

CHAPTER



13



Construction Planning, Equipment,
and Methods

Sixth Edition

BLASTING ROCK

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ENCE 420 – Construction Equipment and Methods

Spring 2003

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INTRODUCTION

& **BLAST DESIGN** is not an exact science, but by considering the rock formation it is possible to produce the desired result.

& This is a step-by-step procedure for designing the blast hole layout and calculating the amount of explosives for blasting rock.



INTRODUCTION

- ⊕ "Blasting" is performed to break rock so that it may be quarried for processing in an aggregate production operation, or to excavate a right-of-way.
- ⊕ Blasting is accomplished by discharging an explosive that has either been placed in an unconfined manner, such as mud capping boulders, or is confined as in a borehole.



INTRODUCTION

- ⊕ There are two forms of energy released when high explosives are detonated, shock and gas. An unconfined charge works by shock energy, whereas a confined charge has a high gas energy output.
- ⊕ There are many types of explosives and methods for using them.



TOPICS

- ✉ **Blast design**
- ✉ **Powder factor**
- ✉ **Vibration**
- ✉ **Trench rock**
- ✉ **Presplitting**
- ✉ **Production**



GLOSSARY OF TERMS

Face

Bench height

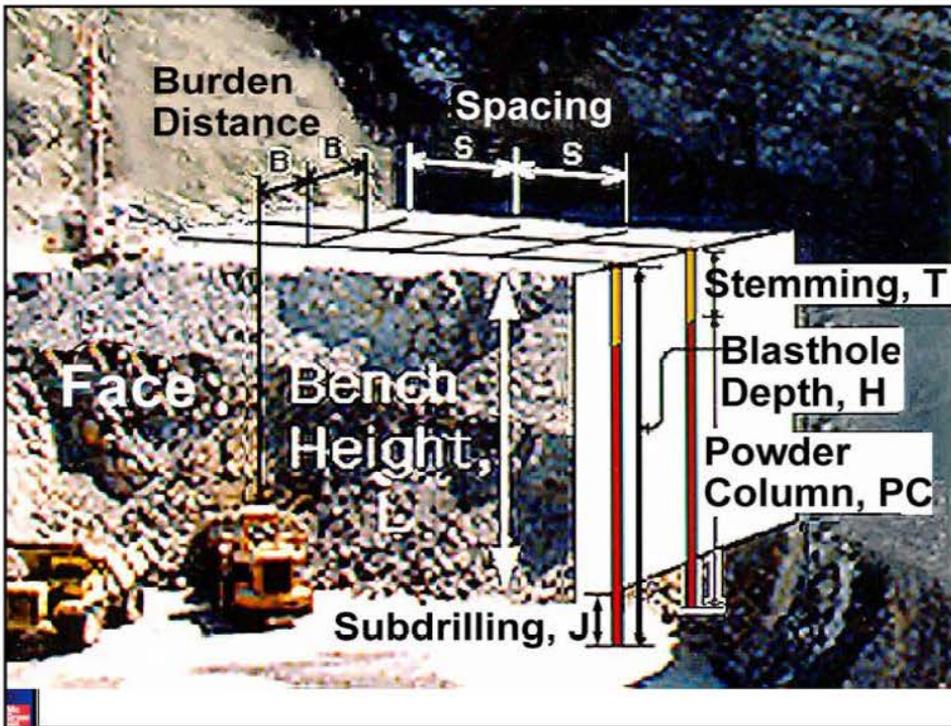
Burden distance

Spacing

Blasthole depth

Stemming

Subdrilling



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OVERVIEW

- Rock breakage results from gas pressure in the blasthole.
- Radial cracking
- Individual wedge
- Flexural rupture
- **Stiffness ratio**

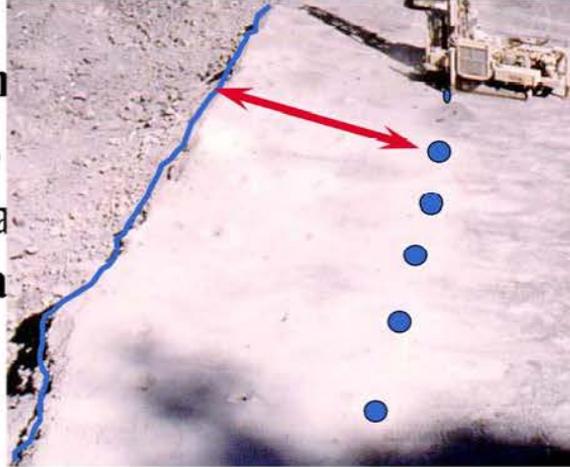
$$\frac{\text{bench height}}{\text{burden distance}}$$

The diagram shows a top-down view of a blasthole. A red circle in the center represents the hole. Red lines radiate outwards from the hole, representing radial cracks. A yellow arrow points to these cracks, and a red arrow points to a specific wedge-shaped region of rock that has broken away.



BURDEN

Burden distance is the most critical dimension in blast design. It is the distance to the free face of the excavation.



COMMERCIAL EXPLOSIVES

- ✚ There are four main categories of commercial high explosives:
 1. Dynamite,
 2. Slurries,
 3. ANFO, and
 4. Two-component explosives.



COMMERCIAL EXPLOSIVES

- ⊕ The first three categories, dynamite, slurries, and ANFO, are the principal explosives used for borehole charges.
- ⊕ Two-component or binary explosives are normally not classified as an explosive until mixed.



DYNAMITE

- ⊕ **Dynamite** is nitroglycerin-based product.
- ⊕ It is the most sensitive of all the generic classes of explosives in use nowadays.
- ⊕ It is available in many grades and sizes to meet the requirements of a particular job.

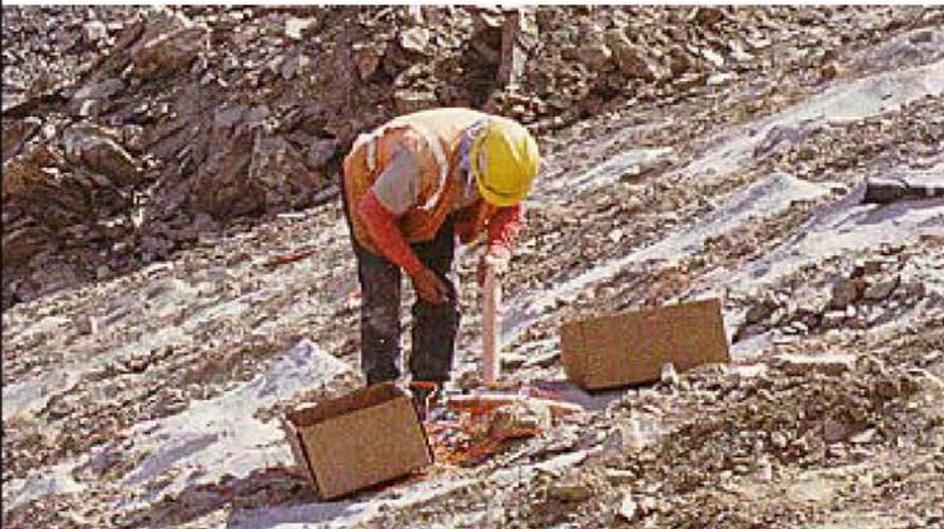


DYNAMITE

- ⊕ The approximate strength of a dynamite is specified as a percentage (weight of nitroglycerin to the total weight of a cartridge).
- ⊕ Cartridges vary in size from approximately 1 to 8 in. in diameter and 8 to 24 in. long.
- ⊕ Dynamite is used extensively for charging *boreholes*, especially for the smaller sizes.



Dynamite Cartridge





Dynamite Cartridge



SLURRIES

- ⊕ Slurries is generic term used for both *water gels* and *emulsion*
- ⊕ They are water-resistant explosive mixtures of ammonium nitrate and a fuel sensitizer
- ⊕ The primary sensitizing methods are:
 - ✓ introduction of air throughout the mixture
 - ✓ the addition of aluminum particles
 - ✓ or the addition of nitrocellulose



SLURRIES

- ⊕ In comparison to different explosives (such as ANFO), slurries have a higher cost per pound and have less energy
- ⊕ However, their higher cost can be justified if used in wet condition
- ⊕ They are not water-sensitive
- ⊕ An advantage of slurries over dynamite is that the separate ingredients can be hauled to the project in bulk and mixed immediately before loading the blastholes



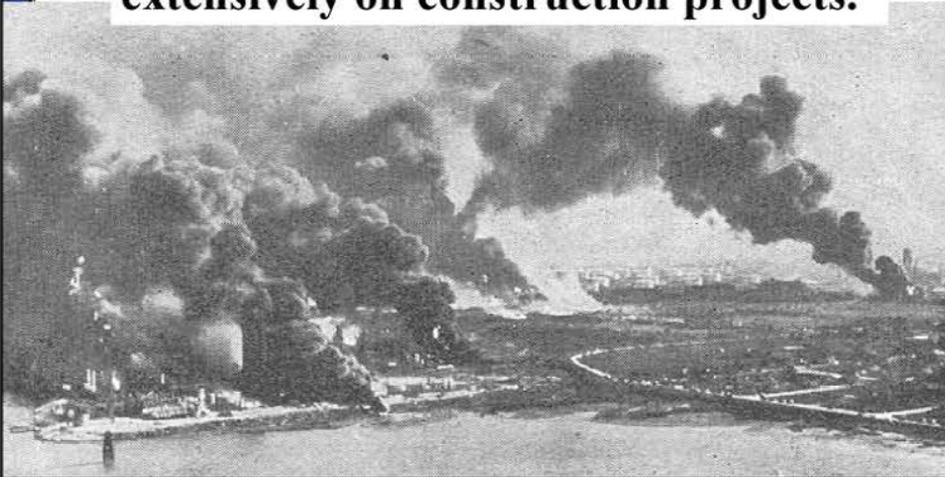
ANFO

- ⊕ ANFO is blasting agent that is produced by mixing prilled ammonium nitrate and fuel oil
- ⊕ This explosive is used extensively on construction project and represents about 80% of all explosives used in the United States
- ⊕ ANFO is the cheapest and safest among others



ANFO Texas City, 16 April 1947

ANFO is an explosive used extensively on construction projects.



ANFO

- ⊕ The ANFO is made by blending 3.5 quarts of fuel oil with 100 lb of ammonium nitrate blasting prills
- ⊕ This the optimum ratio.
- ⊕ The detonation efficiency is controlled by this ratio.
- ⊕ Because the mixture is free-flowing, it can be blown or augered from the bulk trucks directly into the blasholes.



INITIATING AND DELAY DEVICES

- ⊕ It is common practice to fire several holes or rows of holes at one time.
- ⊕ Fragmentation, backbreake, vibration, and violence of a blast are all controlled by the firing sequence of the individual blastholes.



INITIATING AND DELAY DEVICES

- ⊕ The order and timing of the detonation of the individual holes is regulated by the initiation system. Electric and non-electric initiation systems are available.
- ⊕ When selecting the proper system, one should consider both blast design and safety.



ELECTRIC BLASTING CAPS

- ⊕ With an electric cap an explosion is caused by passing an electric current through a wire bridge, similar to an electric light bulb filament.
- ⊕ A current of approximately 1.5 amps heats the bridge to ignite a heat-sensitive flash compound.
- ⊕ The ignition sets off a primer which in turn fires a base charge in the cap.



DELAY BLASTING SYSTEMS

- ⊕ Delay blasting caps are used to obtain a specified firing sequence.
- ⊕ These caps are available for delay intervals varying from a small fraction of second to about 7 seconds.
- ⊕ When explosives charges in two or more rows of holes parallel to the face are fired in one shot, it is desirable to fire the charges in the holes nearest the face a short time ahead of those in the second row.



DELAY BLASTING SYSTEMS

- ⊕ This procedure will reduce the burden in the second row, and hence, will permit the explosives in the second row to break more effectively.
- ⊕ In the case of more than two rows of explosives, this same delayed firing sequence will be followed for each successive row.



DETONATING CORD

- ⊕ The detonating cord is a non-electric initiation system consisting of a flexible cord having a center core of high explosive.
- ⊕ It is used to detonate dynamite and other cap-sensitive explosives.



ROCK BREAKAGE

- ⊕ The major mechanisms of rock breakage result from the sustained gas pressure buildup in the borehole by the explosion.
- ⊕ First, this pressure will cause radial cracking. Such cracking is similar to what happens in the case of frozen water pipes—a longitudinal split occurs parallel to the axis of the pipe.



ROCK BREAKAGE

- ⊕ A borehole is analogous to the frozen pipe in that it is a cylindrical pressure vessel. But there is a difference in the rate of loading. A blasthole is pressurized instantaneously. Failure, therefore, instead of being at the one weakest seam, is in *many* seams parallel to the borehole.





BLAST DESIGN

- Every blast must be designed to meet the existing conditions of the rock formation and overburden, and to produce the desired final result. There is no single solution to this problem.



BLAST DESIGN

- Rock is not a homogeneous material. There are fracture planes, seams, and changes in burden to be considered.
- Wave propagation is faster in hard rock than in soft rock.



BLAST DESIGN

- Initial blast designs use idealized assumptions. The engineer does this realizing that discontinuities will be encountered in the field. Because of these facts, it must always be understood that the theoretical blast design is only the starting point for blasting operations in the field.



BLAST DESIGN

- A **trial blast** should always be performed. It will either validate the initial assumptions or provide the information needed for final blast design.



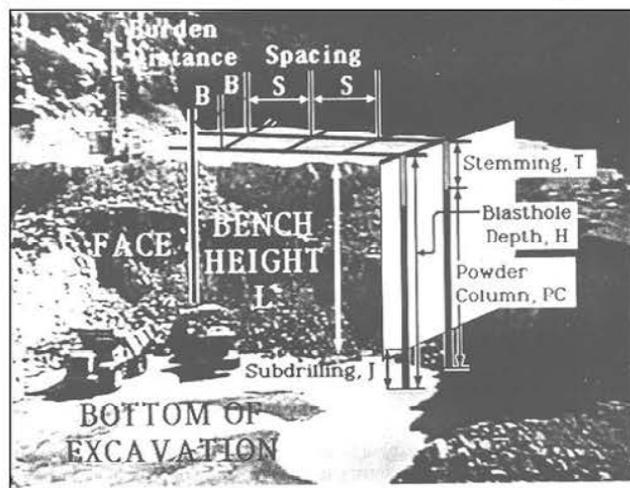
BURDEN

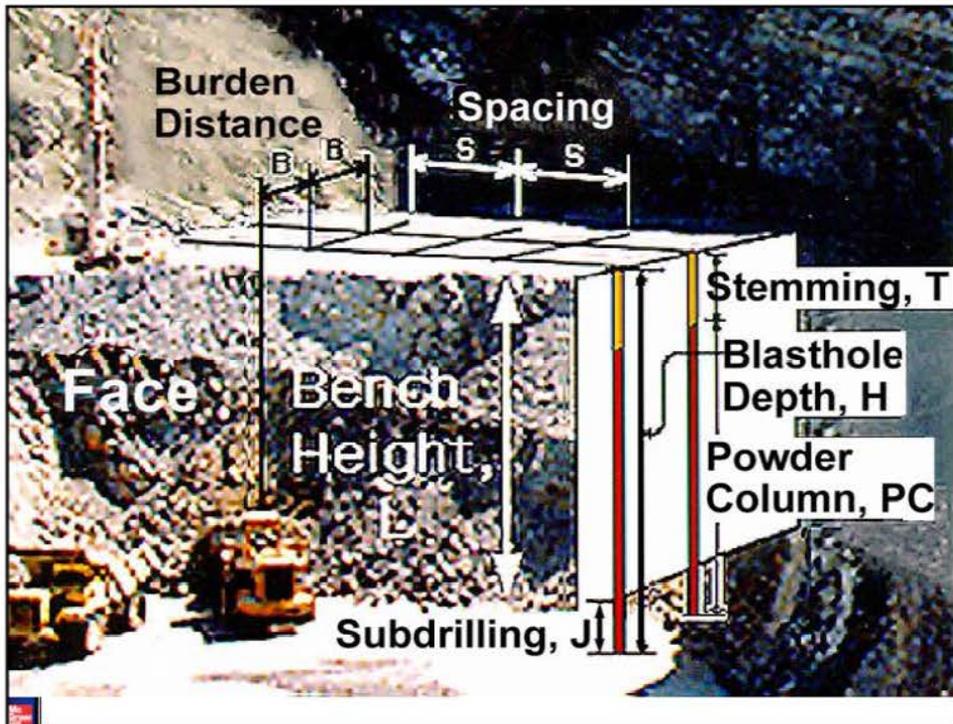
- ⊕ The most critical dimension in blast design is the burden distance as shown in Figure 1 (Fig 13-1, Text)
- ⊕ Burden distance is the shortest distance to stress relief at the time a blasthole detonates. It is normally the distance to the free face in an excavation, whether a quarry situation or a highway cut.



BURDEN

Figure 1. Blasthole Dimensional Terminology





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BURDEN

- Internal faces can be created by blastholes fired on an earlier delay within a shot. When the burden distance is insufficient, rock will be thrown for excessive distances from the face, fragmentation may be excessively fine, and air blast levels will be high.



BURDEN

- An empirical formula for approximating a burden distance to be used *on* a first trial shot is

$$B = \left(\frac{2SG_e}{SG_r} + 1.5 \right) D_e \quad (1)$$

where

B = burden, ft

SG_e = specific gravity of the explosive

SG_r = specific gravity of the rock

D_e = diameter of the explosive, in.



BURDEN

- The actual diameter will depend on the manufacturer's packaging container thickness
- If the specific product is known, the exact information should be used
- Rock density is an indicator of strength, which in turn governs the amount of energy required to cause breakage
- The approximate specific gravities of rocks are given in Table 1 (T13-1,Text)



BURDEN

Table 1. Density by Nominal Rock Classifications (Table 13-1, Text)

Rock Classification	Specific Gravity	Density Broken (ton/cu yd)
Basalt	1.8 – 3.0	2.36 – 2.53
Dabase	2.6 – 3.0	2.19 – 2.53
Diorite	2.8 – 3.0	2.36 – 2.53
Dolomite	2.8 – 2.9	2.36 – 2.44
Gneiss	2.6 – 2.9	2.19 – 2.44
Granite	2.6 – 2.9	2.19 – 2.28
Gypsum	2.3 – 2.8	1.94 – 2.26
Hematite	4.5 – 5.3	3.79 – 4.47
Limestone	2.4 – 2.9	1.94 – 2.28
Marble	2.1 – 2.9	2.02 – 2.28
Quartzite	2.0 – 2.8	2.19 – 2.36
Sandstone	2.0 – 2.8	1.85 – 2.36
Shale	2.4 – 2.8	2.02 – 2.36
Slate	2.5 – 2.8	2.28 – 2.36
Trap Rock	2.6 – 3.0	2.38 – 2.53



BURDEN

- ⊕ Explosive density is used in Eq. 1 because of the proportional relationship between explosive density and strength.
- ⊕ There are, however, some explosive emulsions which exhibit differing strengths at equal densities.
- ⊕ In such a case Eq. 1 will not be valid.
- ⊕ An equation based on relative bulk strength instead of density can be used in such situations.





Example 1

A contractor plans to use dynamite that has specific gravity of 1.3 to open an excavation in granite rock. The drilling equipment available will drill a 3-in blasthole. Dynamite comes packaged in 2 3/4-in diameter sticks. What is the recommended burden distance for the first trial shot?

From Table 1 (Table 14-1 Text):

$$\text{Specific Gravity of Granite} = \frac{2.6 + 2.9}{2} = 2.8$$

$$B = \left(\frac{2SG_e}{SG_r} + 1.5 \right) D_e = \left(\frac{2(1.3)}{2.8} + 1.5 \right) (2.75) = 6.7 \text{ ft}$$



BULK STRENGTH

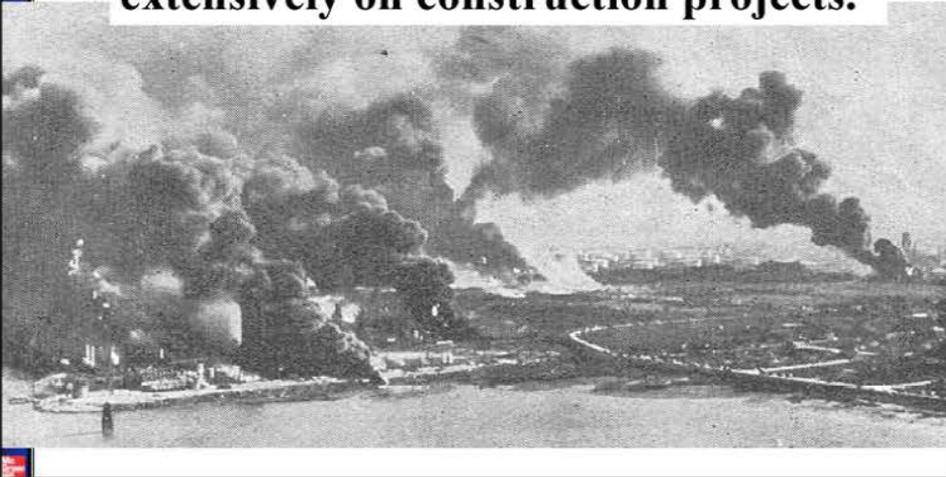
- Relative bulk strength is the strength ratio for a constant volume compared to a standard explosive such as ANFO
- ANFO, ammonium nitrate and fuel oil, is the standard explosive with an energy-level rating of 100
- The relative bulk strength rating should be based on test data under specified conditions



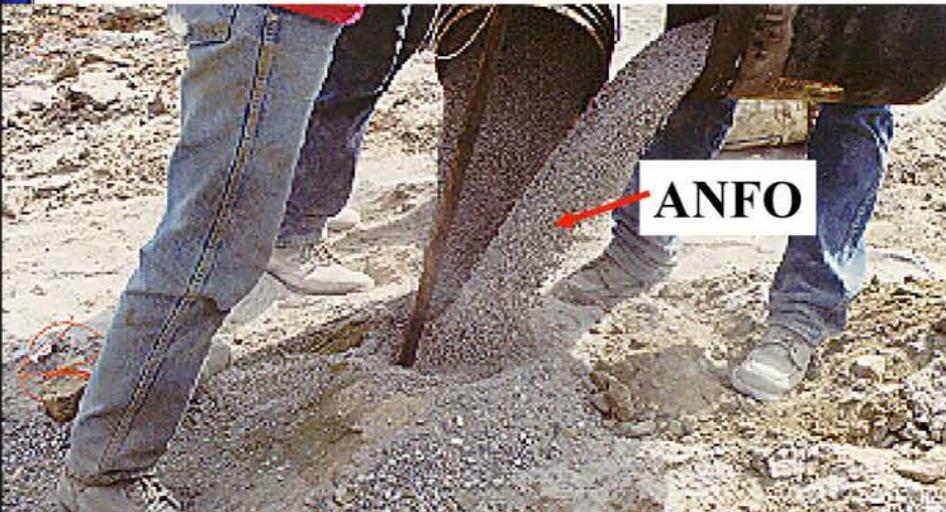


ANFO Texas City, 16 April 1947

ANFO is an explosive used extensively on construction projects.



Explosive diameter and blasthole size are the same.





BULK STRENGTH

- The burden distance, B , based on relative bulk energy is given by

$$B = 0.67 D_e \sqrt[3]{\frac{St_v}{SG_r}} \quad (2)$$

SG_r = specific gravity of the rock

D_e = diameter of the explosive, in.

St_v = relative bulk strength compared to ANFO



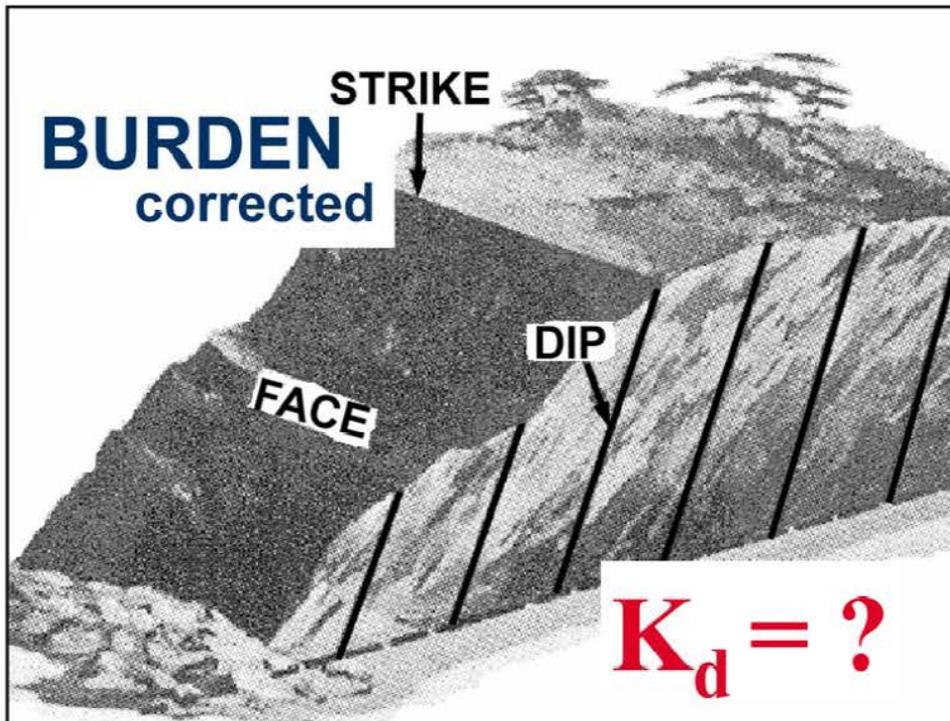
BURDEN DISTANCE

- When one or two rows of blastholes are used, the burden distance between rows will usually be equal.
- If more than two rows are to be fired in a single shot, either the burden distance of the rear holes must be adjusted or delay devices must be used to allow the face rock from the front rows to move.



BURDEN DISTANCE

- ⊕ The burden distance should also be adjusted because of the geological variations.
- ⊕ Rock is not homogeneous material as assumed by all formulas
- ⊕ Therefore, it is always necessary to use **correction factors** for specific geological conditions.





BURDEN DISTANCE

- ✦ The corrected burden distance can be computed from the following equation:

$$B_{\text{corrected}} = B \times K_d \times K_s \quad (3)$$

Where

K_d = correction factor for rock deposition

K_s = correction factor for rock structure

Table 2 gives burden distance correction factors for rock deposition and rock structure



BURDEN DISTANCE CORRECTION FACTORS

Table 2. Density by Nominal Rock Classifications (Table 13-2, Text)

Rock Deposition	K_d
Bedding steeply dipping into cut	1.18
Bedding steeply dipping into face	0.95
Other cases of deposition	1.00
Rock Structure	K_s
Heavily cracked, frequent weak joints, weakly cemented layers	1.30
Thin, well-cemented layers with tight joints	1.10
Massive intact rock	0.95



Example 2

A new quarry is being opened in a limestone formation having horizontal bedding with numerous weak joints. From a borehole test drilling program it is believed that the limestone is highly laminated with many weakly cemented layers. Because of possible wet conditions, a cartridged slurry (relative bulk density of 140) will be used as explosive. The 6.5-in blastholes will be loaded with 5-in diameter cartridges. What is the burden distance?



Example 2 (continued)

From Table 1 (Table 13-1, Text):

For limestone, the specific gravity is between 2.4 and 2.9

$$\text{Average Specific Gravity} = \frac{2.4 + 2.9}{2} = 2.9$$

$$B = 0.67 D_c \sqrt[3]{\frac{St_v}{SG_r}} = 0.67(5) \sqrt[3]{\frac{140}{2.6}} = 12.65 \text{ ft}$$

$Kd = 1$ (horizontal bedding, see Table 2)

$Ks = 1.3$ (numerous weakly cemented layers, Table 2)

$$B_{\text{corrected}} = B \times Kd \times Ks = 12.65(1)(1.3) = \underline{16.4 \text{ ft}}$$



Example 2 (continued)

Table 1. Density by Nominal Rock Classifications (Table 13-1, Text)

Rock Classification	Specific Gravity	Density Broken (ton/cu yd)
Basalt	1.8 – 3.0	2.36 – 2.53
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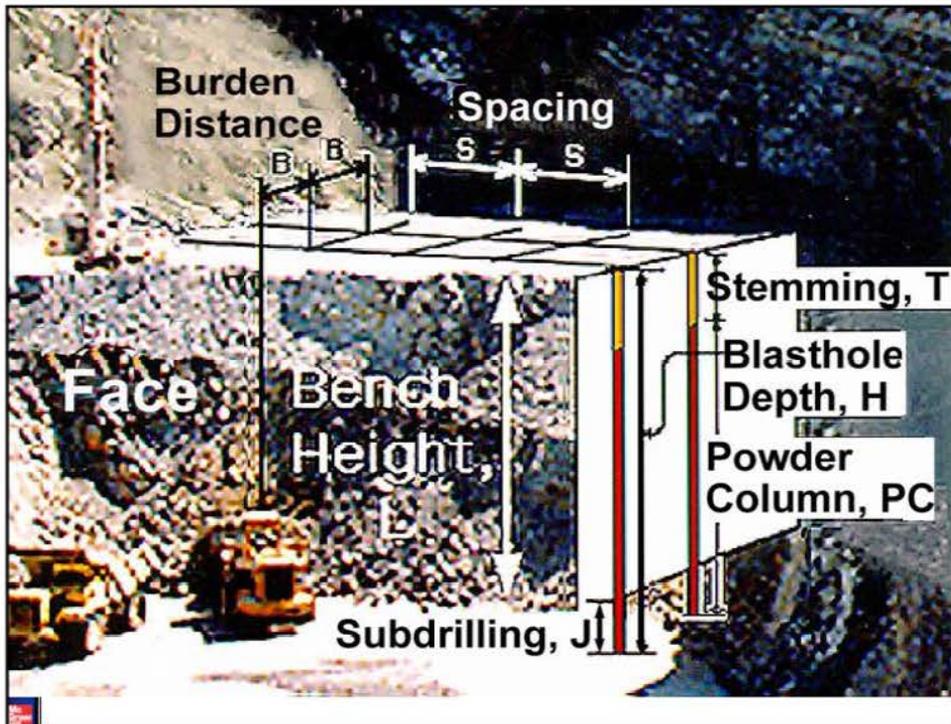


STEMMING

Definition:

Stemming is the adding of an inert material, such as drill cuttings, on top of the explosive in a blasthole for the purpose of confining the energy of the explosive

- To function properly the material used for stemming must lock into the borehole.



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STEMMING

- ⊕ It is common practice to use drill cuttings as the stemming material.
- ⊕ To function properly, the stemming material should have an average diameter 0.05 times the diameter of the hole and should be angular.
- ⊕ If the stemming distance is too great, there will be poor top breakage from the explosion and backbreak will increase.



STEMMING

- ⊕ When the stemming distance is inadequate, the explosion will escape prematurely from the hole.
- ⊕ Under normal conditions, properly designed burden and explosive, and good stemming material, a stemming distance, T , of 0.7 times the burden distance, B , will be satisfactory.

$$T = 0.7 \times B \quad (4)$$



SUBDRILLING

- ⊕ A shot will normally not break to the very bottom of the blasthole. This can be understood by remembering that the second mechanism of breakage is flexural rupture.
- ⊕ To achieve a specified grade, one will need to drill below the desired floor elevation. This portion of the blasthole below the desired final grade is termed "subdrilling."



SUBDRILLING

- ✦ The subdrilling distance, J , required can be approximated by the following formula:

$$J = 0.3 \times B \quad (5)$$

- ✦ Subdrilling represents the depth required for explosive placement, not a field drilling depth



SUBDRILLING

- ✦ During the drilling operation there will be random drilling depth errors, holes will slough, and material will accidentally fall into some holes. Therefore, for practical reasons drilling should be to a depth slightly greater than that calculated.



BLASTHOLE SIZE

- ⊕ The size (diameter) of the blasthole will affect blast considerations concerning fragmentation, air blast, flyrock, and ground vibration.
- ⊕ The economics of drilling is the second consideration in determining blasthole size.
- ⊕ Larger holes are usually more economical to drill but they introduce possible blast problems.



BLASTHOLE SIZE

- ⊕ Once again, the second mechanism of rupture and the stiffness ratio (SR) need to be considered.
- ⊕ The **stiffness ratio (SR)** for blasting purposes is the bench height (L) divided by the burden distance (B).

$$SR = \frac{L}{B} \quad (6)$$



STIFFNESS RATIO

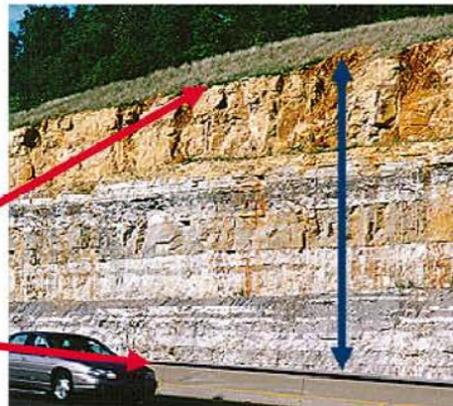
Stiffness ratio $\left(\frac{\text{bench height}}{\text{burden distance}} \right)$
affects several critical blasting considerations.

- Fragmentation
- Air blast
- Flyrock
- Ground vibration



STIFFNESS RATIO

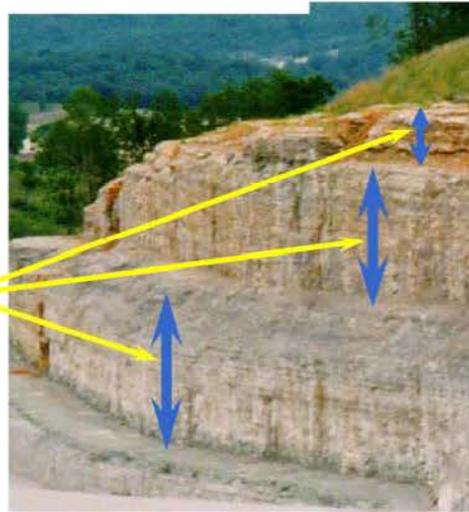
The bench height is usually set by physical constraints, the existing ground elevation and plan grade.





STIFFNESS RATIO

In the case of deep cuts it may be possible to adjust the bench height with stepped cuts.



STIFFNESS RATIO

The bench height should be matched to the reach of the excavation equipment (optimum height of cut).





BLASTHOLE SIZE

- ⊕ In some situations, as in a quarry, the blaster can adapt the bench height to optimize the blast, but on a road project the existing ground and the specified final roadway grades set limits on any bench height modification.
- ⊕ The following table (Table 3, Table 13-3, Text) gives the relationship between the stiffness ratio and the critical blasting factors.



BLASTHOLE SIZE

Table 3. Stiffness Ratio's Effect on Blasting Factors (Table 13-3, Text)

Stiffness Ratio (RS)	1	2	3	> 4*
Fragmentation	Poor	Fair	Good	Excellent
Air Blast	Severe	Fair	Good	Excellent
Flyrock	Severe	Fair	Good	Excellent
Ground Vibration	Severe	Fair	Good	Excellent

*Stiffness Ratios above 4 yield no increase in benefit



BLASTHOLE SIZE

- One of the parameters in both Eqs. 1 and 2 was the diameter of the explosive, D_e . The diameter of the explosive is limited by the diameter of the blasthole

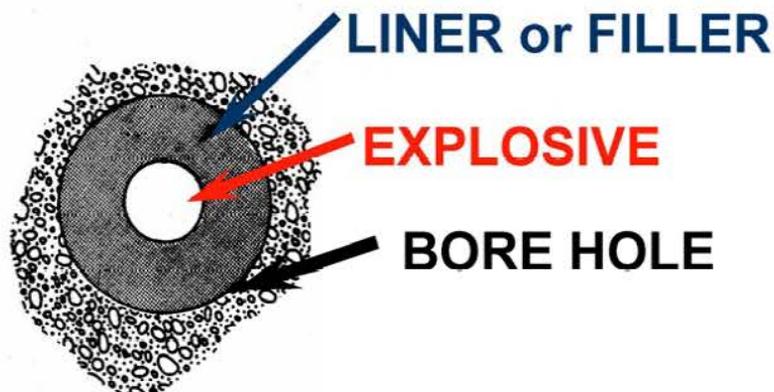
$$B = \left(\frac{2SG_e}{SG_r} + 1.5 \right) D_e \quad B = 0.67 D_e \sqrt[3]{\frac{St_v}{SG_r}}$$

- If it is desirable to drill larger blastholes for economic reasons (usually cheaper), the burden distance will be affected



BLASTHOLE SIZE

Explosive diameter and bore hole diameter may not be the same.





Example 3

- A contractor plans to use dynamite that has specific gravity of 1.3 to open an excavation in granite rock. The drilling equipment available will drill a 5-in blastholes. Dynamite comes packaged in 2.75-in and 4.5-diameter sticks. If the specifications call for a 13-ft bench height and the extent of the excavation perpendicular to the face is 100 ft, how many rows of blastholes will be required for both the 2.75 and 4.5-diameter packages? Which package of dynamite will result in lesser blasting problems?



Example 3 (cont'd)

For the 2.75-in dia. package:

$$\text{Specific Gravity of Granite} = \frac{2.6 + 2.9}{2} = 2.8$$

$$B_1 = \left(\frac{2SG_e}{SG_r} + 1.5 \right) D_e = \left(\frac{2(1.3)}{2.8} + 1.5 \right) (2.75) = 6.7 \text{ ft}$$

$$\text{No. of rows required} = \frac{100}{6.7} + 1 = 15.93 \approx \underline{16 \text{ rows}}$$

For the 4.5-in. dia. package:

$$B_2 = \left(\frac{2SG_e}{SG_r} + 1.5 \right) D_e = \left(\frac{2(1.3)}{2.8} + 1.5 \right) (4.5) = 10.9 \text{ ft}$$

$$\text{No. of rows required} = \frac{100}{10.9} + 1 = 10.17 \approx \underline{10 \text{ rows}}$$



Example 3 (cont'd)

For the 2.75-in. dia. explosive package:

$$SR_1 = \frac{L}{B_1} = \frac{13}{6.7} = \underline{1.94}$$

For the 4.5-in. dia. explosive package:

$$SR_2 = \frac{L}{B_2} = \frac{13}{10.9} = \underline{1.19}$$

Comparing the results of the stiffness ratios using Table 3 (Table 13-3, Text), the 2.5-in. diameter explosive package has lesser blasting problem



Example 3 (cont'd)

Table 3. Stiffness Ratio's Effect on Blasting Factors (Table 13-3, Text)

Stiffness Ratio (RS)	1	2	3	> 4*
Fragmentation	Poor	Fair	Good	Excellent
Air Blast	Severe	Fair	Good	Excellent
Flyrock	Severe	Fair	Good	Excellent
Ground Vibration	Severe	Fair	Good	Excellent

*Stiffness Ratios above 4 yield no increase in benefit



Example 4

Suppose that the rock blasting in Example 3 should be accomplished with a minimum stiffness ratio of 3, what will be the ideal explosive diameter?

$$SR = \frac{L}{B} \Rightarrow B = \frac{L}{SR} = \frac{13}{3} = 4.33$$

$$B = \left(\frac{2SG_e}{SG_r} + 1.5 \right) D_e = \left(\frac{2(1.3)}{2.8} + 1.5 \right) D_e = 4.33 \text{ ft}$$

$$\therefore D_e = 1.783 \text{ in}$$

$$\therefore \text{ideal explosive diameter} = 1.75 \text{ or } 1 \frac{3}{4} \text{ - diameter}$$

CHECK :

$$B = \left(\frac{2(1.3)}{2.8} + 1.5 \right) (1.75) = 4.25 \Rightarrow SR = \frac{L}{B} = \frac{13}{4.25} = 3.06 > 3 \text{ OK}$$



SPACING

- ➊ Proper spacing of blastholes is controlled by the initiation timing and the stiffness ratio.
- ➋ When holes are spaced too close and fired instantaneously, venting of the energy will occur with resulting air blast and flyrock.
- ➌ When the spacing is extended, there is a limit beyond which fragmentation will become harsh.



SPACING

- ⊕ Before beginning a spacing analysis, two questions must be answered concerning the shot:
 1. Will the charges be fired instantaneously or will delays be used?
 2. Is the stiffness ratio greater than 4?



SPACING

Spacing is controlled by initiation timing and stiffness ratio.

- ☞ *Instantaneous initiation: SR greater than 1 but less than 4*
- ☞ *Instantaneous initiation: SR equal to or greater than 4*

Text p. 388, equations (13-6 and 13-7)



SPACING

Spacing is controlled by initiation timing and stiffness ratio.

☞ ***Delayed initiation:*** SR greater than 1 but less than 4

☞ ***Delayed initiation:*** SR equal to or greater than 4

Text p. 388, equations (13-8 and 13-9)



SPACING

⊕ An SR of less than 4 is considered a low bench and a high bench is a SR value of 4 or greater. This means that there are four cases to be considered:

1. ***Instantaneous initiation.*** with the SR greater than 1 but less than 4.

$$S = \frac{L + 2B}{3} \quad (7)$$

where S = spacing

L = bench height



SPACING

2. *Instantaneous initiation*, with the *SR* equal to or greater than 4.

$$S = 2B \quad (8)$$

3. *Delayed initiation*, with the *SR* greater than 1 but less than 4.

$$S = \frac{L + 7B}{8} \quad (9)$$



SPACING

4. *Delayed initiation*, with the *SR* equal to or greater than 4.

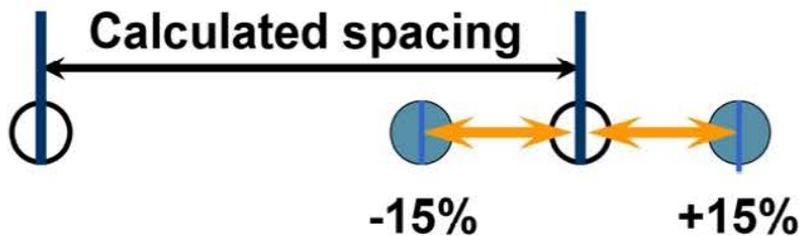
$$S = 1.4B \quad (9)$$

Note: The actual spacing utilized in the field should be within 15% plus or minus the calculated value.



SPACING

Spacing in the field should be within plus or minus 15% of the calculated value.



Example 5

It is proposed to load 4-in diameter blastholes with bulk ANFO. The contractor would like to use an 8 X 8 drill pattern. Assuming the burden distance is correct, will the 8-ft spacing be acceptable? The bench height is 35 ft and each hole is to be fired on separate delay.



Example 5 (cont'd)

$$B = 8 \text{ ft} \quad \text{and} \quad L = 35 \text{ ft}$$

Check the stiffness ratio, L/B for high or low bench:

$$\frac{L}{B} = \frac{35}{8} = 4.4 \text{ ft}$$

Delay timing; therefore, use Eq. 9:

$$S = 1.4(8) = 11.2 \text{ ft}$$

$$\text{Range} = 11.2 \pm 0.15(11.2); \quad S = 9.5 \text{ to } 12.9 \text{ ft}$$

The spacing is not OK. As a minimum, the pattern should be:

$$8 \times 9.5$$



Example 6

A project in granite rock will have an average bench height of 20 ft. An explosive having a specific gravity of 1.2 has been proposed. The contractor's equipment can easily drill 3-in diameter holes. Assume the packaged diameter of the explosives will be 2.5 in. Delay blasting techniques will be used. Develop a blast design for the project.

From Table 1 (Table 13-1 Text):

$$\text{Specific Gravity of Granite} = \frac{2.6 + 2.9}{2} = 2.75$$

$$B = \left(\frac{2SG_e}{SG_r} + 1.5 \right) D_e = \left(\frac{2(1.2)}{2.75} + 1.5 \right) (2.5) = 5.93 \text{ ft}$$



Example 6 (cont'd)

Table 1. Density by Nominal Rock Classifications (Table 13-1, Text)

Rock Classification	Specific Gravity	Density Broken (ton/cu yd)
Basalt	1.8 – 3.0	2.36 – 2.53
Dabase	2.6 – 3.0	2.19 – 2.53
Diorite	2.8 – 3.0	2.36 – 2.53
Dolomite	2.8 – 2.9	2.36 – 2.44
Gneiss	2.6 – 2.9	2.19 – 2.44
Granite	2.6 – 2.9	2.19 – 2.28
Gypsum	2.3 – 2.8	1.94 – 2.26
Hematite	4.5 – 5.3	3.79 – 4.47
Limestone	2.4 – 2.9	1.94 – 2.28
Marble	2.1 – 2.9	2.02 – 2.28
Quartzite	2.0 – 2.8	2.19 – 2.36
Sandstone	2.0 – 2.8	1.85 – 2.36
Shale	2.4 – 2.8	2.02 – 2.36
Slate	2.5 – 2.8	2.28 – 2.36
Trap Rock	2.6 – 3.0	2.38 – 2.53



Example 6 (cont'd)

Hence, use 6 in for the burden distance B .

$$SF = \frac{L}{B} = \frac{20}{6} = 3.3 \Rightarrow \text{good (according to Table 3)}$$

$$\text{The stemming depth } (T) = 0.7 \times B = 0.7(6) = 4.2 \text{ ft}$$

Use 4 ft for the stemming depth, T .

$$\text{The subdrilling } (J) = 0.3 \times B = 0.3(6) = 1.8 \text{ ft}$$

Use 2 ft for subdrilling depth, J

$$1 < SR < 4 \text{ and delayed initiation} \Rightarrow S = \frac{L + 7B}{8} = \frac{20 + (7)(6)}{8} = 7.75 \text{ ft}$$

$$\text{Range} = 7.75 \pm 0.15(7.75): \quad S = 6.6 \text{ to } 8.9 \text{ ft}$$

As a first trial, use a 6-ft burden X 8-ft spacing pattern



Example 6 (cont'd)

Table 3. Stiffness Ratio's Effect on Blasting Factors (Table 13-3, Text)

Stiffness Ratio (RS)	1	2	3	> 4*
Fragmentation	Poor	Fair	Good	Excellent
Air Blast	Severe	Fair	Good	Excellent
Flyrock	Severe	Fair	Good	Excellent
Ground Vibration	Severe	Fair	Good	Excellent

*Stiffness Ratios above 4 yield no increase in benefit



POWDER COLUMN AND POWDER FACTOR

- ⊕ The amount of explosive required to fracture a cubic yard of rock is a measure of economy of blast design.
- ⊕ Table 5 (Table 13-4, Text) is a loading density chart which allows the engineer to easily calculate the weight of explosive required for a blasthole.



POWDER COLUMN AND POWDER FACTOR

Table 4. Explosive Loading Density Chart in lb per ft of Column for a Given Explosive Specific Gravity (Table 13-4, Text)

Column diam. (in.)	Explosive specific gravity							
	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50
1	0.27	0.31	0.34	0.37	0.41	0.44	0.48	0.51
1½	0.43	0.48	0.53	0.59	0.64	0.69	0.74	0.80
1¾	0.61	0.69	0.77	0.84	0.92	1.00	1.07	1.15
1½	0.83	0.94	1.04	1.15	1.25	1.36	1.46	1.56
2	1.09	1.23	1.36	1.50	1.63	1.77	1.91	2.04
2½	1.70	1.92	2.13	2.34	2.55	2.77	2.98	3.19
3	2.45	2.76	3.06	3.37	3.68	3.98	4.29	4.60
3½	3.34	3.75	4.17	4.59	5.01	5.42	5.84	6.26
4	4.36	4.90	5.45	6.00	6.54	7.08	7.63	8.17
4½	5.52	6.21	6.89	7.58	8.27	8.96	9.65	10.34
5	6.81	7.66	8.51	9.36	10.22	11.07	11.92	12.77
5½	8.24	9.27	10.30	11.33	12.36	13.39	14.42	15.45
6	9.81	11.03	12.26	13.48	14.71	15.93	17.16	18.39
6½	11.51	12.95	14.39	15.82	17.26	18.70	20.14	21.58
7	13.35	15.02	16.68	18.35	20.02	21.69	23.36	25.03
8	17.43	19.61	21.79	23.97	26.15	28.33	30.51	32.69
9	22.06	24.82	27.58	30.34	33.10	35.85	38.61	41.37
10	27.24	30.64	34.05	37.46	40.86	44.26	47.67	51.07



POWDER COLUMN

Powder column length is the blasthole depth minus the stemming depth.

**Blasthole depth =
bench height + subdrilling**

**Powder column =
blasthole depth - stemming**



POWDER COLUMN AND POWDER FACTOR

➤ Definition:

“The powder column length is the total hole length less stemming” that is

$$\text{Powder Length} = L + J - T \quad (10)$$



POWDER COLUMN AND POWDER FACTOR

➤ Definition:

“The powder factor is the ratio of the total weight (lb) of explosive in powder column length to the total volume (cu yd) of rock fractured by one blasthole under the pattern area to a depth of bench depth equal L” that is

$$\text{Powder Factor} = \frac{\text{Total Weight (lb) of Powder Column Length}}{\text{Total Volume under Pattern Area (cu yd)}} \quad (11)$$



Example 7

For Example 6, calculate the powder column length, the total weight of explosive used per blasthole, and the powder factor.

From Example 6, $L = 20$ ft, $J = 4$ ft, and $T = 4$ ft, Pattern = 6 X 8
Specific Gravity of Explosive = 1.2
Explosive diameter = 2.5

From Table 4 (Table 14-4 Text): Loading Density = 2.55 lb per ft

Powder Column Length = $(L + J) - T = 20 + 4 - 4 = 18$ ft

The Total Weight of Explosive per Column = $18 \times 2.55 = 45.9$ lb

$$\begin{aligned} \text{Powder Factor} &= \frac{\text{Total Weight of Explosive per Hole}}{\text{Volume of Rock Fractured under Pattern Area}} = \\ &= 45.9 \div \frac{6(8)20}{27} = \underline{1.29} \text{ lb/cu yd} \end{aligned}$$



POWDER COLUMN AND POWDER FACTOR

- ⊕ In all the examples presented so far, it has been assumed that only one explosive was used in a blasthole.
- ⊕ If a hole is loaded with ANFO, it will require a primer to initiate the explosion.
- ⊕ For example, in the case of a powder column that is 18 ft, and that will be loaded with ANFO ($G_s = 0.8$), a primer will have to be placed at the bottom of the hole.



POWDER COLUMN AND POWDER FACTOR

- ⊕ A stick dynamite ($G_s = 1.3$) will require a minimum of 8 in (0.667 ft). Therefore, there will be 208 in (17.33 ft) of ANFO and 8 in (0.67 ft) of dynamite
- ⊕ The weight of explosives based on a 2.5-in explosive diameter will be:

$$1.70 \text{ lb/ft} \times 17.33 \text{ ft} = 29.46 \text{ lb}$$

$$2.77 \text{ lb/ft} \times 0.67 \text{ ft} = 1.85 \text{ lb}$$

$$31.31 \text{ lb}$$

The total per hole is 31.31 lb for 18 ft of powder column



MATERIAL HANDLING CONSIDERATIONS

- ⊕ The economics of handling the fractured rock is a factor which should be considered in blast design.
- ⊕ Although it is critical to achieve good breakage, the blast pattern will affect such considerations as the type of equipment and the bucket fill factor.
- ⊕ The appropriate piling of the blasted rock by the shot is dependent on the blast design.



MATERIAL HANDLING CONSIDERATIONS

- ⊕ To utilize the blast to accomplish good breakage and appropriate piling, one should apply the following principles:
 1. Rock movement will be parallel to the burden dimension.
 2. Instantaneous initiation along a row causes more displacement than delayed initiation.
 3. Shots delayed row by row scatter the rock more than shots fired in a V pattern.
 4. Shots designed in a V pattern firing sequence give maximum piling close to the face.



MATERIAL HANDLING CONSIDERATIONS

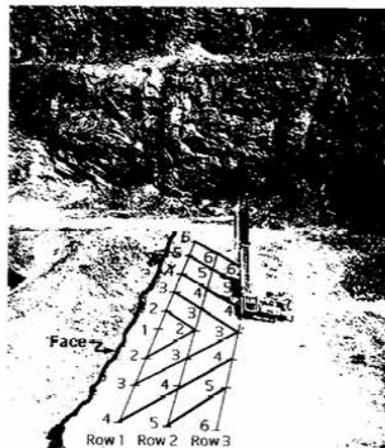
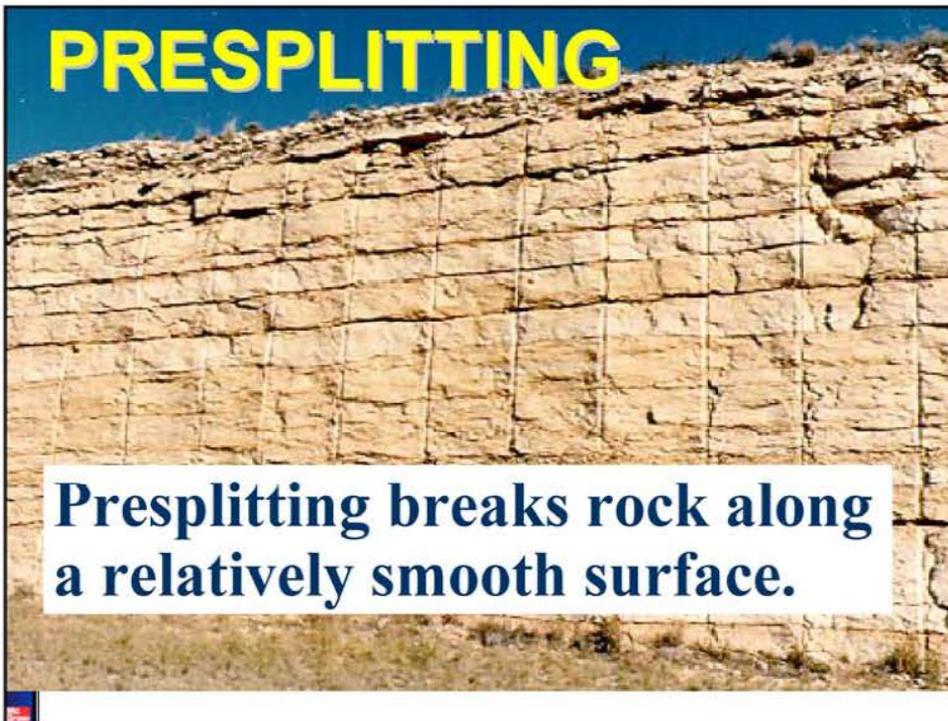


FIGURE 14-2
Square layout center firing sequence with progressive delays, numbers indicate firing order



PRESPLITTING ROCK

- Presplitting Rock is a technique of drilling and blasting which breaks rock along a relatively smooth surface (see next figure).
- The holes usually are 2.5 to 3 in. in diameter and are drilled along the desired surface at spacings varying from 18 to 36 in depending on the characteristic of the rock.





PRESPLITTING ROCK

- The holes are loaded with one or two sticks of dynamite at the bottoms, with smaller charges, such as 1.25 x 4- in. sticks spaced at 12-in intervals to the top of the portion of the holes to be loaded.



PRESPLITTING ROCK

- It is important that the charges be less than half the blasthole diameter and they should not touch the walls of the holes
- The appropriate load of explosive per foot of presplit blasthole is given by

$$d_{ec} = \frac{D_h^2}{28} \quad (12)$$

where d_{ec} = explosive load, lb per ft
 D_h = diameter of blasthole, in



PRESPLITTING ROCK

- When the formula given by Eq. 12 is used to arrive at an explosive loading, the spacing between blastholes can be determined by the following equation:

$$S_p = 10D_h \quad (13)$$

where S_p = presplit blasthole spacing, in

- Presplit blastholes are not extended below grade. In the bottom of the hole a concentrated charge of 2 to 3 times d_{ec} should be placed instead of subdrilling



Example 8

By contract specification the walls of a highway excavation through rock must be presplit. The contractor will be using drilling equipment capable of drilling a 3-in hole. What explosive load and hole spacing should he try for the first presplit shot on the project?

$$d_{ec} = \frac{D_h^2}{28} = \frac{(3)^2}{28} = 0.32 \frac{\text{lb}}{\text{ft}}$$

$$S_p = 10D_h = 10(3) = 30 \text{ in}$$

The bottom load should be $3 \times 0.32 = 0.96 \text{ lb}$



SAFETY CONSIDERATIONS

- ⊕ An accident involving explosives may easily kill or cause serious injury.
- ⊕ The prevention of such accidents depends on careful planning and faithful observation of proper blasting practices.
- ⊕ There are federal and state regulations concerning the transportation and handling of explosives.



SAFETY CONSIDERATIONS

- ⊕ Safety information on specific products is provided by the manufacturer.
- ⊕ In addition to regulations and product information, there are recommended practices, such as the evacuation of the blast area during the approach of an electrical storm whether electric or nonelectric initiation systems are used.



SAFETY CONSIDERATIONS

- ⊕ A good source for material on recommended blasting safety practices is the Institute of Makers of Explosives in New York City.
- ⊕ **Misfire:** In shooting charges of explosives, one or more charges may fail to explode. This is referred to as a "misfire."
- ⊕ It is necessary to dispose of this explosive before excavating the loosened rock
- ⊕ The most satisfactory method is to shoot it if possible.



FACTORS AFFECTING VIBRATION

Some of the critical factors that should be considered are:

- | | |
|-------------------------|------------------------------|
| 1. Burden | 10. Rock Type |
| 2. Spacing | 11. Rock Physical Properties |
| 3. Subdrilling | 12. Geological Features |
| 4. Stemming Depth | 13. Number of Holes in a Row |
| 5. Type of Stemming | 14. Number of Rows |
| 6. Bench Height | 15. Row-to-Row Delays |
| 7. Number of Decks | 16. Initiator Precision |
| 8. Charge Geometry | 17. Face Angle to Structure |
| 9. Powder Column Length | 18. Explosive Energy |



SPACING don't forget -- SAFETY



FACTORS AFFECTING VIBRATION

- ⊕ The U.S. Bureau of Mines has proposed a formula to evaluate vibration and as a way to control blasting operation as follows:

$$D_s = \frac{d}{\sqrt{W}} \quad (14)$$

where D_s = scaled distance (nondimensional factor)
 d = distance from shot to structure, ft
 W = maximum charge weight per delay, lb

- ⊕ A scale value of 50 or greater indicates that a shot is *safe* with respect to vibration
- ⊕ Some regulatory agencies require a value of 60 or greater



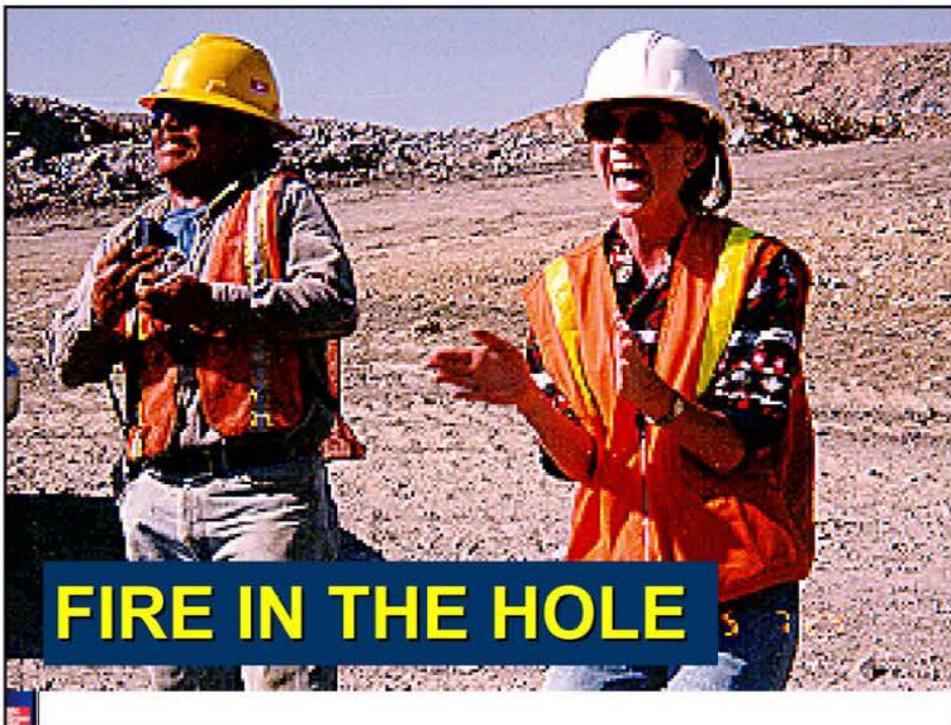
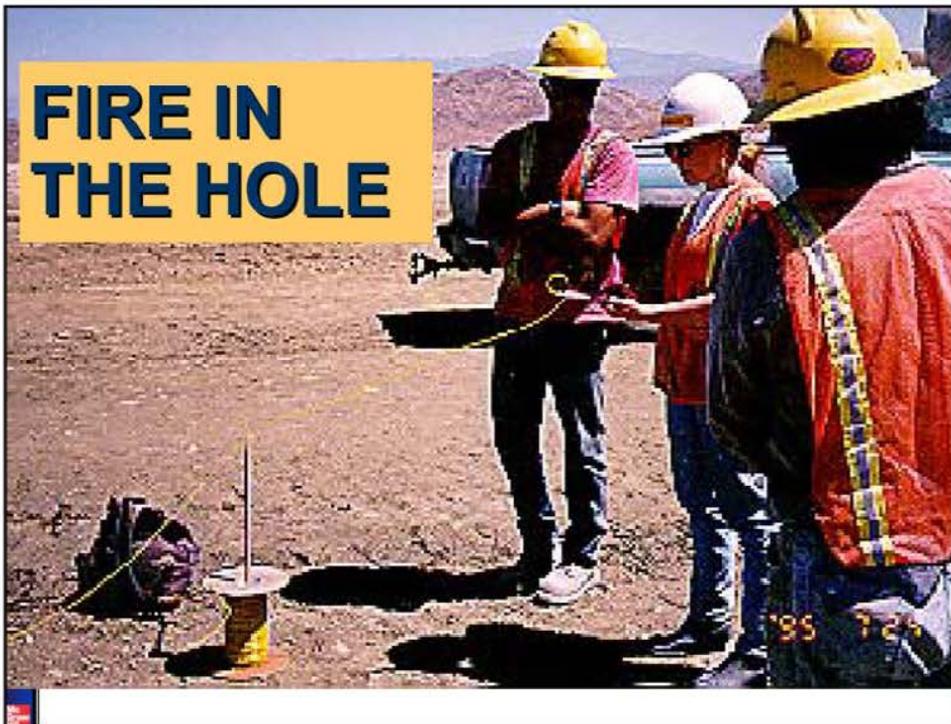
VIBRATION

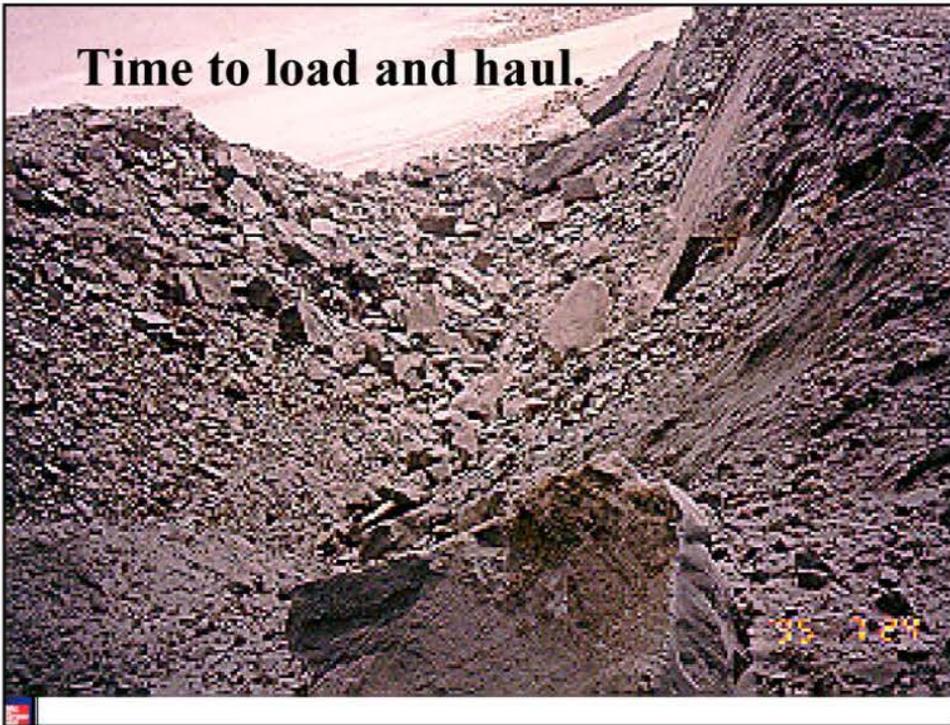
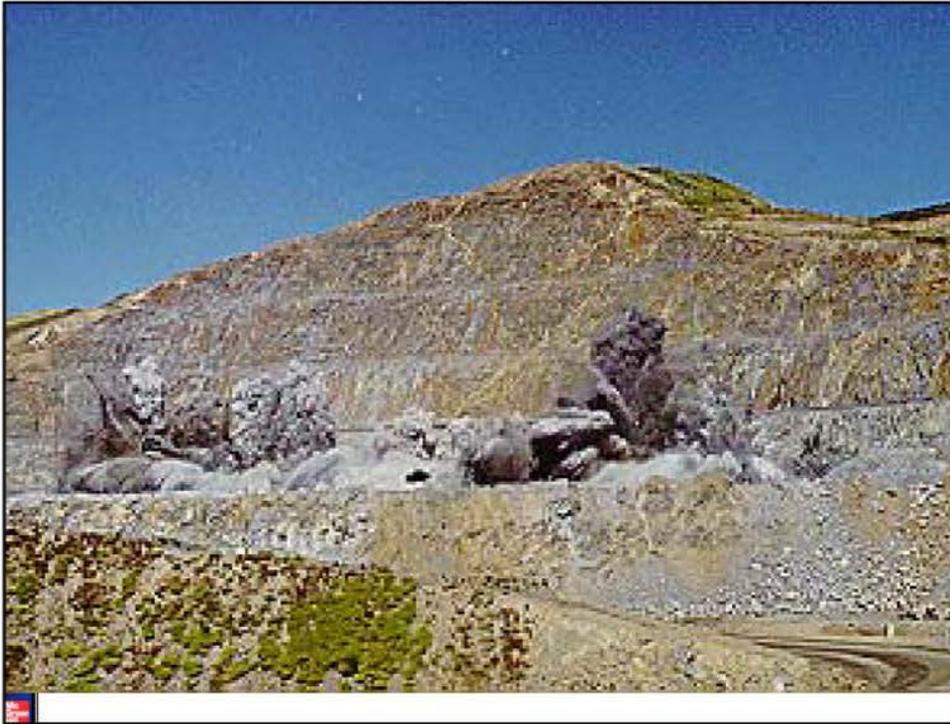
Check vibration by **formula 13-12** and adjust amount of explosive per delay if necessary.

$$D_s = \frac{d}{\sqrt{W}}$$

Text p. 397









Where to get more information

- **Blasters' Handbook, E. I. du Pont de Nemours & Co., Wilmington, DE**
- **Rock Blasting and Overbreak Control, National Highway Institute, Washington, DC**