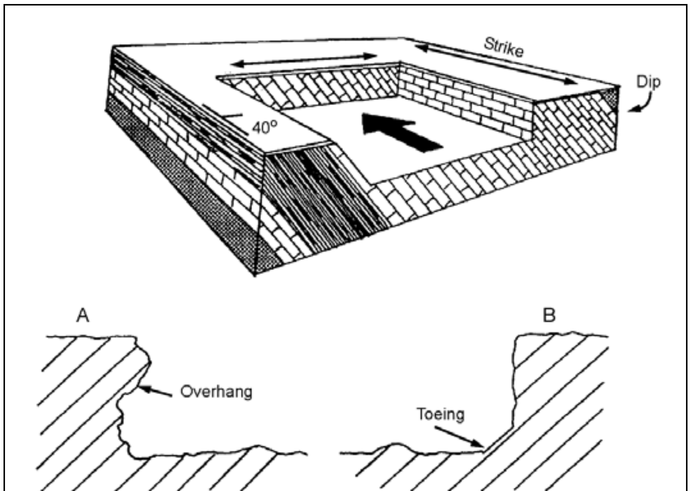


Figure 4-7. Strike and dip symbols of sedimentary rock

DIRECTION OF WORK

4-8. Regardless of the actual dimensions of the final excavation, the quarry working face should be oriented to minimize the undesirable influences of the rock mass to be excavated. Quarries should be developed in the direction of the strike so that the quarry face is perpendicular to the strike. This orientation is especially important where rocks are steeply inclined because it optimizes drilling and blasting efforts by creating a vertical or near-vertical rock face after each blast. Quarries may be worked parallel to the strike direction in instances where the rocks are not steeply inclined, but drilling and blasting will prove to be more difficult. In addition, if the rocks dip away from the excavation, overhang and oversized rocks can be expected. If the rocks dip toward the excavation, problems with slope instability and toeing may result. In massive igneous rock bodies and horizontal sedimentary rock layers, the direction of quarrying should be chosen based on the most prominent joint set or other discontinuity (figures 4-8 and 4-9 [page 4-6]).



Note. Stability at A, because of overhang, will cause rock to fall straight down. Stability at B, because it lies on the plane of rock movement, will cause rock to slide toward the toe.

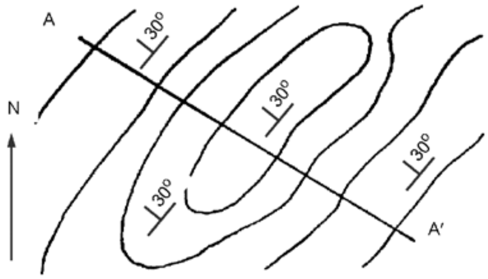
Figure 4-8. Quarry in the direction of strike

4-9. The internal structure of unfractured, massive, or horizontally layered rocks has no impact on the direction of work. Other criteria (the site topography, access, and amount and variety of overburden) may be used to determine the best orientation of the quarry face.

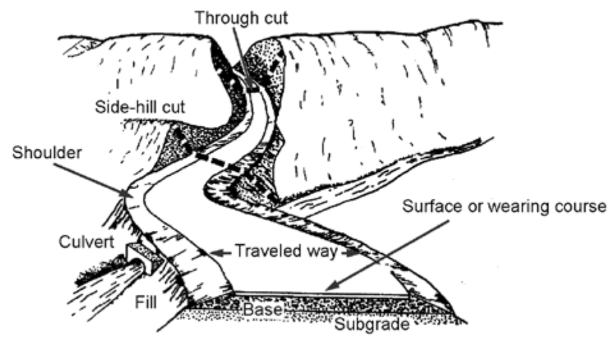
4-10. When the rock mass contains parallel layers or fractured surfaces that are slightly inclined, the quarry face should be oriented parallel to the strike of the rock. In this case, work may proceed up the dip of the sloping rock surfaces. This allows the bedding or fracture planes to be used for maintaining an even, well-drained quarry floor (figures 4-10, page 4-6, and 4-11, page 4-7).

4-11. When the rocks are folded or contain steeply inclined layers or fractures, the quarry face should be oriented perpendicular to the strike of the rock structure. This eases the problem of maintaining a vertical face and reduces drilling, blasting, and other safety hazards. If the quarry face is parallel to the strike of the rock (with rock layers or fractures inclined toward or away from the face), problems with toes, overhangs, rockfalls, and rockslides will extend along the entire width of the working area along the face.

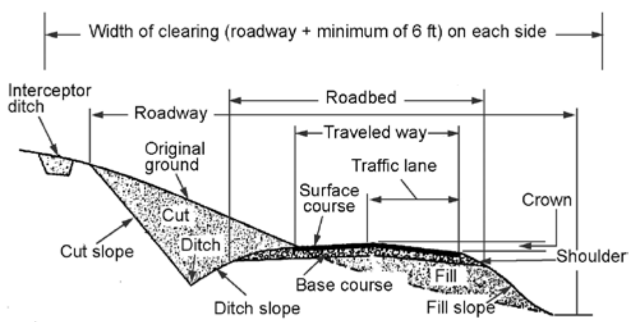
4-12. When rock layers are essentially vertical, the quarry face may be worked parallel or perpendicular to the strike. Blasting is usually more efficient when the face is parallel to the strike.



Map view, illustrating strike and dip symbols. The best road alignment (based on the structural geology) is NW-SE, perpendicular to the strike.



Through cut in the hill, illustrating rock dipping along the road.



Road cross section and nomenclature.

Legend:

ft	feet
NW	northwest
SE	southeast

Figure 4-9. Road cut alignment

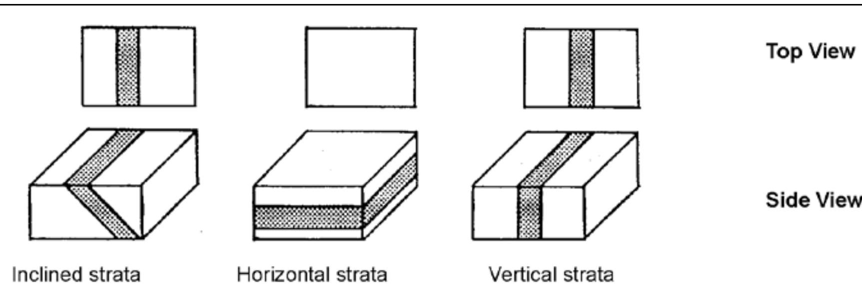


Figure 4-10. Strike of rock strata (top and side views)

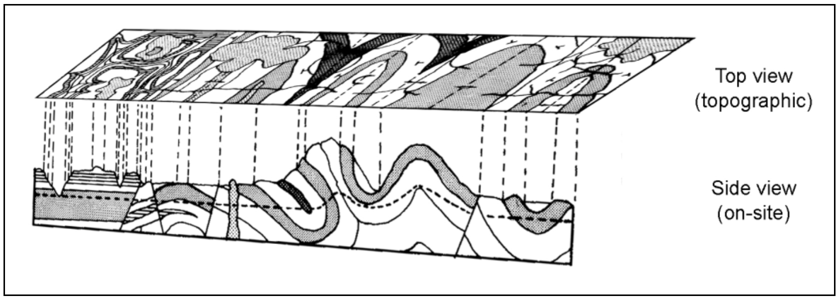


Figure 4-11. Geologic map and cross section

EARTHQUAKES OR FAULT MOVEMENTS

4-13. Movement along active faults produces powerful ground vibrations that may cause rock displacement that can seriously disrupt engineering operations. Unless proven otherwise by geological or historical evidence, faults that have disrupted recent geologic deposits should be considered active.

OVERBURDEN

4-14. Once the direction of work has been planned, consider what to do with the overburden (spoil). An important aspect for removing the overburden is the location of the spoil pile. If the overburden is not intended to be recycled, used for fill, or restored, it should be cleared from areas planned for future use. This reduces the need to handle the material a second time. When the overburden will be recycled, it should be located at a site that allows for the most efficient operation. Strive to separate and stockpile topsoil for future reclamation. For safety reasons, the overburden should never be placed within 50 feet of the quarry rim, especially when operating a subsurface quarry.

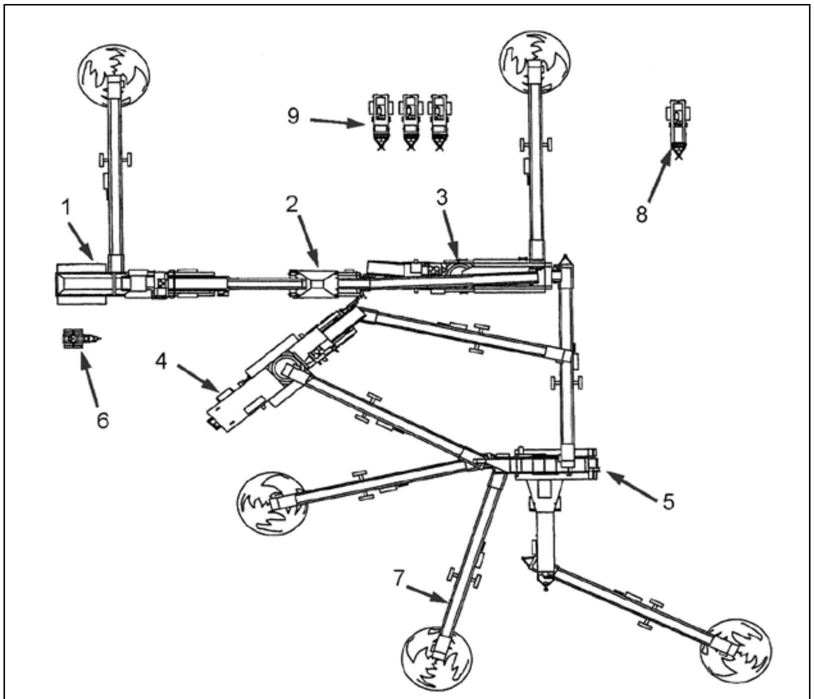
HAUL ROAD AND QUARRY ROUTES

4-15. Roads leading to the rim of the pit should follow the shortest and easiest route practical. Plan haul roads considering the limitation of projected equipment to avoid rebuilding or causing undue wear and tear. Design the grade to accommodate the equipment using the roads, normally not exceeding 10 to 15 percent, especially haul trucks. Design curves for safe negotiation by loaded dump trucks, and have them superelevated. For access to, from, and within the quarry, it may be necessary to construct a straight ramp, a spiral ramp, or switchbacks for the equipment. Surface haul roads with crushed rock, and keep them drained to reduce the amount of road maintenance required. Maintain haul roads in top condition, and keep them free of debris to improve safety and dramatically reduce maintenance. Control dust by applying water, geotextiles, asphalt, or road oil; do not use waste oil.

CRUSHER SITE

4-16. The actual crusher site should be a secure area of stable ground that is large enough to accommodate the plant and its related equipment (conveyors, bins, generators), stockpiles of crushed rock, and loading operations. The terrain should be able to support heavy-equipment movement with only minor earthmoving improvements and sloped enough to provide good drainage. By locating the crusher on a hillside or slope, gravity will help move material from the face to the crusher, from the plant to a storage area, or from a storage area to the haul units. The site should be accessible to construction operations and, if aggregates are to be washed, to a water source. (See figure 4-12, page 4-8, for a side view of a sample crusher setup and figure 4-13, page 4-8, for a top view of a sample plant layout.)

Figure 4-12. Sample crusher setup (side view)



Legend:

1	primary crushing unit (Model M3042)
2	surge bin feeder (Model PSF-12)
3	secondary crushing and screening unit (Model M1313)
4	tertiary crushing unit (Model C45)
5	washing and screening unit (Model M1122)
6	dolly converter (Model 58-840)
7	product conveyor (Model PC1245)
8	water pump unit (Model GB2060)
9	motor generator set (Model GB125)

Figure 4-13. Sample plant layout (top view)

4-17. The crushing, screening, and washing plant should be located close to the quarry, but far enough away so that it and the operating crew are not endangered by blasting. The advantage of locating the crusher nearby is that it minimizes the haul time. This is important because the raw material from the quarry may contain product and by-product materials. The material hauled from the plant to the construction site contains only product-sized material. If the primary crusher can be located close enough to the quarry face, it can be loaded directly from the blast site with 5-cubic-yard, front-end loaders or a combination of loaders, excavators, and dozers. This will prevent extreme wear on haul trucks caused by shot rock and reduce the overall haul truck usage.

DUAL LEVEL CRUSHER OPERATIONS

4-18. Two levels are usually used for crushing operations, which requires a retaining wall or a vertical or nearly vertical rock face (figure 4-14). The quarry-run rock is dumped directly onto the apron feeder or into a loading chute by the haul units or front-end loader on the upper level, processed through the plant, and discharged on the lower level via conveyor belts. For short durations, the single-level operation could be used. In this manner, the rock could be dumped onto the ground and lifted to the apron feeder by a clamshell. However, this method is far less efficient and normally results in increased safety hazards.

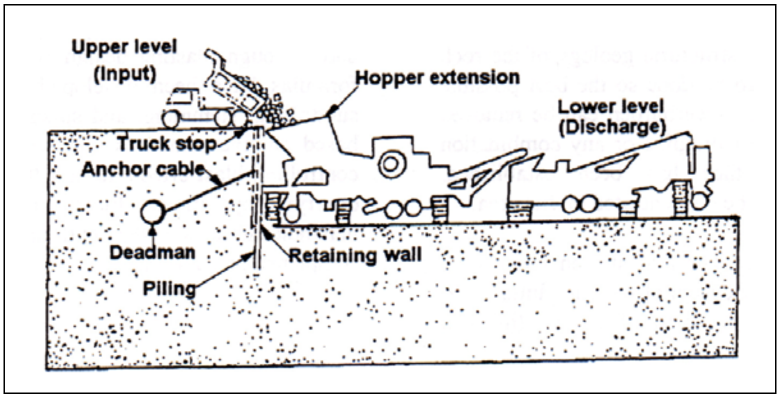


Figure 4-14. Crusher setup showing two working levels

EQUIPMENT

4-19. Quarry and crushing operations require large quantities of diversified equipment that are subject to extreme wear. For this reason, a maintenance facility should be considered for the quarry operation. In addition to normal repair and maintenance capabilities, this facility should also be equipped for heavy-duty welding and other welding needs that frequently occur during a quarry operation. The location of the maintenance facility should be convenient for efficient operation and access, yet out of the way of future and current excavation processes.

Crushing Equipment

4-20. Due to the varied environments and factors that can be encountered, it is important to understand the equipment limitations and strengths. Each mission will have its own tactical situation and parameters, with varied options available for equipment selection. Army crushing systems work in rock-processing situations. Depending on the mission, a system designed specifically for the task may be supplied instead of using on-hand equipment. Ancillary equipment may be required to increase efficiencies or to produce an acceptable product. If conducting recycle operations, ensure that the correct equipment is being used, especially if recycling material contains steel. Steel can block certain configurations, and the practice of removing it from a moving conveyor belt can cause serious injury or casualties. Feed only the appropriate-size material to the system. It is easier and safer to remove oversized or unwanted material from the feeder than from the plant. A plugged plant can cause serious damage, and more importantly, unplugging it, in most cases, is a dangerous operation.

DANGER (ARMY) WARNING (NAVY/AIR FORCE)

Do not enter the Vibrating Grizzly Feeder to clear debris or rocks that have bridged.

4-21. A knowledge of basic crushing operations is essential to estimate what equipment will be needed and the type of production that can be expected. When possible, use the equipment or operator’s manual for the specific equipment to make these determinations.

4-22. Rock is crushed by using the following primary methods:

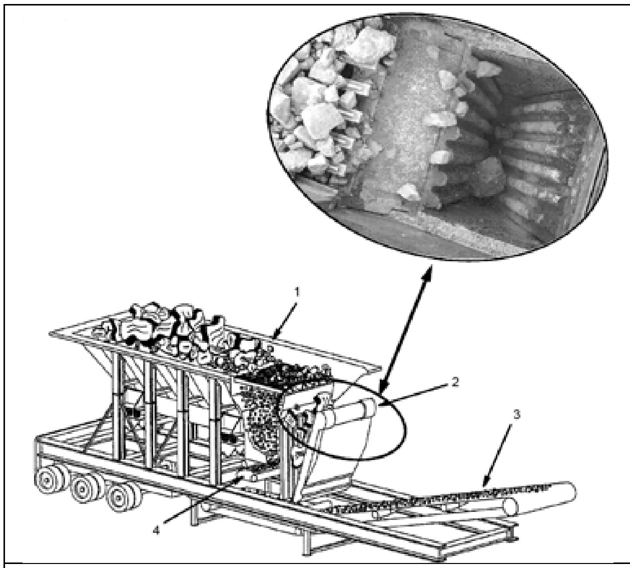
- **Compression.** Compression crushers squeeze the rock between two surfaces. Included are jaw crushers, roll crushers, and cone crushers. These crushers operate most efficiently and with the least amount of wear when fed to capacity. This also produces the most uniformity of shape and gradation. Compression crushers, in general, are not tolerant of plastic feed material.
- **Impact.** Impact crushers cause breakage by impacting and accelerating the rock to strike other rock on the inside of the crushing chamber. This breaks the stone along existing axes of cleavage. It also tends to make a more cubical product out of slabby or elongated material by breaking off the thin edges. In a deposit with a mixture of soft rock, it can be used to selectively explode the soft undesirable rock for removal.

CAUTION

Crushers can be damaged if operated in excess of production rates, particularly at fine settings and low reduction ratios.

Jaw Crushers

4-23. The overhead, eccentric jaw crusher is the most universally applicable primary crusher (figure 4-15). In sedimentary rock to the hardest granites or basalts, this primary crusher operates effectively. The jaw crusher is a compression machine with a 6:1 reduction ratio. In shot rock, material that is 90 percent of the feed opening is acceptable. In gravel, because of the tendency of the material to be more rounded, material that is 80 percent of the feed opening is recommended. As a general rule, discharge material is twice the crusher setting. Closing or opening the discharge setting changes the output gradation.



Legend:

1	Vibrating Grizzly Feeder
2	jaw crusher
3	undercrusher conveyor
4	feeder side discharge conveyor

Figure 4-15. Primary jaw type crushing unit

Roll Crushers

4-24. When a special product size is required, a roll crusher may be a good tool. This compression type crusher produces more of a banded product range than other crushers. A dual-roll crusher is limited to a 2:2 or a 1/2:1 reduction ratio. The triple roll is a 4:1 or 5:1 reduction machine. It is vitally important that feed material is spread across the face of the rollers to maximize production and prevent uneven wear. Opening or closing the discharge setting changes output gradation. The rollers are not affected by moisture or plasticity, as are cone crushers.

Three-Roll Crushers

4-25. Three-roll crushers can provide twice the reduction ratio of a dual-roll crusher. A single-feed, three-roll crusher with a 20 to 80 or up to 66 2/3 to 33 1/3 split will produce a greater capacity and a smaller percentage of overage as its second stage does not have to recrush material reduced to finished size by the first stage. These particles fill the voids at the second stage, resulting in a denser material ribbon. At higher material-size split ratios, the dual feed will outproduce the single feed, but a much larger screen is required to handle the large recirculating load. For this reason, the single-feed method is preferred in a closed-circuit operation. The best application for dual feeding is in open-circuit operation with other suitable crushers following to handle the high percentage of oversize material passing through the three-roll crusher.

Cone Crushers

4-26. Cone crushers have the same universal acceptance for secondary (figure 4-16) and tertiary (figure 4-17, page 4-12) crushing as jaws do for primary work. Cone crushers can be the all-purpose machine in most sand and gravels where a feed size up to 13 inches requires no primary crusher. In shot rock, cones perform as intermediate and/or finishing crushers following a primary crusher. Cones, with a reduction ratio of 6:1 to 8:1 reduce material to a minimum of 3/4 inch minus. Cones can reduce material to a minimum of 1/4 inch minus with a reduction ratio of 4:1 to 6:1. Various liner configurations adapt each machine according to feed size and product requirements. Opening or closing the closed-side setting changes discharge gradation (figure 4-18, page 4-12).

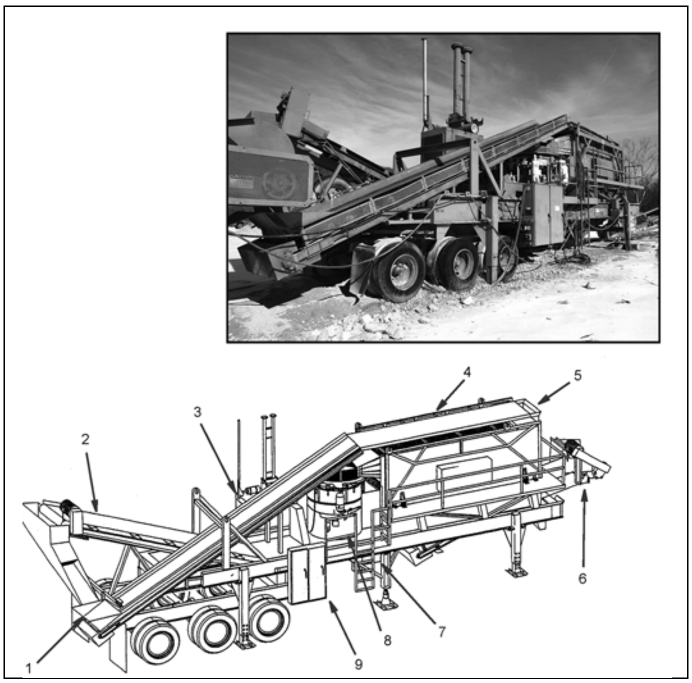
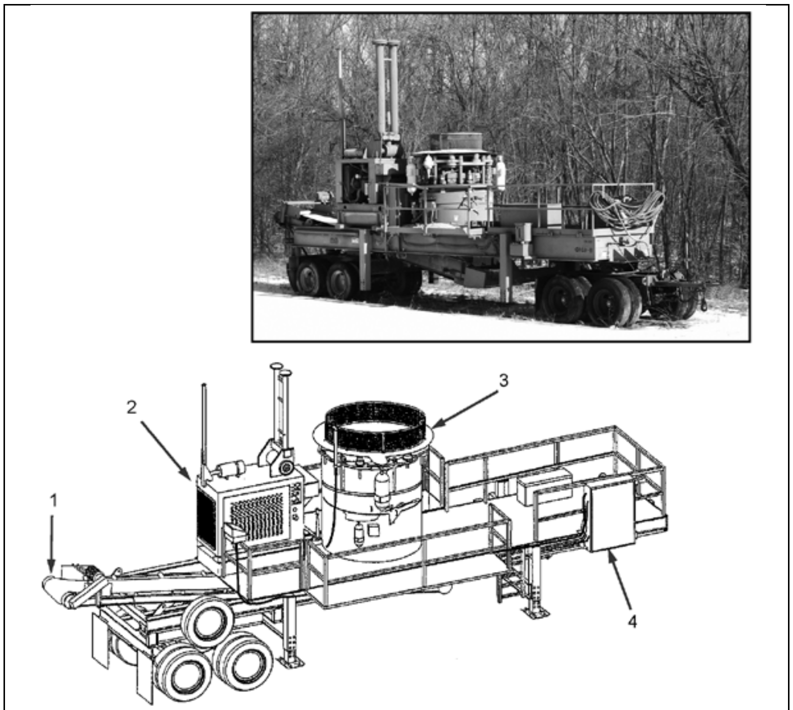


Figure 4-16. Secondary crushing unit

Legend:

1	infeed conveyor
2	undercrusher conveyor
3	diesel engine
4	screen
5	sand scalper
6	underscreen conveyor
7	middle and bottom deck discharge chutes
8	roller cone
9	power distribution panel

Figure 4-16. Secondary crushing unit (continued)



Legend:

1	undercrusher conveyor
2	diesel engine
3	roller cone
4	power distribution panel

Figure 4-17. Tertiary cone crushing unit

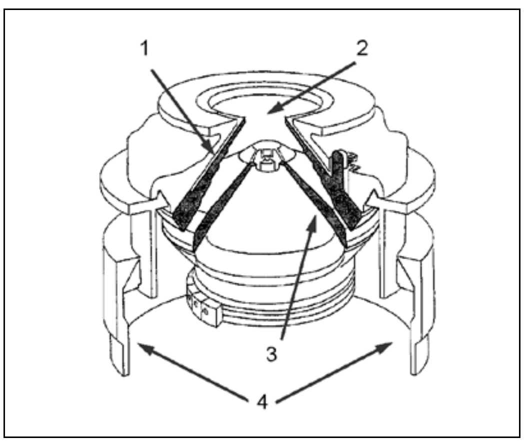


Figure 4-18. Cone crusher setting

Legend:

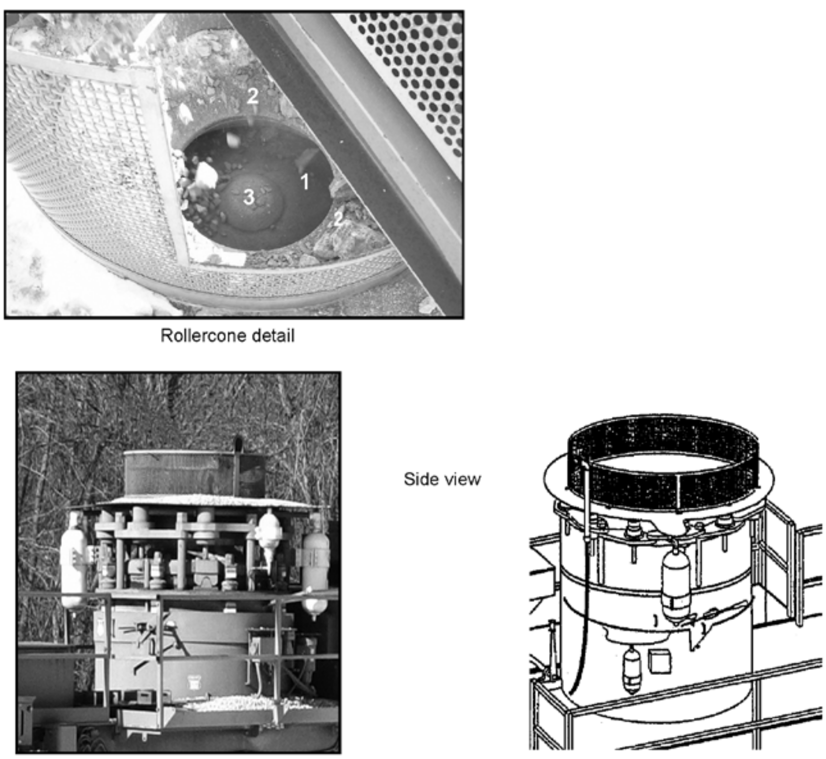
1	fixed mantle
2	infeed
3	moveable cone
4	discharge area

Figure 4-18. Cone crusher setting (continued)

Rollercone® Crusher

4-27. The Cedarapids™ Rollercone (figure 4-19) equipment manual shows capacity ranges based on igneous rock (basalt, granite). Those charts are to be used as guides to crusher and liner selection. Material processing includes many different factors that affect crusher performance. The charts are based on the following factors:

- Less than 10 percent undersize (smaller than the closed-side setting) in crusher feed.
- Plastic material limited; no pancakes created.
- Moisture content of feed material below 5 percent.
- Uniform feed gradation.
- Proper feed distribution 360º around the feed opening.
- Use of the fine-head feed control device when required.
- Proper crusher revolutions per minute under full load.
- Support equipment properly sized and in good operating condition. These include conveyors, screens, electric motors, V-belt drives, support structures, and undercrusher hoppers and feeders.



Legend:

1	fixed mantle
2	infeed
3	move

Figure 4-19. Rollercone

4-28. Feed openings are based on new and ideal screening conditions. Due to the wear pattern, it is not possible to maintain a constant feed opening if a stake up occurs.

4-29. The minimum closed-side setting is that point just above bowl float under the maximum allowable pressure on the tramp iron relief system. This setting can vary widely, depending on the nature and condition of the material being crushed. Under some conditions, when the setting is too close, pancakes will form and the bowl will float. If this condition exists, the setting must be increased until bowl float is eliminated.

4-30. This data is offered as a guide only. Crushing characteristics of various rock-and-crusher operations will affect results. Capacities are based on a material weight of 100 pounds per cubic foot.

Primary Impact Crushers

4-31. Recommended mainly for limestone and lower abrasive applications, single-impeller impact breakers provide a cubical product even in slabby material, improve aggregate quality, and increase plant capacity. The impact breaking action acts along natural cleavage lines to produce material with fewer thin, sharp edges. The size of the impact breaker generally indicates the net feed opening after the Vibrating Grizzly Feeder is placed into the chamber opening. With reduction ratios up to 20:1, secondary crushing requirements are reduced using the impact breaker when compared with a compression type primary crusher. Impact breakers are normally used when material is 10 to 15 percent abrasives or less. Varying the crusher speed and the breaker bar setting generally changes output gradation. In recycle applications, the primary impact crusher is very effective at liberating steel from concrete and breaking up asphalt feed.

Horizontal-Shaft Impactor Crushers

4-32. Combining the benefits of impact crushing with the application of high-chrome technology, the secondary impactor provides a cubical product in material that was previously too abrasive for impacting. With a reduction ratio of up to 12:1, secondary impactors can reduce or replace finish crushing. Top-size feed is about 12 to 22 inches with the minimum product being 3/4 inch. Output gradation is varied in two ways. The primary means is changing the rotor speed. The higher the speed, the finer the product. Unfortunately, increasing the speed also increases wear. The second means is adjusting the aprons, which also affects output gradation.

Vertical-Shaft Impact Crusher

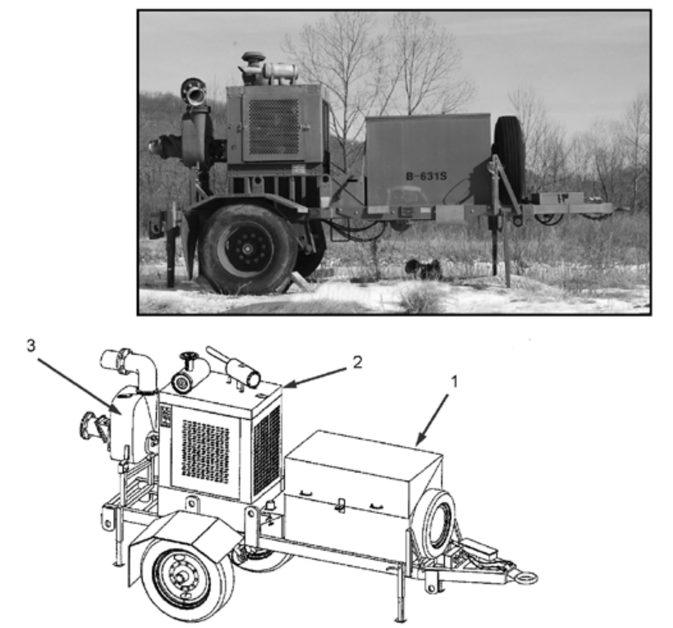
4-33. Like the secondary impactor, the vertical-shaft impact crusher combines impacting benefits with high-chrome metallurgy. It is a finish crusher that produces a desirable cubical product. Depending on the crusher configuration, material as abrasive as 70 to 90 percent can be handled by the vertical-shaft impact. Feed size maximum is limited to 3/8 to 6 inches depending on the crusher model and the crushing chamber configuration. The vertical-shaft impact is an excellent machine for producing concrete rock, chips, and manufactured sand. Anvils give better control of reduction capability; they have higher impeller speeds, which generate a finer product. Enclosed rock rotors save wear cost from high-abrasion materials, while offering the highest production rate.

Vibrating Screen

4-34. Before the capacity of a screen can be estimated, it is necessary to know the various factors and conditions that regulate screen production. When selecting a screen to separate crusher-run material, it is necessary to tabulate from a gradation curve the percent passing the screen cloth size required and the percent passing 1/2 the screen cloth size. For exact calculations on this process, see the manufacturer’s equipment or operating manual.

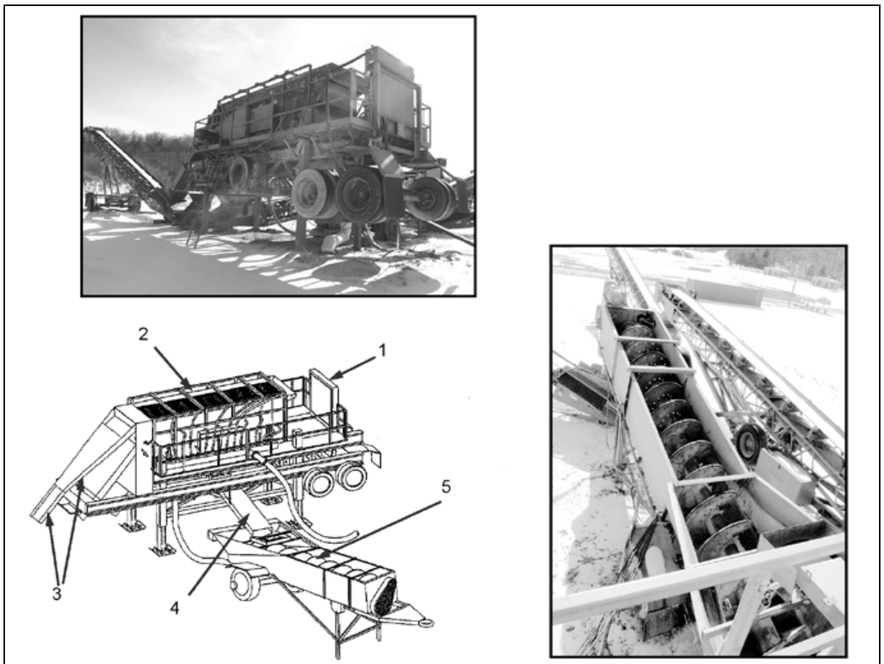
Water Requirements

4-35. A two-pond system is used to support washing and dust abatement. One pond is used as a settling pond; the other is used for supply to the spray pump unit. Pond sizes required vary based on pump unit capability plus 10 percent. Spray bars should be mounted so that the spray is with or toward the flow of material. Using high-pressure spray perpendicular to the screen surface will only drive near-size material into the screen surface, causing blinding. (See figure 4-20, page 4-16, for a water pump unit and figure 4-21, page 4-16, for a washing and screening unit.)



Legend:	
1	hose storage
2	diesel engine
3	pump

Figure 4-20. Water pump unit



Close up of dewatering screw

Figure 4-21. Washing and screening unit

Legend:	
1	power distribution panel
2	screen
3	discharge chutes
4	underscreen flume
5	dewatering screw

Figure 4-21. Washing and screening unit (continued)

Sand Classification

4-36. Capacities, horsepower, and screw speeds are based on washing concrete sand. In washing, classifying, and/or dewatering material of the finer mesh sizes or material with over 15 percent passing the number 50 mesh screen, turbulence becomes a critical problem. To correct this, turbulence must be reduced by slowing down the screw speed, allowing the fine-mesh particles to settle and be conveyed out as part of the product. The amount of slowdown required is dependent on the percentages of fine sand present. Refer to the manufacturer operating manual for screw specifications for recommended screw speed reductions.

4-37. When determining the number of gallons needed, water (water used for the sealed bearing and drain-board flushing pipe, water already in the feed, additional dilution water if needed when handling high-percentage silt feed) must be included in the total gallons per minute in considering water capacities for fine-material units. It is a common mistake to try and to retain more fines by reducing the amount of water. This is generally the worst action to take since it raises the specific gravity in the tub, causing an even larger loss of fines. If more water cannot be added, then the feed volume must be reduced. Maintain a specific gravity of less than 1.05, if possible. For specific applications, contact the sand washing equipment manufacturer.

CONVEYORS

4-38. Conveyors have a simple purpose; they move material from place to place. They can be found within and around the crushing plant (figure 4-22). Conveyors are used to create stockpiles and replace trucks as a means to transport material. Using a conveyor system to move rock from a face that is located primary to the finishing plant is rapidly gaining popularity because of its innate efficiencies and removing the maintenance intensive truck fleet from the process.

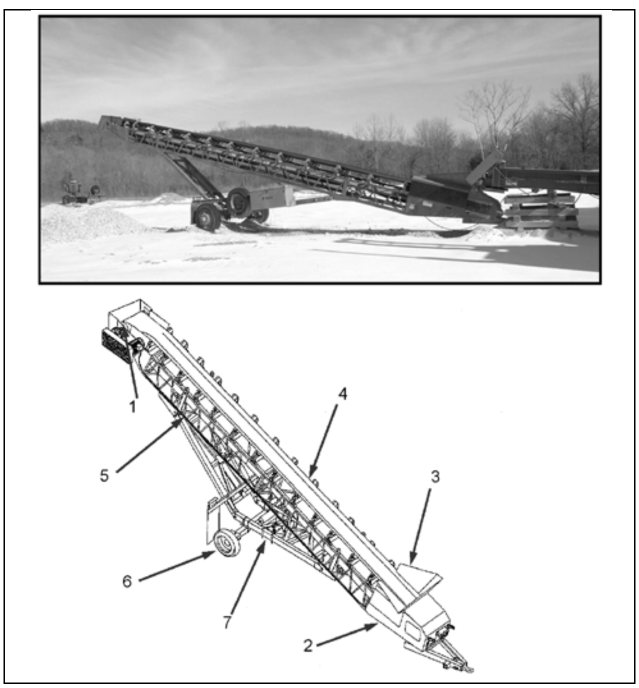


Figure 4-22. Conveyor

Legend:	
1	head pulley
2	tail section
3	hopper
4	troughing rolls
5	return rolls
6	swivel wheels
7	elevating pump

Figure 4-22. Conveyor (continued)

4-39. The standard 50-foot conveyor will not create a large stockpile. If a plant is going to be static for any length of time, the use of radial stacking conveyors should be considered. Many makes and models are commercially available, with the lower end models requiring manual manipulation to the top-of-the-line models that automatically build a desegregated stockpile.

SEGREGATION

4-40. Material discharged from a conveyor will have varying degrees of segregation due to physics. It is important not to send a product to the user if it is not blended back, as this will cause great problems at a construction site. The movement of the belts will cause the smaller material to filter down to the belt. When discharged from the belt, the already segregated material will be further segregated due to the larger particles, tendency to keep moving in the direction of movement. This results in a pile with the larger material on the outside of the pile in line with the conveyor, graduating to the finest directly under the conveyor. Methods to minimize this tendency include keeping the discharge end of the conveyor as close to the top of the pile as possible, running a slower speed, having a narrow range of products on the conveyor, and blending the pile while loading.

4-41. To minimize production time, follow the manufacturer recommendations. Never run a conveyor with the belt out of alignment or if it is rubbing on a frame member. Never run a conveyor with rollers that are not turning. Never take material off a moving belt by hand.

VOLUME

4-42. Calculate the volume of a stockpile as shown below. Calculate to the one-hundredth place; for example, 123.45. Use normal rounding rules (if below 5, round down; if 5 or above, round up).

$$V = (h \div 3) \text{ x area of base}$$

where—
V = volume
H = height of stockpile

Example.

- ***Step 1.*** Use the pole-and-tape method to measure stockpile height in feet and inches. Convert stockpile height to a decimal number (15 feet, 6 inches equals 15.5).
- ***Step 2.*** Measure the circumference of the stockpile in feet and inches. Convert the circumference to a decimal number; for example, 75 feet, 9 inches equals 75.75.
- ***Step 3.*** Find the area of the base by using the following formula:

$$c \div \pi = d \ (75.75 \text{ feet} \div 3.1465 = 24.12 \text{ feet})$$

where—
c = circumference of a circle
π = 3.1465d = diameter
d ÷ 2 = r (24.12 feet ÷ 2 = 12.06 feet)
d = diameter
r = radius

πr^2 = area of base (π x 12.06 feet x 12.06 feet = 456.69, rounded to 457 feet^2)

- ***Step 4.*** Finish the calculation as follows:

V = (h÷ 3) x area of base = (15.5 feet ÷ 3 = 5.166, rounded to 5.17 feet) x 475 feet^2 = 2,455.75, rounded to 2,456 feet^3

- ***Step 4a.*** Convert the volume of the stockpile (2,456 feet^3) to cubic yards by dividing the square feet by 27.

2,456 feet^3 ÷ 27 = 90.96, rounded to 91 cubic yards

- ***Step 4b.*** The volume of the stockpile is 91 cubic yards.

Cleaning

4-43. A log washer can be used to remove tough plastic clays from an aggregate. It consists of two parallel shafts with paddles in a tub. The tub uses water and the rotating action of the paddles and stone against stone scrubbing to liquefy the clays. The clays are flushed away, discharging clay-free stone from the end for further processing. A scrubber drum (rotary scrubber) is capable of processing large quantities of material. Similar to a rotary mixing drum, contaminated stone and water are fed in one end. Through a tumbling action, soluble clays and soft rock are placed into suspension to be rinsed off on a screen.

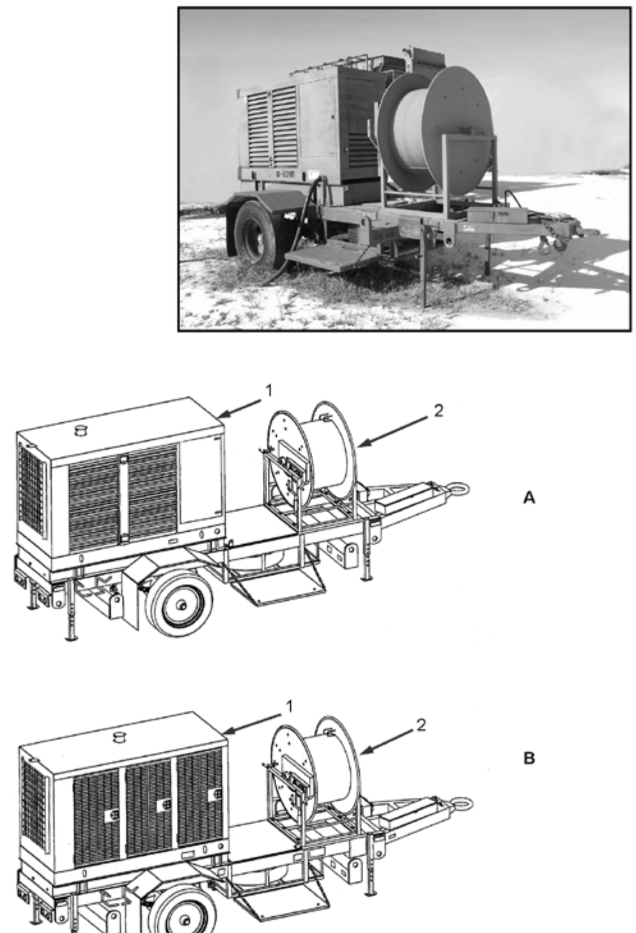
Generators

4-44. Most rock-processing plants are powered by electricity. If power must be generated on-site, the generators (figure 4-23) should be located under a shelter near the plant. Position generators so that cables do not run across traffic paths, and protect them from falling rock. Consider burying the cables in conduit. Take care to limit the amount of dust drifting or blowing into the generator. Power lines should be mounted on poles high enough to clear traffic. Consider operations that will be taking place in the vicinity of the overhead lines to ensure that they are not contacted or knocked down.

Loading Chute

4-45. A loading chute (figure 4-24) may be incorporated into the quarry operation. When the crusher retaining walls are high, a chute will allow equipment to be placed at a greater distance from the edge of the retaining wall, thus reducing the pressure against the wall. When processing large rock, the chute, bins, and hoppers should be kept one-third full to absorb the impact of falling rock without damage to the structure or equipment.

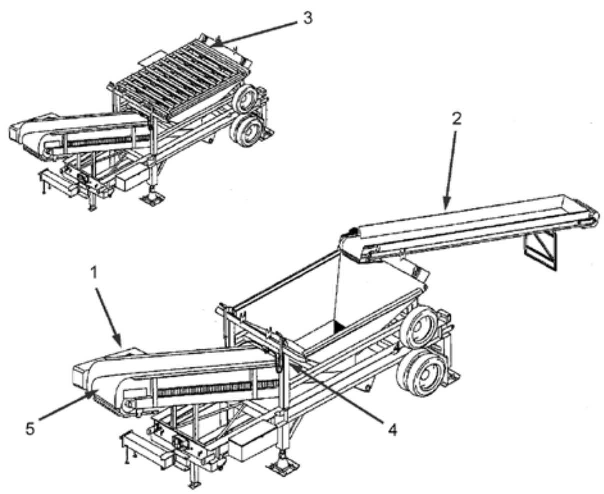
4-46. Crushers can be loaded by dump truck, excavator, or bucket loader. The crusher is designed to function best when the bin is charged full. This forces rocks to impact or crush against each other and through the impact of the force of the jaws. Additionally, cleanup around the loading chute and conveyors is best conducted with small front-end loaders or skid steer loaders. These small loaders work extremely well for rock cleanup in tight spaces. Without them, this type of cleanup has to be done with shovels and lots of physical labor, which can be time consuming and decrease overall production.



Legend:

1	diesel engine/generator
2	cable reel

Figure 4-23. Generator sets



Legend:

1	variable speed discharge
2	infeed conveyor
3	Grizzly Bars
4	adjustable discharge gate
5	discharge conveyor

Figure 4-24. Loading chute with surge bin feeder and Grizzly

Loading Chute and Grizzly

4-47. A Grizzly is a coarse screen used for sizing rock before crushing. A Grizzly consists of a durable, rigid, rectangular frame with steel rails spaced at intervals determined by the jaw setting (figure 4-25). As a rule of thumb, the optimum-size material fed to a crusher is 75 percent of the jaw dimensions. A Grizzly constructed of parallel bars without cross pieces would use a bar spacing of 75 percent of the smallest dimension or less. The screening bars of a Grizzly without cross pieces are always sloped and oriented in the direction in which the oversized material is to be cast. A Grizzly may be constructed for use at the crusher site, equipped with loading ramps, or constructed on skids for use with excavators or loaders. A Grizzly may also be constructed of very fine screens as a means of scalping off fine waste material (silts, clays) from quarry or pit material. In this case, the screen would be sloped in the direction that the select material is to be moved. Generally, a Grizzly is not practical for anything other than small production demands. Rely instead on the skill of the operators loading the rock to prevent oversize material.

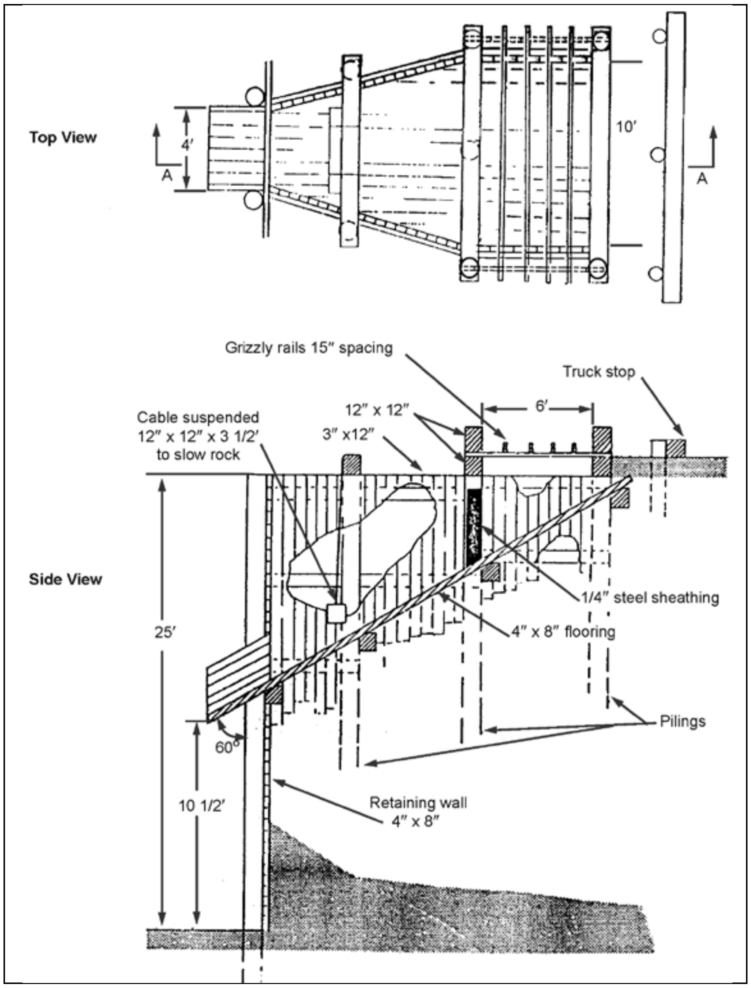


Figure 4-25. Loading chute with a Grizzly

Dimensions

4-48. The bench height of the quarry is determined in the layout phase because of its relationship to the quarry access. Equipment limitations and geologic conditions influence the bench height. Where layers of undesirable material occur within a deposit, plan benches so that the undesirable and desirable materials can be excavated separately to prevent contamination. Level bedding or fractured surfaces can also be used to define benches. Such surfaces reduce subdrilling requirements and help maintain an even quarry floor.

4-49. The availability of drill steel may limit the bench height. If the length of drill steel is limited, the maximum bench height will be limited to the drill steel length (in feet) minus the amount of subdrilling (in feet). Most quarrying operations use track-mounted drills equipped with sectional drill steels that are 10 or 12 feet long. These sectional steels can be joined if necessary. Drill holes are usually subdrilled 2 to 3 feet below the quarry floor to ensure complete rock fragmentation between holes during blasting. For convenience, benches are often developed to accommodate the limitations of the drilling machine. Because drill efficiency decreases about 20 percent for each additional length of steel used, lower benches are usually preferred when drilling is difficult (as with extremely hard or unfavorably fractured rock). Relatively lower benches are also preferred where rockfall and rockslide hazards exist along the face and where front-end loaders are used to load blasted rock.

Quarry Floor

4-50. The quarry floor is the very bottom of the quarry as determined by the geology and the aggregate requirements and restrictions within the site. The bottom may be achieved in lifts or working floors, as in the case of a multiple-bench quarry. For example, if the rock is to be excavated to a depth of 60 feet and the bench height is determined to be 20 feet, then the quarry floor will be exposed at the third lift or bench.

4-51. Geologic factors that may limit the quarry depth are the thickness of usable mineral material and the depth of the water table. It is possible to work below the water level as long as plans are made to control the amount of water entering the quarry during the operation.

4-52. The floor of a subsurface quarry may be limited by the total working area within the quarry. When laying out a subsurface quarry, the minimum length of a uniformly sloping access road will be about equal to the quarry depth divided by the grade capabilities or limitations of the equipment using the road. For example, if the trucks used for hauling from a 60-foot-deep quarry are capable of negotiating a 10 percent grade under load, then the minimum length of the haul road required to leave the pit will be about 600 feet.

4-53. After the level of the quarry floor has been determined, the quarry surface dimensions are calculated based on the total rock requirement. For example, a 30-foot (10-yard) bench is to be maintained, and the total requirement of rock is estimated at 1,500,000 cubic yards. Use the following formula to calculate the surface dimension:

$$\textit{Total area of bench required} = \textit{total volume required} \div \textit{bench height}$$

$$\textit{150,000 square yards of bench surface required} = \textit{1,500,000 yards}^3 \div \textit{10 yards}$$

Initial-Face Determination

4-54. When determining the location of the initial face, develop a quarry plan view with profiles across the length and width of the quarry site to show the surface configuration of the in-place rock. Reference the elevations of these drawings against a fixed benchmark on rock outside the quarry. This benchmark may be assigned a nominal elevation for local use. Superimpose the quarry floor or the first working bench at a depth equal to the bench height. Begin excavation where the floor or ramp intersects with the existing grade (figures 4-26 and 4-27).

4-55. For steeply sloped hillsides, begin excavating at the uppermost working level. Then establish a second, lower working level as the upper working floor approaches its intended dimensions or as soon as it has been excavated enough to provide sufficient working space for further operations. Establish additional working levels in a similar manner.

4-56. For gently sloping sites, begin excavating at the level of the final working floor. As the excavation progresses, establish a second, higher working floor when the initial bench reaches its intended working height. Establish additional higher working levels in similar, step-like stages.

4-57. Excavate subsurface quarries from the top down (as when excavating steep hillside quarries). As the excavation of the first bench nears completion, begin a second lower level, and so on. Excavation plans should include provisions for access ramps and drainage sumps as needed.

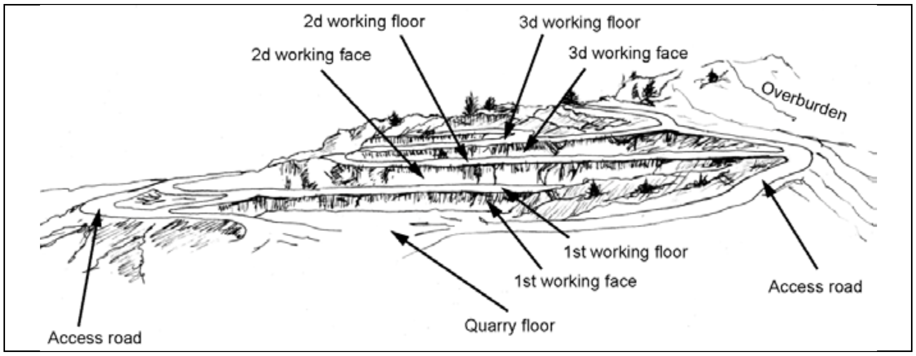
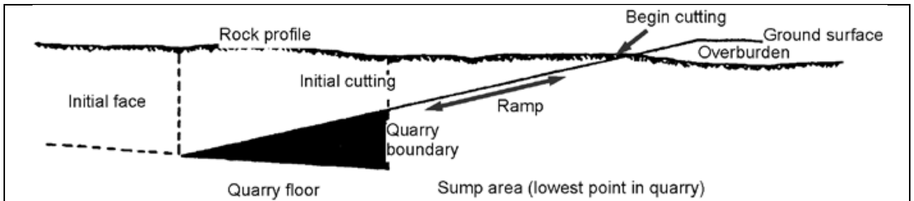


Figure 4-26. Operating a hillside quarry



Note. The ramp extends the quarry and the sump prevents water accumulation at the foot of the ramp.

Figure 4-27. Opening a subsurface quarry

4-58. Operate open-pit quarries with vertical or nearly vertical faces for ease in drilling and blasting rock. Toe cuts and ramp cuts are typical initial cuts. Full-face cuts parallel to the strike of the rock may also be needed during the initial site development.

COMMUNICATION DEVICES

4-59. A warning (radio, wire, or special signaling device) before blasting is needed for safe quarry operations. Ensure that support personnel have direct radio communication with the blasting supervisor. Communication devices are also essential for the efficient and safe conduct of other quarry and pit operations.

DEVELOPMENT

4-60. An operations plan should be developed once the quarry layout has been planned. The entire life span of the quarry should be planned and the following factors taken into consideration: production, equipment availability, rock formation geology, maintenance, training, and environmental and safety procedures. Once the quarry is established, an SOP should also be established.

4-61. Once the site is accessible, begin installing the crushing, screening, and washing plant, while simultaneously continuing work on quarry access and haul roads and on stripping and opening the quarry. (See figures 4-13 and 4-14, pages 4-9 and 4-10, for a typical crusher setup.) Two levels are generally required—one for crushing and the other for hauling. Quarry-run rock is dumped directly on the apron feeder or into a loading chute and discharged on the lower level over conveyer belts.

4-62. Dual-level crushing involves the construction of a retaining wall. If a vertical or nearly vertical rock face exists, it can be used as the retaining wall. Initially, the lower level of the site is cut to grade and proper dimensions. A predetermined portion of the material is stockpiled above the retaining wall anchor to be used for backfill.

4-63. Construct the retaining wall anchors as soon as excavation for the anchors is completed. Anchor construction can be accomplished by placing large logs or pouring concrete walls with the capacity to support the retaining wall.

4-64. The retaining wall may be constructed after the earthwork on the lower level is completed. It is essential to support the retaining wall. Piles driven and supported by concrete usually provide adequate support. Other material or methods may be used based on the availability of suitable substitute material. (See paragraph 4-66 for further discussion of retaining walls.

DRAINAGE

4-65. Drainage is an important consideration throughout a quarry operation. The quarry working floor should slope away from the face (a 3 percent slope is sufficient) to prevent water accumulation in the working area. In cases where water may not drain off naturally, provide a collection point or sump. Locate sumps away from traffic areas or areas that interfere with efficient operation. Consider erosion control as part of the drainage plan. Excess erosion causes a high amount of suspended solids to wash into existing streams and lakes, which dramatically changes the water quality and potentially affects the organisms living there. Coordinate with local environmental offices to ensure that environmental regulations are followed.

MAINTENANCE

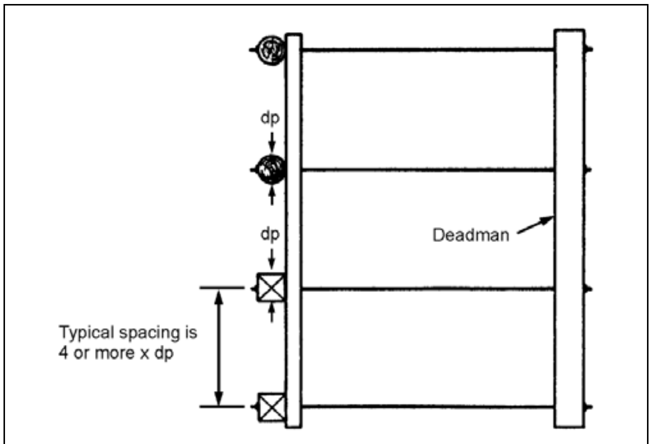
4-66. Construct a maintenance area at a location that is convenient to crusher and quarry equipment to avoid hauling equipment long distances on primary roads. The maintenance area must conform to Environmental Protection Agency laws governing the collection, spill prevention, and storage of petroleum products and other hazmat. The maintenance area should comply with the unit field maintenance SOP. Identify trained spill response teams in advance, and establish plans for removing and transporting contaminants.

TIMBER PILE OR POST RETAINING WALL

4-67. The field-expedient retaining walls provide a discharge platform for a rock-crushing plant. When selecting a headwall design, it is important to consider the mission and the materials available. The more elaborate the design, the longer construction will generally take. If it is estimated that operations at a site will be short-term, keep the design simple and safe and build a minimal platform that will support loading with a front-end loader or excavator. If, however, the platform is estimated to be in the same location repeatedly or for an extended duration, build a more efficient headwall that provides loading options and ease of use. (See FM 5-125 for additional information on retaining walls.)

4-68. Use the following specifications for timber pile or post walls (figures 4-28 and 4-29):

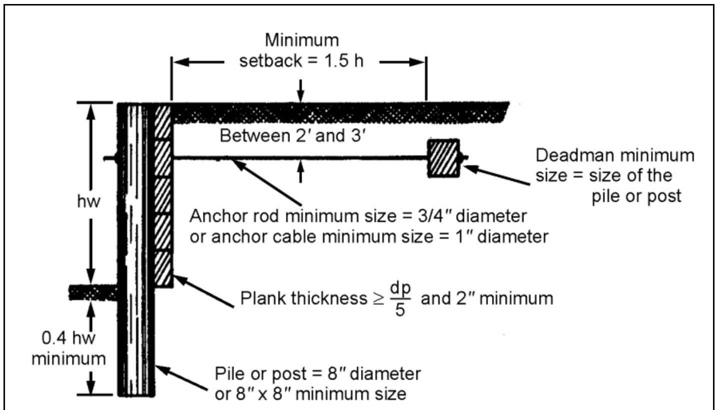
- Use 8-inch piles or 8- by 8-inch posts (minimum).
- Ensure that the maximum spacing between piles or posts is four times the diameter of the pile or the least diameter of the post.
- Ensure that the thickness of lumber behind the piles or posts is greater than the diameter of post ÷ 5 with a 2-inch minimum thickness. Steel landing mats have been used successfully in the field.
- Ensure that penetration of the piles or posts into the ground is greater than 0.4 times the height of the wall, with a minimum penetration of 3 feet.
- Use a 3/4-inch steel rod or a 1-inch cable as a minimum size for anchor rods or cables. Ensure that the minimum setback from the wall equals 1.5 times the height of the wall. For example, if the headwall is 40 feet high, the setback for the deadman should be 60 feet. The anchor rod should have a turnbuckle or another device for tightening. Coat the metal rod or cable with waterproof material before backfilling.
- Use the same size material as the piles or posts for the deadman. Attach the deadman to each pile or post with the anchor rod. Bury the deadman between 2 and 3 feet, with the setback greater than 1.5 times the height of the wall.



Legend:

dp	diameter of post

Figure 4-28. Timber pile or post wall (plan view)



Legend:

dp	diameter of post
h	height
hw	height of wall

Figure 4-29. Timber pile or post wall (close-up)

STEEL SHEET PILE WALL

4-69. Use the following specifications for steel sheet pile walls (figures 4-30 and 4-31, page 4-26):

- Use steel sheet piles or 3-inch (minimum thickness) timber sheeting.
- Ensure that the ground penetration is greater than 0.4 of the headwall. For example, if the headwall is 40 feet high, there should be 16 feet of pile or post belowground, which will require a pile length of 56 feet.
- Ensure that the anchor rod or cable is at a minimum 3/4-inch steel rod or 1-inch cable with a maximum spacing of 4 feet.
- Ensure that the minimum size of the wale is 3 by 12 inches.
- Ensure that the deadman is a minimum of 8 by 8 inches or 8 inches in diameter.

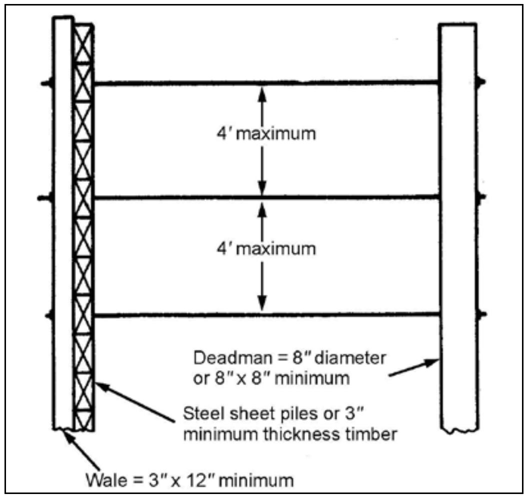


Figure 4-30. Sheet pile wall (plan view)

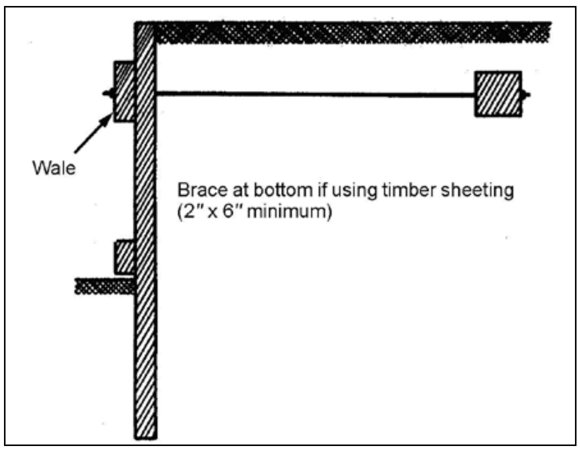


Figure 4-31. Sheet pile wall (close-up)

4-70. The dimensions that are not listed should be the same as for timber pile or post walls. The backfill behind the wall must be granular to allow for drainage. Ensure that water is not allowed to collect and stand behind the wall (figure 4-32). Provide drainage holes at the wall bases to drain water from the granular backfill.

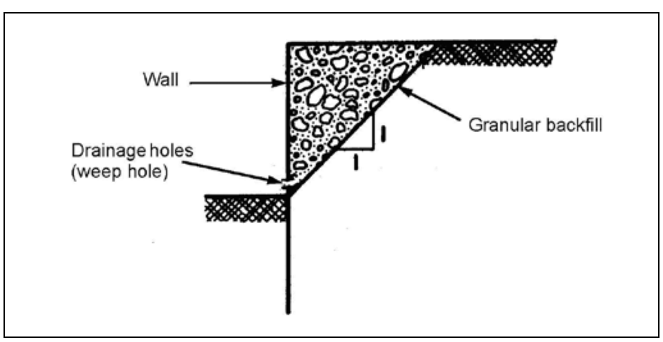


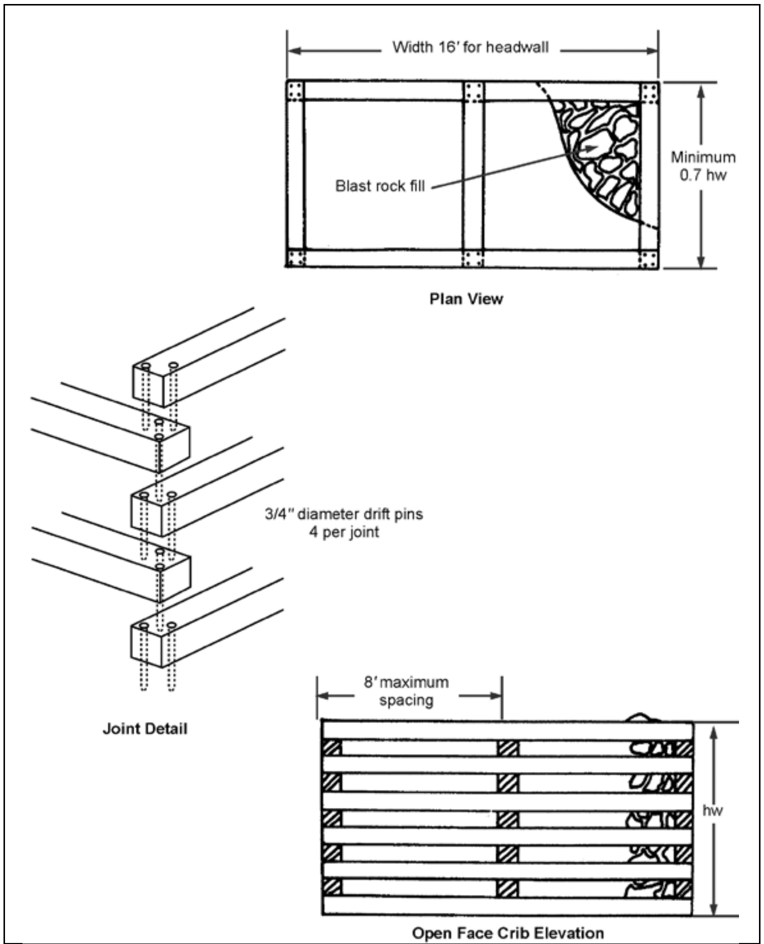
Figure 4-32. Use of granular backfill for distance

TIMBER CRIB WALL

4-71. Pressure-treated timber crib walls with cells or compartments filled with suitable material (blast rock or earth) can be built satisfactorily on almost any soil. Design the base width so that the foundation load is distributed over a sufficient area to keep unit pressures small. Cribs may be erected by unskilled labor and with simple equipment. Ensure that the space or opening between face members is not wide enough to allow the fill material to spill through. For blast rock fills, log cabin type construction is ideal. Make field adjustments to the design of crib walls based on past experience. The following are conservative specifications for designing timber crib walls (figure 4-33, page 4-28):

- The ratio of base width to the height of the wall is 70 percent (as a minimum).
- Timber should be 8 by 8 inch, rough cut (minimum), but larger timber may be used.
- Drift pins, pole barn nails, or cutoff pieces of rebar should be installed in a staggered pattern in every other timber section.
- Drift pins, pole barn nails, or cutoff pieces of rebar should be at least 3/4 inch in diameter and of sufficient length to penetrate two members.
- The maximum height of the wall should not exceed 22 feet.
- Cutting, framing, and boring of the timber should be done before treatment with a wood preservative. Cuts and boreholes must be treated with preservative before assembly.

4-72. Table 4-1, page 4-28, shows an example of a bill of materials for a headwall. Figures 4-34 and 4-35, page 4-28, show examples of possible headwall designs.



Legend:
hw height of wall

Figure 4-33. Timber crib wall

Table 4-1. Sample bill of materials

Materials	*Size*	*Quantity*
Treated piles	12 inches x 33 feet	25
Treated lumber	1 foot x 3 inches x 33 feet	266
Hardware	***Size***	***Quantity***
Cable clamps	1 inch	6 each per cable = 480
Reinforced wire rope	1 inch	2,100 feet (30 feet + 5 feet per pile, deadman, and turnbuckle)
Turnbuckles	1 1/2 inches	40 each
Spikes (pole barn)	8 inches	1,104 each

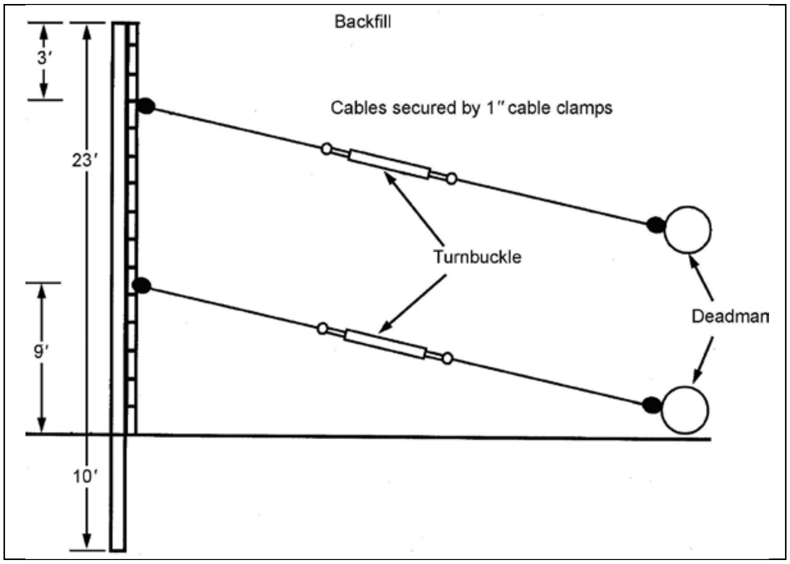


Figure 4-34. Sample of a headwall design

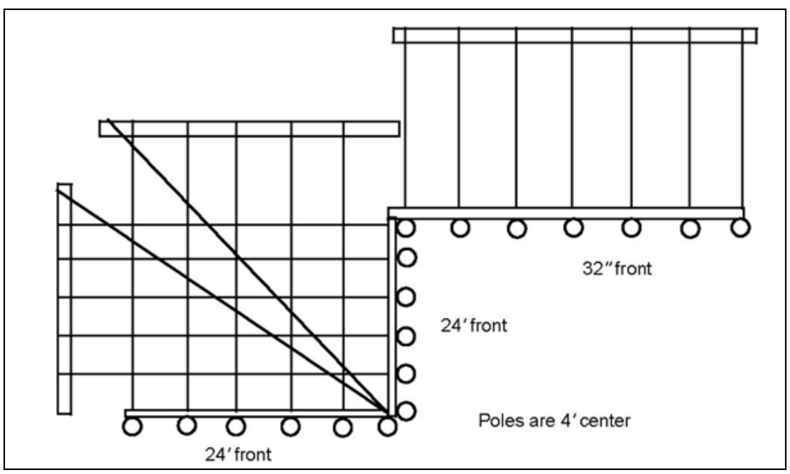


Figure 4-35. Sample of a headwall (overhead view)

Chapter 5
Cut Design

Cut design is an extremely important consideration of quarry operations. By efficiently producing the maximum amount of product from each blast, the time and effort spent during this phase of operations will greatly enhance the productivity of the quarry, thereby enhancing the overall effectiveness of the Army mission.

CUT DESIGN

5-1. The width and depth of material taken out of the bench in a single blast is referred to as the *cut.* The first step in removing rock from a quarry is to design the cut. When designing the cut, it is important to calculate for the blast before drilling. The volume of the cut should be equal to the bench height times the length times the width. Each is defined as follows:

- Bench height = depth.
- Width = total burden.
- Length = total spacing.

5-2. The volume should be sufficient to support the crushing operation between blasts. The width of the cut should be no less than the effective working radius of the equipment being used for excavation. The cut may also be determined by limitations of explosives, drilling capabilities, and required blasting controls.

5-3. The burden, subdrilling, stemming, and spacing are determined based on the rock type and geologic conditions. The type of explosive is determined based on the rock type, geologic conditions, the size of the borehole drilled, the type of drilling equipment available, the required blasting controls, and the desired end product.

DRILLING

5-4. Two types of cuts are initially required for developing a quarry—the toe cut and the ramp cut. In addition to these cuts, full-face cuts parallel to the strike may be needed in the initial development.

SUBDRILLING

5-5. Cuts are intended to break the rock to a depth of 1 to 3 feet below grade. Backfilling may be necessary to make the surface a smooth, usable grade at the desired elevation. Backfilling will not be necessary if controlled blasting results in a suitable working floor.

Toe Cut

5-6. Unless the rock in the hillside quarry has a vertical face, it will be necessary to remove the rock toe before starting excavation. Figure 5-1, page 5-2, shows the preferred drilling pattern that allows better control and shows a pattern that allows the drilling to be done with minimal setups. However, this pattern has excessive spacing between the holes at the bottom. Vertical, steeply inclined, and lifter holes should be subdrilled 1 to 3 feet below the desired final grade.

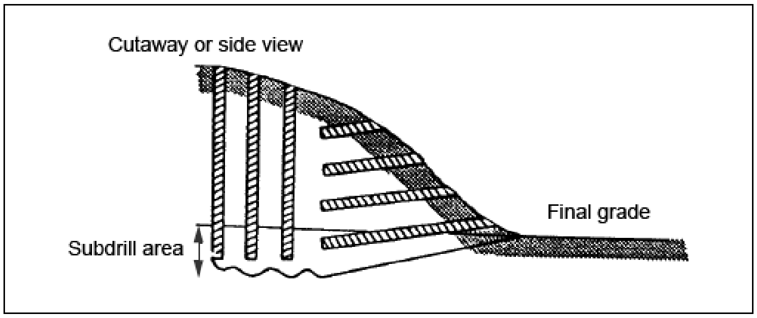


Figure 5-1. Toe removal by horizontal and vertical holes

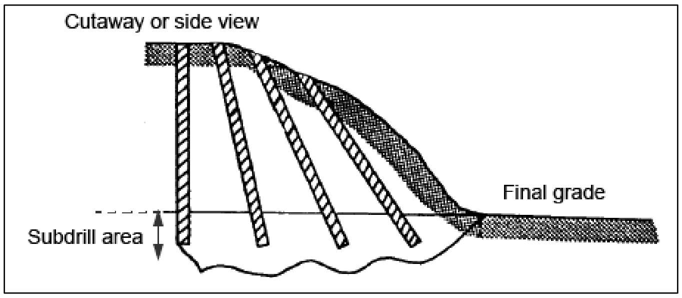
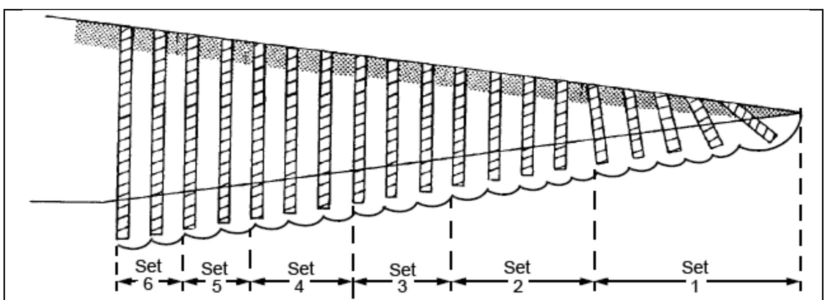


Figure 5-2. Establishing a vertical face using inclined and vertical holes

Ramp Cut

5-7. A ramp cut is used for excavating a ramp into a subsurface quarry (figure 5-3). The first blast establishes a vertical face. This method allows the easiest possible loading of blasted rock. An alternative method involves establishing a vertical face near the low end of the ramp using a V cut or a pyramid cut (figure 5-4). Blasting then proceeds simultaneously up and down the ramp.



Note. Blasting sets are shown in sequential order from the bottom of the hill to the top.

Figure 5-3. Drill patterns to excavate a ramp

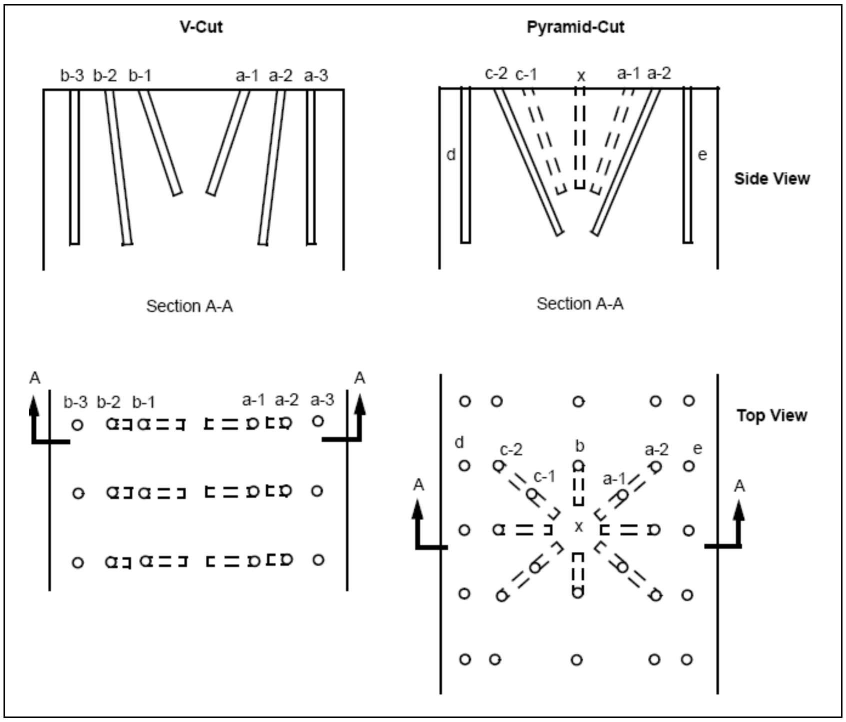


Figure 5-4. Cuts to open a subsurface rock excavation

Parallel Cut

5-8. When it is necessary to develop a quarry with a face parallel to the strike, satisfactory results may be obtained by drilling inclined holes parallel to the dip and working on the inclined face (figure 5-5). The total width of initial cuts is determined by the working-space requirement of the loading and hauling equipment. Generally, this width will be the same as the width desired at the initial face. However, in the case of cuts below grade, it may be advantageous to load heavily with the objective of removing as much material from the cut as possible with the blast. Pushing aside broken rock from subsurface cuts is easier than loading. When using this method, consider the proximity of personnel and structures to the area and the damage resulting from air blasts and flying material (fly rock).

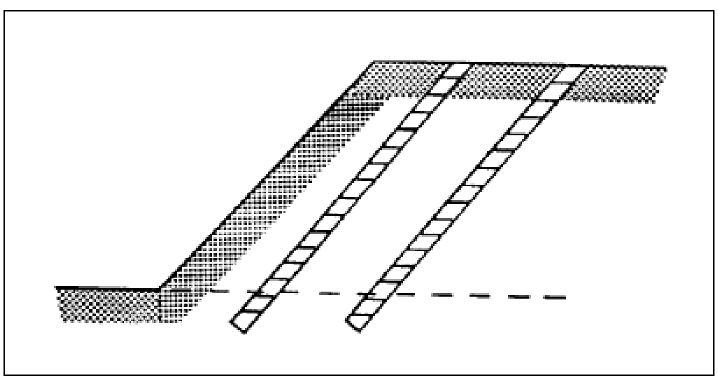
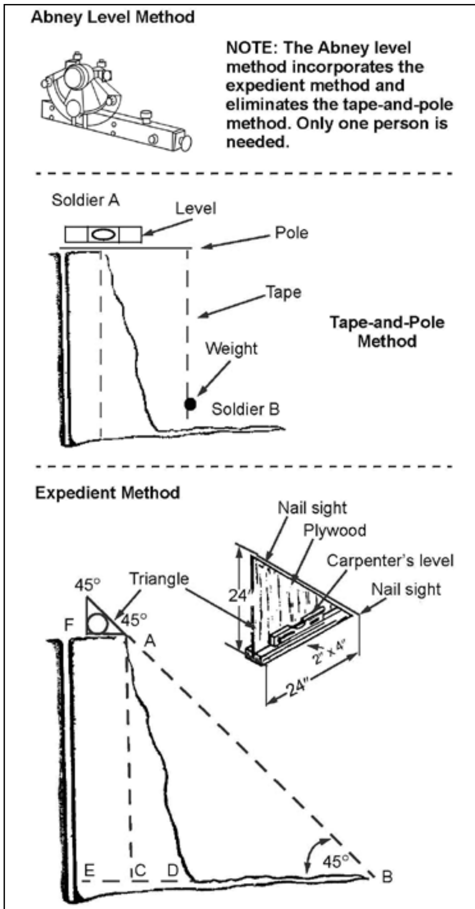


Figure 5-5. Inclined holes (dip parallel to face)

BENCH HEIGHT

5-9. The bench height or face height should be equivalent to between 100 to 120 times the borehole diameter (in inches) divided by 12 (to convert to feet). Low, nearly vertical faces are easily measured with a tape measure since the burden is practically the same at the top and bottom. This is accomplished by laying a board or pole on the ground, extending it past the face (use a carpenter's level to level the board or pole), and then measuring the distance from the board or pole to the bottom of the toe. This is referred to as the *tape-and-pole method* (figure 5-6).



1. Set the triangle level at the top of the face.
2. Sight along the nails, and mark Point B on the quarry floor.
3. Measure distance AB and BD with a tape.
4. The vertical face height is *AC = 0.71AB*.
5. Since *BC = AC, CD = AC - BD*.
6. *Average burden = 0.5DC x top burden (AF)*.

AB	AC	AB	AC	AB	AC	AB	AC
11	8	51	36	91	64	131	93
12	8	52	37	92	65	132	93
13	9	53	37	93	66	133	94
14	10	54	38	94	66	134	95
15	10	55	39	95	67	135	95
16	11	56	40	96	68	136	96
17	12	57	40	97	68	137	97
18	13	58	41	98	69	138	98
19	14	59	42	99	70	139	98
20	14	60	42	100	71	140	99
21	15	61	43	101	71	141	100
22	16	62	44	102	72	142	100
23	16	63	45	103	73	143	101
24	17	64	45	104	74	144	102
25	18	65	46	105	74	145	103
26	18	66	47	106	75	146	103
27	19	67	47	107	76	147	104
28	20	68	48	108	76	148	105
29	20	69	49	109	77	149	105
30	21	70	50	110	78	150	106
31	22	71	50	111	78	151	106
32	23	72	51	112	79	152	107
33	23	73	52	113	80	153	108
34	24	74	52	114	81	154	109
35	25	75	53	115	81	155	110
36	25	76	54	116	82	156	111
37	26	77	54	117	83	157	111
38	27	78	55	118	83	158	112
39	28	79	56	119	84	159	113
40	28	80	57	120	85	160	114
41	29	81	57	121	86	161	114
42	30	82	58	122	86	162	115
43	30	83	59	123	87	163	116
44	31	84	59	124	88	164	116
45	32	85	60	125	88	165	117
46	32	86	61	126	89	166	118
47	33	87	62	127	90	167	119
48	34	88	62	128	91	168	119
49	35	89	63	129	91	169	120
50	35	90	64	130	92	170	121

Figure 5-6. Determining the face height and average burden of a uniformly sloping face

5-10. When working with inclined benches a simple method of measuring the bench height is by using an Abney level. Set the Abney level at 45º. Stand on the top of the quarry face and sight in on a spot on the bottom floor. Measure the distance between these two locations. Multiply that distance by 0.71 (0.71 is a constant when using a 45º angle), and then subtract the eye height of the individual using the Abney level. This is the vertical bench height. Refer to the inset in figure 5-6 for an example of how to use an Abney level.

5-11. When an Abney level is not available, use a carpenter's 45º level to determine the height of the face and burdens with a practical degree of accuracy. A 45º triangle made of 2- by 2-inch wood with 18- to 24-inch sides can also be used. Set the level on the edge of the top of the quarry face as shown in figure 5-6. If a wooden triangle is used, the bottom side should be blocked in a horizontal position as determined by a carpenter's level. By sighting along the slanting edge of the triangle, Point B can be located on the quarry floor and the slant distance (denoted as AB) can be measured with a tape.

> ***Note.*** If the table in figure 5-6 is used, it is not necessary to calculate the height of the face and burdens. However, if the table is not used, it will be necessary to perform the calculations in paragraph 5-12.

5-12. Line AB is the hypotenuse of a 45º right triangle. One leg of the triangle is the bench height of the quarry face (denoted as AC), and the other is the base of the triangle (denoted as BC). These two distances are the same and may be found by multiplying the distance AB by 0.71, the sine of 45º. The distance from the point in the quarry floor to the bottom of the face (denoted as BD) can be measured easily. Subtract BD from BC to find the distance that the toe extends beyond the crest of the face (denoted as CD).

BENCH HEIGHT COMPUTATION

5-13. As an example, the distance of AB is 100 feet and the distance of BD is 55 feet. Using the table in figure 5-6, the distance of AC or BC is 71 feet. The distance of the toe (CD) will be 16 feet (71 minus 55). Therefore, this particular quarry face will have a height of 71 feet and a toe of 16 feet. If the drill holes are placed 10 feet to the back of the crest at F, the burden at the toe (ED) would be 26 feet (10 plus 16).

5-14. When calculating the actual face height, it is necessary to make proper allowance for the difference in elevation between points B and D on the quarry floor and between points A and F on the top of the ledge. This method of measurement is satisfactory for quarry faces about 100 to 120 feet high. For higher faces, it is generally considered too cumbersome and inaccurate because of the difficulty of sighting such long distances over the triangle and the errors of measurement introduced from a sagging or swaying tape. In such cases, it is advisable to use a transit and conventional surveying procedures.

5-15. In addition to measuring a blast already prepared, a 45º triangle is useful for spotting the holes to be drilled for a new blast. For example, a line of holes must be located 15 feet apart so that each hole will have a burden of 20 feet at the toe. Each hole must be drilled 3 feet below grade in a quarry where AB measures 98 feet and BD measures 60 feet. The table in figure 5-6 shows that AC and BC are 69 feet, so the toe extends 9 feet (69 minus 60) beyond the crest of the face. Therefore, to give a burden of 20 feet in front of the hole, it is necessary to measure 11 feet (20 minus 9) back from the edge of the face to find the proper place to drill. As each hole is extended 3 feet below grade, the depth in this case will be 72 feet (69 plus 3). Repeating this simple procedure at 15-foot intervals will ensure that each hole is drilled to the proper depth and carries the proper burden. This method is valuable in quarries where the top of the face is irregular.

5-16. Occasionally, the detailed measurements needed to compute the blast volume cannot be determined by this procedure. In such instances, a transit or some form of surveying instrument offers the only practical means of obtaining the necessary field information. Subsequent trigonometric calculations may be required.

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Chapter 6

Blasting Equipment and Accessories

The blasting equipment used to test and fire the blast is an integral part of a blasting operation and should be of excellent quality. This equipment must be maintained in top condition. Never attempt to use a blasting machine or test instrument that is not in proper operating condition. Electric blasting equipment must be checked for proper operation at least once a month and before using.

ELECTRIC

6-1. The following paragraphs describe the types of electric blasting machines.

CAPACITOR DISCHARGE BLASTING MACHINES

6-2. These machines have a capacitor or bank of capacitors that store a large quantity of electrical energy supplied by dry cell batteries. The blaster can discharge stored energy in the capacitors into the blasting circuit in a fraction of a second through the two terminal posts by pushing down a firing switch or button. Capacitor discharge blasting machines can fire many electric blasting detonators and even nonelectric detonators with special attachments. These machines, in relation to their weight and size, are the most reliable firing devices available. General maintenance is restricted to changing the batteries.

Note. Ready-to-fire lights and/or voltage meters indicate full voltage across the capacitors. However, these do not provide a capacitor check; therefore, they do not ensure that the machine will deliver its rated energy output. Frequent testing is recommended to ensure that the machine delivers full energy output.

DANGER (ARMY) WARNING (NAVY/AIR FORCE)

The electrical discharge from electric blasting machines can be lethal.

PYROTECHNIC BLASTING MACHINES

6-3. These devices are handheld and fire pyrotechnic lead initiators (MK24 and MK25).

MK24 SINGLE PYROTECHNIC LEAD INITIATOR

6-4. The MK24 is a waterproof device used to initiate the detonators of pyrotechnic leads. It can be used for two single leads, one dual lead, or one single lead. It is 3.3 inches long and 0.9 inches in diameter. The MK24s are packaged 100 per PA60 ammunition box. It can be fired with a MK54 or MK55 firing device. (See figure 6-1, page 6-2.)

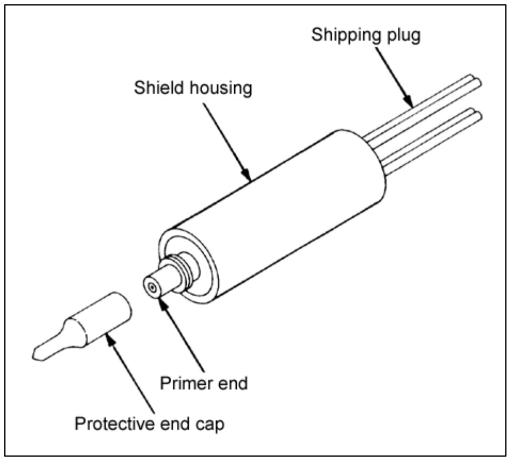


Figure 6-1. MK24 single pyrotechnic lead initiator

MK55 Handheld Firing Device

6-5. The MK55 has a single aluminum cylinder that is internally threaded to receive the MK24 initiator. It has one safety, and the device is fired with a pull ring. It will only fire a MK24 pyrotechnic lead initiator. (See figure 6-2.) Shock tube functioning is usually evident by a bright flash within the tube. The flash is well contained by the olive drab coating, but can be seen in the clear coating of military shock tubes. The flash can produce a burn if a piece of shock tube is held when it is functioning, even through the coating of the shock tube. Therefore, never hold a shock tube while detonating an explosive system. The free end of the shock tube blasting cap is always sealed. Cutting the shock tube exposes the open ends to moisture and should only be done if absolutely necessary. Dampening the explosive dust on the inside of the shock tube will stop a detonation from going beyond such a damp spot. Care should be used when cutting shock tubes. When cutting a shock tube, a sharp knife or other single blade should be used to produce a square cut. Never use pliers, crimpers, or scissors when cutting shock tube because they will cause narrowing of the small-diameter hole in the shock tube. Narrowing or overlapping of the hole could block the explosive path and result in a failure to ignite the explosive dust in the shock tube.

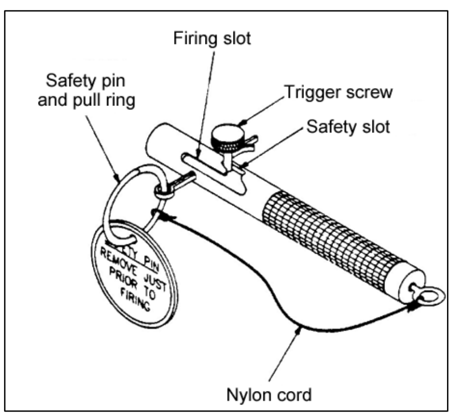


Figure 6-2. Pyrotechnic blasting machine

WARNING

Although the detonation along the shock tube is normally contained within the blasting tube, burns may occur if the shock tube is held. Failure to comply could result in immediate personal injury or damage to equipment.

MK54 Dual Handheld Firing Device

6-6. The MK54 has two stainless steel cylindrical assemblies connected by a trigger mechanism. The cylinders are internally threaded to receive the applicable pyrotechnic lead initiator. It will fire the MK24 and MK25. (See figure 6-3.)

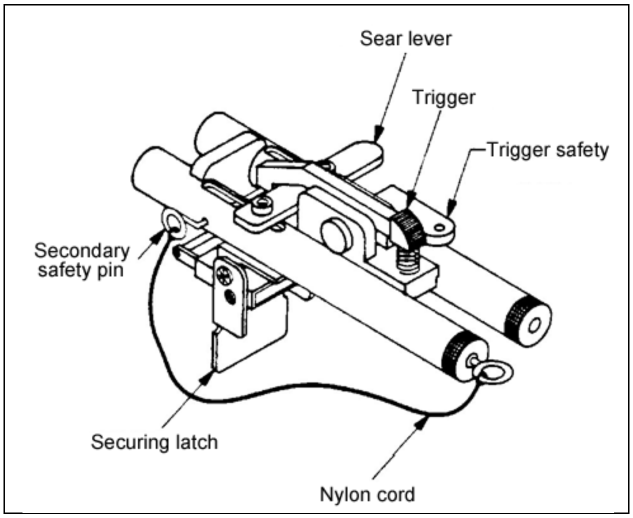


Figure 6-3. MK54 handheld firing device

CD450-4J Blasting Machine

6-7. The CD450-4J blasting machine is a single-circuit, capacitor discharge blasting machine using solid state electronics with output energy of 4 joules. The primary power to charge the capacitor and to operate the electronics is derived from an internal, 9-volt, alkaline, dry cell battery. (See figure 6-4.)

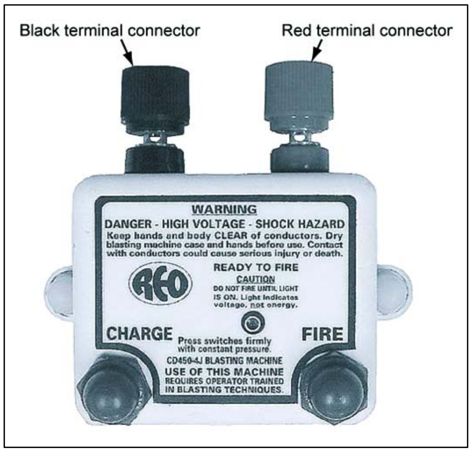


Figure 6-4. CD450-4J Dual handheld firing device

M34 Blasting Machine

6-8. This small, lightweight machine produces adequate current to initiate 50 electrical caps that are connected in a series. It has a black band around the base and a reinforced-steel actuating handle. (See figure 6-5.)

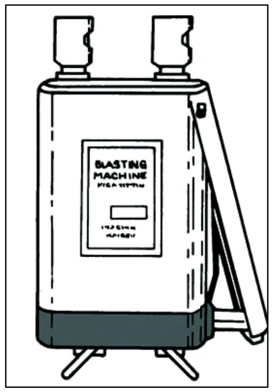


Figure 6-5. M34 blasting machine

TEST EQUIPMENT

RHEOSTAT

6-9. This instrument will test the efficiency of a generator type blasting machine. It can also be used to test capacitor discharge machines. The rheostat consists of a series of coils of varying resistance, each labeled in ohms and in terms of an equivalent number of 30-foot copper wire electric blasting caps. To test the output of a generator machine, a few electric blasting caps (and the equivalent resistance of caps in rheostat) are wired in series and energized by blasting machines being tested. Be certain the caps are positioned so that injury cannot occur from shrapnel or flying debris. If the electric blasting caps fire, the machine output is sufficient to fire a series of electric blasting caps with the same resistance.

BLASTING GALVANOMETER

6-10. The blasting galvanometer (figure 6-6) can measure the resistance in ohms of the blasting circuit. Some galvanometers require a special chloride battery; check the galvanometer for specific battery replacement. The galvanometer has an adjustment screw on the back of the instrument that can be used to zero the needle when a conductor is placed across the two contact points. When the silver chloride cell is depleted, it should be replaced when the instrument cannot be adjusted to a 0-ohm reading on the top scale and a 25-ohm reading on the bottom scale. The instrument must checked for proper operation before each use. When the cell is exhausted, it must be replaced with the same type silver chloride cell. The galvanometer assists in—

- Determining if the bridge wires of the individual electric blasting caps are intact.
- Determining the continuity of an electric blasting cap series circuit.
- Locating broken wires and connections in a circuit.
- Measuring resistance with the compact instrument. Place each of the two wires from the open end of the circuit on the two contact posts that extend out the top of the galvanometer. The top scale approximates circuit resistance (number of ohms) reference points and does not relate to the actual number of ohms in the circuit.

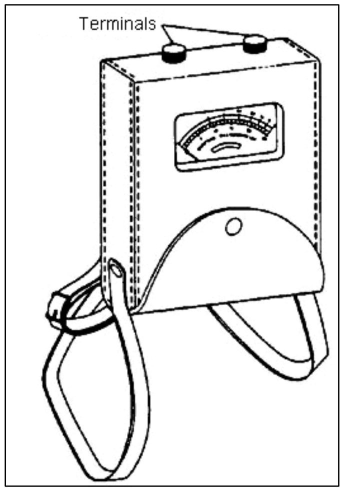


Figure 6-6. Blasting galvanometer

> **CAUTION**
>
> Never change batteries near electric blasting caps. Do not substitute another type battery for the silver chloride battery.

M51 BLASTING CAP TEST SET

6-11. The M51 is a self-contained unit with a magneto type impulse generator, an indicator lamp, a handle to activate the generator, and two binding posts for attaching firing leads. The test set is waterproof and capable of operating at temperatures as low as 40°F. (See figure 6-7.) The continuity of the firing wire, blasting cap, and firing circuit (in land operations, an electrical circuit and/or pyrotechnic loop designed to detonate connected charges from a firing point should be checked by connecting the leads to the test set binding posts and then depressing the handle sharply. If there is a continuous (intact) circuit, even one created by a short circuit, the indicator lamp will flash. When the circuit is open, the indicator lamp will not flash.

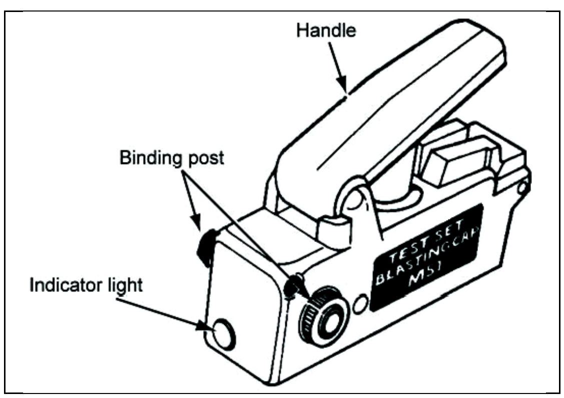


Figure 6-7. M51 blasting cap test set

BLASTER'S MULTIMETER

6-12. The blaster's multimeter is a compact volt-ohm-millivolt meter specifically designed to measure resistance, voltage, and current in electric blasting operations.

WARNING

Blasters must use only the recommended batteries in these machines. Other batteries will produce a hazardous current level. Never test an electric detonator or blasting circuit directly with a battery, recommended or otherwise, and never allow a battery to come in direct contact with electric detonators.

6-13. This versatile meter can be used to—

- Measure the resistances of a single blasting circuit for continuity and the total resistance in a series-in-parallel circuit with a high degree of precision and accuracy.
- Survey blast sites to determine if extraneous current hazards exist.
- Measure a wide range of resistance necessary to investigate static electricity hazards (such as those possible in pneumatic loading operations).

EXTRANEOUS ELECTRICITY

6-14. If extraneous electricity is suspected in an area where electric detonators are used, loading is suspended until tests determine that stray current does not exceed 0.05 amperes through a 1-ohm resistor when measured at the location of the electric detonators. If greater levels of extraneous electricity are found, the source is determined and no loading takes place until the condition is corrected.

IGNITERS

6-15. Refer to appendix B for Department of Defense identification codes (DODICs) on the items discussed below.

M60 WEATHERPROOF FUSE IGNITER

6-16. The M60 ignitor is designed to ignite a safety fuse in various weather conditions, even underwater if properly waterproofed. The fuse is inserted through a sealing rubber grommet and into a split collet, which secures the fuse when the end cap on the igniter is tightened. A pull on the pull ring releases the striker assembly, allowing the firing pin to drive against the primer, which ignites the fuse (figure 6-8).

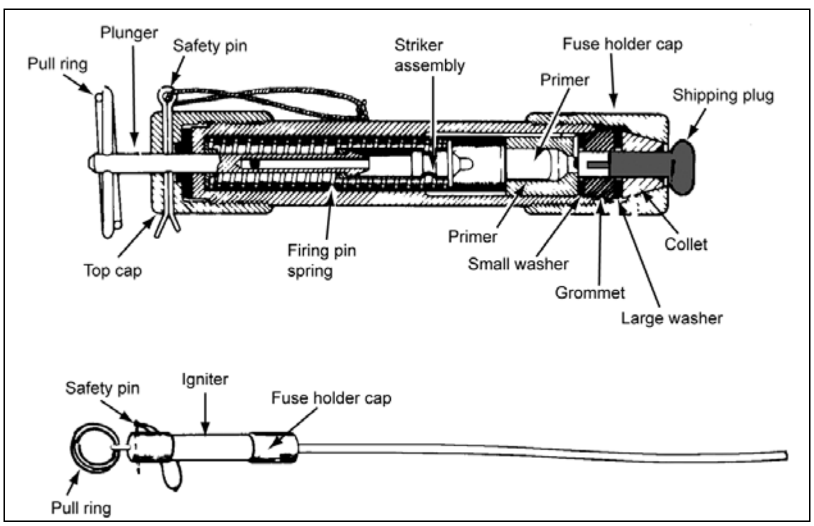


Figure 6-8. M60 weatherproof fuse igniter

M81 TIME BLASTING FUSE IGNITER WITH SHOCK TUBE CAPABILITY

6-17. The M81 igniter will initiate the time fuse and shock tube end of the modernized demolition initiator (MDI) components (figure 6-9). The M81 is almost identical to the older M60 igniter, except that the M81 has a screw end cap with a green shipping plug and a silicon shock tube reducer. The cap allows the M81 to accommodate the standard shock tube or the standard-diameter time blasting fuse (M700). Extra care is required when connecting the shock tube to an M81 igniter to ensure proper initiation of an explosive system.

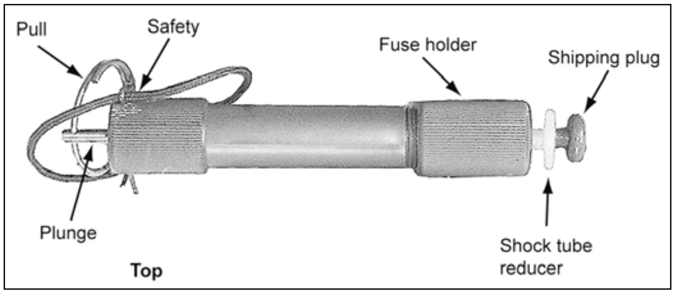


Figure 6-9. M81 time blasting fuse igniter with shock tube capability

MK25 DUAL PYROTECHNIC LEAD INITIATOR

6-18. The MK25 is a waterproof device used to initiate the detonators of pyrotechnic leads. It can be used for the single initiation of four single leads, dual initiation of two single leads, single initiation of two dual leads, and dual initiation of one dual lead. The MK25 is 3.3 inches long, and 0.9 inches in diameter, and 2 inches wide. It can be only be fired with a MK54 firing device. The MK25s are packaged 60 per PA60 ammunition box.

MK120 AND MK127 NONELECTRIC PYROTECHNIC LEADS

6-19. The MK120 and MK127 are used as initiating leads to transmit the blast signal to the shot. They consist of single- or double-strand, nonfragmenting, plastic pyrotechnic (shock tube) leads connected to nonelectric detonators and come in 100- or 1,000-foot spools. They have eight different configurations, including different color shock tubes, lengths, and number of strands. (See figure 6-10.)

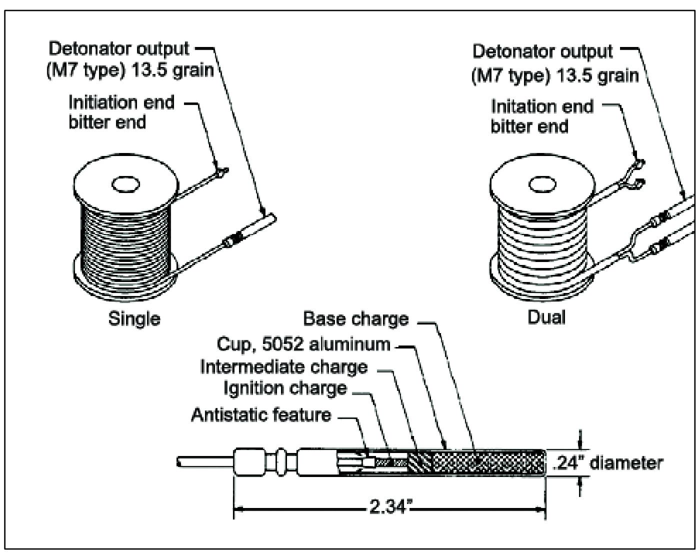


Figure 6-10. MK120 and MK127 nonelectric detonators

6-20. The shock tube is a thin, plastic tube of extruded polymer with a dusting of cyclotetramethylenetetranitramine (HMX) and aluminum powder deposited on its interior surface. This special explosive dust propagates a detonation wave. The wave moves along the shock tube to a factory-crimped and -sealed blasting cap (which is moisture-resistant). The detonation is normally contained within the plastic tubing; and if strands of tubing touch or cross over each other, there is no concern that an inadvertent ignition would occur. Fragments from blasting caps or other explosive charges travel at speeds three to five times faster than the detonating wave in the shock tube. These fragments could cause damage to other shock tube assemblies. Punctures in the shock tube in front of the dust explosion provides a path for the explosive wave to vent. The shock tube offers the instantaneous action of electric initiation without the risk of accidental initiation of the blasting cap (and the charge) by radio transmitters in the area or by static electricity discharge. The shock tube medium is extremely reliable.

Note. To prevent misfire, MDIs used at high altitude must be precut and a temporary moisture seal applied to the ends before moving from low altitude to high altitude. This action prevents the HMX from escaping the shock tube when cut at high altitudes due to the air pressure difference between the inside of the shock tube and the surrounding atmosphere.

BLASTING CAPS

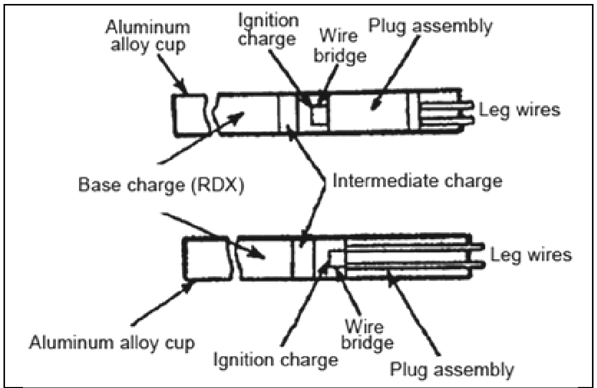
6-21. Military explosives require a substantial shock to be initiated. This shock is provided by a high-strength blasting cap (nonelectric M7 or electric M6). To replace the M6 and M7, there are high-strength and low-strength MDI blasting caps. Each blasting cap is factory-crimped and -sealed, making the caps extremely reliable.

ELECTRIC BLASTING CAP

6-22. The electric blasting cap is a cylindrical metal shell that contains powder charges (figure 6-11). Electrical energy is delivered into the cap by two plastic-insulated, metal wires called *leg wires*, which enter the cap through a rubber or plastic plug. The plug, securely crimped in the open end of the cap shell, forms a water-resistant closure and firmly positions the leg wires that are joined together inside the cap by a short length of high-resistant wire called the *bridge wire*, which is embedded in the ignition mixture of the cap. When sufficient electrical current passes through the system, the bridge wire becomes hot enough to ignite the ignition mixture. In instantaneous electric blasting caps, the ignition mixture causes the primer charge to detonate, subsequently detonating a high-explosive base charge. In a delay electric blasting cap, the ignition mixture initiates the delay powder train, which burns a predetermined time before igniting the cap primer charge. The burning rate of the delay powder and the length of its column determine the time interval between the application of the adequate electrical energy and the detonation of the cap. Blasting caps are available in instant and delay blasting and will improve rock fragmentation and displacement; provide greater control of vibration, noise, and fly rock; reduce the powder factor; and reduce blasting cost.

WARNING

Electric blasting caps of different manufacturers should not be used in the same series. Their ignition systems may not be electrically compatible, and misfires may occur, resulting in serious injury.



Legend:
RDX cyclotrimethylenetrinitramine

Figure 6-11. Electric blasting cap

NONELECTRIC BLASTING CAPS

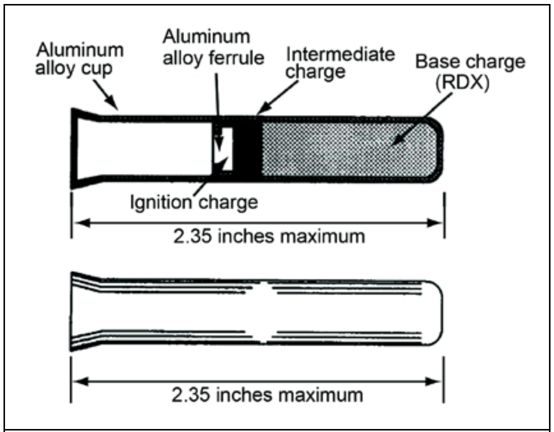
6-23. Nonelectric blasting caps provide a nonelectric method of initiating explosive charges when properly used in conjunction with a safety fuse. The safety fuse conveys a flame at a relatively uniform rate to the blasting cap where it ignites the ignition charge. The nonelectric blasting cap consists of an aluminum or copper shell about 1 3/8 to 1 3/4 inches long, loaded with three charges (figure 6-12). The caps have—

- A base charge of high-velocity explosive in the bottom of the shell.
- A primer charge in the middle.
- A charge of ignition powder on the top.

6-24. The ignition powder ensures flame pick up from the safety fuse; the primer charge converts the burning into detonation and ignites the high-explosive base charge.

WARNING

Since the ignition powder is exposed in the open end of the shell, nonelectric blasting caps should not be tampered with. Such treatment can lead to premature detonation resulting in serious injury.



Legend:
RDX cyclotrimethylenetrinitramine

Figure 6-12. Nonelectric blasting caps

HIGH-STRENGTH BLASTING CAPS

6-25. High-strength caps include the M11, M14, M15, M18, M19, M21, and M23. These caps are nonelectric and come with a length of shock tube attached. The function of the shock tube is to transfer a small initiating impulse to the explosive end of the cap (an explosive-filled aluminum tube or detonator), which produces a detonation shock strong enough to initiate military explosives.

M11

6-26. The M11 (figure 6-13, page 6-10) is essentially instantaneous in its action. It is a high-strength blasting cap, factory-crimped to a 30-foot length of shock tube. A movable plastic connector (a detonating cord clip) is attached to the free end of the shock tube. The hook allows for a quick and easy attachment to a detonating cord. Two brightly colored plastic flags are attached to the shock tube near the blasting cap. A red flag is attached 1 meter from the blasting cap, and a yellow flag is attached 2 meters from the blasting cap. M11s are packaged with an issue of six M11s per subpackage. Subpackages maintain the same hazard classification as the wooden crate.

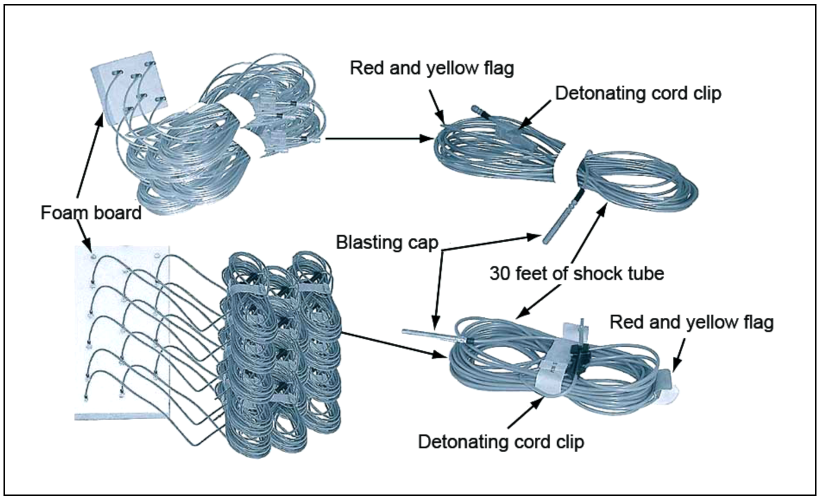


Figure 6-13. M11 blasting cap component (various vendors)

Use

6-27. The M11 can be used to prime standard military explosives. It can also be used to initiate detonating cord or shock tube.

Function

6-28. The M11 functions by sending an initiating shock or small detonation through the shock tube to the blasting cap. The shock tube itself must be initiated by a relay-type blasting cap, booster, or igniter (M81). The M11 detonation is instantaneous. The following are the functions of the various types of caps:

- The M14 consists of a military strength and size nonelectric blasting cap, factory-crimped to a factory-calibrated, nominal 5-minute length of M700 time blasting fuse.
- The M15 has *pyrotechnic* (used to introduce a delay into an explosive train because of its known burning time [the definition was shortened, and the complete definition is printed in the glossary]) (FM 1-02) (JP 1-02) devices installed to provide a small time delay between the initiation of the M15 and the firing of its two detonators. One detonator is low-strength with a 25-millisecond delay, and the other is high-strength with a 200-millisecond delay.
- The M18 consists of a military strength and size nonelectric blasting cap, factory-crimped to a factory-calibrated, nominal 20-minute length of M700 time blasting fuse.

- The M19 consists of a 200-foot length of dual minitube with an in-line initiator built into one end of each of the two minitubes and a nonelectric, nondelay high-strength blasting cap attached to the other end of each minitube. The minitube is smaller in diameter and possesses the same characteristics as the shock tube. The M81E1 igniter is attached to each in-line initiator.
- The M21 consists of a high-strength blasting cap precrimped to a 500-foot length of minitube. The M21 is about one-third the size and weight of the existing M12. The M81E1 igniter is attached to the in-line initiator.
- The M23 consists of a high-strength blasting cap factory crimped to a 1,000-foot length of minitube. The M23 is about one-third the size and weight of the existing M13. The M81E1 igniter is attached to the in-line initiator.

Note. High-strength caps must be in original packaging or a protective foam cylinder when carried by Soldiers.

M21

6-29. The M21 (figure 6-14) consists of a high-strength blasting cap precrimped to a 500-foot length of minitube. The M21 is about one-third the size and weight of the M12. The M21 has a modified M81E1 igniter moisture cap with a protected ignition primer that is factory-installed to an in-line initiator on the minitube. The M21 has an M9 holder already connected to the high-strength cap.

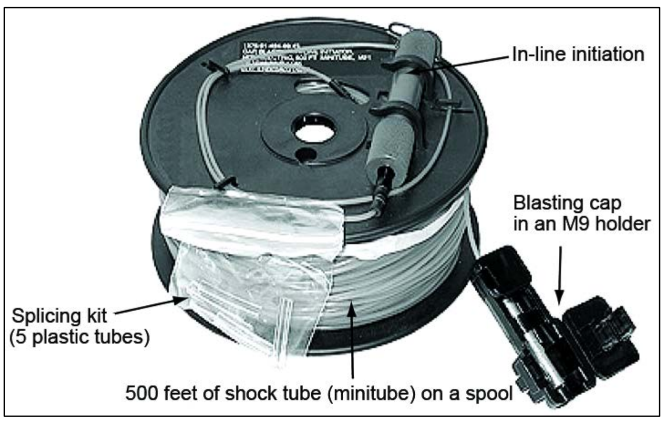


Figure 6-14. M21 MDI with a 500-foot shock tube component and splicing kit

Use

6-30. The M21 is used to transmit a shock tube detonation impulse from an initiator (or another relay cap). Unlike the M12, a high-strength blasting cap or booster will not have to be added as part of the transmission line. The M21 high-strength cap can be secured into an M9 holder to provide the capability to initiate up to five additional shock tubes, five low-strength detonating cords, or one strand of high-strength detonating cord. The M21 high-strength cap can also be used to prime military explosives. The M21 functions by sending an initiating shock or small detonation through the shock tube to the blasting cap. This blasting cap then actuates five shock tubes, five low-strength detonating cords, or one strand of high-strength detonating cord held by the plastic connector. The shock tube of the M21 must be initiated by another blasting cap or by the M81E1 in-line initiators.

M23

6-31. The M23 (figure 6-15) consists of a high-strength blasting cap precrimped to a 1,000-foot length of minitube. The M23 is about one-third the size and weight of the M13. The M23 has a modified M81E1 igniter moisture cap with a protected ignition primer that is factory-crimped and installed to an in-line initiator on the minitube. The M23 has a M9 holder already connected to the high-strength cap.

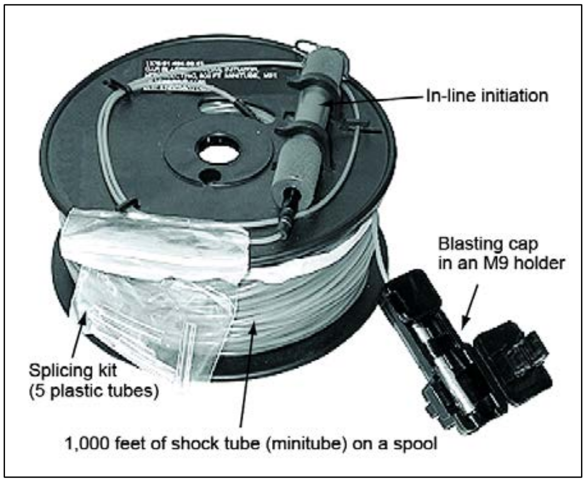


Figure 6-15. M23 MDI 1,000-foot shock tube component

Use

6-32. The M23 is used to transmit a shock tube detonation impulse from an initiator (or another relay cap). Unlike the M13, a high-strength blasting cap or booster will not have to be added as part of the transmission line. The M23 high-strength cap can be secured into an M9 holder to provide the capability to initiate up to five additional shock tubes, five low-strength detonating cords, or one strand of high-strength detonating cord. The M23 high-strength cap can also be used to prime military explosives. The M23 functions by sending an initiating shock or small detonation through the shock tube to the blasting cap. This blasting cap then actuates five shock tubes, five low-strength detonating cords, or one strand of high-strength detonating cord held by the plastic connector. The shock tube of the M23 must be initiated by another blasting cap or by the M81E1 in-line initiators.

LOW-STRENGTH BLASTING CAPS

6-33. The M12 and M13 are the two low-strength MDI blasting caps. These relay-type blasting caps come with factory-attached lengths of shock tube (500 feet for the M12 and 1,000 feet for the M13). The detonators of the relay type caps are purposely made larger than standard military blasting caps (and the high-strength MDI blasting caps) so that they will not fit in standard cap wells. These low-strength, relay type caps cannot reliably set off standard military explosives. However, low-strength caps of the MDI M12 and M13 will initiate a detonating cord.

M12

6-34. The M12 is a low-strength blasting cap, factory-crimped to a 500-foot length of shock tube. A special plastic connector is attached to the detonator to facilitate a quick and easy attachment to the shock tube of up to five shock tubes, five low-strength detonating cords, or one strand of standard detonating cords. The M12 is provided on a spool as shown in figure 6-16.

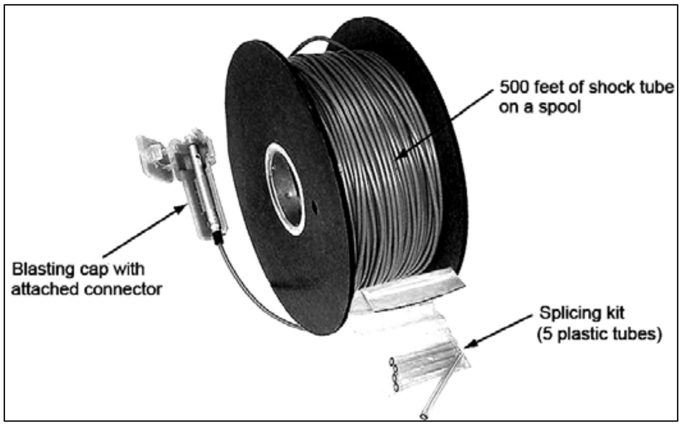


Figure 6-16. M12 shock tube component and blasting cap with a splicing kit

Use

6-35. The M12 is used as a transmission line in a firing system. It does not have enough output to initiate military explosives reliably. The M12 functions by sending an initiating shock or small detonation through the shock tube to the blasting cap. This blasting cap then actuates five shock tubes, five low-strength detonating cords, or one strand of high-strength detonating cord held by the plastic connector. The shock tube of the M12 must be initiated by another blasting cap or by the M81 fuse igniter.

M13

6-36. The M13 is a low-strength blasting cap, factory-crimped to a 1,000-foot length of shock tube. A special plastic connector is attached to the detonator to facilitate quick and easy attachment to the shock tube of up to five shock tubes, five low-strength detonating cords, or one strand of standard detonating cord. (See figure 6-17.)

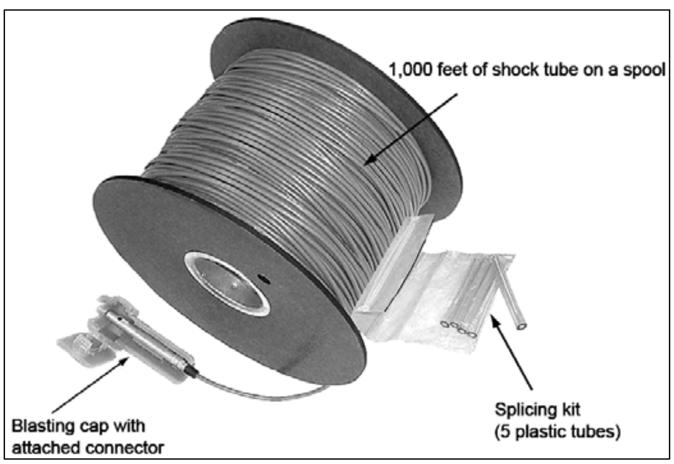


Figure 6-17. M13 shock tube component and blasting cap with a splicing kit

Use

6-37. The M13 is used as a transmission line in a firing system. It does not have enough output to initiate military explosives reliably. The M13 functions by sending an initiating shock or a small detonation through the shock tube to the blasting cap. This blasting cap then actuates five shock tubes, five low-strength detonating cords, or one strand of high-strength detonating cord held by the plastic connector. The shock tube of the M13 must be initiated by another blasting cap or by the M81 fuse igniter.

M19

6-38. The M19 consists of a 200-foot length of dual minitube with an in-line initiator built into one end of each of the two minitubes and a nonelectric, nondelay high-strength blasting cap attached to the other end of each minitube. The minitube is smaller in diameter and possesses the same characteristics of a shock tube. The M81E1 igniter is attached to each in-line initiator. M9 plastic holders are provided in the packaging for each M19 to facilitate quick and easy attachment to the minitube of additional blasting cap components (figure 6-18, page 6-14).

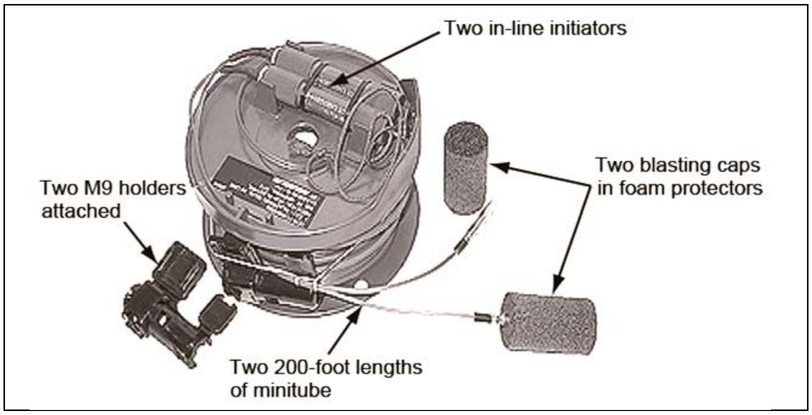


Figure 6-18. M19 dual minitube and blasting cap component

Use

6-39. The M19 is used to initiate standard military explosives and demolition charges by inserting the blasting caps directly into an explosive or the cap well of demolition charges. The M19 is particularly suited for urban terrain missions when very high reliability is required. The M19s minitube must be initiated by a blasting cap or by activating the firing assembly of the M81E1 igniter. To actuate the M81E1, remove the cotter pin and then pull the pull ring to the limit of its travel. The pull ring rod then releases the firing pin. The firing assembly of the M81E1 igniter strikes the M42C1 primer. The small detonation impulse (shock wave) from the primer is transmitted through the minitube into a less sensitive explosive contained within its blasting cap. The blasting cap can actuate an additional number of components held by the M9 plastic holder or can directly initiate explosive charges or demolition devices.

TIME FUSE

6-40. The following paragraphs describe the types of nonelectrical blasting initiation.

TIME (SAFETY) FUSE

6-41. The time fuse is used for general demolition. The time fuse consists of ammonium nitrate (AN) black powder that is tightly wrapped with layers of fiber and waterproofing material. Every coil of fuse or remnant of a coil must be tested using the burning rate test before use. One test per day per coil is enough. The first and last 6 inches of a coil are never used because moisture may have penetrated the coil to this length. The burning rate may vary for the same or different rolls under different atmospheric and climatic conditions. A fuse burns appreciably faster when it is confined by tamping or some other means of confinement. The greater the confinement, the faster the burning rate. Conversely, a fuse burns more slowly when it is subject to reduced external pressure. Other factors being equal, a fuse will burn about 2 seconds per foot slower at an altitude of 5,000 feet than at sea level. Although a burn rate of about 120 seconds per yard (as measured unconfined at sea level) is considered standard for time fuses in the United States; fuses with different burning rates are manufactured.

Note. Do not depend on fuses burning at 120 seconds per yard.

6-42. Test each roll's burn rate per service-specific procedures. The fuse is ignited, and the time it takes for the fuse to burn is noted. The burning rate per foot is computed by dividing the burn time (in seconds) by the length (in feet). Another test is performed to verify the results if the test burn does not fall within 5 seconds of a 40-second-per-foot burn rate. The coil is placed in the foil packet and marked with its corresponding burn rate once the burn rate is calculated.

DANGER (ARMY) WARNING (NAVY/AIR FORCE)

Soldiers should practice until they know how the ignition spit is supposed to look. The core of the safety fuse may be burning inches ahead of the visible burn of the outer jacket. Persons who do not recognize the ignition spit or who are misled by the burning of the cover, have been killed or injured by trying to relight the fuse which has been ignited.

Test-burn a 3-foot length of time blasting fuse to determine the exact burn rate before use. Failure to comply may cause death or permanent injury.

PREPARE THE TIME FUSE

6-43. The fuse is cut long enough to allow the person detonating the charge to reach safety (walking at a normal pace) before the explosion. This distance is walked and timed before cutting the fuse to length. The formula for determining the fuse length is—

$$\frac{Time\ required\ (minutes)\ x\ 60\ (seconds/minutes)}{Burning\ rate\ (seconds/feet)} = Fuze\ length\ (feet)$$

MAKE THE CUT SQUARELY ACROSS THE FUSE

6-44. The fuse should not be cut too far in advance since it may absorb moisture into the open ends. The time fuse should not be allowed to bend sharply because the black powder core may crack, resulting in a misfire.

Note. The minimum burn rate will not be less than 5 minutes.

M14

6-45. The M14 is a high-strength blasting cap, factory-crimped to about a 7 1/2-foot length of time fuse. The M14 is marked with yellow or black bands that represent a nominal 1 minute of burn time instead of having a yellow band every 18 inches as on the M700 time fuse. The free end of the fuse is moisture-sealed and must be cut off to the selected time band when being prepared for ignition (figure 6-20).

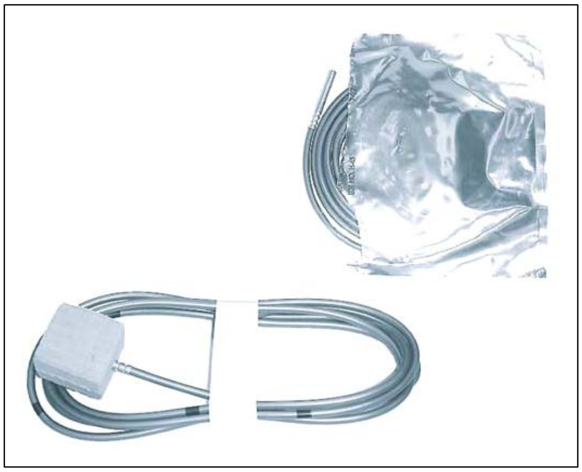


Figure 6-20. M14 time fuse component (various vendors)

Use

6-46. The M14 is used to detonate military explosives and initiate shock tube, low-strength detonating cord, and detonating cord after being ignited. In dual initiation, an M14 can be connected to a line main or transmission line and be used as the primary or secondary initiation system. The M14 functions by sending an initiating flame (from a time blasting fuse igniter or a match) slowly through the length of the time blasting fuse to the blasting cap. The 1-minute bands on the time fuse have been factory-calibrated. The burn time will increase with altitude and colder temperatures. The M14 has been designed to allow a nominal 5-minute delay, under all weather and altitude conditions, to allow personnel to move to the minimum safe distance (MSD) from the explosive charges being detonated. If greater time accuracy is required under specific altitude and weather conditions, an M14 from the same lot should be tested. The M14 being tested should be timed to the detonation of the cap to provide an actual burn time. This will allow the operator to adjust the time for the detonation of the explosive system or main charge.

M18

6-47. The M18 (figure 6-21) is a high-strength blasting cap, factory-crimped to about a 30-foot length of time blasting fuse. The black bands represent 1 minute of burn time. The free end of the fuse is moisture-sealed and must be cut off to the selected time band when being prepared for ignition (figure 6-21).

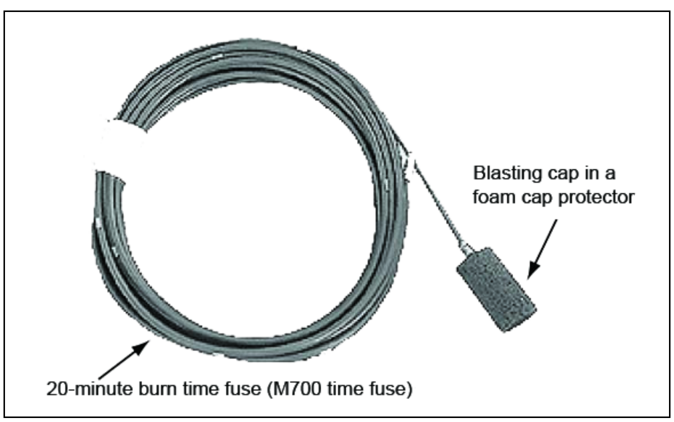


Figure 6-21. 20-minute burn time M18 component

Use

6-48. The M18 is used to detonate standard military explosives. It is also used to initiate shock tube blasting caps and detonating cord up to 20 minutes after being ignited. The M18 functions by sending an initiating flame (from a fuse igniter or a match) slowly through the length of the time blasting fuse to the factory-crimped blasting cap. The 1-minute bands on the time fuse have been calibrated at sea level at a temperature of 125° Fahrenheit. The burn time will increase with altitude and colder temperatures. The M18 has been designed to allow a nominal 20-minute delay under various weather and altitude conditions. This allows personnel to move to the MSD from the emplaced explosive charges being detonated.

DETONATING CORD

6-49. Detonating cord (figure 6-22) consists of a core of high explosive (6.4 pounds of pentaerythrite tetranitrate [PETN] per 1,000 feet) wrapped in a reinforced, waterproof, plastic coating. Detonating cord can be used to prime and detonate other cap-sensitive explosive charges. This detonating cord is about 0.2 inch in diameter, weighs about 18 pounds per 1,000 feet, and has a breaking strength of 175 pounds. It will transmit a detonating wave from one point to another at a rate 20,000 to 26,000 feet per second. Detonating cord is functional in the same temperature range as plastic explosive, although the cover becomes brittle at lower temperatures. Great care is required in using detonating cord primer in arctic conditions. Moisture can penetrate the explosive filling to a maximum distance of 6 inches from a cut or break in the coating. Water-soaked detonating cord will detonate if there is a dry end to allow initiation. A 6-inch tail should be left when making connections or when priming charges.

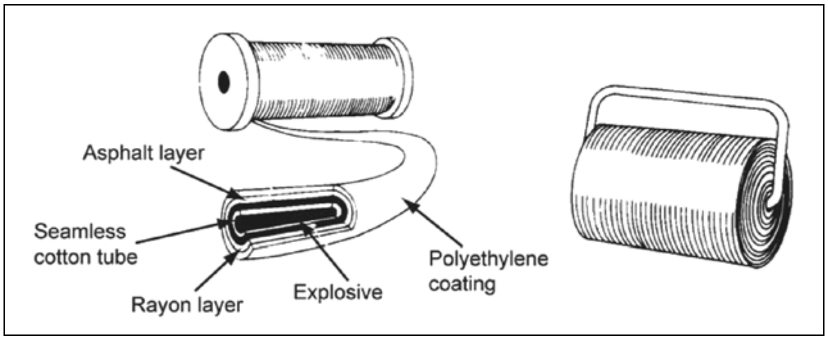


Figure 6-22. Detonating cord

MILLISECOND CONNECTORS

6-50. MS connectors are nonelectric short-interval, millisecond-delay devices for use on delaying blasts which are surface-initiated by detonation cord. MS connectors are made of a molded plastic sleeve. Each of the sleeves is made so that the detonation cord can be looped and locked in. Commercial MS connectors are color coded for different time intervals.

CAUTION

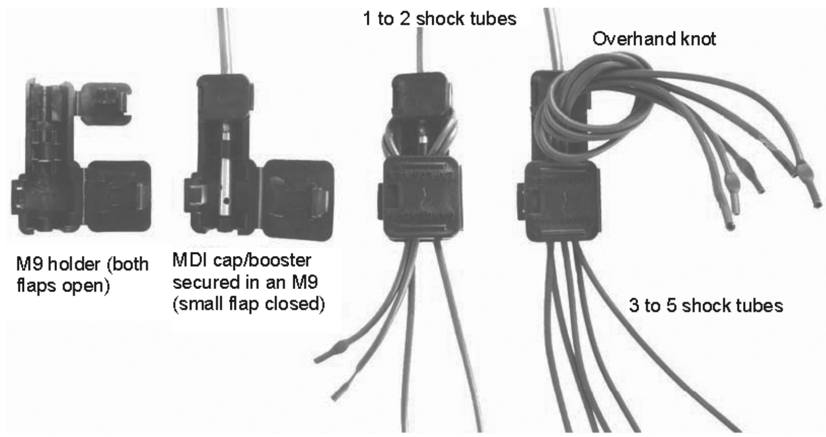
Protect MS connectors from flame, excessive heat, sparks, and accidental impact, such as falling rocks or other heavy objects.

BLASTING CAP HOLDERS

6-51. Blasting cap holders are described in the following paragraphs.

M9

6-52. Plastic holders allow the connection of shock tubes to high-strength blasting caps and boosters (figure 6-23). The M9 holder helps secure the connection of up to five shock tubes or low-strength detonating cords to high-strength caps or boosters. The M9 holder can also be used to connect high-strength blasting caps and boosters to detonating cord. When using the M9 holder, tape it closed.



Legend:
MDI modernized demolition initiator

Figure 6-23. M9 blasting cap and shock tube holder

Use

6-53. The M9 can accommodate and ensure proper proximity for initiating up to five shock tubes, or one strand of detonating cord from the blasting cap or booster. The M9 can also be used to connect the MDI blasting cap or booster to a detonating cord line or ring main.

Function

6-54. Shock tubes must be positioned straight through the holder with an overhand knot when using one or more shock tubes. The blasting cap or booster is inserted and secured by closing the smaller hinged flap. Insert the ends of the shock tubes through the channels in the holder. Close the large flap to secure the overhand knot. Use tape to secure the large flap in place. In the event an M9 holder becomes unserviceable or is not available, use tape to make MDI connections. To attach a blasting cap to MDI components using tape, ensure that strands of shock tube or low-strength detonating cord being connected are in contact with the blasting cap or booster and are secured with tape.

WARNING

Do not connect the shock tube, low-strength detonating cord, or detonating cord in the same holder. Detonating cord functions at a higher velocity than the High-Molecular-weight Research Department Explosive (HMX) and aluminum in the shock tube and may cause a break in the shock tube. Failure to comply could result in immediate personal injury or damage to equipment.

BOOSTERS

6-55. The types of boosters are described in the following paragraphs.

M151

6-56. The M151 is a nonelectric, insensitive initiation system that is factory-assembled by crimping a secondary explosive booster onto a 10-foot length of low-strength detonating cord to allow the user to preprime explosives for military operations and bury explosives primed with M151. The M151 has a detonating cord clip like other MDI components for easy attachment to a line or ring main detonating cord. A pentagonal-shaped tag affixed to the low-strength detonating cord identifies it as an M151 to preclude incorrect connection within a firing system.

CAUTION

Do not use M151 low-strength detonating cord as a line or ring main. The M151 is only used as a branchline and cannot be substituted for standard detonating cord. Personal injury or damage to equipment may result from long-term failure to follow correct procedures.

Use

6-57. The M151 is used to prime charges in situations where simultaneous initiation and detonation are desired. Prepriming of charges allows a Soldier to transport the preprimed charge in the vehicle or on his person. This also allows for the burial of an explosive charge.

DANGER (ARMY) WARNING (NAVY/AIR FORCE)

Never attach an M60 or M81 igniter to the M151. Failure to comply could result in immediate personal injury or damage to equipment.

Function

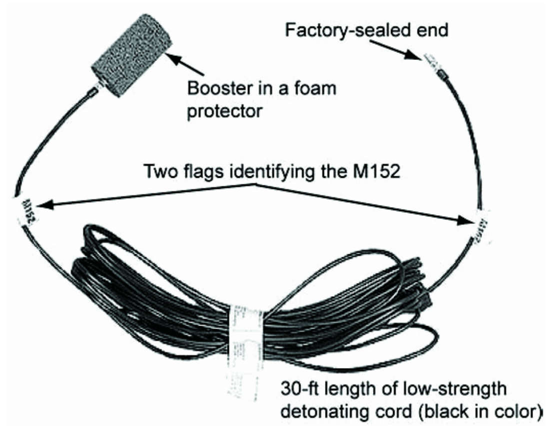
6-58. The M151 functions upon receiving an initiating shock from a blasting cap or other booster. When the booster functions, it detonates the primed explosive charge. The M151 booster can be secured in the M9 holder by using the small flap.

M152

6-59. The M152 is a nonelectric insensitive initiation system that is factory-assembled by crimping a secondary explosive booster onto a 30-foot length of low-strength detonating cord. This allows the user to preprime explosives for military operations and bury explosives primed with M152. The M152 has a detonating cord clip like other MDI components for easy attachment to a line or ring main detonating cord. A pentagonal-shaped tag affixed to the low-strength detonating cord identifies it as an M152 to preclude incorrect connection within a firing system (figure 6-24).

CAUTION

Do not use M152 low-strength detonating cord as a line or ring main. The M152 is only used as a branchline and cannot be substituted for standard detonating cord. Personal injury or damage to equipment may result from long-term failure to follow correct procedures.



Legend:
ft foot

Figure 6-24. M152 low-strength detonating cord component

Use

6-60. The M152 is used to prime charges in situations where simultaneous initiation and detonation are desired. Prepriming of charges allows a Soldier to transport the preprimed charge in the vehicle or on his person. This also allows for the burial of an explosive charge.

WARNING

Never attach an M60 or M81 igniter to the M152. Failure to comply could result in immediate personal injury or damage to equipment.

Function

6-61. The M152 functions upon receiving an initiating shock from a blasting cap or other booster. When the booster functions, it detonates the primed explosive charge. The M152 booster can be secured in the M9 holder by using the small flap.

NONELECTRIC, DOWN-HOLE DETONATORS

6-62. Nonelectric, down-hole detonators have a shock tube of a desired length with a factory-sealed and -crimped detonator at the end**.** The nonelectric, down-hole detonators have the following major components:

- A shock tube to transmit a signal to the down hole delay detonator.
- A detonator with an integral delay element.
- A delay tag, which indicates the MS delay period number and normal firing time.
- A J hook to facilitate easy connection to the detonating cord.

M15

6-63. The M15 (figure 6-25) consists of two blasting caps, factory-crimped at each end of a 70-foot length of shock tube. The blasting caps are slightly different in size and contain different delay elements. The shorter, low-strength blasting cap is designed to initiate another piece of shock tube in the firing system, while the longer high-strength blasting cap is designed to prime explosives. Since the M15 high-strength blasting cap is commercially used in boreholes, two brightly colored plastic flags are attached to the shock tube near the detonator. A red flag is attached 1 meter from the longer high-strength blasting cap, and a yellow flag is attached 2 meters from the low-strength blasting cap.

Figure 6-25. M15 delay blasting cap

DANGER (ARMY) WARNING (NAVY/AIR FORCE)

The M15 can only be used belowground in quarry operations. Failure to comply may cause death or permanent injury.

Use

6-64. The M15 is used to provide a delay element in a combination firing system to obtain staged detonations. Delayed and staged detonations are essential in quarrying operations, but are also used in relieved-face cratering. The M15 sends an initiating shock (or small detonation) through the shock tube to both blasting caps. These contain pyrotechnic delay elements. The delay times in the two detonators are different; one is 25 milliseconds (low-strength, small cap with a shock tube connector), and the other is 200 milliseconds (high-strength, large cap with a shock tube connector). The high-strength blasting cap is slightly larger in diameter than a standard blasting cap and will not fit in a standard cap well. The M15 shock tube must be initiated by another MDI component.

Nonelectric, Surface Delay Detonators

6-65. The nonelectric, surface delay detonators are used as surface trunk line delays, which transmit a signal to a delay cap. They have the following major components:

- A shock tube to transmit a signal to the delay detonator.
- A detonator with an integral delay element.
- A color-coded delay tag, which indicates the MS delay period and normal firing time.
- A J hook to facilitate easy connection to the detonating cord.

CAUTION

The caps in these surface delays are microdetonators and only have enough strength to initiate a shock tube.

BLASTING ACCESSORIES

6-66. The following are blasting accessories:

- **Cap crimper.** The cap crimper (figure 6-26) is used to squeeze the shell of a nonelectric blasting cap around a safety fuse securely enough to keep it from being pulled off, but not tightly enough to interfere with the burning of the powder train in the fuse. Cap crimpers are made of a soft, nonsparking metal, which will not conduct electricity and must not be used as pliers because such use damages the crimping surface. Although there are numerous manufacturers of crimpers, the above description is that of the DuPont™ number 4 crimper which is the most commonly found or reproduced crimper. Blasters should visually check the type of crimper for proper operation.

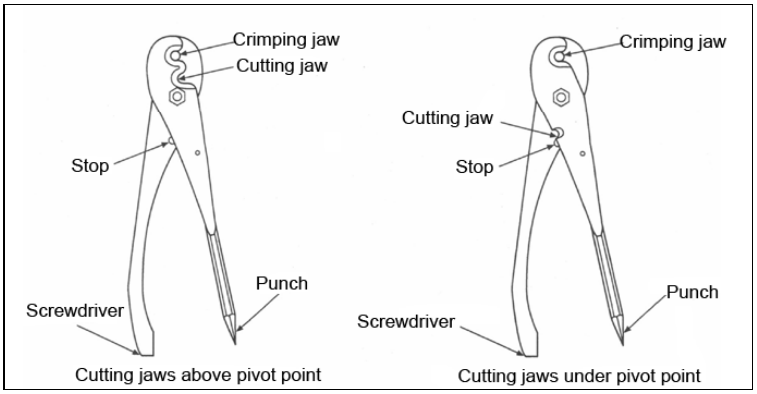


Figure 6-26. Cap crimper

- **Tamping (seating) pole.** A tamping (seating) pole is a nonmetallic pole used to aid in placing and loading explosives in boreholes. No metal parts are permitted in the pole, with the exception of a nonferrous metal coupling to join sections together. The pole must be inspected carefully before use to ensure that no small rock chips are clinging to the end that touches the explosive.
- **Blasting siren.** The blasting siren should produce a signal of sufficient decibel level so that personnel well outside of the area of concern can hear it. It may be vehicle-mounted or a self-contained device powered by batteries or air.
- **Lightning detector.** The lightning detector is used to provide an early warning of approaching electrical storms. It can detect storms out to 100 miles away and ranges in size from a shoebox to a pager. It must be used during explosive handling operations.

Chapter 7

Explosives

Explosives are chemical compounds, mixtures, or devices which have the primary or common purpose of exploding. They include, but are not limited to, dynamite and other high explosives; slurries, emulsions, and water gels; black powder and pellet powder; initiating explosives; detonators; safety fuses; squibs; detonating cords; and igniters. Explosives come in low or high density.

LOW-DENSITY EXPLOSIVES

7-1. Low-density explosives have a low rate of reaction and develop low pressure. The detonation velocity is 3,100 feet per second or less than the speed of sound. An example of a low-density explosive is black powder.

HIGH-DENSITY EXPLOSIVES

7-2. An explosive meeting the high explosive designation will, upon initiation by a detonator or booster charge, decompose very rapidly in a detonation (3,180 to 27,888 feet per second), rapidly releasing heat and large quantities of high-pressure gases, which expand with enough force to overcome confining forces. The energy released by the detonation of explosives produces four basic effects—rock fragmentation, rock displacement, ground vibration, and air blast.

DETONATOR-SENSITIVE EXPLOSIVES

7-3. Detonator-sensitive explosives are more sensitive to shock, heat, and mishandling. These explosives will reliably detonate with a number 8 strength blasting cap. The following are examples of detonator-sensitive explosives:

- Dynamites.
- Cast boosters.
- Water-based explosives (detonator-sensitive water gels, slurries, and emulsions).
- Binary explosives.
- Detonating cords.

NON-DETONATOR-SENSITIVE EXPLOSIVES

7-4. Non-detonator-sensitive explosives will not reliably detonate with a Number 8 strength blasting cap. These explosives require a booster for dependable initiation. They are less likely to accidentally initiate/detonate and are safer to handle and transport than detonator-sensitive explosives. Some examples of non-detonator-sensitive explosives include—

- Ammonium nitrate fuel oil (ANFO).
- Water-based explosives (water gels, slurries, emulsions).

PROPERTIES

7-5. The following common terms and standards apply to demolition activities.

SPECIFIC GRAVITY

7-6. Specific gravity is defined as weight per volume and expressed as grams per cubic centimeter. Water has a density of 1 gram per cubic centimeter. If the explosive has a packaged density of less than 1 gram per cubic centimeter, it will float in water. An explosive with a package density greater than 1 gram per cubic centimeter should sink. The density of an explosive determines the weight of explosive that can be loaded into a hole of a certain diameter.

DETONATION PRESSURE

7-7. Detonation pressure is a measurement of the peak pressure formed just behind the detonation front, propagating through the explosive column.

BOREHOLE PRESSURE

7-8. Borehole pressure is the pressure that develops in a borehole as the result of the high-temperature gases produced by the explosive detonation reaction. It is often referred to as the *constant volume pressure* or, simply, *explosion pressure*.

DETONATION VELOCITY

7-9. Detonation velocity is the rate at which the detonation reaction travels through an explosive column. The typical detonation velocities of commercial explosives range from 5,400 to 25,000 feet per second. The velocity for a given explosive remains constant depending on the following:

- **Charge diameter.** The larger the explosive charge diameter, the greater the detonation velocity, up to the maximum that can be achieved for that product.
- **Particle density.** As density increases, the detonation velocity also increases. When the product becomes too dense (dead pressed), it fails.
- **Particle size.** The smaller the size of the ingredients, the better they are mixed and more the contact they have with the fuel. This increases the detonation velocity. Examples include—
  - Emulsion explosives are made up of very small cells surrounded by fuel and have high detonation velocities.
  - ANFO is made up of relatively coarser particles surrounded by fuel and has much lower detonation for the same diameter.
- **Confinement.** The greater the confinement of an explosive charge, the higher the detonation velocity.

WATER RESISTANCE

7-10. Water resistance is the ability of the explosive to withstand water penetration without losing sensitivity or efficiency. It is expressed as the number of hours it may be submerged in static water and still be detonated reliably. The universally accepted ratings are as follows:

- Excellent—72 hours.
- Good—24 hours.
- Fair—8 hours.
- Poor—1 hour.

POSTBLAST FUMES

7-11. Explosives produce some toxic gases upon detonation and exposure to them may be fatal. The most common are carbon monoxide and nitrogen oxide. Sufficient time must be allowed after the blast for fumes to dispersed before personnel are allowed to return to the blast area. Explosives have a fume classification rated by the Institute of Makers of Explosives and approved by the Mine Safety and Health Administration. Explosives are permissible or nonpermissible. Permissible explosives are the only approved explosives for use in underground mines. (See table 7-1.)

SENSITIVITY

7-12. Sensitivity is a measure of the ease of initiation and the ability of the explosive product to propagate.

- **Explosive initiation.** Explosive initiation is what is required to reliably initiate a particular explosive in applications. The explosive product data sheets usually specify the minimum recommended primer.
- **Propagation ability.** Propagation ability is the ability of the explosive to detonate reliably throughout the length of a powder column. Extremely sensitive explosives may propagate from hole to hole.
- **Sensitiveness (gap sensitivity).** Sensitiveness (gap sensitivity) refers to the ability of an explosive to propagate across an air gap. Under most conditions, it is important that the individual charge does not propagate between holes, but rather detonate independently with a predetermined delay interval.
- **Detonator sensitivity.** Detonator sensitivity is the most frequently used sensitivity test to determine the sensitivity of explosives. The detonator sensitivity test uses a Number 8 strength blasting cap as the industry standard.

ENERGY OUTPUT/STRENGTH

7-13. The performance of an explosive is not determined simply by knowing the total energy released by the explosive. It also depends on the rate of energy released and how effectively the energy is used in fragmenting and moving the material being blasted. The explosive energy is the thermochemical heat of reaction and is released in the surrounding rock in the following forms:

- Shock energy (detonation pressure).
- Heave energy (borehole pressure).

7-14. This energy release is determined by—calculation and measurement.

Calculated Energy

7-15. Calculated energy is the theoretical potential of the explosive based on mathematical calculations. It is based on ideal temperatures, environments, and applications. Calculated energy values may not be comparable between similar products manufactured by different companies.

Measured Energy

7-16. Measured energy is a measurement of the shock and gas energy released by an explosive. These give us the ability to quantify the potential energy for an explosive. There are various ways to express this energy.

- **Absolute weight strength.** Absolute weight strength is the absolute amount of energy available in each gram of explosive.
- **Absolute bulk strength.** Absolute bulk strength is the absolute amount of energy available in each cubic centimeter of explosive.
- **Relative weight strength.** Relative weight strength compares explosive energy per weight to the energy of an equal weight of standard ANFO.
- **Relative bulk strength.** Relative bulk strength compares explosive energy per volume to the energy of an equal volume of standard ANFO.

FLAMMABILITY

7-17. Flammability refers to the ease with which an explosive or blasting agent can be ignited by heat. Most dynamites ignite readily and burn violently. Water gels and emulsions are more difficult to ignite than dynamite and, in many cases, an outside source of flame must be applied continuously to support burning in the open.

SHELF LIFE

7-18. Explosives deteriorate over time, and their ability to reliably detonate is affected by age. It is extremely important to continuously rotate all stock, using up the oldest first according to the manufacturer's recommendations.

EXPLOSIVE PRODUCTS

7-19. The following paragraphs describe types of explosive products.

CAST BOOSTERS

7-20. Cast boosters are solid, extruded, high-explosive cartridges, usually with high strength and velocity, used to initiate other less sensitive explosives or blasting agents. A Number 8 strength cap or 50-grain detonating cord is used to initiate the booster. Cast boosters typically contain TNT and other sensitive explosives in the casting material and have excellent resistance to water.

DYNAMITES

7-21. Dynamite is the best known and one of the most widely used commercial high explosives. The name *dynamite* includes different chemical groups, each wrapped and marketed in about the same manner. Only the most general distinctions can be made between them, since manufacturing and research steadily widen their applications in blasting and quarry operations.

Commercial

7-22. The three main types of commercial dynamites are straight (standard), ammonia, and gelatin. Most dynamites (with the notable exception of military dynamite) contain nitroglycerin plus varying combinations of absorbents, oxidizers, antacids, and freezing point depressants. The straight dynamites consist primarily of a mixture of nitroglycerin, sodium nitrate, and combustible absorbents (such as wood pulp), wrapped in strong paper to make a cylindrical cartridge. Although a wide variety of sizes are available, the most popular are 8 1/4 inches in length. Dynamites vary greatly in strength and sensitivity, depending on (among other factors) the percentage of nitroglycerin they contain (usually from 15 to 60 percent).

7-23. Dynamites are used for general blasting and demolitions, including land clearing, cratering and ditching, and quarrying. Strength does not increase in proportion to the percentage of nitroglycerin because the other ingredients also contribute gas and heat. Higher percentages are faster and more sensitive. Speed is desirable in hard rock and where the explosive is not confined, as in boulder blasting. Straight dynamites have fair water resistance. Their fumes are poor; however, and they are never recommended for underwater blasting. Dynamites of general-purpose strength 40 to 60 percent will explode if subjected to a sharp concussion (blasting cap explosion, rifle bullet impact) or excessive heat (produced by fire, friction, impact, or sparks).

7-24. When dynamite is burned, usually to destroy surplus or deteriorated stock, it is spread in a thin layer on straw, hay, sawdust, or other combustible material that is then ignited. Personnel should keep at a safe distance from the fire. Dynamite will usually burn without incident, but there is always a chance that it may explode. Spoiled dynamite may soak into its containers and render them explosive. The cases and wrappings should, therefore, be burned with the same precautions as would be taken with dynamite.

7-25. Ammonia dynamites use AN as the principal explosive, in combination with some nitroglycerin. They do not catch fire as easily as straight dynamites and are less sensitive to shock and friction. Water resistance is generally inferior, but fumes are less objectionable. These are rated on a percentage-strength basis. The figures do not indicate chemical composition, but simply that performance is comparable to that of a straight dynamite of the same rating.

7-26. Gelatin dynamite is made by dissolving nitrocotton in nitroglycerin. Various other ingredients are then added. Gelatin dynamites are dense, plastic, cohesive, and practically waterproof. Their fumes are excellent in all but the highest strengths, which vary up to 90 percent. A 100 percent gelatin is produced, but is not used in construction or mining; it has a high-end demolition application. When shot with a standard cap and when not confined, ordinary gelatin dynamites will explode at a velocity of about 5,000 feet per second. If confined or shot with a straight dynamite primer, velocities of 13,000 to 22,000 feet per second, depending on the strength, will be obtained.

7-27. Certain types of dynamite may be obtained that will always detonate at a higher velocity. Gelatin dynamites are relatively insensitive to shock and often will not explode by propagation from adjacent holes. Their plasticity makes them easy to load solidly into boreholes and to pack tightly in cracks for boulder blasting or other applications. The velocity of the higher grades and their high density suit them for hard, tight blasting, and their waterproof qualities for underwater work not requiring propagation. These types of explosives are best initiated or set off by timing devices, remote electrical controls, or a combination of these methods.

Military

7-28. Military dynamite is a composite explosive that contains 75 percent cyclotrimethylenetrinitramine (RDX), 15 percent trinitrotoluene (TNT), and 10 percent desensitizers and plasticizers. Military dynamite is not as powerful as commercial dynamite; its equivalent strength is 60 percent of commercial dynamite. Because military dynamite contains no nitroglycerin, it is safer and more stable to store and handle than commercial dynamite. Military dynamite is packaged in 0.5-pound, paraffin-coated, cylindrical paper cartridges which have a nominal diameter of 1.25 inches and nominal length of 8 inches. It will not freeze in cold storage nor exude in hot storage. The composition does not absorb or retain moisture. It is safer to store, handle, and transport; and shipping containers do not require turning during storage. It has a good rating good for water resistance, but is reliable underwater only up to 24 hours. Because of its low sensitivity, sticks of military dynamite must be well compacted to ensure complete detonation of the entire charge. There must not be voids in loading of boreholes in quarrying. Military dynamite will eventually detonate if set afire in a confined space. Thus, a secondary explosion can result from a borehole with a void in its loading. After the first blast, it may take up to 15 minutes for such an explosion to occur.

Table 7-1. Typical dynamites

Type		***Grade***	***Density***		***Velocity***		***Water Resistance***	***Fumes***
			Grams Per Cubic Centimeter	***1 ¼" x 8" Sticks per 50-Pound Case***	***Feet per Second***	***Meters per Second***		
Grandular	Straight dynamite	Ditching dynamite 50%	1.32	108	17,400	5,300	Good	Very poor
	Ammonia dynamite	40%- 60%	1.32 1.30	106 112	9,760 12,470	3,000 3,800	Fair Good	Very good Very good
Semi-gelatin	Ammonia dynamite		1.29 1.16 0.94	110 122 150	13,100 12,600 11,300	4,000 3,850 3,450	Very good Very good Good	Very good Very good Very good
Gelatins	Straight gelatin	80%	1.35	106	18,700	5,700	Excellent	Poor
	Ammonia gelatin	40%- 60%	1.54 1.43	94 101	15,400 17,400	4,700 5,300	Excellent Excellent	Very good Very good
Permis-sible	Ammonia grandular		1.15 1.02 0.94 0.86	120 135 150 165	9,000 9,200 9,000 8,500	2,750 2,800 2,750 2,600	Very good Good Good Good	Mine Safety and Health Administration-approved
	Ammonia gelatin		1.37	102	16,500	5,030	Excellent	Mine Safety and Health Administration-approved

COMPOSITE MIX (SOLID STICKS OR BLOCKS)

7-29. The following paragraphs describe composite mixes.

Amatol

7-30. Amatol is a mixture of AN and TNT. It is a substitute for TNT in bursting charges. Some older bangalore torpedoes use 80-20 amatol (80 percent AN and 20 percent TNT). Because amatol contains AN, it is a hygroscopic compound and should be kept in airtight containers. If properly packaged, amatol remains viable for long periods with no change in sensitivity, power, or stability.

Black Powder

7-31. Black powder is the oldest known explosive and propellant. It is a composite of potassium, sodium nitrate, charcoal, and sulfur. Time fuses, some igniters, and some detonators contain black powder.

Composition A3

7-32. Composition A3 is a composite explosive containing 91 percent RDX and 9 percent wax. The purpose of the wax is to coat, desensitize, and bind the RDX particles. Composition A3 is the booster charge in some newer models of shaped charges and bangalore torpedoes. High-explosive plastic projectiles may also contain Composition A3 as a main charge.

Composition B

7-33. Composition B is a composite explosive containing about 60 percent RDX, 39 percent TNT, and 1 percent wax. It is more sensitive than TNT. Because of its shattering power and high rate of detonation, Composition B is the main charge in shaped charges.

Composition B4

7-34. Composition B4 contains 60 percent RDX, 39.5 percent TNT, and 0.5 percent calcium silicate. Composition B4 is the main charge in newer models of bangalore torpedoes and shaped charges.

Composition C4

7-35. Composition C4 is a composite explosive containing 91 percent RDX and 9 percent nonexplosive plasticizer. Burster charges are composed of Composition C4. Composition C4 is effective in temperatures between -70ºF to 170ºF; however, it loses its plasticity in colder temperatures.

Cyclotrimethylenetrinitramine

7-36. RDX is also a highly sensitive and very powerful military explosive. It forms the base charge in M6 electric and M7 nonelectric blasting caps. When RDX is desensitized, it serves as a subbooster, booster, bursting charge, or demolition charge. The principal use for RDX is in composite explosives (Composition A, B, and C explosives).

Nitroglycerin

7-37. Nitroglycerin is one of the most powerful high explosives. Its explosive potential is comparable to RDX and PETN. Nitroglycerin is the explosive base for commercial dynamites. It is highly sensitive and extremely temperature-sensitive. Military explosives do not contain nitroglycerin because of its sensitivity. Commercial dynamites should not be used in combat areas.

Pentaerythrite Tetranitrate

7-38. PETN is a highly sensitive and very powerful military explosive. Its explosive potential is comparable to RDX and nitroglycerin. Boosters, detonating cord, and some blasting caps contain PETN. It is also used in composite explosives with TNT or nitrocellulose. A PETN nitrocellulose composite (M118 sheet explosive) is a demolition charge. The PETN explosive is a good underwater demolition because it is almost insoluble in water.

Pentolite

7-39. Pentolite is a mixture of PETN and TNT. Because of its high power and detonating rate, a mixture of 50-50 pentolite makes an effective booster charge in certain models of shaped charges.

Tetryl

7-40. Tetryl is an effective booster charge in its noncomposite form and a bursting or demolition charge in composite form. Tetryl is more sensitive and powerful than TNT. However, RDX- and PETN-based explosives (which have increased power and shattering effects) are replacing tetryl and composite explosives containing tetryl.

Tetrytol

7-41. Tetrytol is a composite explosive containing 75 percent tetryl and 25 percent TNT. It is the explosive component in demolition charges. Booster charges require different mixtures of tetryl and TNT. Tetrytol is more powerful than its individual components; it is better at shattering than TNT and is less sensitive than tetryl.

Trinitrotoluene

7-42. TNT is the most common military explosive. It comes in a composite form (a booster, bursting, or demolition charge) or in a noncomposite form. Since TNT is a standard explosive, it is used to rate other military explosives.

SLURRIES, LIQUIDS, EMULSIONS, AND GELS

7-43. The following paragraphs describe slurries, liquids, emulsions, and gels.

COMPOSITION

7-44. Slurries, liquids, emulsions, and gels are dense blasting agents. They are usually mixtures of a sensitizer, an oxidizer, a thickener and, possibly, water. The sensitizer may be a number of reducing (oxygen-hungry) chemicals. This is usually the explosive TNT, but may be (or include) finely divided aluminum and/or other substances that may or may not be explosive themselves. They may be in sand-size granules, very fine powder, or other forms. The oxidizer is an oxygen-rich chemical (AN, sodium nitrate).

CHARACTERISTICS

7-45. Consistency is regulated by the amount of thickener or gelling agent (often guar gum) that is used. The consistency varies from that of pancake syrup to soft jelly (flows if jiggled) at room temperature. Stiffening occurs at low temperatures, but most formulas are resistant to damage from freezing. Water resistance varies from good to excellent, unless water flow is sufficient to wash it away.

7-46. Loading gel in its sealed plastic packages is recommended for severe water conditions. Packaged slurries are generally jelled in cylindrical shapes, slightly smaller in diameter than the boreholes in which they are to be used. They are shipped in polyethylene bags, within protective material. The bags are usually soft enough to allow slump to fill the borehole almost completely and can be obtained in even softer, more expandable bags.

7-47. Some water gels have unique gelatin qualities that are designed to permit them to be poured into the hole. Water gel does not mix readily with water, and its weight (specific gravity is 1.1 to 1.5) causes it to flow to the bottom, displacing water and filling the borehole space. But if it is very thick, it may bridge over and retain water pockets.

7-48. For large-scale use, slurries may be shipped and even mixed in tank trucks and pumped into holes. If the hose can be extended to the bottom of the hole, the danger of bridging is eliminated. Most slurries are nonsensitive and have the same Class B rating as nitrocarbonitrate for shipping and storage purposes. They cannot be detonated by blasting caps or shock tubes and require special booster primers.

7-49. Recently developed, small intermediate-diameter grades of water gel are cap-sensitive, so they require shipment and storage as Class A explosives. This type is finding wide acceptance as a replacement for dynamite in bottom loads.

APPLICATION

7-50. Slurries are less expensive than dynamite, but cost more than nitrocarbonitrate. They are used chiefly in open-pit quarries where rock is hard. The high density of slurry (1.37 to 1.68) permits the use of smaller-diameter boreholes or wider spacing to obtain the same explosive power and fragmentation. The higher price of slurry may be more than offset by the reduced drilling time and cost. In wet holes, nitrocarbonitrate is not practical, so the choice is between dynamites and slurries. Here the slurries have a small advantage in density and price. Some slurries have been employed successfully in boreholes as small as to 1 1/2 inches in diameter, using a special small-diameter booster.

Water Gels

7-51. Water gel explosives prove to be much safer than dynamite, they contain no nitroglycerin, and they are sensitive to conventional priming methods, yet are more resistant than dynamite to accidental initiation from abusive impact, shock, or fire. They can be string-loaded to build out of water to use ANFO farther up the column. Water gel may not be used in extreme cold conditions due to the sensitivity of the product. Some other advantages include—

- Greater control of borehole density. The borehole density of water gel explosives can be greatly increased by slitting or tamping the cartridge.
- Excellent fragmentation.
- Minimimal danger of hole-to-hole propagation.
- Reduced smoke and toxic fumes.
- Elimination of nitroglycerin effects.
- Excellent water resistance. Water gel explosives are packaged in a heavy, rugged film in diameters from 1 1/2 to 4 inches and lengths to 16 inches. They are available in cap-sensitive and non-cap-sensitive types.

Blast Emulsion

7-52. Blast emulsion is a booster-sensitive, water-resistant, packaged emulsion explosive designed to satisfy a majority of the medium-diameter explosive applications for quarry and construction blasting. It is a cost-effective alternative to most detonator-sensitive, water-resistant, packaged emulsion explosives. Blast emulsion is available in three grades, with increasing energy levels for each.

7-53. Package diameter and type affect product density. Use a cartridge count to determine the actual explosive charge weight. A cast booster is always recommended as a primer for blast emulsion to ensure maximum performance. At temperatures higher than 0ºF, always use a 12-ounce or larger cast booster. For temperatures below 0ºF and higher than -30ºFarenheit, use a16-ounce or larger cast booster. Blast emulsion should not be used at temperatures below -30ºF. At temperatures below -30ºF, adequate product warm-up time must be allowed after loading into boreholes and before initiation.

7-54. Use with detonating cord is ***not*** recommended. Maximum water depth is 330 feet. Ensure continuous column loading. For column lengths in excess of 20 feet or when column separation is suspected, multiple priming is recommended. Emulsion explosives are susceptible to dynamic shock and may detonate at low order or fail completely when applied in very wet conditions where explosive charges or decks are closely spaced and/or where geological conditions promote this effect. Consult the manufacturer for alternative product recommendations when these conditions exist.

Emulsions (Cartridge)

7-55. Emulsions are explosive materials containing substantial amounts of oxidizers dissolved in water droplets surrounded by an immiscible fuel or droplets of an immiscible fuel surrounded by water containing substantial amounts of oxidizer. They come in 1 1/4 inch to 4-inch cartridges sizes and can be cap or non-cap-sensitive. A non-cap-sensitive emulsion in a 2 1/2-inch cartridge, must be primed with at least a 1-

pound booster or according to the manufacturer's specifications. Emulsion explosives have an excellent water resistance.

Nitrocarbonitrate

7-56. Ammonium nitrate fuel oil (ANFO) is the least sensitive, safest to handle, and least expensive explosive. This makes it the most widely used explosive in the world. Free-running AN and fuel oil are ideal for use in highly jointed and dense material. The mixture ratio is critical to the sensitivity of the explosive. A mixture of 94 percent by weight of AN and 6 percent by weight of fuel oil (Number 2 diesel), or 50 pounds of AN unoiled prills and 3 quarts of fuel oil will produce an nonsensitive explosive that is capable of filling voids in the hole. Mixing may be done at the factory, by mobile equipment, or by hand at the borehole or in the borehole. Factory mixing is more thorough and expensive and is less trouble than mixing on the job. It is insensitive due to the lack of nitroglycerin in its composition; therefore, it requires an explosive primer. ANFO or composite explosives containing ANFO are not suitable for underwater use unless they are packed in waterproof containers or detonated immediately after placement.

7-57. The mixed nitrocarbonitrate is more dangerous to handle than unmixed AN. Various mild precautions must be taken, and vehicles carrying it must be marked ***dangerous*.** The relative cost of using this agent largely depends on the size of the borehole and the size of the job. Nitrocarbonitrate should not be handled or transported in the original AN bags unless the change in contents is plainly marked. Nitrocarbonitrate may be made dangerously sensitive or even caused to explode spontaneously if left standing in stemmed boreholes for long periods due to contamination with unidentified, naturally occurring chemicals. Therefore, it should be detonated as quickly as possible once prepared.

7-58. Borehole diameter is the most important single factor affecting propagation of the explosion. The propagation of the explosion dies out much more quickly in small holes than in large holes. Although nitrocarbonitrate has been successfully used in holes as small as 2 1/2 inches, variable results and the cost of extra boosters limit its use in holes smaller than 4 inches. This minimum diameter may be expected to get smaller as research develops. Poor confinement may also cause the detonation to slow or stop. A soft-rock or mud seam between layers of hard rock may not confine the nitrocarbonitrate sufficiently for it to carry the explosion throughout the blast. In general, there should be a primer at the bottom and top of the hole and one at least every 20 feet.

7-59. The density of AN ranges from 47 pounds per cubic foot for the prilled variety to 64 pounds for fine-grained types. This compares with dynamite densities of 37 to 90 pounds. In loading calculations, the low density of prilled nitrocarbonitrate compared to heavier dynamites is offset to a variable degree by the complete filling of hole space by the free-running material. That is, if a dynamite with a 60-pound density filled only 80 percent of the bore space in spite of slitting and seating the cartridges, then its effective density in the hole would be 48 (0.8 x 60) pounds per cubic foot, about the same as AN. The finer and denser types of AN are not well suited for use as blasting agents with present blasting methods. They are more sensitive and less powerful than prills and are more difficult to mix with fuel. Some increase in the density of prills may be obtained by mixing two or more sizes, but the heavier charge may still be offset by slower detonation.

7-60. Dry holes are loaded by placing the primers with the detonating cord or wire, then pouring the mixture or the two ingredients separately until the proper amount is placed. Stemming is then added. There is a tendency to load holes higher with nitrocarbonitrate than with dynamite because of its lower cost and to use less stemming. Overloading is likely to be a waste of the explosive, and it compounds the hazard of high-flying rocks.

7-61. Unprotected nitrocarbonitrate cannot be expected to perform dependably in wet holes; it can, however, be protected by putting plastic bags over it in the hole. It may be protected this way or protected by plastic sheets with the help of a sealing or bagging machine. Bagged nitrocarbonitrate tends to float on water in the hole and must be forced down by the weight of explosive above it. Even with firm seating, the bags will reduce the amount that can be placed because they will not conform perfectly to the walls. Bags may tear and allow water to ruin their contents, possibly cutting off part of the blast.

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Chapter 8

Blast Planning and Design

Blast designs are meant to optimize the energy released by the detonation of explosives and to fragment and displace rock while minimizing the adverse effects, (fly rock, airburst, vibration). The importance of proper measurements, mathematical skills, experience, and safety cannot be understated. Blasting experience is the most critical and important of these factors. Various factors, some unknown or out of the user's control (such as geology), influence the results of a blast design, but a fundamental principle of blast design is the distribution of explosives within the rock mass. This relationship is known as the powder factor.

Notes. The term *rule of thumb* is used throughout this chapter and simply means a good starting point. Although these rules of thumb allow a blaster to enter a new location and have a good starting point, each location and situation is unique; therefore, each blaster must determine what works best for the situation.

The terms used in this chapter are not standard within the industry, so beware of this if referencing other publications.

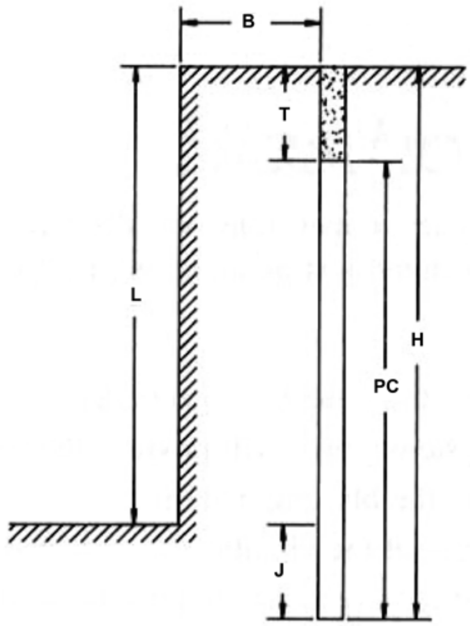
Ninety percent of rock has a specific gravity of 2.2 to 2.8; therefore. For specific rock densities, refer to appendix C.

COLLAR

8-1. The collar is the opening (mouth) of a borehole.

BOREHOLE DIAMETER

8-2. The borehole diameter is the mean width of the cross-section of the borehole. To determine the borehole diameter to be used, one must consider the drilling conditions, equipment, and size and type of explosives to be used. Other considerations to consider when determining the borehole diameter are the required production and the bench height. Boreholes are normally drilled 1/2 inch larger than the blasting agent or explosive diameter to be used to ease the loading process.



Legend:

B	burden
H	hole depth
J	subdrill
L	bench (face) height
PC	powder column
T	stremming

Figure 8-1. Blast planning and design diagram

BENCH HEIGHT

8-3. Bench height is the vertical distance from the top of a bench to the floor or the top of the next lower bench. Bench heights that are too low or too high may cause problems. When blast hole lengths are less than two times the burden, the breakage mechanisms change. As blast hole lengths approach the dimension of burden distance, the breakage mechanism becomes one of cratering with the explosive force predominantly working in the direction parallel to the axis of the borehole. This change of mechanism with more confined conditions will require a different powder factor. A bench height that is too high can cause borehole deviation that results in drilling inaccuracies, variable burden and spacing, fly rock, oversize material, and toes. As a rule of thumb, bench height should equal four times the burden. Use the following formula to calculate bench height:

$$L = 4 \times B$$

where—
B = burden
L = bench height

Example.

$$L = 4 \times 7.59$$
$$L = 30.36 \text{ feet}$$

EXPLOSIVE DENSITY

8-4. Explosive density is the grams of explosives per cubic centimeter. Manufacturer technical data sheets contain the specific density of each product. Generally, explosives used in quarry operations fall within the following categories and are based on their explosive density:

- ANFO: 0.8 to 1.15 grams per cubic centimeter (low).
- Emulsions and slurries/gels: 1.10 to 1.35 grams per cubic centimeter (medium).
- Military dynamite: 1.35 to 1.45 grams per cubic centimeter (high).

EXPLOSIVE DIAMETER

8-5. The explosive density and borehole diameter help determine the explosive loading density which is used in determining the pounds of explosives per foot of borehole. If using package products, the cartridge diameter is used; for free-running explosives, the borehole diameter will be considered the cartridge size for this calculation.

BURDEN

8-6. Burden is one of the most critical measurements in blast design when rock fragmentation and burden velocity are considered. True burden is the distance measured perpendicularly between the nearest free face and the first row of holes that displacement is most likely to occur. Apparent burden is the distance between rows. Burdens that are too large can produce oversized rock or a high muck pile, while burdens that are too small can result in a violent blast, a scattered muck pile, possible hole-to-hole propagation, or excessive fly rock. Three characteristics of the shot are required for this calculation: specific gravity of the rock, explosive density, and diameter of the explosives. Test shots will be small and adjustments may be required. Use the following formula to calculate burden:

$$B = \left(\frac{2SG_e}{SG_r} + 1.5\right)De$$

where—
B = burden
De = explosive diameter (paragraph 8-5)
SG_e = explosive density (paragraph (8-4)
SG_r = rock density (Table 1-2)

Example.

specific gravity of rock – 2.7, explosive density – 1.25, 3-inch explosive

$$B = \left(\frac{2\ x\ 1.25}{2.7} + 1.5\right)3$$

$$B = \left(\frac{2.8}{2.7} + 1.5\right)3$$

$$B = (1.03 + 1.5)3$$

$$B = 7.59\ feet$$

SPACING

8-7. Spacing is the distance measured between boreholes within the same row. Spacing is an important factor in securing uniform rock breakage of suitable size. The interaction of forces transmitted through the rock from one blast hole to the next is very complex. However, as a rule, charges fired simultaneously in the same row may have greater spacing than delayed charges in the same row. Spacing is burden times one for a square pattern and burden times 1.1 to 1.5 for a rectangle pattern. Spacing is not recommended to be less than one times the burden distance. Spacing distance less than burden distance can lead to fracture between holes, causing propagation or borehole cutoff and a misfire of individual holes. It is more desirable to change spacing distances than adjust an established burden when a desired muck pile has resulted. To determine spacing, use the following formula:

S = B x 1 (for square pattern)
S = B x 1.1 – 1.5 (for rectangle pattern)

Example.

S = 9.87 = 9 feet, 10 1/2 inches

BOREHOLE DEVIATION

8-8. Borehole deviation (drill drift) is the unwanted drift of the drill bit during drilling. The most frequent cause of drill drift is inexperience, geology, improper calculations, and/or the capabilities of the equipment. Regardless of the reason, it should be a consideration when determining bench height. (See figure 8-2.)

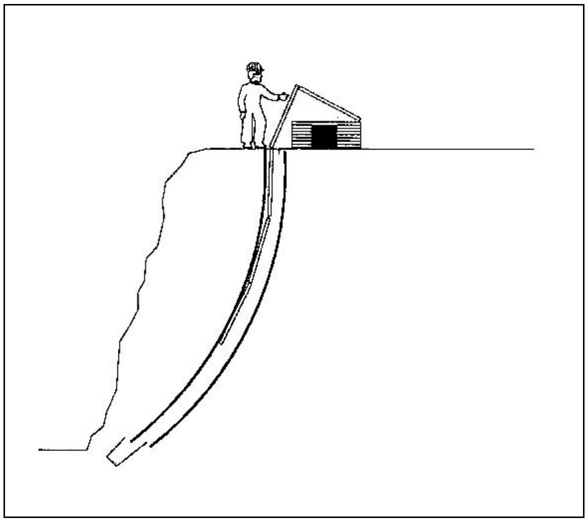


Figure 8-2. Borehole deviation

STEMMING

8-9. Stemming is an inert material of dense consistency (clean crushed rock is preferred) which is inserted in the top of the borehole after being loaded with explosives to reduce fly rock and air shock waves and to confine the explosive energy, thereby increasing blasting efficiency. It is also used to separate the explosives in deck loading operations and to fill spaces caused by voids or cracks. Stemming may also be used to backfill boreholes that are drilled too deep during subdrilling operations. The stemming length will be between 0.7–1.4 times the burden (see table 8-4). Using too little stemming may result in stemming ejection, allowing the explosive energy to escape, whereas using too much stemming may result in poor breakage in the collar area due to the decreased powder factor in the powder column. As a rule of thumb, the size of the aggregate should be 1/8 inch for every inch of borehole.

Example.

3 inch x 1/8 = 3/8-inch aggregate size

SUBDRILLING

8-10. Subdrilling is the practice of drilling below floor level or working elevation to ensure the breakage of rock to the working elevation. Subdrilling depends on the geology and inclination of the blast holes. If the borehole ends at a natural horizontal seam (bedding plane), subdrilling is not used. As a rule of thumb, the subdrill should equal 0.33 times the burden. Use the following formula to calculate the subdrill:

J = B x 0.33

where—
B = burden
J = subdrill

Example.

B = 7 feet 7 1/16 inches = 7.59
J = 7.59 x 0.3 = 2.27 = 2 feet 3 1/4 inches

HOLE DEPTH

8-11. Hole depth is the total drilled depth of the borehole. Use the following formula to calculate hole depth:

$$H = L + J$$

where—
H = hold depth
J = subdrill
L = bench height

Example.

L = 30 feet 4 inches = 30.36
J = 2 feet 3 1/4 inches = 2.27
H = 2.27 + 26.25 = 28.52 = 28 feet 6 1/4 inches

POWDER COLUMN

8-12. The powder column is the space within the borehole that will be loaded with explosives. If using a free-flowing product, the borehole diameter will be used to determine the powder column. If using a packaged product, the diameter of the product will be used. Use the following formula to calculate the powder column:

$$PC = H - T - decking$$

or

$$PC = H - T$$

where—
H = hole depth
PC = powder column
T = stemming

Example.

$$PC = 35 - 5.6 = 29.4 = 29 \text{ feet } 4\ 3/4 \text{ inches}$$

POUNDS PER FOOT

8-13. Pounds per foot is the weight of explosives loaded per foot of borehole. Although it may be expressed in metric or standard measurements, it is normally expressed in pounds per foot of borehole. Use the following formula to calculate pounds per foot:

$$PPF = \text{explosive density} \times 0.3405 \times \text{explosive diameter}^2$$

where—
PPF = pounds per foot

Example.

$$PPF = 1.41 \times 0.3405 \times 3^2 = 4.32 \text{ pounds per foot}$$

EXPLOSIVE WEIGHT

8-14. Explosive weight is the weight of explosives loaded per borehole. Although it may be expressed in metric or standard measurements, it is normally expressed in pounds per borehole. Use the following formula to calculate explosive weight:

$$EW = PPF \times PC$$

where—
EW = explosive weight
PC = powder column
PPF = pounds per foot

Example.

$$EW = 4.32 \times 29.4 = 127 \text{ pounds per hole}$$

where—
PC = 29 feet 4 3/4 inches = 29.4
PPF = 4.32

SHOT VOLUME

8-15. The shot volume can be calculated per borehole or for the entire shot. When calculating the volume of a shot, if the boreholes do not have the same burden, spacing, and depth, each hole must be calculated individually and added together. The following formulas can be used to calculate shot volume:

$$\text{cubic yards (yards}^3 \text{ per foot)} = \frac{\text{burden} \times \text{space}}{27 \text{ feet per yard}^3}$$

or

$$\textit{cubic yards (yards}^3\textit{/hole) = yards}^3\textit{/ft x bench height}$$

Examples.

7.59 x 9.87
27 feet per yards³ = 2.77 yards³ per foot

2.77 x 30.36 = 84.09 yards³ per hole

TONNAGE CALCULATION

8-16. Tonnage can be calculated as tons per cubic yards or as tons per hole and uses the average of the rock density of the product being quarried. The following formulas can be used to calculate tonnage:

$$\text{pounds per yard}^3 = \text{rock density} \times 62.4 \times 27$$

$$\frac{pounds\ per\ yard^3}{2{,}000\ pounds}$$

Examples.

shale 2.4 – 2.8
$$\text{pounds per yard}^3 = \text{rock density} \times 62.4 \times 27$$
$$\text{pounds per yard}^3 = 2.6 \times 62.4 \times 27$$
$$4{,}380.48 \text{ pounds per yard}^3$$

$$\frac{4{,}380.48\ pounds\ per\ yard^3}{2{,}000\ pounds} = 2.19\ tons\ per\ yard^3$$

8-17. The equations in table 8-1 are used to calculate blast patterns when first opening a quarry. Once test shots have been conducted, adjust formulas within the parameters for each area as listed in Chapter 6. Test shots will also help develop the desired powder factor for that location. Perform the following calculations in the order given in table 8-1.

Table 8-1. Blast pattern equations (new quarry)

Bench height (L)	*L = 25*	
Explosive density (SG_e)	$SG_e = 1.25$	
Rock density (SG_r) (See table C-7)	$SG_1 = 2.5$	
Explosive diameter (De)	*De = 4 inches*	
Burden estimate *Note.* Table 8-2 provides a window of deviance for Step 5.	$\left(\frac{2SG_e}{SG_r} + 1.5\right) De$	$\left(\frac{2 \text{ x } 1.25}{2.5\text{r}} + 1.5\right) 4 = 10$
Corrected burden estimate	$B_C = B \times K_s$	
Geologic structure • Heavily cracked frequent weak joints, weak cemented layers • Thin, well-cemented layers with tight joints • Massive intact rock		K_s *1.3* *1.1* *0.95*

Table 8-1. Blast pattern equations (new quarry) (continued)

Spacing	*S = B x 1* *(for square pattern)* *S = B x 1.1 – 1.5* *(for rectangle pattern)*	*S = 10 x 10* *S = 10 x 11 to 15 rectangle*
Stemming	*T = 0.7 to 1.4 x B* *(see table 8-4)*	*T = 0.7 to 1.4 x 0 = 7 to 14 feet*
Subdrill	*J = B x 0.3*	*J = 10 x 0.3 = 3 feet*
Hole depth	*H = L + J*	*H = 25 + 3 = 28 feet*
Powder column (deck)	*PC = H – T – decking (column)* *PC = H – T*	*PC = 28 – 7 – decking = 21 feet* *PC = 28 - 7 = 21 feet*
Pounds per foot	$PF = SG_e \times 0.3405 \times D_e^2$	*PPF = 1.25 x.3405 x 4 x 4 = 6.81*
Explosive weight (per hole)	*EW = PPF x PC*	*EW = 6.81 x 21 = 143.01 ≈ 143 lbs*
Volume shot (yard³ per hole)	(See table C-3 and table C-4.)	

PRESPLIT

8-18. Presplitting creates an artificial plane along the limits of the excavation, against which the subsequent main blast may break. Cracks for the final contour are created by firing a single row of holes before the initiation of the rest of the holes in the blast pattern. This results in a smooth wall with little or no overbreak. Some of the shock waves from the main blast will be reflected against the presplit plane, preventing them from being transmitted into the remaining rock; this also tends to reduce ground vibrations. After a trial blast, determine the optimum spacing for presplit holes. Load boreholes with 0.25 pounds per foot to produce acceptable results for the trial blast. In most formations, the desired results can be obtained by adjusting the hole spacing and still retain a column load of 0.25 pound per foot. In a very soft, weathered formation, it is occasionally necessary to reduce the hole spacing and the column load. In most cases, the amount of stemming above the explosive column will be half the required amount on the blast pattern, but not less than 3 feet. As a rule of thumb, presplit should equal 12 times the borehole diameter. Use the following formula to calculate presplit:

Presplit = 12 x borehole diameter

Example.

Presplit = 12 x 3 = 36 inches

LINE DRILLING

8-19. Line drilling is used in conjunction with presplitting. It is a technique for blast holes normally drilled within 2 to 4 diameters of one another. These unloaded, closely spaced drillholes under proper geologic conditions can act as stress concentrators or guides to cause cracks to form between them. Unloaded line drill holes are sometimes used in tight corners to guide specific cracks in a specific angle.

PATTERN DESIGNS

8-20. Pattern designs are discussed in the following paragraphs.

SQUARE

8-21. In a square pattern (figure 8-3), the burden and spacing are equal. The holes in each row are aligned directly behind the holes in the row in front of them. The pattern should be kept as square as possible.

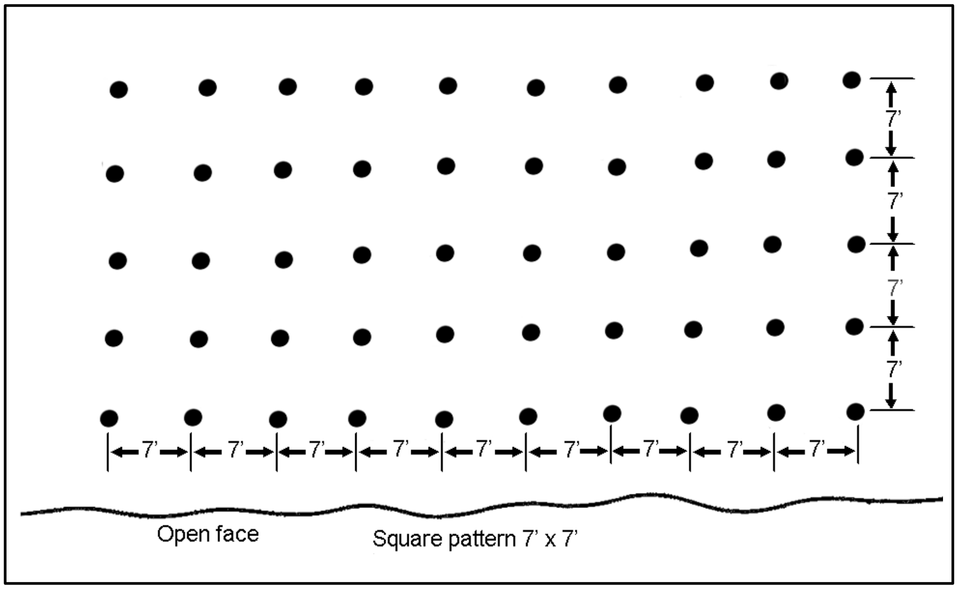


Figure 8-3. Square pattern

RECTANGLE

8-22. In a rectangle pattern (figure 8-4), the burden is less than the spacing. The holes in each row are again aligned directly behind the holes in the row in front of them.

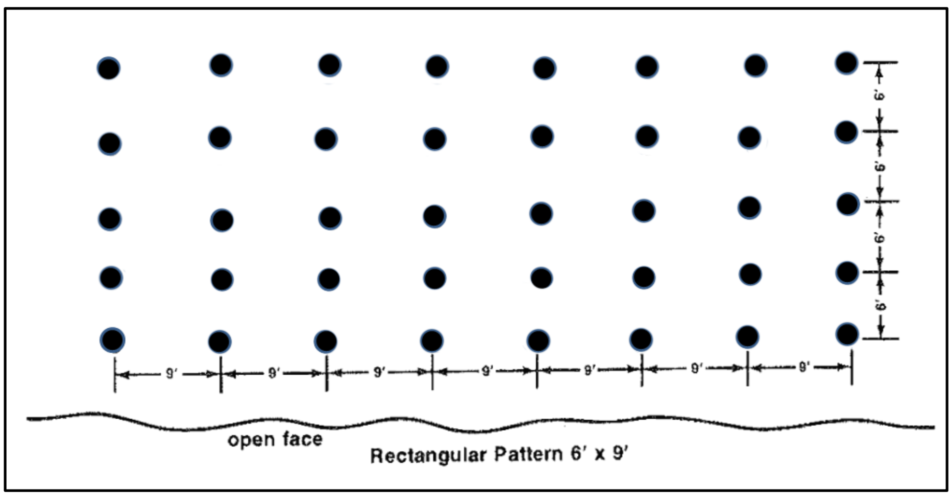


Figure 8-4. Rectangle pattern

STAGGERED

8-23. The staggered pattern (figure 8-5) may have equal burden and spacing. However, it is used more often with the burden versus spacing. The holes in alternate rows are aligned with the spaces between holes in the row in front of it. The staggered pattern usually requires extra holes to achieve a uniform bank on each end of the blast. This pattern is most commonly used in construction blasting.

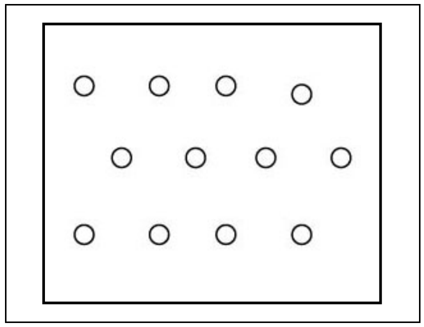


Figure 8-5. Staggered pattern

MUCK

8-24. Muck is the broken material resulting from a blast.

DRILLING LOGS

8-25. Accurate drilling logs are an essential part of the blast design process during priming and loading. The logs identify cracks and seams, type of material, and problems encountered while drilling the boreholes. The head blaster gives the head driller the shot location, shot pattern, borehole depths, and information from previous blasts that may be helpful when drilling. While drilling the pattern, the driller completes the log showing actual depth, cracks, seams, and voids. A diagram of the pattern and bench face is drawn at the bottom of the page.

SHOT RECORD

8-26. The quarry shot record and explosive inventory is a record of the explosives used on the shot, the borehole data, and the explosives expended. It is a reference that may be used to design future shots and must be kept on file for a period of five years. The quarry shot record and explosive inventory is completed by the head blaster and used to show the location of the explosive in the borehole, stemming, and decking if needed. The record must include an overhead view of the shot diagram with surface delays, the point of initiation, and the desired rock movement. It also includes a tool list and time record.

Table 8-2. Burden estimate (in feet)

Charge Diameter (inches)	*Density Ratio Density of Explosive Divided by Density of Rock*						
	0.2	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*
1.25	2.3	2.6	2.9	3.1	3.3	3.5	3.7
1.50	2.8	3.2	3.5	3.8	4.0	4.2	4.4
1.75	3.2	3.7	4.1	4.4	4.6	4.9	5.1
2.00	3.7	4.2	4.6	5.0	5.3	5.6	5.8
2.25	4.1	4.7	5.2	5.6	6.0	6.3	6.6
2.50	4.6	5.3	5.8	6.3	6.6	7.0	7.3
2.75	5.1	5.8	6.4	6.9	7.3	7.7	8.0
3.00	5.5	6.3	7.0	7.5	8.0	8.4	8.8
3.25	6.0	6.9	7.5	8.1	8.6	9.1	9.5
3.50	6.4	7.4	8.1	8.8	9.3	9.8	10.2
3.75	6.9	7.9	8.7	9.4	10.0	10.5	11.0
4.00	7.4	8.4	9.3	10.0	10.6	11.2	11.7

Charge Diameter (inches)	*Density Ratio Density of Explosive Divided by Density of Rock*						
	0.2	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***
4.25	7.8	9.0	9.9	10.6	11.3	11.9	12.4
4.50	8.3	9.5	10.4	11.3	12.0	12.6	13.2
4.75	8.8	10.0	11.0	11.9	12.6	13.3	13.9
5.00	9.2	10.5	11.6	12.5	13.3	14.0	14.6
5.25	9.7	11.1	12.2	13.1	13.9	14.7	15.4
5.50	10.1	11.6	12.8	13.8	14.6	15.4	16.1
5.75	10.6	12.1	13.3	14.4	15.3	16.1	16.8
6.00	11.1	12.7	13.9	15.0	15.9	16.8	17.5
6.25	11.5	13.2	14.5	15.6	16.6	17.5	18.3
6.50	12.0	13.7	15.1	16.3	17.3	18.2	19.0
6.75	12.4	14.2	15.7	16.9	17.9	18.9	19.7
7.00	12.9	14.8	16.2	17.5	18.6	19.6	20.5
8.00	14.7	16.9	18.6	20.0	21.3	22.4	23.4
9.00	16.6	19.0	20.9	22.5	23.9	25.2	26.3
10.00	18.4	21.1	23.2	25.0	26.6	28.0	29.2
11.00	20.3	23.2	25.5	27.5	29.2	30.8	32.2
12.00	22.1	25.3	27.9	30.0	31.9	33.6	35.1
13.00	23.9	27.4	30.2	32.5	34.5	36.4	38.0
14.00	25.8	29.5	32.5	35.0	37.2	39.2	40.9
15.00	27.6	31.6	34.8	37.5	39.9	42.0	43.9

Table 8-3. Burden corrected for geologic structure (in feet)

Average Burden	*Massive Rock*	*Broken, Jointed, Many Weak Layers*
3	2.9	3.9
4	3.8	5.2
5	4.8	6.5
6	5.7	7.8
7	6.7	9.1
8	7.6	10.4
9	8.6	11.7
10	9.5	13.0
11	10.5	14.3
12	11.4	15.6
13	12.4	16.9
14	13.3	18.2
15	14.3	19.5
16	15.2	20.8
17	16.2	22.1
18	17.1	23.4
19	18.1	24.7

20	19.0	26.0
21	20.0	27.3
22	20.9	28.6
23	21.9	29.9
24	22.8	31.2
25	23.8	32.5
26	24.7	33.8
27	25.7	35.1
28	26.6	36.4
29	27.6	37.7
20	28.5	39.0
31	29.5	40.3

Table 8-3. Burden corrected for geologic structure (in feet)

Average Burden	*Massive Rock*	*Broken, Jointed, Many Weak Layers*
32	30.4	41.6
33	31.4	42.9
34	32.3	44.2
35	33.3	45.5
36	34.2	46.8
37	35.2	48.1
38	36.1	49.4
39	37.1	50.7
40	38.0	52.0

TOE

8-27. The toe is the excessive burden (humping) measured at the floor level of the bench. Toes can be extremely problematic because of the reduction in the estimated amount of material to be removed, the potential safety hazard due to the unevenness of the face, and the effect that it has on the drilling of the parallel boreholes on that particular shelf.

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Chapter 9

Priming, Loading, Firing, and Initiation Systems

Many things must be taken into consideration when determining the priming method, the loading, and the assembly of the initiation and firing systems (pattern, delays, components, the type of material to be blasted). Ensure that the proper methodology is employed when using electric, nonelectric, detonating cord, and time fuse during this critical stage and that they are according to the quarrying techniques since they vary from combat demolition missions.

PRIMING

9-1. There are various methods of priming powder columns; cap sensitive, water gels and emulsions, dynamite, cast boosters, and binary boosters are some of them. Priming charges with shock tube components are the preferred methods for quarry operations.

DYNAMITE PRIMING

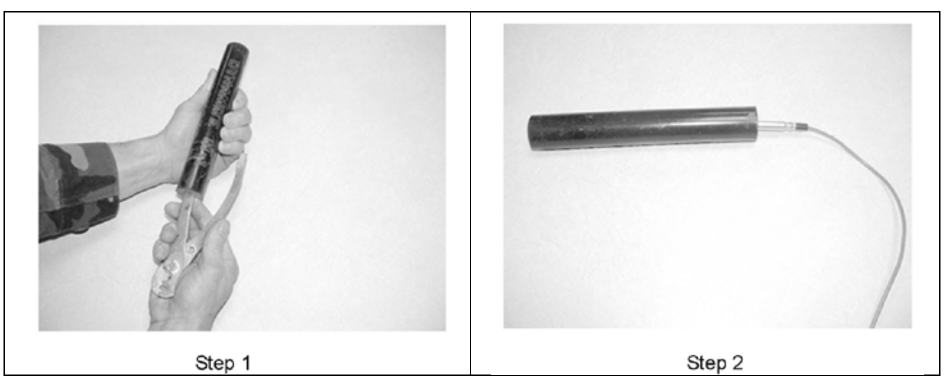
9-2. The method for constructing a field-expedient booster charge using a shock tube with dynamite is as follows:

- ***Step 1.*** Use crimpers to make a cap well in the end of the product using crimpers.
- ***Step 2.*** Insert a blasting cap into the cap well.
- ***Step 3.*** Secure the blasting cap by tying a half hitch with the shock tube. Locate the half hitch a distance equivalent to 1/3 the length of the product up from the blasting cap.

Note. *Tape or other fasteners listed in service directives may be used to secure the shock tube to the product in lieu of half hitches*

- ***Step 4.*** Secure a second half hitch a distance equivalent to 2/3 the length of the product up from the blasting cap.
- ***Step 5.*** Secure the shock tube to the product using electrical tape. The method for constructing a field-expedient booster charge using a shock tube with dynamite is as follows (see figure 9-1):

Note. Ensure that the shock tube is centered in the booster charge.



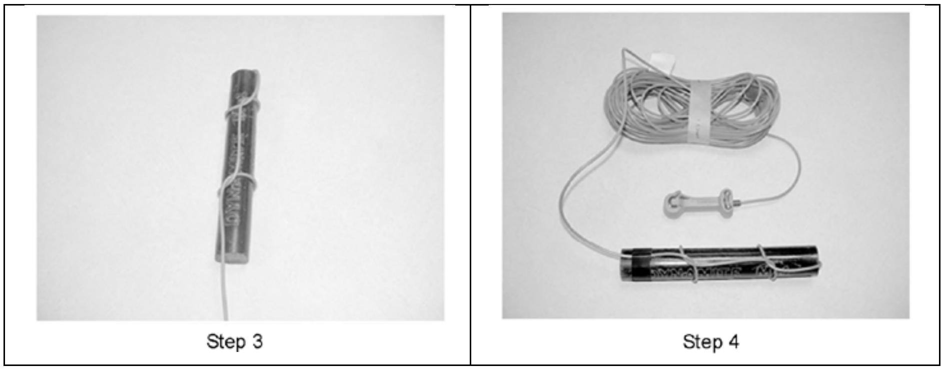


Figure 9-1. Priming dynamite with shock tube

9-3. The method for priming cap-sensitive water gel and emulsion products is as follows:

- ***Step 1.*** Use crimpers to make a cap well in the end of the product using crimpers.
- ***Step 2.*** Insert a blasting cap into the cap well.
- ***Step 3.*** Secure the blasting cap by tying a half hitch with the shock tube. Locate the half hitch a distance equivalent to 1/3 the length of the product up from the blasting cap.

Note. Tape or other fasteners listed in service directives may be used to secure the shock tube to the product in lieu of half hitches

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- ***Step 4.*** Secure a second half hitch a distance equivalent to 2/3 the length of the product up from the blasting cap.
- ***Step 5.*** Secure the shock tube to the product.

9-4. The method for priming cast/binary boosters is as follows:

- ***Step 1.*** Identify the cap well.
- ***Step 2.*** Locate the hole that is on the end opposite of the cap well, and insert a blasting cap through that hole. This step establishes a dual primed system. (cast boosters only).
- ***Step 3.*** Insert the blasting cap into the cap well.
- ***Step 4.*** Pull the shock tube tight (cast boosters only). Secure the blasting cap by tying a half hitch with the shock tube (for binary). Locate the half hitch a distance equivalent to 1/3 the length of the product up from the blasting cap.

Note. Tape or other fasteners listed in service directives may be used to secure the shock tube to the product in lieu of half hitches

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- ***Step 5.*** Secure the shock tube onto the product.

LOADING

9-5. Column loading (see figure 9-2) is the typical method for loading boreholes. These boreholes do not contain imperfections (cracks, seams, voids). Use the following steps to load boreholes:

- ***Step 1.*** Clean debris from around the collar.
- ***Step 2.*** Inspect the loading pole, to include the tip, and remove small rock chips that are clinging to it. Insert the loading pole the depth of the borehole to ensure that the hole does not contain debris or water or has not collapsed. If there is dirt, debris, or water, blow it out using compressed air.
- ***Step 3.*** Place 3 to 6 inches of soft-material padding (sand, drill cuttings) on the bottom of the hole to protect the primer.
- ***Step 4.*** Inspect the loading pole, to include the tip, and remove small rock chips that are clinging to it. Insert the primer into the borehole, and seat the primer at the bottom of the hole.

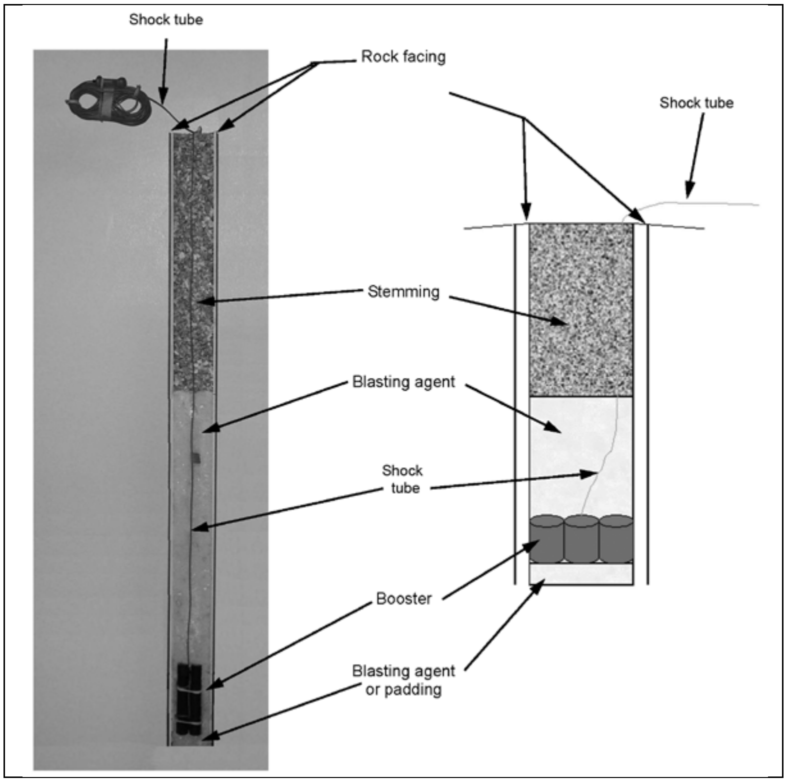

Figure 9-2. Column loading

- ***Step 5.*** Inspect the loading pole, to include the tip, and remove small rock chips that are clinging to it. Load the explosive into the borehole. If using a free-flowing product, monitor the amount of explosive to ensure that a crack, seam, or void was missed during drilling. If using packaged products, after every other package press or seat to ensure that good contact is maintained among explosives. Continue loading and seating charges in the borehole until the amount of explosive per the blast design is loaded.
- ***Step 6.*** Stem the borehole per the blast design.

DECK LOADING (DECKING)

9-6. Decking or intermittent loading is the method of using stemming material to bypass imperfections (cracks, seams, voids) discovered during drilling. Allowing cracks and voids to fill with explosives is extremely dangerous. Decking is also used to separate explosives within the borehole to more equally distribute the blast agent and to help control the vibrations associated with blasting. Possible decking materials include crushed rocks, borehole plugs, plastic bottles, or other inert material that control the product. When decking, a separate delay and booster must be used for each deck. (See figure 9-3, page 9-4.)

9-7. As a rule of thumb when decking to control vibration, the amount of decking for dry holes should be 6 times the diameter of the borehole and the amount of decking for wet holes should be 12 times the diameter of the borehole. The reason for the increased distance for wet holes is that wet materials transfer shock much better and may cause sympathetic detonation or dead pressing problems.

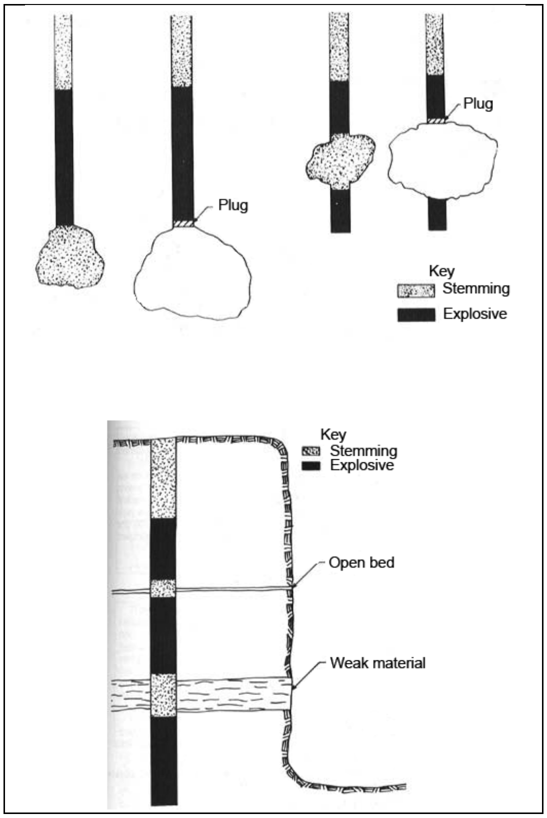

Figure 9-3. Borehole defects

9-8. Deck-load boreholes (figure 9-4) with detonating cord or primers and explosives as follows:

- ***Step 1.*** Clean debris from around the collar.
- ***Step 2.*** Inspect the loading pole, to include the tip, and remove small rock chips that are clinging to it. Insert the loading pole the depth of the borehole to ensure that the hole does not contain debris or water or has not collapsed. If there is dirt, debris, or water, blow it out using compressed air. If the borehole has collapsed, redrill it if the hole can be reached without driving on pattern.
- ***Step 3.*** Place 3 to 6 inches of soft-material padding (sand, drill cuttings) on the bottom of the hole to protect the primer.
- ***Step 4.*** Inspect the loading pole, to include the tip, and remove small rock chips that are clinging to it. Insert the primer into the borehole, and seat the primer at the bottom of the hole.

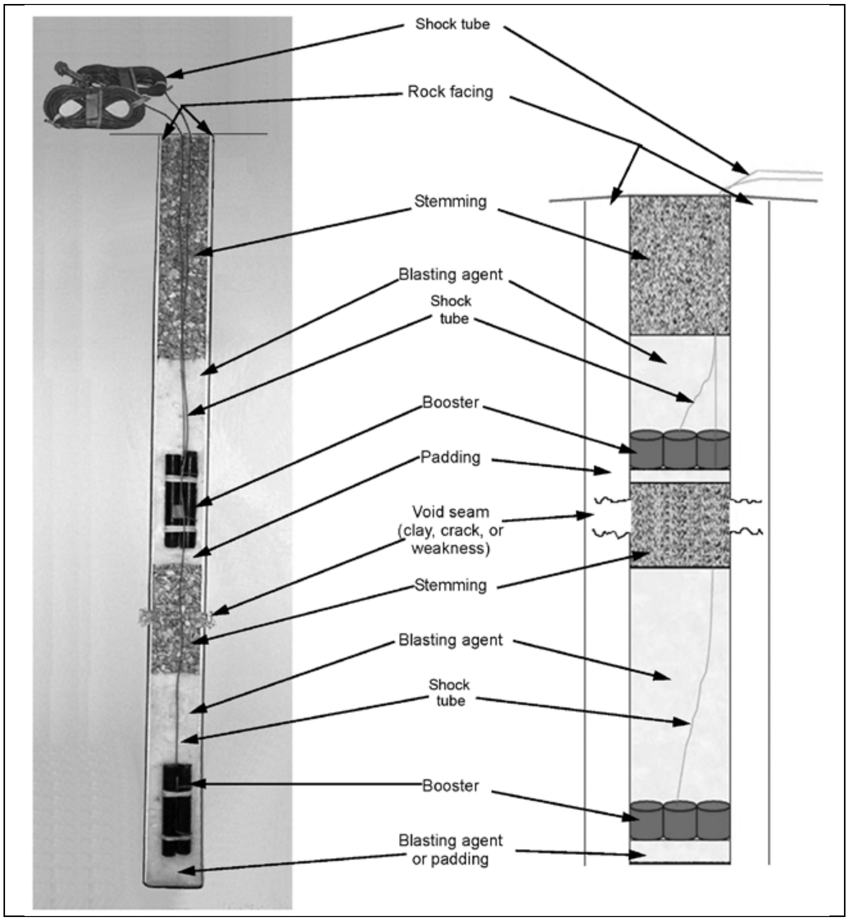

Figure 9-4. Deck loading

- ***Step 5.*** Inspect the loading pole, to include the tip, and remove small rock chips that are clinging to it. Load explosive into the borehole. Continue loading and seating charges in the borehole until the amount of explosive per the blast design is loaded below the crack, seam, or void. If using packaged products, press or seat after every other package to ensure good contact is maintained among explosives.
- ***Step 6.*** Fill the borehole with stemming material, following the rule of thumb for stemming, at a minimum of 6 inches before and 6 inches past the crack, seam, or void.
- ***Step 7.*** Repeat Steps 1 through 5 until the amount of explosive per the blast design is loaded.
- ***Step 8.*** Stem the borehole per the blast design.

NONELECTRIC INITIATING SYSTEMS

9-9. A nonelectric system uses a nonelectric blasting cap as the initiator. The initiating set consists of a fuse igniter (which produces the flame that ignites the time blasting fuse), a time blasting fuse (that transmits the flame that fires the blasting cap), and a nonelectric blasting cap (which provides adequate shock to detonate the explosive) (figure 9-5, page 9-6).

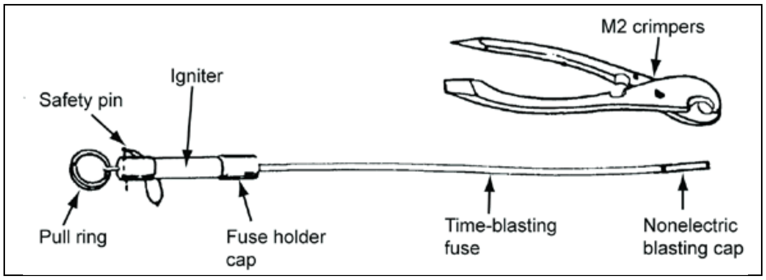

Figure 9-5. Nonelectric initiating set

WARNING

Inspect the nonelectric blasting cap by looking into the open end to ensure no foreign material is present inside the cap. A yellow-colored ignition charge should be seen inside the nonelectric blasting cap.

9-10. Preparing demolitions for nonelectric initiation requires specified processes as follows:

- ***Step 1.*** Cut 6 inches off the end of the time fuse.
- ***Step 2.*** Conduct a test burn to establish a burn rate.
- ***Step 3.*** Determine the burn time required, and cut to length.
- ***Step 4.*** Attach the fuse igniter.
  - Grasp the fuse with with your thumb and ring finger while applying slight pressure with your forefinger on the closed end of the cap.
  - Use your opposite hand is used to grasp the crimpers. Place the crimping jaws around the cap at a 1/8 to 1/4 inch from the open end. Ensure that you thumb and ring finger holding the fuse are below the crimpers. Rest the second finger of your hand holding the fuse is rested on top of the crimpers to prevent the crimpers from sliding up the cap.
  - Point the fuse is pointed away from your body and away from other personnel.
  - Firmly squeeze the crimper handles together, and inspect the crimp when finished.

WARNING

To avoid cap detonation, crimp blasting caps 1/8 to 1/4 inch from the open end of the cap. Failure to comply could result in immediate personal injury or damage to equipment.

- ***Step 5.*** Attach the nonelectric blasting cap the end of the time fuse. See service specific guidance for attaching techniques.

Note. Do not remove the safety pin until the charge is ready to be detonated.

Note. Protect the joint between the cap and the time blasting fuse with a coat of sealing compound or a similar substance if the blasting cap is to remain in place days before firing. This sealing compound does not make a waterproof seal

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FUSE INITIATION

9-11. To fire the assembly, hold the M60 or M81 igniter in one hand and then remove the safety pin with the other. While grasping the pull ring, give it a quick, hard pull. In the event of a misfire, reset the M60 or M81 by pushing the plunger all the way in (for the M60 only, rotate it left or right 180°), and attempt to fire as before.

9-12. If a fuse igniter is not available, light the time blasting fuse with a match. The fuse at the end (figure 9-6), and place the head of an unlit match in the powder train. Light the inserted match head with a flaming match, or rub it against the abrasive on the matchbox. It may be necessary to use two match heads during windy conditions.

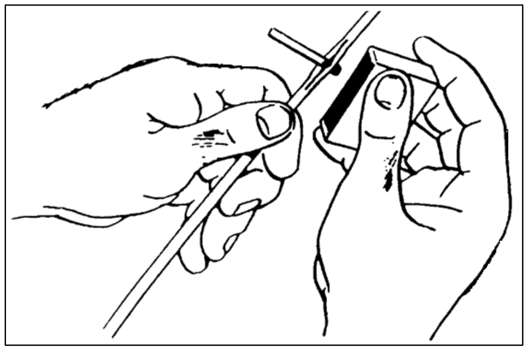

Figure 9-6. Lighting a time fuse with a match

ELECTRIC COMPONENTS ASSEMBLY

9-13. An electric system uses an electric blasting cap as the explosion initiator. The initiating set consists of an electric blasting cap, the firing wire, and a blasting machine (figure 9-7). An electric impulse (usually provided by a blasting machine) travels through the firing wire and blasting cap leads, detonating the blasting cap, which initiates the explosion. Radio waves can also detonate electric blasting caps. A single initiating set can be used to initiate the detonating cord or multiple charges. TM 9-1375-213-34&P provides detailed information about electric blasting equipment.

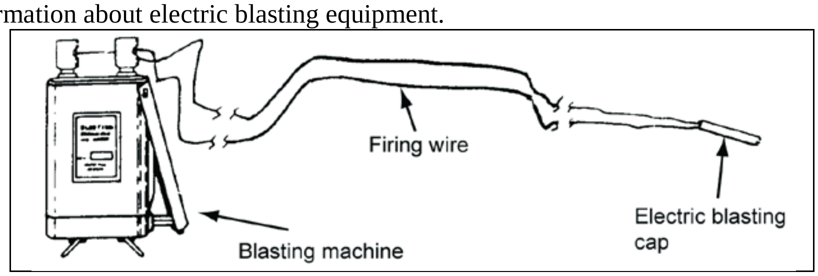

Figure 9-7. Electric initiating set

9-14. The blasting machine should not be connected until personnel are accounted for and clearance is received to fire the demolition. When personnel are clear, call “Fire in the Hole” three times, install the blasting machine, and initiate the demolition.

ELECTRIC INITIATING SETS

DANGER (ARMY) WARNING (NAVY/AIR FORCE)

Use proper grounding procures when working with electric blasting caps and electric circuits. This will prevent premature detonation of the blasting cap of explosive charges.

9-15. Use the following steps to make an electric initiating set:

- ***Step 1.*** Test and maintain control of the blasting machine.
  - Test the blasting machine to ensure that it is operating properly.
  - Control access to blasting machines (responsibility of the head blaster).
- ***Step 2.*** Test the firing wire on the reel (shunted and unshunted). Separate the firing wire leads at both ends, and connect the leads at one end to the posts of the test set. Squeeze the test set handle.
- ***Step 3.*** Lay out the firing wire from the charges to the firing point after locating a firing point. Ensure that this firing point is located a safe distance away from the charges.
- ***Step 4.*** Retest the firing wire (shunted and unshunted).
  - Perform the open- and close-circuit tests again. Ensure that the process of unreeling the wire did not separate broken wires not found when the wire was tested on the reel.
  - Guard the firing position continually from this point on. Ensure that no one tampers with the wires or fires the charges prematurely.
  - Shunt both ends of the firing wire after completing the tests.
- ***Step 5.*** Secure blasting caps under a sand bag or make a hole in the ground using the pointed end of the crimpers and place blasting cap into hole. This will present injury in the event that the blasting cap detonates during testing for continuity. The operator should always have their back to the blasting cap during the test and the lead wires to the cap should be fully extended in order to ensure they are as far away from the blasting cap as the wires will allow. Test the electric blasting caps. Ensure that the cap wires are kept shunted when not testing them.
- ***Step 6.*** Connect the firing wire to the leg wire, and protect the open wire from grounding.

WARNING

Priming the charges with the electric blasting cap is the last step prior to moving to the safe area/initiation point.

- ***Step 7.*** Prime the charges, and return to the firing point. Perform this as the last step before returning to the firing point and firing the circuit.

WARNING

Prime the charges with the minimum number of personnel onsite. Failure to comply could result in immediate personal injury or damage to equipment.

DETONATING CORD FIRING SYSTEMS

9-16. A firing system uses detonating cord to transmit a shock wave from the initiating set to the explosive charge. Detonating cord is versatile and easy to install. It is useful for underwater, underground, and aboveground blasting because the blasting cap of the initiating set may remain above water or aboveground and does not have to be inserted directly into the charge. Detonating cord firing systems combined with detonating cord priming are the safest and most efficient ways to conduct military demolition missions. Nonelectric or electric initiating sets should be used to initiate detonating cord. The two types of detonating cord firing systems are the single firing system and the dual firing system.

WARNING

Never attach an M60 or M81 igniter to the high-strength cap shock tube, or detonating cord. Failure to comply could result in immediate personal injury or damage to equipment.

SINGLE FIRING SYSTEM

9-17. Each charge is single-primed with a branchline. The branchline is tied to the line main or ring main. Tying to the ring main is preferred, but construction of a ring main may not be possible because of the amount of detonating cord. The ring main decreases the chances of a misfire if a break or cut occurs within the ring main. The electric, nonelectric, or combination initiating sets are taped onto the firing system. When using a combination initiating set, the electric initiation system is always the primary means of initiation. When using dual, nonelectric initiating sets, the shorter time fuse is the primary initiating set.

DUAL FIRING SYSTEM

9-18. Each charge is dual-primed with two branchlines. One branchline is tied to one firing system, and the other branchline is tied to an independent firing system. Line mains or ring mains may be used; however, they should not be mixed. Detonating cord will be used as crossovers. Crossovers are used to tie both firing systems together at the ends. The initiating sets are taped in with the primary initiating set going to one firing system and the secondary initiating set going to the other firing system.

ATTACH THE BLASTING CAP

9-19. Prepare electric and nonelectric blasting caps and firing circuits per paragraph 9-10 and 9-15, respectively. With tape, attach the electric or nonelectric blasting cap to the detonating cord. String, cloth, or fine wire can be used if tape is not available. To overcome moisture contamination, tape the cap securely to a point 6 inches from the end of the detonating cord. The tape must not conceal either end of the cap. Taping in this way allows cap inspection in case of misfire. No more than 1/8 inch of the cap needs to be left exposed for inspection (paragraph 9-10).

DETONATING CORD CONNECTION

9-20. Use square knots or detonating cord to splice the ends of the detonating cord (figure 9-8). Always reinforce the splice with tape. Square knots may be placed underwater or underground, but the cord must be detonated from a dry end or aboveground. To prevent misfires from moisture contamination, allow 6-inch tails on square knots.

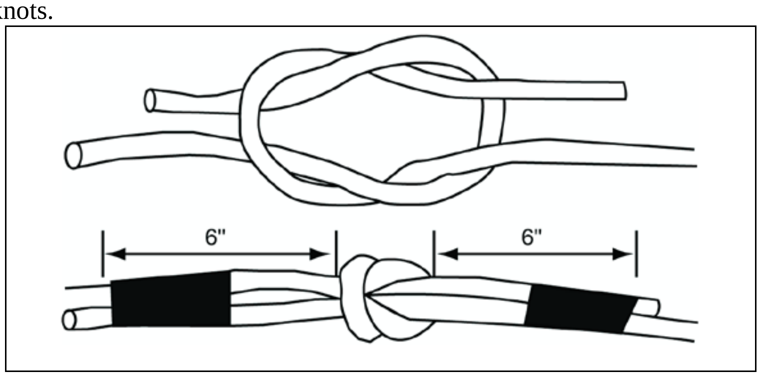

Figure 9-8. Square knot connections for detonating cord

RING MAIN (SAFETY LOOP)

9-21. Ring mains are preferred over line mains because the detonating wave approaches the branchlines from two directions. The charges will detonate even when there is a break in the ring main. A ring main will detonate an unlimited number of charges. Branchline connections to the ring main should be at right angles. Kinks in the lines should not be sharp. Branchlines can be connected to the ring main; however, never connect a branchline (at the point) where the ring main is spliced. When making branchline connections, avoid crossing lines. If a line crossing is necessary, provide at least 1 foot of clearance between the detonating cords. Otherwise, the cords may cut each other and may destroy the firing system. The methods below describe how to make a ring main (figure 9-9, page 9-10).

- **Method 1.** Make a ring main by bringing the detonating cord back in the form of a loop, and attach it to itself.
- **Method 2.** Make a ring main by making a U shape with the detonating cord, and attach a detonating cord crossover at the open end of the U.

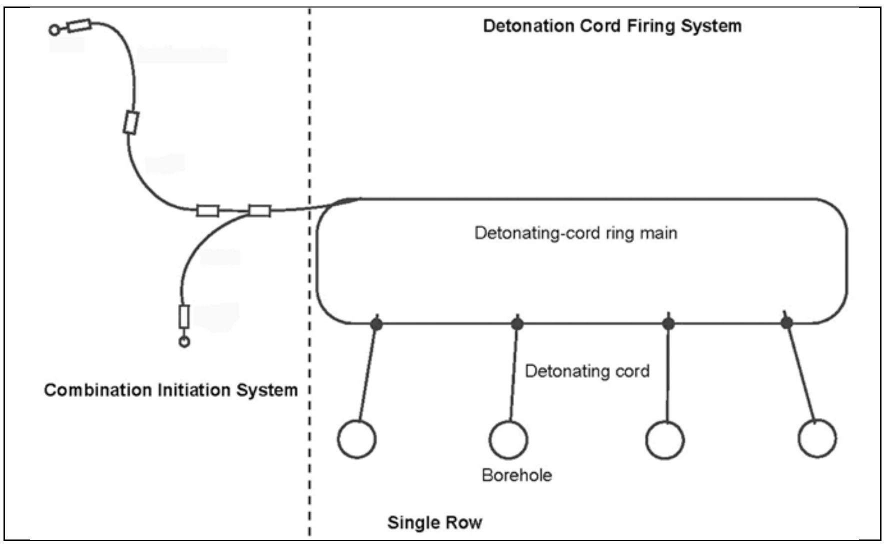

Figure 9-9. Ring mains

FIRING SYSTEM

9-22. The two types of firing systems are the single-initiated and dual-initiated.

NONELECTRIC INITIATION SYSTEM

9-23. When using shock tube—

- Connections with other initiation devices are secured in a manner that provides uninterrupted propagation.
- Connections between blast holes are not made until immediately prior to clearing the blast site when surface delay detonators are used.

9-24. When the nonelectric initiation system uses detonating cord—

- The line of detonating cord extending out of a blast hole is cut from the supply spool immediately after the attached explosive is correctly positioned in the hole.
- In multiple row blasts, the trunkline layout is designed so that the detonation can reach each blast hole from at least two directions.
- Connections are tight and kept at right angles to the trunkline.

- Detonators are attached securely to the side of the detonating cord and pointed in the direction in which detonation is to proceed.
- Connections between blast holes are not made until immediately prior to clearing the blast site when surface delay detonators are used.
- Lead-in lines are manually unreeled if connected to the trunk lines at the blast site.

ELECTRICAL SYSTEM

9-25. Initiation systems should be used according to the manufacturer's instructions.

FIRING SYSTEM

9-26. Thoroughly reconnoiter the pattern site before loading the boreholes (figure 9-10). Use the following steps to reconnoiter the site:

- ***Step 1.*** Identify the firing point and observe the safe distances.
- ***Step 2.*** Load the boreholes according to the shot record.
- ***Step 3.*** Begin loading the boreholes farthest from the firing point and protect the surface cap.

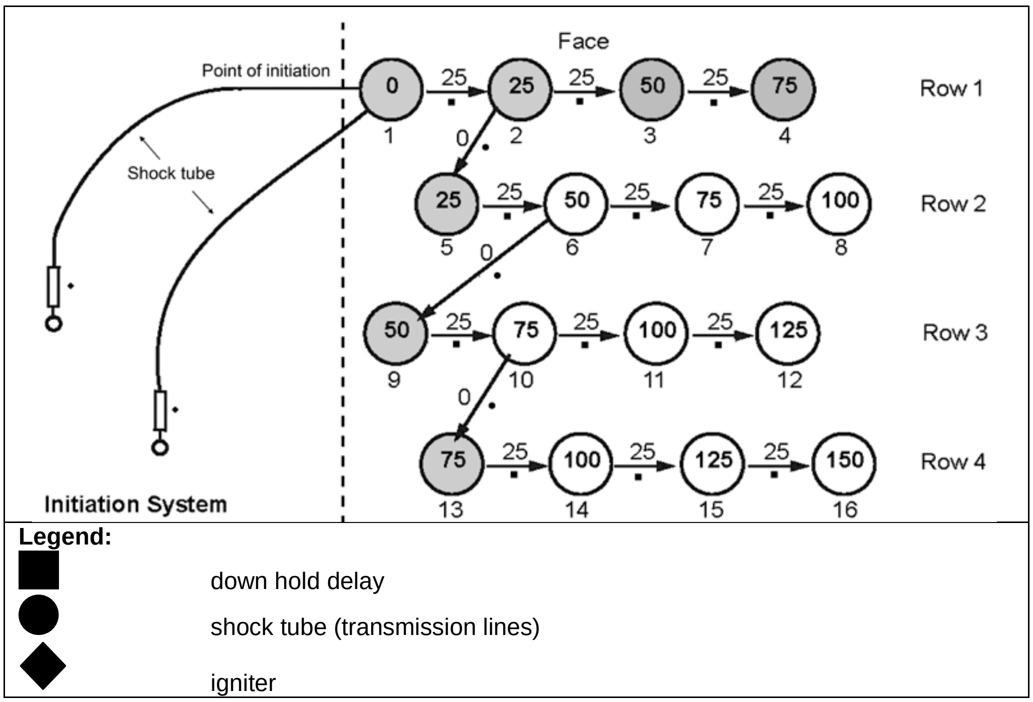

Figure 9-10. Staggered-pattern, shock tube firing system and initiation system

9-27. Assemble a nonelectric firing circuit with shock tube as follows:

- ***Step 1.*** Select one of the front-row end holes as the first hole. This hole will be the start point.
- ***Step 2.*** Connect the surface cap from the first hole to the shock tube in the second hole of the same row.
- ***Step 3.*** Continue this process for the entire length of the row.
- ***Step 4.*** Repeat steps 1, 2, and 3 for each additional row.
- ***Step 5.*** Connect Hole 2 of Row 1 with Hole 1 of Row 2 using a cap holder.
- ***Step 6.*** Repeat step 5 for each additional row.
- ***Step 7.*** Visually inspect the connections before initiation of the charges for problems that might cause a misfire.

9-28. Initiate the system as follows:

- ***Step 1.*** Attach the shock tube of the surface blasting cap in Hole of Row 1.
- ***Step 2.*** Unreel the shock tube to the firing point.
- ***Step 3.*** Return to the firing point, and initiate the system using the procedures previously discussed.

9-29. After successful initiation of the firing system one individual, preferably the head blaster, will proceed to the explosive site and conduct a survey to ensure all explosive material has been consumed. One other operator should accompany the head blaster from a safe distance as a safety backup during the survey. Once the head blaster confirms that all explosive material has been consumed he/she can signal all other operators to enter the detonation point. If explosive residue or material is found the head blaster should notify all operators of the situation and prepare a plan to remove and dispose of the explosive residue and material. The head blaster is responsible for ensuring proper disposal of the residue. The used shock tube and blasting caps are not recyclable and may be sent directly to an approved landfill.

Chapter 10

Secondary Breakage

Secondary breakage is required when primary blasting fails to produce rock that is small enough to handle. This requirement can be reduced considerably by properly calculating the charge, packing the hole, and deck loading. Normally, boulders are dozed out of the way to be broken later to permit personnel and equipment to resume work. Perform secondary breakage by using a mechanical means or light blasting. Perform secondary blasting by snakeholing, blockholing, mud capping, or hydrobreaking.

MECHANICAL MEANS

10-1. Use mechanical means for secondary breakage. Mechanical means will reduce the dangers involved with secondary blasting (fly rock, time delays for clearing the area, the inability to control the size of resultant pieces).

LIGHT BLASTING

10-2. Boulder blasting includes loosening shallow or small outcrops of rock and breaking boulders. It may require that the entire job be done in connection with or while excavating, or it could be a follow-up to a heavy blast which has failed to cut to grade or slope lines or left chunks of rock that are too large to move or load into the crusher. Methods of light blasting include the following:

- **Snakeholing.** Snakeholing consists of boring an inclined hole with a drill or crowbar beneath and against the bottom of a boulder and firing a charge in it. (See figure 10-1.)

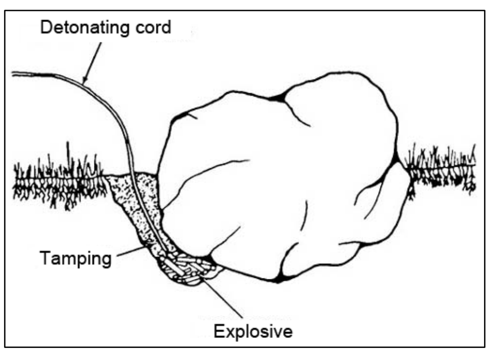

Figure 10-1. Snakehole method of blasting rock

- **Blockholing.** Blockholing is sometimes called *chip blasting.* It consists of drilling a borehole to a depth of about 1/3 the diameter of the boulder. Prime the charges, and place them at the bottom of the hole. Seat the stemming into the rest of the hole, and fire the charge. This method is usually the cheapest and most efficient way of reducing oversized rock by means of blasting. An even more effective method is to remove the explosive from the cartridge and pack it tightly against the stone. (See figure 10-2, page 10-2.)
- **Mudcapping.** The mudcap method of blasting rock is the easiest and quickest method of blasting rock and is the best method for hard, round stones, but it requires the most explosive and cannot be used underwater. In mudcapping, the charge is placed on top of the rock and covered with a shovel full of mud or moist earth. The best location for placing the charge is at a weak looking

point, where one would normally try to shatter the rock with a hammer. Take advantage of seams or depressions. The detonation of the charge gives a downward push effect, with little scatter of rock particles. Because the mudcap has little confining effect, much of the energy of the explosion is dispersed into the air and is lost. (See figures 10-3 and 10-4.) Use table 10-1 identifies boulder-blasting charges to determine the size of the charge needed.

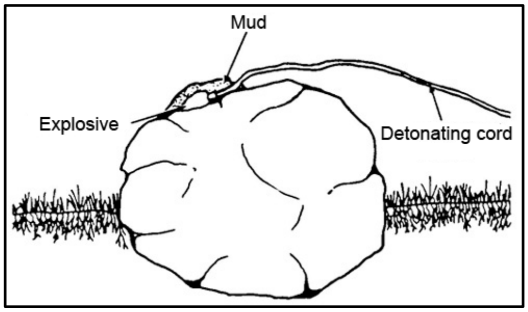

Figure 10-2. Mudcap method of blasting rock

Table 10-1. Boulder blasting charges

Boulder Diameter (In Feet) Pounds of Explosive Required	***Pounds of Explosive Required***		
	Blockholing	***Snakeholing***	***Mud Capping***
1 1/2	1/8	1/2	1
2	1/8	1/2	1 1/2
3	1/4	3/4	2
4	3/8	2	3 1/2
5	1/2	3	6

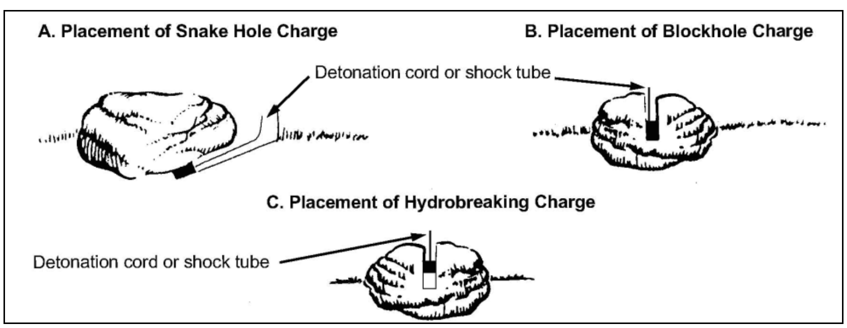

Figure 10-3. Boulder blasting

- **Hydrobreaking.** Hydrobreaking allows for boulder eradication in congested areas at an economical cost (figure 10-4). Determine the boulder size as follows:

$$L \times W \times H \div 27 = yards^3$$

where—
L = length (in feet)
W = width (in feet)
H = height (in feet)

  - ***Step 1.*** Drill a borehole to in the center and from the top a depth that is equivalent to 2/3 the height of the boulder (figure 10-4).

- ***Step 2.*** Begin with a powder factor that is equivalent to 0.25 pound of explosives per 10 cubic yards of boulder.
- ***Step 3.*** Place the charge at 1/3 the height of the boulder. For example, if the boulder is 12 feet high, drill an 8-foot hole in the center from the top. Place the charge 4 feet from the top.
- ***Step 4.*** Fill the borehole with water.
- ***Step 5.*** Fire the charge.

Note. When breaking boulders that are not symmetrical in shape, multiply the powder factor by the width:height ratio.

WARNING

Exercise extreme caution to ensure that no explosive from the primary blast remains in the rock being drilled. Fragments may be thrown for long distances, so protection should be provided for the blaster and support personnel. Failure to follow the correct procedure may result in immediate personnel injury or damage to equipment.

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Chapter 11
Blasting Safety

Fragments thrown by an explosion are a greater danger to personnel than the blast effect (an increase in air pressure). The blast effect is a hazard only on occasions when special protective features are used at detonation or demolition sites to eliminate flying debris or confine fragments and to provide for the detonation of charges close to personnel. Personnel who are provided the minimum protection prescribed will not generally be endangered by blast effects (per Service-specific regulatory guidance).

WARNING

Personnel close to explosions may experience permanent hearing loss or other injury from the pressure wave caused by the explosions. Hearing protection should be worn during blasting operations.

CAUTION

Always practice individual grounding procedures when working with electric caps and electric firing systems.

FRAGMENTATION HAZARD

11-1. Explosives can propel lethal fragments great distances. How far an explosion-propelled fragment will travel in air depends primarily on the relation between weight, shape, density, initial angle of projection, and initial speed. The fragmentation hazard from steel-cutting charges extends a greater distance under normal conditions than that from quarrying or surface charges of bare explosives.

PACKAGE CARE AND REPAIR

11-2. Careless, rough handling and disregard for safety rules may cause premature explosions, misfires, and serious accidents. Pack issued explosives and auxiliary items in moisture-resistant containers and proper packing boxes to withstand field conditions of transportation and storage. Do not handle containers and boxes roughly; they must never be broken, cracked, or dented. Some items, if distorted, lose part of their effectiveness. Repair damaged packing boxes and containers immediately. All explosives and packing material must be removed from the container prior to repair. All repair operations must not occur in explosives storage locations and all explosives must be removed from the container prior to repair. Transfer defaced parts of marking to new parts of the boxes. Destroy broken airtight containers.

MALFUNCTION REPORTS

11-3. Identify explosives by lot number. If frequent misfires, failures, or malfunctions occur, note the lot number of the item and report the incident according to Service regulatory guidance.

HANGFIRES

11-4. Hangfires occur when the explosive material in a borehole begins to burn, which can result in an explosion. A possible cause of burning explosive material is the arcing of a delay electrical detonator. Using energy-limiting firing switches or capacitor discharge blasting machines can eliminate arcing.

DANGER

Do not approach burning explosives/bore holes. Wait at least 60 minutes after all evidence of burning has ceased. Inspect the site and follow service-specific procedures to dispose of any remaining explosive hazards.

MISFIRES

11-5. A misfire is a malfunction of the firing circuitry or blasting cap (no secondary explosives were initiated). When a misfire cannot be disposed of safely, follow the Service-specific procedures for proper disposal.

11-6. Faces and muck piles must be examined for misfires after each blasting operation. Only work necessary to remove a misfire and protect the safety of personnel engaged in the removal are permitted in the affected area until the misfire is disposed of in a safe manner. When a misfire cannot be disposed of safely, follow the service-specific procedures for proper disposition.

DANGER

Misfire, Electric – wait 30 minutes before approaching. Then cut the blasting cap wires and shunt them. Test a new blasting cap, connect to the circuit and place in the charge. Do not remove original blasting cap. Depart to a safe area and detonate.

Misfire, Non-electric – wait 60 minutes before approaching. Then insert and initiate a new non-electric blasting cap / set up. Do not remove original blasting cap. Depart to a safe area and detonate.

SAFETY PRECAUTIONS

11-7. General safety precautions include the following:

- Determine the MSD based on formulas presented in DoD 6055.09-M.
- Maintain the MSD between electromagnetic-radiating sources and electro-explosive devices as prescribed in Service-specific regulatory guidance.
- Always use the preferred, nonelectric firing system for conducting blasting operations when an electromagnetic radiation hazard is present.
- Always observe applicable safety precautions during training with inert material to promote safe operating procedures for use with live items.
- Always use service-specific approved demolition/blasting equipment.
- Always evacuate personnel, in response to explosives-related emergencies, to a safe location, and guard the vacated area against intruders.
- Always store and handle explosives per DoD 6055.09-M, *DoD Ammunition and Explosives Safety Standards, DoDI 6055.16, Explosives Safety Management Program,* and as prescribed in Service-specific regulatory guidance.

- Never conduct blasting operations during an electrical, dust, sand, or snow storm of a severity great enough to produce atmospheric static electrical charges or when such a storm is nearby (about 10 miles). Under such conditions, operations will be suspended, cap and lead wires short-circuited, and personnel removed from the blast site. Extraneous electricity should be monitored using a lightning detector.
- Never operate a handheld two-way radio within 50 feet (vehicle radio within 100 feet) of an area in which explosives are being handled or used. All electromagnetic emitting equipment must be verified for electrical voltage transmission safe distance use against the Joint Spectrum Center (JSC) Ordnance Electromagnetic Environmental Effects (E3) Risk Assessment Database (JOERAD).
- Never work with electric blasting caps or other electro-explosive devices while wearing static electricity-producing clothing (nylon, silk, synthetic hair).
- Never ingest explosive material.
- Never get in the smoke of burning explosives. The smoke will penetrate ordinary clothing, and severe dermatitis may result.
- Never inhale the gaseous products of high-explosive detonations. Many of these gases produced are highly toxic.
- Never permit more than the required types and amounts of explosive required for the operation to be brought to the blast site.
- Always carry blasting caps in approved containers, and keep them out of the direct rays of the sun.
- Never handle, use, or remain near explosives during the approach or progress of an electrical storm as prescribed in Service-specific explosives safety regulatory guidance.
- Never use explosives or accessory equipment that is unserviceable.
- Never abandon explosives.
- Never leave explosives, empty cartridges, boxes, liners, or other materials used in the packing of explosives lying around where children, unauthorized persons, or animals can get at them. Fatal or serious accidents can result from such careless practice.
- Never allow wood, paper, or other materials used in packing explosives to be burned in a stove, fireplace, or other confined space or to be used for another purpose. Serious accidents can result. Such materials should be destroyed by burning at an isolated location outdoors. No one should be permitted within a 100-foot radius after burning has started.
- Never fight fires involving explosive materials. Remove personnel to a safe location as prescribed in Service-specific explosives safety regulatory guidance and guard the area (i.e. close approach roads).

SAFE DISTANCES

11-8. Subsurface blasting in quarry operations must be recognized as a totally different process than surface blasting. Most surface blasting has the effect of immediate expansion of material through detonation, which quickly causes items to separate or fragment. However, in quarry operations this is not the case. The old theory of the big boom with lots of explosives is not the goal. That method causes excessive fly rock and creates personnel and equipment hazards that could very easily be avoided by using new blasting products and methods. Through low-detonation, high-yield explosives and new blasting designs, the blaster can now get better blasting results.

11-9. The intent is to use only the amount of explosives needed to cause the shock wave to fracture and produce with enough force to shove the rock out of its current rigid state. This new and safer practice allows the detonation point to occur much closer to the blaster than in previous practices. Because of the reduced explosive force, the safe distance required from the blast can also be reduced, thereby minimizing operating space. This has proven to be invaluable to operations near highway construction or housing sites. The MSD for essential personnel in a missile-proof shelter is 91.4 meters.

11-10. Quarrying is a specialized operation that must be done in accordance with many different standards and requires safety considerations (e.g., ground-shock, charge placement) that are addressed by criteria throughout this publication. MSD criteria established by the below formula is considered conservative for air-blast and fly-rock hazards.

11-11. The NEWQD for quarrying is the sum of all explosive materials loaded into all the bore holes for a specific operation.

11-12. Essential personnel are individuals as identified by the DoD component associated with the explosive operation. Non-essential personnel are identified by the DoD component not associated with the explosive operation.

11-13. Safe Distances for Essential Personnel: Safe Distance for Essential Personnel. These personnel are considered essential and directly related to the explosives operation as determined by the DoD Component. The minimum safe distance for essential personnel will be calculated as D (distance) = 1.5 x NEWQD with a 300' (91.4 meters) minimum separation. When position at distances closer than that prescribed for non-essential personnel, essential personnel must have and use adequate frontal and overhead protection (e.g. a shelter capable of defeating all potential blast debris fragments) for the operation being performed:

Safe distance = 1.5 x net explosive weight of boreholes along open face(s)

Example 1.

500 pounds net explosive weight of explosives
Safe distance = 1.5 x 500 = 750 feet = 1,000 feet (the MSD)

Example 2.

2,000 pounds net explosive weight of explosives
Safe distance = 1.5 x 2,000 = 3,000 feet

11-14. Safe Distances for Non-essential personnel:

- When the NEWQD ≤ 2000 lbs [907.2 kg], the MSD for non-essential personnel will be calculated as D = 1.5(NEWQD) [D(m) = 1.0079Q], with a minimum of 1500 ft [457 m].
- When the NEWQD > 2000 lbs [907.2 kg], the MSD for non-essential personnel will be calculated as D = 328(NEWQD1/3) [D(m) = 130.1Q1/3]

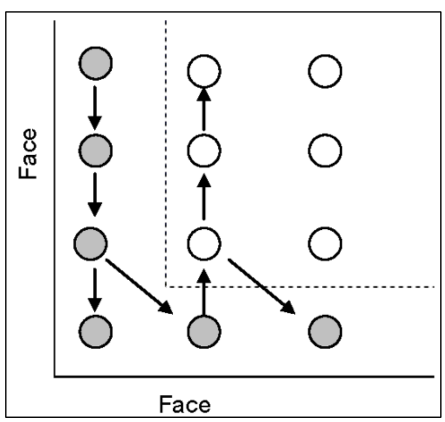

Figure 11-1. Safe distance face diameter (D)

PRIMER PREPARATION

11-15. When preparing the primer—

- Always prepare primers according to the established methods. Ensure that the detonator is completely encased in the explosive and so secured that, in loading, no tension will be placed on the wires, safety fuse, shock tube, or detonating cord at the point of entry into the detonator.

- Always inspect nonelectric blasting caps by looking into the open end to ensure no foreign material is present inside the cap. A yellow-colored ignition charge should be seen inside the nonelectric blasting cap.
- Always test electric caps before using them.
- Never force a detonator into explosive material. Insert the detonator in a hole made with a punch suitable for that purpose.
- Never make up primers in a magazine or near other large quantities of explosive materials and never make more than are necessary for immediate needs.
- Never use sparking metal tools to open explosive containers.
- Never smoke or have matches or another source of fire or flame within 50 feet of an area in which explosives are being handled or used.
- Never place explosives where they may be exposed to flame, excessive heat, sparks, or impact.
- Never replace or close the cover of explosive cases or packages after using the explosives.
- Never carry explosives in clothing pockets or elsewhere on your person.
- Never strike, tamper with, or attempt to remove the contents of a detonator or try to pull the wires of an electric detonator.
- Never allow unauthorized or unnecessary personnel to be present where explosives are being handled or used.
- Never handle, use, or be near explosives during the approach or progress of an electrical storm. Persons should relocate to a place of safety.
- Never use deteriorated or damaged explosives or accessory equipment.
- Never attempt to reclaim or use fuse detonators or other explosives that have been water soaked, even if they have dried out.

DRILLING AND LOADING

11-16. When drilling and loading—

- Recognize the possibility of static electrical hazards and take adequate precautionary measures.
- Carefully examine the surface or face before drilling to determine the possible presence of unfired explosive materials. Never drill into explosive materials or into a hole that has contained explosive materials.
- Ensure that holes are cleaned out before loading.
- Never force explosive materials into a borehole.
- Use tamping poles that are made of wood or nonstatic-producing plastic. Wooden tamping poles are joined with nonferrous metals. Never tamp the primer. Avoid violent tamping, and never churn.
- Do not lean forward when loading or tamping and keep your head and body away from the borehole.
- Never slit, drop, deform, tamp, or abuse the primer, and never drop another cartridge directly on the primer.
- Ensure that the shock tube, lead wires, and detonation cord are not damaged in the process of tamping.
- Never stack more explosive materials than are needed near working area during loading.
- Focus firefighting on preventing fire from reaching the explosives. Once the fire is in the area of explosives, retreat personnel to a safe location and notify proper emergency personnel of the amount and type of explosive and notify the chain of command. Do not fight fires involving explosive materials. Remove personnel to a safe location immediately, and guard the area against intruders.

HANDLING EXPLOSIVE MATERIALS

11-17. When handling explosive materials—

- Always keep explosive materials away from children, unauthorized persons, and livestock. Never use explosive materials unless completely familiar with safe procedures or under the direction of a qualified supervisor.
- Never handle explosive materials during, or during the approach, of an electrical storm. Find a safe location away from the explosive materials, per Service-specific regulatory guidance.
- Never fight fires involving explosive materials. Remove personnel to a safe location and guard the area.
- Never put explosive materials in pockets of clothing.
- Always close partially used packages of explosive materials.
- Always store explosives in their original package.
- Never touch metal fasteners with metal slitters when opening packages of explosive material.
- Never mix different explosives in the same package.
- Never remove explosive material from its package unless it is designed to be used in that manner. Ensure that there are no foreign objects, loose powder, or moisture in a fuse detonator before inserting the safety fuse.
- Never use explosive materials that have been water-soaked, even if they appear to be dried out.
- Never investigate the contents of a detonator.
- Never pull wires, a safety fuse, a shock tube, plastic tubing, or a detonating cord out of a detonator or delay device.
- Never take apart or alter the contents of explosive materials.
- Never expose explosive materials to sources of heat exceeding 150° Fahrenheit or to open flame, unless such materials or procedures for their use have been recommended for such exposure by the manufacturer.
- Never strike explosive materials with, or allow them to be hit by, objects other than those required in loading.
- Never subject explosive materials to excessive impact or friction.

INITIATION SYSTEMS

11-18. When using initiation systems—

- Always test the circuit for continuity and proper resistance using a blasting galvanometer, or an instrument specifically designed for testing electric blast circuits.
- Always fire electric detonators with firing currents in the range recommended by the manufacturer.
- Always keep electric detonator wires or lead wires disconnected from the power source and shunted until ready to test or fire.
- Always keep the firing circuit completely insulated from ground or other conductors.
- Always be sure that wire ends are clean before connecting.
- Never use instruments (such as electrician's meters) that are not specifically designed for testing blasting circuits or detonators.

DANGER

Some electrician's meters produce enough electrical energy to prematurely initiate electric detonators, which can result in injury or death.

- Never mix electric detonators made by different manufacturers in the same circuit.
- Never mix electric detonators of different types in a circuit, even if made by the same manufacturer, unless such use is approved by the manufacturer.
- Never use aluminum wire in a blasting circuit.

- Never make final hookup to a power source until personnel are clear of the blast area.
- Always ensure that shock tubing connections to detonating cord are at right angles to prevent angle cut-offs.
- Always avoid situations where initiation system components can become entangled in machines, equipment, vehicles, or moving parts.
- Always lead the shock tube to the hole in a straight line and keep it taut.
- Always follow the manufacturer’s recommendations when cutting and splicing lead-in trunk line shock tube.
- Never drive vehicles over explosives and/or initiation systems.
- Never tie together two lengths of shock tube. An initiation signal will not pass through a knotted connection.
- Never pull, stretch, kink, or put tension on a shock tube such that the tube could be caused to break or otherwise malfunction.

DETONATING CORD

11-19. When using detonating cord—

- Always use a detonating cord matched to the blasting methods and type of explosive materials being used.
- Always handle the detonating cord as carefully as other explosive materials.
- Always cut the detonating cord from the spool before loading the rest of the explosive material.
- Always use a service-approved instrument designed for cutting detonating cord.
- Always make tight connections, following the manufacturer’s directions.
- Always attach detonators to the detonating cord with tape or methods recommended by the manufacturer.
- Always point the detonators toward the direction of detonation.
- Always attach the cord initiating the detonator at least six inches from the cut end of the detonating cord.
- Never make loops, kinks, or sharp angles in the cord which might direct the cord back toward the oncoming line of detonation.
- Never damage the detonating cord before firing.
- Never attach detonators for initiating the blast to the detonating cord until the blast area has been cleared and secured for the blast.
- Never use damaged detonating cord.

SMOKING AND OPEN FLAMES

11-20. Smoking and use of open flames are not permitted within 50 feet of explosive material except when separated by permanent noncombustible barriers. This standard does not apply to devices designed to ignite safety fuse or to heating devices which do not create a fire or explosion hazard.

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Appendix A

Map Symbols and Outcrop Patterns

This appendix contains symbolic patterns for rock types, geologic map symbols, and various outcrop patterns. (See figure A-1 through A-10, pages A-2 through A-6.)

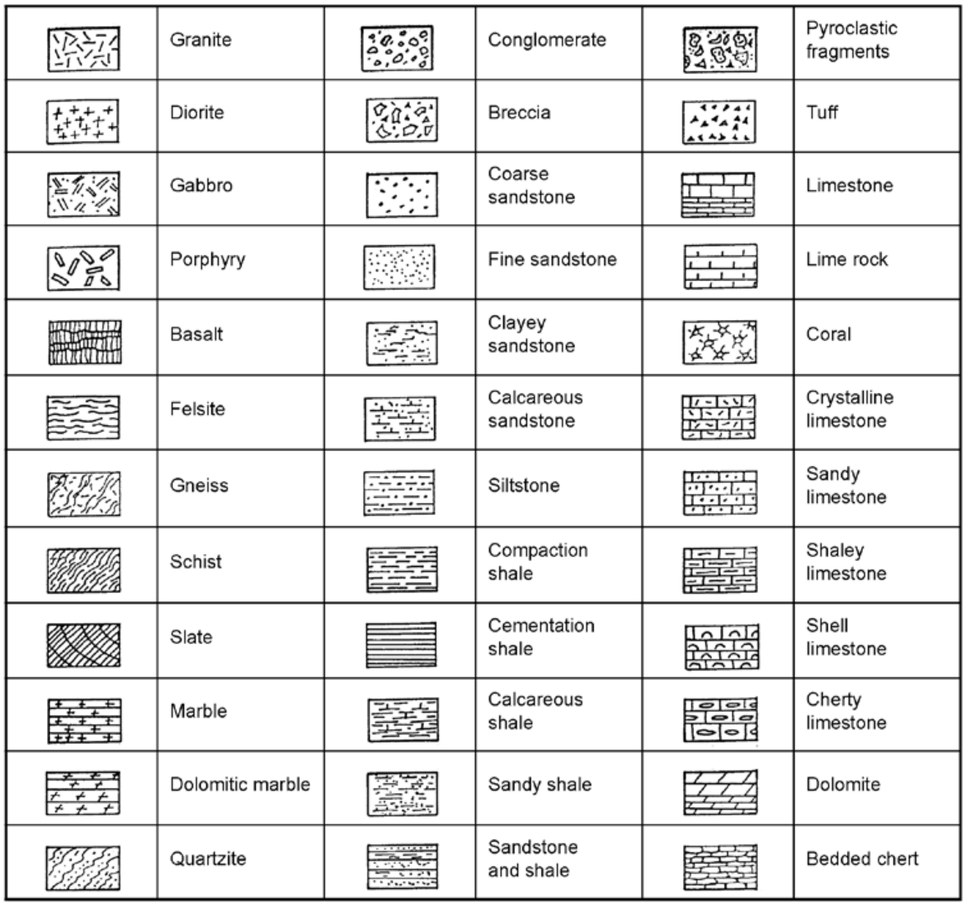

Figure A-1. Symbolic patterns for rock types

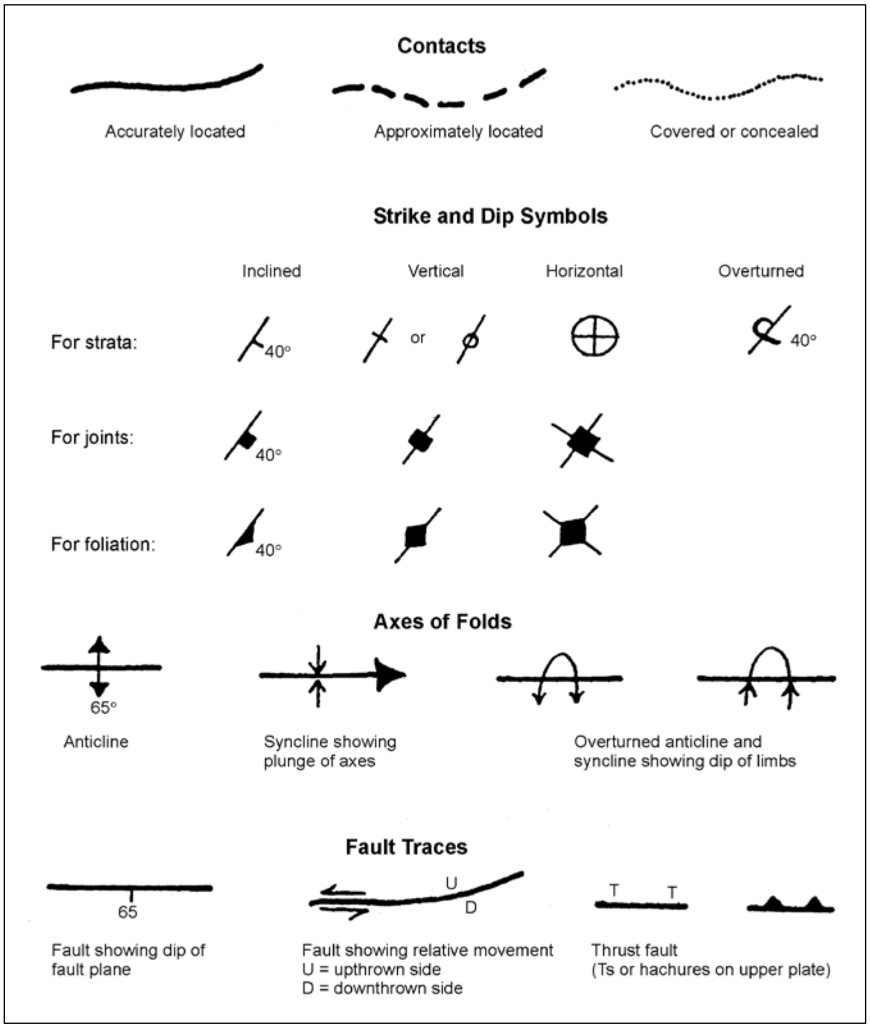

Figure A-2. Geologic map symbols

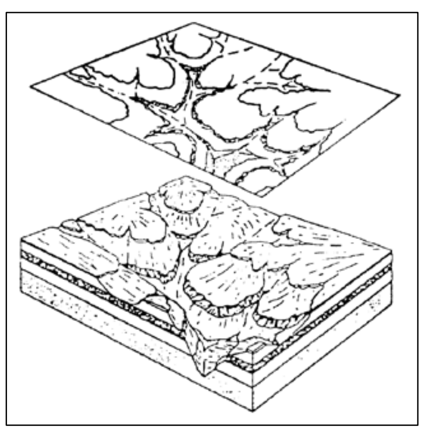

Figure A-3. Outcrop patterns of horizontal strata

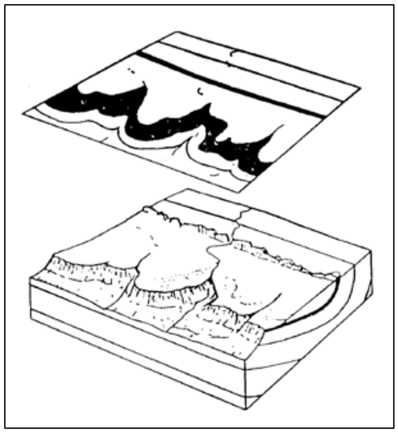

Figure A-4. Outcrop patterns of inclined strata

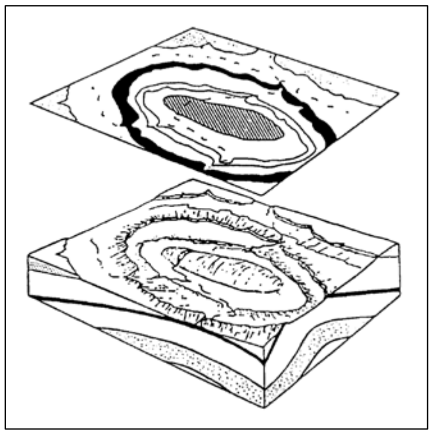

Figure A-5. Outcrop patterns of an eroded dome

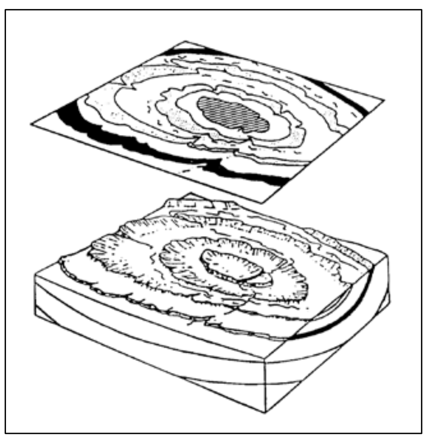

Figure A-6. Outcrop patterns of an eroded basin

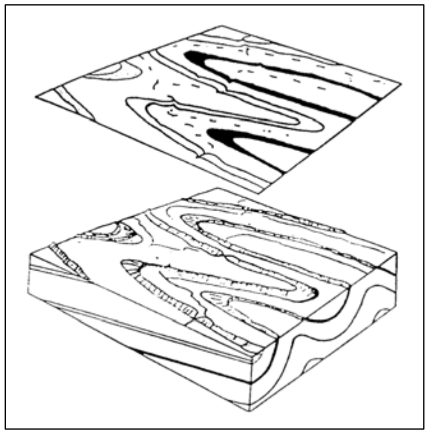

Figure A-7. Outcrop patterns of plunging folds

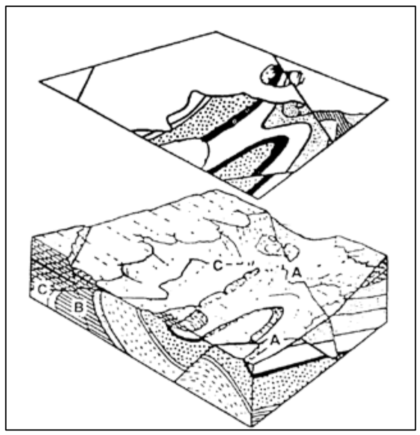

Figure A-8. Outcrop patterns produced by faulting

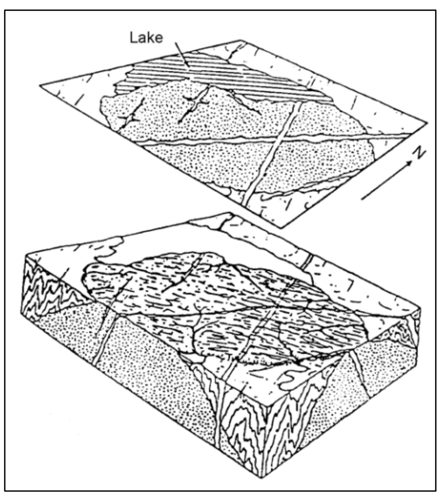

Figure A-9. Outcrop patterns of intrusive rocks

Appendix B

Department of Defense Identification Codes

Table B-1 lists the available DODICs for military explosives. Consult the material safety data sheets for specific details of each explosive.

Table B-1. DODICs

DODIC	*Nomenclature*	*ILO*	*Remarks*
Blasting Caps			
M130	Cap blast electric M6		Replaced by ML47, MN02, MN03, MN07, MN39, MN68, MN69, MN86, MN88, and MN90.
M131	Cap blast nonelectric M7		Used in conjunction with M670, replaced by MN06 and MN41.
M098	Cap blast practice electric		Inert trainer for M130; replaced by MN35, MN36, MN38, MN75, MN87, and MN8.9
M097	Cap blast practice nonelectric	MN37	Inert trainer for M131; replaced by MN37.
Detonators and Firing Devices			
M644	Firing device demolition MK24 Module 2		
MN12	Firing device handheld MK55 Module 0		
Destructors/Destroyers			
M327	Coupling base		Training requirements, use with firing devices.
M455	Detonating cord PETN		
M456	Detonating cord type-1		Mission requirements
M458	Detonating cord inert		Inert trainer
M591	Military dynamite M1		Exhaust stock through training
M671	Fuse blasting time inert		Inert trainer
M670	Fuse blasting time M700		Mission requirements. Being replaced by MN06 and MN41.
M766	Igniter time blasting fuse M60	MN08	Replaced by MN08. Used in conjunction with M131/MN06/MN41.
MM50	Charge demolition shaped clip		

Table B-1. DODICs (continued)

DODIC	Nomenclature	ILO	Remarks
Modern Demolition Initiators			
ML45	Holder blast cap and shock tube, M9		
MN03	Blasting cap 1,000 feet, M13	MN88 MN90	Replaces M130 and is replaced by MN90. Used in conjunction with MN08.
ML47	Blasting cap 30 feet, M11	MN68 MN69	Replaces M130 and is replaced by MN69. Used in conjunction with MN08.
MN02	Blasting cap 500 feet, M12	MN88 MN90	Replaces M130 and is replaced by MN88. Used in conjunction with MN08.
MN06	Blasting cap delay M14 (5 minutes, 7.5 to 8.0 feet)	MN41	Replaces combination of M131and M670. Used in conjunction with MN08.
MN07	Blasting cap delay M15		Quarry item, partially replaces M130.
MN08	Igniter time blasting fuse, with shock tube capability, M81		Replaces M766. Used in conjunction with M131, ML47, MN02, MN03, MN06 and MN41.
MN35	Blasting cap practice shock tube, M12; formerly MZ21	MN89	Replaces M098. Replaced by MN89.
MN36	Blasting cap practice shock tube, M11; formerly MZ22	MN75 MN87	Replaces M098. Replaced by MN75 and MN87.
MN37	Blasting cap practice delay, M14; formerly MZ23		Replaces combination of M097, M458, and M671. Trainer for MN06 and MN41.
MN38	Blasting cap practice delay, M15; formerly MZ24		Training version of MN07; replaces M098.
MN39	Blasting cap nonelectric 10 feet, M16	MN68 ML47 MN69	Replaced by MN68; replaces M130.
MN41	Blasting cap nonelectric delay, M18	MN06	Replaces combination of M131 and M670. Used in conjunction with MN08.
MN68	Booster demolition 10 feet detonating cord, M151	MN69 ML47 MN39	Replaced MN39 and M130.
MN69	Booster demolition 30 feet detonating cord, M152	MN68 ML47 MN39	Replaced ML47 and M130.
MN75	Booster demolition charge practice 30 feet		Trainer for MN69; replaces MN36 and M098.
MN86	Blasting cap, dual, in-line initiator 200 feet shock tube, M19		Replaces M130. This item includes two in-line initiators.
MN88	Blasting cap, in-line initiator 500 feet shock tube, M21	MN02	Replaces MN02 and M130. This item includes an in-line initiator.

MN90	Blasting cap, in-line initiator 1,000 feet shock tube, M23	MN03	Replaces MN03 and M130. This item includes two in-line initiators.
MN80	Receiver radio firing device, M17		SOF unique.
MN87	Blasting cap nonelectric, inert, 200 feet minitube M20		Trainer for MN86; replaces M097 and MN36.
MN89	Blasting cap nonelectric, inert, minitube M22		Trainer for MN88/MN90; replaces M098 and MN35.
Legend: DODIC Department of Defense identification code ILO in lieu of PETN pentaerythrite tetranitrate			

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Appendix C

Calculation Tables

Tables C-1 through C-6, pages C-2 through C-6, may be used for quick reference.

Table C-1. Column loading density (pounds per foot)

Column Diameter (inches)	*Explosive Density (grams per cubic centimeter)*													
	0.80	0.82	0.85	0.90	0.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40
1.00	0.27	0.28	0.29	0.31	0.32	0.34	0.36	0.37	0.39	0.41	0.43	0.44	0.46	0.48
1.25	0.43	0.44	0.45	0.48	0.51	0.53	0.56	0.59	0.61	0.64	0.67	0.69	0.72	0.74
1.50	0.61	0.63	0.65	0.69	0.73	0.77	0.80	0.84	0.88	0.92	0.96	1.00	1.03	1.07
1.75	0.83	0.86	0.89	0.94	0.99	1.04	1.09	1.15	1.20	1.25	1.30	1.36	1.41	1.46
2.00	1.09	1.12	1.16	1.23	1.29	1.36	1.43	1.50	1.57	1.63	1.70	1.77	1.84	1.91
2.25	1.38	1.41	1.47	1.55	1.64	1.72	1.81	1.90	1.98	2.07	2.15	2.24	2.33	2.41
2.50	1.70	1.75	1.81	1.92	2.02	2.13	2.23	2.34	2.45	2.55	2.66	2.77	2.87	2.98
2.75	2.06	2.11	2.19	2.32	2.45	2.58	2.70	2.83	2.96	3.09	3.22	3.35	3.48	3.61
3.00	2.45	2.51	2.60	2.76	2.91	3.06	3.22	3.37	3.52	3.68	3.83	3.98	4.14	4.29
3.25	2.88	2.95	3.06	3.24	3.42	3.60	3.78	3.96	4.14	4.32	4.50	4.68	4.86	5.04
3.50	3.34	3.42	3.55	3.75	3.96	4.17	4.38	4.59	4.80	5.01	5.21	5.42	5.63	5.84
3.75	3.83	3.93	4.07	4.31	4.55	4.79	5.03	5.27	5.51	5.75	5.99	6.22	6.46	6.70
4.00	4.36	4.47	4.63	4.90	5.18	5.45	5.72	5.99	6.27	6.54	6.81	7.08	7.35	7.63
4.25	4.92	5.04	5.23	5.54	5.84	6.15	6.46	6.77	7.07	7.38	7.69	8.00	8.30	8.61
4.50	5.52	5.65	5.86	6.21	6.55	6.90	7.24	7.58	7.93	8.27	8.62	8.96	9.31	9.65
4.75	6.15	6.30	6.53	6.91	7.30	7.68	8.07	8.45	8.83	9.22	9.60	9.99	10.37	10.76
5.00	6.81	6.98	7.24	7.66	8.09	8.51	8.94	9.36	9.79	10.21	10.64	11.07	11.49	11.92
5.25	7.51	7.70	7.98	8.45	8.92	9.39	9.85	10.32	10.79	11.26	11.73	12.20	12.67	13.14
5.50	8.24	8.45	8.76	9.27	9.79	10.30	10.82	11.33	11.85	12.36	12.88	13.39	13.91	14.42
5.75	9.01	9.23	9.57	10.13	10.69	11.26	11.82	12.38	12.95	13.51	14.07	14.64	15.20	15.76
6.00	9.81	10.05	10.42	11.03	11.65	12.26	12.87	13.48	14.10	14.71	15.32	15.94	16.55	17.16
6.25	10.64	10.91	11.31	11.97	12.64	13.30	13.97	14.63	15.30	15.96	16.63	17.29	17.96	18.62
6.50	11.51	11.80	12.23	12.95	13.67	14.39	15.11	15.82	16.54	17.26	17.98	18.70	19.42	20.14
6.75	12.41	12.72	13.19	13.96	14.74	15.51	16.29	17.07	17.84	18.62	19.39	20.17	20.94	21.72
7.00	13.35	13.68	14.18	15.02	15.85	16.68	17.52	18.35	19.19	20.02	20.86	21.69	22.52	23.36
7.38	14.82	15.19	15.74	16.67	17.59	18.52	19.45	20.37	21.30	22.22	23.15	24.08	25.00	25.93
7.88	16.89	17.32	17.95	19.00	20.06	21.12	22.17	23.23	24.28	25.34	26.40	27.45	28.51	29.56
8.00	17.43	17.87	18.52	19.61	20.70	21.79	22.88	23.97	25.06	26.15	27.24	28.33	29.42	30.51
8.50	19.68	20.17	20.91	22.14	23.37	24.60	25.83	27.06	28.29	29.52	30.75	31.98	33.21	34.44
9.00	22.06	22.62	23.44	24.82	26.20	27.58	28.96	30.34	31.72	33.10	34.48	35.85	37.23	36.61
9.88	26.56	27.23	28.22	29.88	31.54	33.20	34.86	36.52	38.18	39.84	41.51	43.17	44.83	46.49
10.00	27.24	27.92	28.94	30.65	32.35	34.05	35.75	37.46	39.16	40.86	42.56	44.27	45.97	47.67
10.63	30.75	31.52	32.67	34.60	36.52	38.44	40.36	42.28	44.21	46.13	48.05	49.97	51.89	53.81
11.00	32.96	33.78	35.02	37.08	39.14	41.20	43.26	45.32	47.38	49.44	51.50	53.56	55.62	57.68
12.25	40.88	41.90	43.43	45.99	48.54	51.10	53.65	56.21	58.76	61.32	63.87	66.43	68.98	71.53
12.50	42.56	43.63	45.22	47.88	50.54	53.20	55.86	58.52	61.18	63.84	66.50	69.16	71.82	74.48
15.00	61.29	62.82	65.12	68.95	72.78	76.61	80.44	84.27	88.10	91.94	95.77	99.60	103.43	107.26
17.50	83.42	85.51	88.64	93.85	99.06	104.28	109.49	114.71	119.92	125.13	130.35	135.56	140.78	145.99
18.00	88.26	90.46	93.77	99.29	104.81	110.32	115.84	121.35	126.87	132.39	137.90	143.42	148.93	154.45
24.00	156.90	160.82	166.71	176.52	186.32	196.13	205.93	215.74	225.55	235.35	245.16	254.97	264.77	274.58

Table C-2. Column loading density (kilograms per meter)

Column Diameter (milli-meters)	*Explosive Density (grams per cubic centimeter)*													
	0.80	0.82	0.85	0.90	0.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40
25.40	0.41	0.42	0.43	0.46	0.48	0.51	0.53	0.56	0.58	0.61	0.63	0.66	0.68	0.71
31.75	0.63	0.65	0.67	0.71	0.75	0.79	0.83	0.87	0.91	0.95	0.99	1.03	1.07	1.11
38.10	0.91	0.93	0.97	1.03	1.08	1.14	1.20	1.25	1.31	1.37	1.42	1.48	1.54	1.60
44.45	1.24	1.27	1.32	1.40	1.47	1.55	1.63	1.71	1.78	1.86	1.94	2.02	2.09	2.17
50.80	1.62	1.66	1.72	1.82	1.92	2.03	2.13	2.23	2.33	2.43	2.53	2.63	2.73	2.84
57.15	2.05	2.10	2.18	2.31	2.44	2.56	2.69	2.82	2.95	3.08	3.20	3.33	3.46	3.59
63.50	2.53	2.60	2.69	2.85	3.01	3.17	3.32	3.48	3.64	3.80	3.96	4.11	4.27	4.43
69.85	3.06	3.14	3.26	3.45	3.64	3.83	4.02	4.21	4.40	4.60	4.79	4.98	5.17	5.36
76.20	3.65	3.74	3.87	4.10	4.33	4.56	4.79	5.01	5.24	5.47	5.70	5.93	6.15	6.38
82.55	4.28	4.39	4.55	4.81	5.08	5.35	5.62	5.88	6.15	6.42	6.69	6.95	7.22	7.49
88.90	4.96	5.09	5.27	5.58	5.89	6.20	6.51	6.82	7.13	7.44	7.76	8.07	8.38	8.69
95.25	5.70	5.84	6.05	6.41	6.77	7.12	7.48	7.83	8.19	8.55	8.90	9.26	9.61	9.97
101.60	6.48	6.64	6.89	7.29	7.70	8.10	8.51	8.91	9.32	9.72	10.13	10.53	10.94	11.34
107.95	7.32	7.50	7.78	8.23	8.69	9.15	9.61	10.06	10.52	10.98	11.43	11.89	12.35	12.81
114.30	8.20	8.41	8.72	9.23	9.74	10.26	10.77	11.28	11.79	12.31	12.82	13.33	13.85	14.36
120.65	9.14	9.37	9.71	10.28	10.86	11.43	12.00	12.57	13.14	13.71	14.28	14.85	15.43	16.00
127.00	10.13	10.38	10.76	11.40	12.03	12.66	13.29	13.93	14.56	15.19	15.83	16.46	17.09	17.73
133.35	11.17	11.45	11.87	12.56	13.26	13.96	14.66	15.35	16.05	16.75	17.45	18.15	18.84	19.54
139.70	12.26	12.56	13.02	13.79	14.55	15.32	16.09	16.85	17.62	18.38	19.15	19.92	20.68	21.45
146.05	13.40	13.73	14.23	15.07	15.91	16.74	17.58	18.42	19.26	20.09	20.93	21.77	22.61	23.44
152.40	14.59	14.95	15.50	16.41	17.32	18.23	19.14	20.06	20.97	21.88	22.79	23.70	24.61	25.53
158.75	15.83	16.22	16.82	17.80	18.79	19.78	20.77	21.76	22.75	23.74	24.73	25.72	26.71	27.70
165.10	17.12	17.55	18.19	19.26	20.33	21.40	22.47	23.54	24.61	25.68	26.75	27.82	28.89	29.96
171.45	18.46	18.92	19.61	20.77	21.92	23.08	24.23	25.38	26.54	27.69	28.84	30.00	31.15	32.31
177.80	19.85	20.35	21.09	22.33	23.58	24.82	26.06	27.30	28.54	29.78	31.02	32.26	33.50	34.74
187.33	22.04	22.59	23.41	24.79	26.17	27.55	28.92	30.30	31.68	33.06	34.43	35.81	37.19	38.56
200.03	25.13	25.75	26.70	28.27	29.84	31.41	32.98	34.55	36.12	37.69	39.26	40.83	42.40	43.97
203.20	25.93	26.58	27.55	29.17	30.79	32.41	34.03	35.65	37.27	38.90	40.52	42.14	43.76	45.38
215.90	29.27	30.00	31.10	32.93	34.76	36.59	38.42	40.25	42.08	43.91	45.74	47.57	49.40	51.23
228.60	32.82	33.64	34.87	36.92	38.97	41.02	43.07	45.12	47.18	49.23	51.28	53.33	55.38	57.43
250.83	39.51	40.50	41.98	44.45	46.92	49.39	51.86	54.33	56.79	59.26	61.73	64.20	66.67	69.14
254.00	40.52	41.53	43.05	45.58	48.11	50.65	53.18	55.71	58.24	60.77	63.31	65.84	68.37	70.90
269.88	45.74	46.88	48.60	51.46	54.31	57.17	60.03	62.89	65.75	68.61	71.47	74.33	77.18	80.04
279.40	49.02	50.25	52.09	55.15	58.22	61.28	64.34	67.41	70.47	73.54	76.60	79.66	82.73	85.79
311.15	60.80	62.32	64.60	68.40	72.20	76.00	79.80	83.60	87.40	91.20	95.00	98.80	102.60	106.40
317.50	63.31	64.89	67.26	71.22	75.18	79.13	83.09	87.05	91.00	94.96	98.92	102.87	106.83	110.79
381.00	91.16	93.44	96.86	102.56	108.25	113.95	119.65	125.35	131.04	136.74	142.44	148.14	153.83	159.53
444.50	124.08	127.18	131.84	139.59	147.35	155.10	162.86	170.61	178.37	186.12	193.88	201.63	209.39	217.14
457.20	131.27	134.55	139.48	147.68	155.89	164.09	172.29	180.50	188.70	196.91	205.11	213.32	221.52	229.73
609.60	233.37	239.21	247.96	262.54	277.13	291.72	306.30	320.89	335.47	350.06	364.64	379.23	393.82	408.40

Table C-3. Cubic yards of rock per foot of borehole

Spacing	Cubic Yards of Rock Per Foot of Borehole																				
	Burden																				
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	22	24	26	30	40
4	0.59	0.74	0.89	1.04	1.19	1.33	1.48	1.63	1.78	1.93	2.07	2.22	2.37	2.52	2.67	2.96	3.26	3.56	3.85	4.44	5.93
5	0.74	0.93	1.11	1.30	1.48	1.67	1.85	2.04	2.22	2.41	2.59	2.78	2.96	3.15	3.33	3.70	4.07	4.44	4.81	5.56	7.41
6	0.89	1.11	1.33	1.56	1.78	2.00	2.22	2.44	2.67	2.89	3.11	3.33	3.56	3.78	4.00	4.44	4.89	5.33	5.78	6.67	8.89
7	1.04	1.30	1.56	1.81	2.07	2.33	2.59	2.85	3.11	3.37	3.63	3.89	4.15	4.41	4.67	5.19	5.70	6.22	6.74	7.78	10.40
8	1.19	1.48	1.78	2.07	2.37	2.67	2.96	3.26	3.56	3.85	4.15	4.44	4.74	5.04	5.33	5.93	6.52	7.11	7.70	8.99	11.90
9	1.33	1.67	2.00	2.33	2.67	3.00	3.33	3.67	4.00	4.33	4.67	5.00	5.33	5.67	6.00	6.67	7.33	8.00	8.67	10.00	13.30
10	1.48	1.85	2.22	2.59	2.96	3.33	3.70	4.07	4.44	4.81	5.19	5.56	5.93	6.30	6.67	7.41	8.15	8.89	9.63	11.10	14.80
11	1.63	2.04	2.44	2.85	3.26	3.67	4.07	4.48	4.89	5.30	5.70	6.11	6.52	6.93	7.33	8.15	8.96	9.78	10.60	12.20	16.30
12	1.78	2.22	2.67	3.11	3.56	4.00	4.44	4.89	5.33	5.78	6.22	6.67	7.11	7.56	8.00	8.89	9.78	10.70	11.60	13.30	17.80
13	1.93	2.41	2.89	3.37	3.85	4.33	4.81	5.30	5.78	6.26	6.74	7.22	7.70	8.19	8.67	9.63	10.60	11.60	12.50	14.40	19.30
14	2.07	2.59	3.11	3.63	4.15	4.67	5.19	5.70	6.22	6.74	7.26	7.78	8.30	8.81	9.33	10.40	11.40	12.40	13.50	15.60	20.70
15	2.22	2.78	3.33	3.89	4.44	5.00	5.56	6.11	6.67	7.22	7.78	8.33	8.89	9.44	10.00	11.10	12.20	13.30	14.40	16.70	22.20
16	2.37	2.96	3.56	4.15	4.74	5.33	5.93	6.52	7.11	7.70	8.30	8.89	9.48	10.10	10.70	11.90	13.00	14.20	15.40	17.80	23.70
17	2.52	3.15	3.78	4.41	5.04	5.67	6.30	6.93	7.56	8.19	8.81	9.44	10.10	10.70	11.30	12.60	13.90	15.10	16.40	18.90	25.20
18	2.67	3.33	4.00	4.67	5.33	6.00	6.67	7.33	8.00	8.67	9.33	10.00	10.70	11.30	12.00	13.30	14.70	16.00	17.30	20.00	26.70
19	2.81	3.52	4.22	4.93	5.63	6.33	7.04	7.74	8.44	9.15	9.85	10.60	11.30	12.00	12.70	14.10	15.50	16.90	18.30	21.10	28.10
20	2.96	3.70	4.44	5.19	5.93	6.67	7.41	8.15	8.89	9.63	10.40	11.10	11.90	12.60	13.30	14.80	16.30	17.80	19.30	22.20	29.60
22	3.26	4.07	4.89	5.70	6.52	7.33	8.15	8.96	9.78	10.60	11.40	12.20	13.00	13.90	14.70	16.30	17.90	19.60	21.20	24.40	32.60
24	3.56	4.44	5.33	6.22	7.11	8.00	8.89	9.78	10.70	11.60	12.40	13.30	14.20	15.10	16.00	17.80	19.60	21.30	23.10	26.70	35.60
26	3.85	4.81	5.78	6.74	7.70	8.67	9.63	10.60	11.60	12.50	13.50	14.40	15.40	16.40	17.30	19.30	21.20	23.10	25.00	28.90	38.50
28	4.15	5.19	6.22	7.26	8.30	9.33	10.40	11.40	12.40	13.50	14.50	15.60	16.60	17.60	18.70	20.70	22.80	24.90	27.00	31.10	41.50
30	4.44	5.56	6.67	7.78	8.89	10.00	11.10	12.20	13.30	14.40	15.60	16.70	17.80	18.90	20.00	22.20	24.40	26.70	28.90	33.30	44.40
32	4.74	5.93	7.11	8.30	9.48	10.70	11.90	13.00	14.20	15.40	16.60	17.80	19.00	20.10	21.30	23.70	26.10	28.40	30.80	35.60	47.40
34	5.04	6.30	7.56	8.81	10.10	11.30	12.60	13.90	15.10	16.40	17.60	18.90	20.10	21.40	22.70	25.20	27.70	30.20	32.70	37.80	50.40
36	5.33	6.67	8.00	9.33	10.70	12.00	13.30	14.70	16.00	17.30	18.70	20.00	21.30	22.70	24.00	26.70	29.30	32.00	34.70	40.00	53.30
38	5.63	7.04	8.44	9.85	11.30	12.70	14.10	15.50	16.90	18.30	19.70	21.10	22.50	23.90	25.30	28.10	31.00	33.80	36.60	42.20	56.30
40	5.93	7.41	8.89	10.40	11.90	13.30	14.80	16.30	17.80	19.30	20.70	22.20	23.70	25.20	26.70	29.60	32.60	35.60	38.50	44.40	59.30

Table C-4. Cubic meters of rock per meter of borehole

Spacing	Cubic Meters of Rock Per Meter of Borehole																				
	Burden																				
	1.00	1.50	2.00	2.50	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00
1.00	1.00	1.50	2.00	2.50	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.50	6.00	6.50	7.00	7.50	8.00	9.00	10.00
1.50	1.50	2.25	3.00	3.75	4.50	4.88	5.25	5.63	6.00	6.38	6.75	7.13	7.50	8.25	9.00	9.75	10.50	11.25	12.00	13.50	15.00
2.00	2.00	3.00	4.00	5.00	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	11.00	12.00	13.00	14.00	15.00	16.00	18.00	20.00
2.50	2.50	3.75	5.00	6.25	7.50	8.13	8.75	9.38	10.00	10.63	11.25	11.88	12.50	13.75	15.00	16.25	17.50	18.75	20.00	22.50	25.00
3.00	3.00	4.50	6.00	7.50	9.00	9.75	10.50	11.25	12.00	12.75	13.50	14.25	15.00	16.50	18.00	19.50	21.00	22.50	24.00	27.00	30.00
3.25	3.25	4.88	6.50	8.13	9.75	10.56	11.38	12.19	13.00	13.81	14.63	15.44	16.25	17.88	19.50	21.13	22.75	24.38	26.00	29.25	32.50
3.50	3.50	5.25	7.00	8.75	10.50	11.38	12.25	13.13	14.00	14.88	15.75	16.63	17.50	19.25	21.00	22.75	24.50	26.25	28.00	31.50	35.00
3.75	3.75	5.63	7.50	9.38	11.25	12.19	13.13	14.06	15.00	15.94	16.88	17.81	18.75	20.63	22.50	24.38	26.25	28.13	30.00	33.75	37.50
4.00	4.00	6.00	8.00	10.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	22.00	24.00	26.00	28.00	30.00	32.00	36.00	40.00
4.25	4.25	6.38	8.50	10.63	12.75	13.81	14.88	15.94	17.00	18.06	19.13	20.19	21.25	23.38	25.50	27.63	29.75	31.88	34.00	38.25	42.50
4.50	4.50	6.75	9.00	11.25	13.50	14.63	15.75	16.88	18.00	19.13	20.25	21.38	22.50	24.75	27.00	29.25	31.50	33.75	36.00	40.50	45.00
4.75	4.75	7.13	9.50	11.88	14.25	15.44	16.63	17.81	19.00	20.19	21.38	22.56	23.75	26.13	28.50	30.88	33.25	35.63	38.00	42.75	47.50
5.00	5.00	7.50	10.00	12.50	15.00	16.25	17.50	18.75	20.00	21.25	22.50	23.75	25.00	27.50	30.00	32.50	35.00	37.50	40.00	45.00	50.00
5.25	5.25	7.88	10.50	13.13	15.75	17.06	18.38	19.69	21.00	22.31	23.63	24.94	26.25	28.88	31.50	34.13	36.75	39.38	42.00	47.25	52.50
5.50	5.50	8.25	11.00	13.75	16.50	17.88	19.25	20.63	22.00	23.38	24.75	26.13	27.50	30.25	33.00	35.75	38.50	41.25	44.00	49.50	55.00
5.75	5.75	8.63	11.50	14.38	17.25	18.69	20.13	21.56	23.00	24.44	25.88	27.31	28.75	31.63	34.50	37.38	40.25	43.13	46.00	51.75	57.50
6.00	6.00	9.00	12.00	15.00	18.00	19.50	21.00	22.50	24.00	25.50	27.00	28.50	30.00	33.00	36.00	39.00	42.00	45.00	48.00	54.00	60.00
6.50	6.50	9.75	13.00	16.25	19.50	21.13	22.75	24.38	26.00	27.63	29.25	30.88	32.50	35.75	39.00	42.25	46.50	48.75	52.00	58.50	65.00
7.00	7.00	10.50	14.00	17.50	21.00	22.75	24.50	26.25	28.00	29.75	31.50	33.25	35.00	38.50	42.00	45.50	49.00	52.50	56.00	63.00	70.00
7.50	7.50	11.25	15.00	18.75	22.50	24.38	26.25	28.13	30.00	31.88	33.75	35.63	37.50	41.25	45.00	48.75	52.50	56.25	60.00	67.50	75.00
8.00	8.00	12.00	16.00	20.00	24.00	26.00	28.00	30.00	32.00	34.00	36.00	38.00	40.00	44.00	48.00	52.00	56.00	60.00	64.00	72.00	80.00
9.00	9.00	13.50	18.00	22.50	27.00	29.25	31.50	33.75	36.00	38.25	40.50	42.75	45.00	49.50	54.00	58.50	63.00	67.50	72.00	81.00	90.00
10.00	10.00	15.00	20.00	25.00	30.00	32.50	35.00	37.50	40.00	42.50	45.00	47.50	50.00	55.00	60.00	65.00	70.00	75.00	80.00	90.00	100.00
11.00	11.00	16.50	22.00	27.50	33.00	35.75	38.50	41.25	44.00	46.75	49.50	52.25	55.00	60.50	66.00	71.50	77.00	82.50	88.00	99.00	110.00
12.00	12.00	18.00	24.00	30.00	36.00	39.00	42.00	45.00	48.00	51.00	54.00	57.00	60.00	66.00	72.00	78.00	84.00	90.00	96.00	108.00	120.00
13.00	13.00	19.50	26.00	32.50	39.00	42.25	45.50	48.75	52.00	55.25	58.50	61.75	65.00	71.50	78.00	84.50	91.00	97.50	104.00	117.00	130.00
14.00	14.00	21.00	28.00	35.00	42.00	45.50	49.00	52.50	56.00	59.50	63.00	66.50	70.00	77.00	84.00	91.00	98.00	105.00	112.00	126.00	140.00

Table C-5. Trigonometric functions

Degree of Angle	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	Degree of Angle
0					1.000	1.000	90
1	0.017	57.30	0.017	57.29	1.000	1.000	89
2	0.035	28.65	0.035	28.64	1.001	0.999	88
3	0.052	19.11	0.052	19.08	1.001	0.999	87
4	0.070	14.34	0.070	14.30	1.002	0.998	86
5	0.087	11.47	0.087	11.43	1.004	0.996	85
6	0.105	9.567	0.105	9.514	1.006	0.995	84
7	0.122	8.206	0.123	8.144	1.008	0.993	83
8	0.139	7.185	0.141	7.115	1.010	0.990	82
9	0.156	6.392	0.158	6.314	1.012	0.988	81
10	0.174	5.759	0.176	5.671	1.015	0.985	80
11	0.191	5.241	0.194	5.145	1.019	0.982	79
12	0.208	4.810	0.213	4.705	1.022	0.978	78
13	0.225	4.445	0.231	4.331	1.026	0.974	77
14	0.242	4.134	0.249	4.011	1.031	0.970	76
15	0.259	3.864	0.268	3.732	1.035	0.966	75
16	0.276	3.628	0.287	3.487	1.040	0.961	74
17	0.292	3.420	0.306	3.271	1.046	0.956	73
18	0.309	3.236	0.325	3.078	1.051	0.951	72
19	0.326	3.072	0.344	2.904	1.058	0.946	71
20	0.342	2.924	0.364	2.747	1.064	0.940	70
21	0.358	2.790	0.384	2.605	1.071	0.934	69
22	0.375	2.669	0.404	2.475	1.079	0.927	68
23	0.391	2.559	0.424	2.356	1.086	0.921	67
24	0.407	2.459	0.445	2.246	1.095	0.914	66
25	0.423	2.366	0.466	2.145	1.103	0.906	65
26	0.438	2.281	0.488	2.050	1.113	0.899	64
27	0.454	2.203	0.510	1.963	1.122	0.891	63
28	0.469	2.130	0.532	1.881	1.133	0.883	62
29	0.485	2.063	0.554	1.804	1.143	0.875	61
30	0.500	2.000	0.577	1.732	1.155	0.866	60
31	0.515	1.942	0.601	1.664	1.167	0.857	59
32	0.530	1.887	0.625	1.600	1.179	0.848	58
33	0.545	1.836	0.649	1.540	1.192	0.839	57
34	0.559	1.788	0.675	1.483	1.206	0.829	56
35	0.574	1.743	0.700	1.428	1.221	0.819	55
36	0.588	1.701	0.727	1.376	1.236	0.809	54
37	0.602	1.662	0.754	1.327	1.252	0.799	53
38	0.616	1.624	0.781	1.280	1.269	0.788	52
39	0.629	1.589	0.810	1.235	1.287	0.777	51
40	0.643	1.556	0.839	1.192	1.305	0.766	50
41	0.656	1.542	0.869	1.150	1.325	0.755	49
42	0.669	1.494	0.900	1.111	1.346	0.743	48
43	0.682	1.466	0.933	1.072	1.367	0.731	47
44	0.695	1.440	0.966	1.036	1.390	0.719	46
45	0.707	1.414	1.000	1.100	1.414	0.707	45

Table C-6. Average weight of various solid materials

Material	*Specific Gravity*	*Pounds Per Foot³*	*Feet³ Per Ton*	*Tons Per Yard³*
Basalt	2.8-3.0	190	10.5	2.57
Coal-Anthracite	1.3-1.8	100	20.0	1.35
Coal-Bituminous	1.2-1.5	85	23.6	1.15
Diabase	2.6-3.0	175	11.4	2.36
Diorite	2.8-3.0	185	10.8	2.50
Dolomite	2.8-2.9	180	11.2	2.43
Gneiss	2.6-2.9	180	11.2	2.43
Granite	2.6-2.9	170	11.8	2.30
Gypsum	2.3-3.3	175	11.4	2.36
Hematite	4.5-5.3	305	6.6	4.12
Limestone	2.4-2.9	165	12.2	2.23
Limonite	3.6-4.0	235	8.5	3.17
Magnesite	3.0-3.2	200	10.0	2.70
Magnetite	4.9-5.2	315	6.4	4.25
Marble	2.1-2.9	155	12.8	2.09
Mica-Schist	2.5-2.9	170	11.8	2.30
Porphyry	2.5-2.6	160	12.5	2.16
Quartzite	2.0-2.8	160	12.5	2.16
Salt-Rock	2.1-2.6	145	13.8	1.96
Sandstone	2.0-2.8	150	13.3	2.03
Shale	2.4-2.8	160	12.5	2.16
Silica Sand	2.2-2.8	160	12.5	2.16
Slate	2.5-2.8	170	11.8	2.30
Talc	2.6-2.8	165	12.2	2.23
Trap Rock	2.6-3.0	175	11.4	2.36

Glossary

SECTION I – ACRONYMS AND ABBREVIATIONS

AFMAN	Air Force manual
AN	ammonium nitrate
ANFO	ammonium nitrate-fuel oil
ATTN	attention
CFR	Code of Federal Regulations
DA	Department of the Army
DC	District of Columbia
DODIC	Department of Defense identification code
FL	Florida
FM	field manual
HMX	cyclotetramethylene tetranitramine
JP	joint publication
MANSCEN	Maneuver Support Center
MDI	modernized demolition initiator
NAVSEA	Naval Sea Systems Command
NTRP	Navy tactical reference publication
OF	optional form
PETN	pentaerythrite tetranitrate
PPF	pounds per foot
RDX	cyclotrimethylenetrinitramine
RI	Rhode Island
SOP	standing operating procedure
TC	training circular
TM	technical manual
TNT	trinitrotoluene
USA	U.S. Army
USAF	U.S. Air Force
USN	U.S. Navy

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DOCUMENTS NEEDED

These documents must be available to the intended users of this publication.

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READINGS RECOMMENDED

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Index

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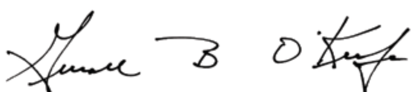

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