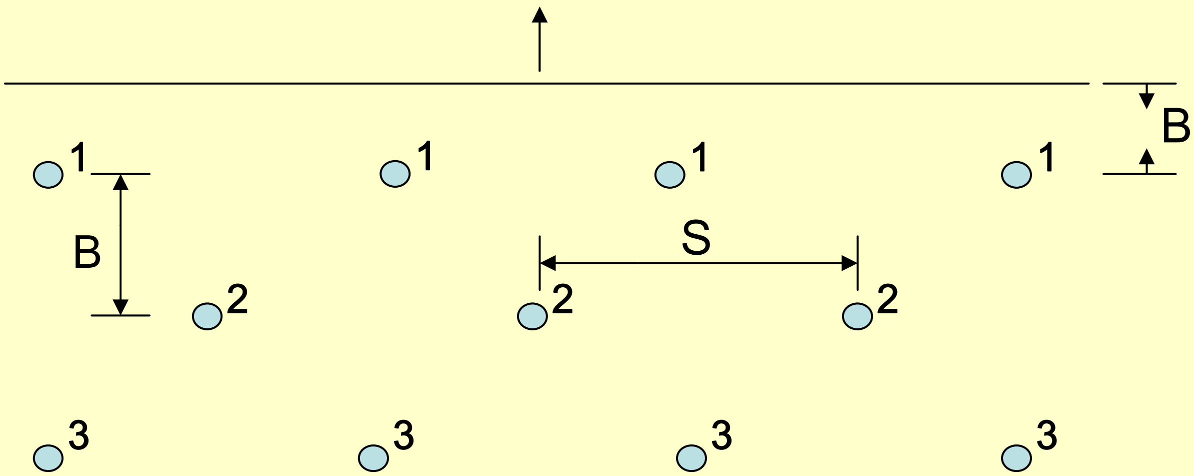
Surface-Blast Design



This blaster-training module was put together, under contract, with Federal funds provided by the Office of Technology Transfer, Western Regional Office, Office of Surface Mining, U.S. Department of the Interior, located in Denver, Colorado.

The module is an example of the technical assistance the Federal government furnishes States to assist them in meeting the requirements of the Surface Mining Control and Reclamation Act of 1977, upon which their State surface coal-mine regulating programs are based. In particular, the module was requested and will be used by the Sheridan District Office, Wyoming Department of Environmental Quality, Land Quality Division.

A word of caution: please note that **this module is not intended to stand alone, nor is it a self-training type module**. Rather, **the information the module provides MUST BE SUPPLEMENTED** by information given by a certified blasting instructor.

DISCLAIMER

The technologies described in the module are for information purposes only. The mention herein, of the technologies, companies, or any brand names, does not constitute endorsement by the U.S. Department of the Interior's Office of Surface Mining.

Surface-Blast Design

This module presents recommended blast-design practices for surface-mine and quarry blasting.

Blast-Design Overview

Objectives in blasting:

- Fragmentation
- Highwall stability
- Movement:
  - Buffer blasting
  - Cast blasting

Blast theory:

- Stress waves
- Crack propagation

Timing:

- Millisecond delay blasting:
  - “V” (chevron) pattern
  - Echelon pattern
  - Row-by-row pattern

Types of blast patterns:

- Square
- Rectangular
- Staggered

Blast-Design Overview

Blast parameters:

- Burden
- Spacing
- Bench height
- Powder column:
  - Hole diameter
  - Hole depth
  - Powder factor
  - Subdrilling
  - Stemming

Controlled blasting techniques:

- Line drilling
- Presplitting
- Smooth blasting
- Cushion blasting

Measurements and calculations:

- Loading density
- Face profiling
- High-speed photography
- Fragmentation distribution
- Velocity of detonation

Objectives in Blasting

The primary objectives in rock blasting are to optimize blast performance and ensure the safety of everyone by implementing safe practices in and around the blast site.

Secondary objectives include:

- Maintaining the stability of highwalls, so that men and equipment working on and under them are safe;
- Fragmenting rock masses to reduce their downstream hauling and crushing costs; and
- Moving rock masses to facilitate their load-out by site-specific equipment.

Safety

Weekly or monthly safety meetings that include the blast crew, drill crew, and production crew keep employees posted as to (1) all site-specific safety procedures and (2) what is expected of them daily.

Fragmentation and Moving

A proper blast design will yield adequate fragmentation, which will lower downstream costs related to hauling, equipment maintenance, and crushing.

Highwall Stability

A safe and stable highwall is critical to virtually all aspects of a blasting operation. Equipment—drills, draglines, and dozers—relies on highwall stability, as do blasting crews loading interburden (parting shots) and shovel operators loading trucks in the pit. Maintaining a stable highwall at your operation requires a good understanding of geology and water conditions, as well as slope and blast design. In addition, you must maintain quality control over the blast design. The strength of a rock mass under shear, tensile, and compressional loading will dictate the overall stability of a highwall.

Rock Failure

Compression failure is caused immediately around a charge when the rock is crushed by extremely high borehole pressures.

Tensile failure occurs when reflecting stress waves rip the rock apart. The damage from such failure is much greater, because rocks are much weaker in their tensile strengths than in their compressive strengths.

Shear failure is controlled by the shear strength of the rock mass, the duration of the blast, and blast-induced vibration levels. Repeated blasting can reduce the shear strength of adjacent rock masses.

Highwall Stability

Blast design will influence the stability of highwalls, in that it affects:

- Horizontal relief away from the wall,
- Energy concentration adjacent to the wall, and
- Blast size and duration.

Modified production blasts are blasts that use reduced charge loads in the rows nearest to the proposed crestline of the new highwall. This reduces the explosive energy adjacent to the highwall and may reduce overbreak beyond the crestline.

Some controlled blasting methods used to reduce **overbreak** and **backbreak** beyond the crestline are discussed in this module.

Movement

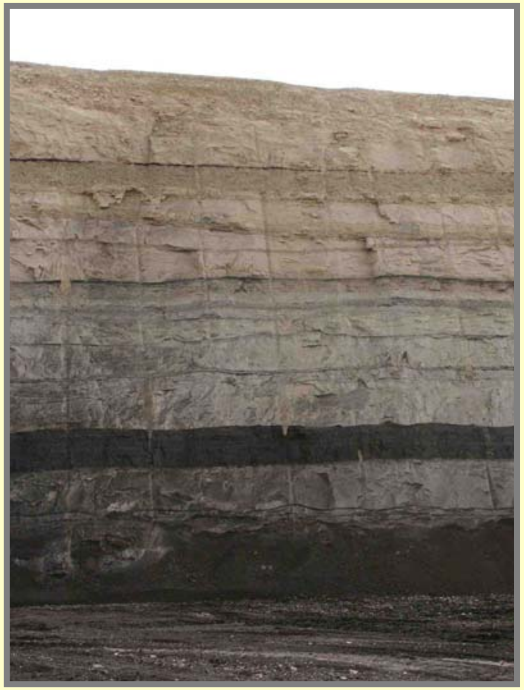
The shape and location of the muckpile is an important element of shot design. Requirements range from a need for extreme throw—for example, to cast overburden under a coal-stripping scenario—to buffer shooting, where the muckpile is confined to a certain area by rock that has been previously blasted. The confined muckpile provides a high bank of shot material that will increase shovel productivity. Mines with a high face that use front-end loaders will often blast for a low muckpile for the sake of safety considerations on the ground. Bench height, powder factor, burden, timing, and buffers all must be considered when movement modifications are made.

Click on the image above to play a buffer-shot blasting clip.

Click on the image above to play a cast-blast blasting clip.

Controlled Blasting

Controlled blasting techniques are used to efficiently distribute explosive charges in a rock mass, thereby minimizing the fracturing of rock beyond the crestline of the highwall or designed boundary of main excavation areas. Such over-fracturing, commonly called **overbreak**, is typically more of a problem in soft or unconsolidated, incompetent overburden formations.



There are several techniques that a blaster can use to minimize overbreak, but trials should be conducted to determine whether any given technique can be applied successfully, as well as to determine the proper hole spacing for the given geology. Modern blasting professionals group controlled blasting techniques into four categories:

- Presplitting,
- Smooth blasting,
- Line drilling, and
- Cushion blasting.

Presplitting

Presplitting is a technique that involves loading a single row of holes that have been drilled along a desired highwall crest or excavation line with small decoupled charges. Such charges reduce the crushing effect around the borehole and are shot before the main production shot. The idea is to minimize or eliminate overbreak from the primary blast and to produce a smooth rock wall. Presplitting will add a large drilling cost to an operation.

Borehole Diameters

Normally, the diameter of a borehole is limited by the capabilities of the drill used to create it. As a rule, open-pit and coal strip mines using large drills will drill presplit holes that range from 9 to 12-¼ inches in diameter. Quarry and construction presplits are much smaller, generally ranging from 2 to 4 inches in diameter. Presplit holes may be drilled on an angle if the geology and drill allow for it.

Spacing

Presplit spacing will vary, depending upon rock characteristics, size of the operation, and bench height. Trials should be conducted to determine the optimal borehole spacing. On average, Western coal strip-mine operations use presplit spacings of from 10 to 12-½ feet, whereas soft-weathered formations at small projects may require presplit spacings of 15 inches or less.

Explosive Charge

Depending upon the rock characteristics and spacing used for the presplit, charge loads will vary; however, powder factors will normally range from 0.1 to 0.3 lbs/ft^3. Many times, detonating cord (25 to 400 grains/foot) is used either as the primary charge in a presplit hole or in conjunction with a small primer. This decoupled charge reduces the amount of explosive energy that is transferred to the rock mass.

Limitations

Results of presplitting cannot be determined until after the excavation has been removed to the presplit line.

Controlled Blasting

The term "*smooth blasting*" refers to lightly loaded holes that have been drilled along excavation limits and are shot after the main excavation is removed. Typically, such holes are shot instantaneously or with little delay, leaving a smooth wall with minimum overbreak. Smooth blasting is the most widely accepted method for controlling overbreak in underground headings and stopes; however, it is is not widely preferred over presplitting in surface mining.

"*Line drilling*" provides a plane of weakness to which a primary blast may break; it may also protect a highwall by reflecting some of the shock wave created by a blast. This plane of weakness is created by drilling a line of closely spaced (3- to 12-inch), small-diameter (1.5- to 3-inch) holes along the excavation line. The distance from the back row to the line drill is normally 50 to 75 percent of the production burden. Line drilling is normally limited to construction projects, dimension stone quarries, and rock sculpting where any overbreak at all can be considered detrimental.

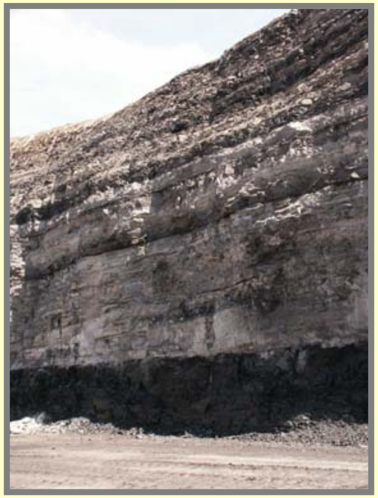
"Cushion blasting," or trim blasting, is similar to smooth blasting in that the holes are shot after the main production shot. Cushion blasting involves backfilling the entire borehole with crushed stone to cushion the shock from the finished wall. This technique is rarely used today, because air decking with good quality gas bags or hole plugs can achieve the same results will less loading time.

Hole Diameter and Depth

The choice of the hole diameter depends upon the geology of the blastsite, primarily the jointing and bedding of the formation. The desired fragmentation, the face height, and economics must also be considered.

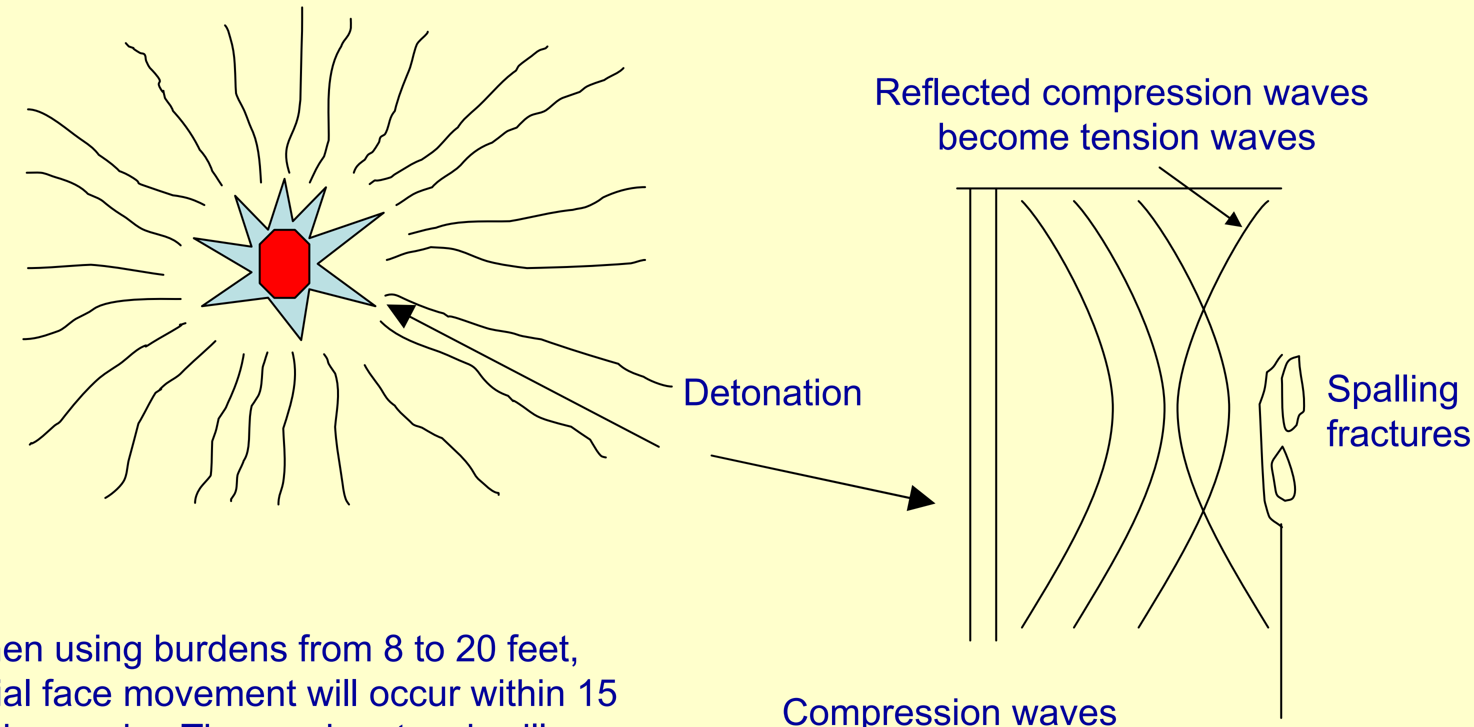
The geology is the only factor in the blast design that cannot be changed. Accordingly, given the geology, the method of operation and the cost of equipment are determined based upon the desired fragmentation, which in turn is a function of hole diameter and the explosive being used.

The bench height is usually designed around the safety of the workers and equipment that will be on top of and under the highwall. Proper blast design will optimize use of the inherent stability of the geological formation in question.



Blast Theory

When explosives detonate in a blasthole, a stress wave moving at 10,000 to 20,000 ft/s (depending upon the rock type) propagates out from the hole. These stress waves cause radial fracturing of the rock mass at 1.5 to 8 feet per millisecond.



When using burdens from 8 to 20 feet, initial face movement will occur within 15 milliseconds. The crack network will establish and rock movement will begin after 1 millisecond per foot of burden on the hole.

Blasting Measurements

The fundamental principle of blast design is most often the distribution of an explosive in the rock, where "distribution" is considered to be a combination of blast pattern and explosive density.

Powder factor is the relationship between a rock mass and the explosive used to fragment it; the term "powder factor" can be used to describe either the weight of explosive per unit volume (lb/yd^3) or the weight of material blasted per weight of explosive (tons/lb). The weight of explosive can be determined using the *column-rise formula*, as follows:

Loading density = K x explosive density x (column diameter)^2,

where

- loading density is measured in pounds of explosive per foot of borehole,
- K = 0.3405,
- explosive density is measured in grams per cubic centimeter, and
- explosive column diameter is measured in inches.

The total weight of explosive per hole is determined by multiplying the loading density (calculated using the column-rise formula) by the length of the powder column. The volume of material to be blasted is calculated by the *rock-volume formula*, as follows:

Volume = burden dimension x spacing dimension x (hole depth – subdrill length)/27,

where

- hole depth – subdrill length = bench height* and
- burden dimension, spacing dimension, and bench height all are measured in feet.

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*Technically, the equation "hole depth – subdrill length = bench height" is correct. However, often, bench height alone equals hole depth, especially at surface coal mines, where subdrilling is not a common practice (subdrilling is more prevalent at quarry operations).

Blast Design

The powder factor for a single borehole is calculated as:

$$PF = \frac{PC \text{ x } (0.34\,\rho) \text{ x } d^2}{B \text{ x } S \text{ x } H/27}$$

where PF = powder factor, pounds of explosives per bank cubic yard of rock;
PC = Powder column, feet of explosive charge♦;
ρ = density, in g/cm^3, of the explosive;
d = charge diameter‡ in inches;
B = burden dimension in feet;
S = spacing dimension in feet;
H = bench height (or hole depth) in feet*.

Typically, blasters will round the powder factor to the nearest tenth or hundredth.

♦Powder column = hole depth (or bench height, H) – stemming – backfill.

‡Charge diameter = hole diameter, when using bulk ANFO or other pumped explosives.

*Again, note that, especially at surface coal mines (as distinguished from quarry operations), not all benches are subdrilled. In cases where subdrilling is used, "H = bench height in feet," where "bench height = hole depth – subdrill length."

Review Question

1. A surface coal mine currently in operation plans to undertake additional blasting loading ANFO with a density of 0.8 g/cm^3. Additional relevant parameters with respect to this proposed shot are:

    - Burden = 28 feet,
    - Spacing = 33 feet,
    - Bench height (or hole depth) = 135 feet,
    - Hole diameter = 11 inches,
    - Stemming = 30 feet, and
    - No. of holes = 200.

    In pounds of explosives per bank cubic yard of rock, what will the powder factor for a single one of these boreholes?

    a. 0.25
    b. 0.5
    c. 0.75

Answer

1. c. is correct. Powder factor for a single borehole is calculated as:

$$PF = \frac{PC \text{ x } (0.34\ \rho) \text{ x } d^2}{B \text{ x } S \text{ x } H/27}$$

where PF = powder factor, pounds of explosives per bank cubic yard of rock;
PC = length, in feet, of the explosive charge;
ρ = density, in g/cm^3, of the explosive;
d = charge or hole diameter in inches;
B = burden dimension in feet;
S = spacing dimension in feet; and
H = bench height or hole depth in feet.

Remembering that PC = bench height – stemming, and using the parameters in our example,

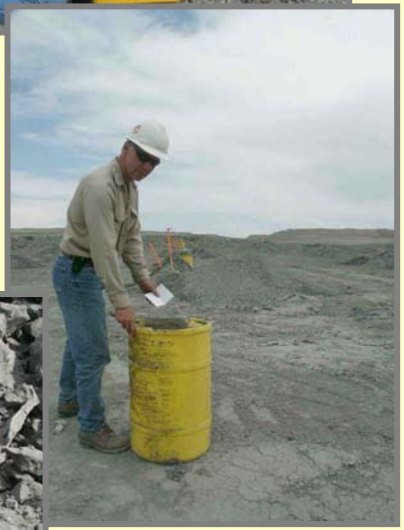
$$PF = \frac{105 \text{ x } (0.34 \text{ x } 0.8) \text{ x } 11^2}{28 \text{ x } 33 \text{ x } 135/27}$$

or 0.7491 (rounded to 0.75) pounds of explosive per bank cubic yard of rock at our surface coal-mine shot.

Blast Measurements

It is important for the blaster to know the face height and toe burden of a shot. In cast blasting, knowing the face burden can allow you to accurately calculate the placement and angle of the face holes and to set any remaining rows of holes. These parameters can be determined by surveying the face in one of many ways. Modern laser transits are available for detailed 2D and 3D face profiling.

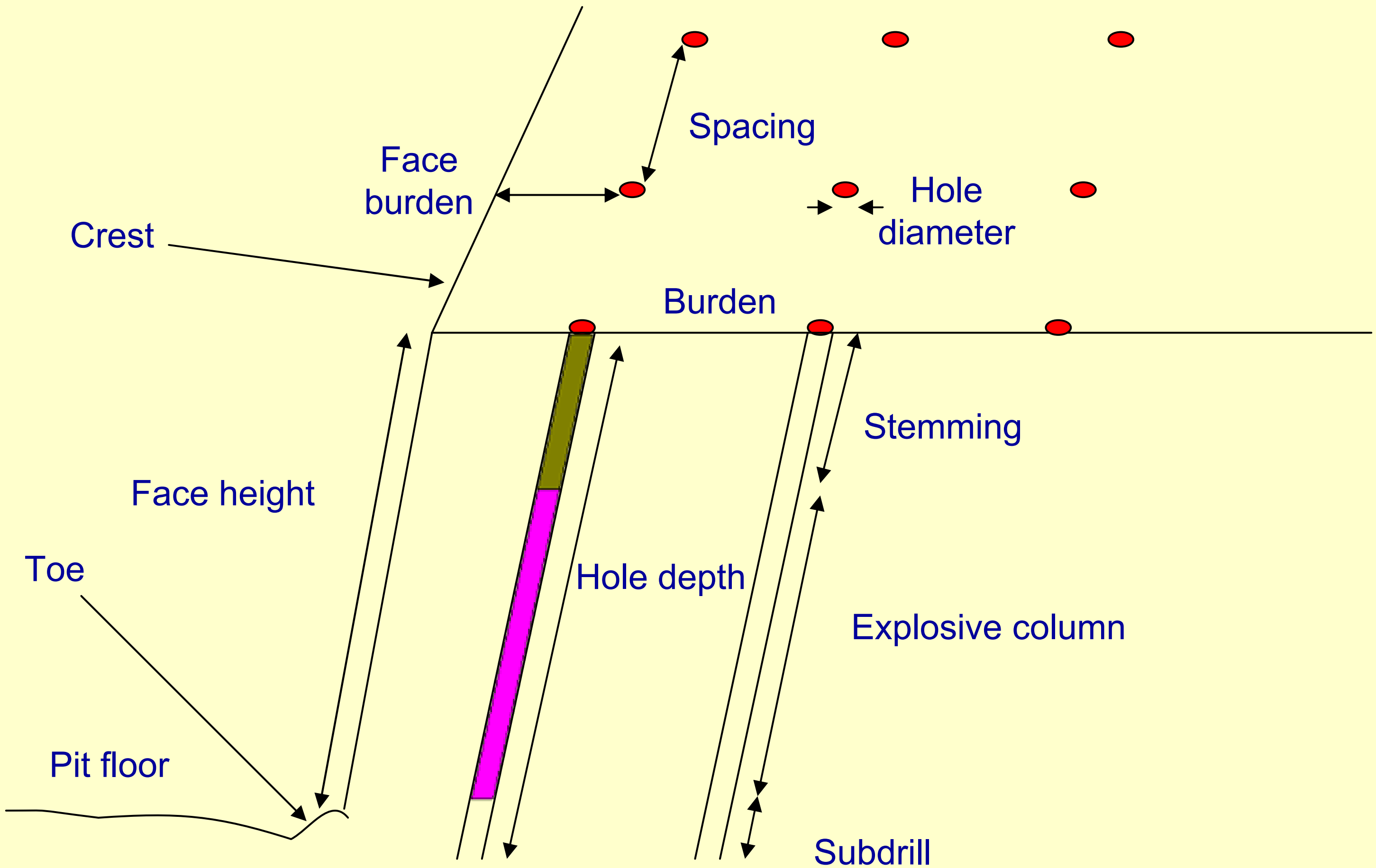
High-speed photography can be used to evaluate the movement or flexing of the face and top of the shot and to determine the velocity of rock moving away from a highwall.



Fragmentation distribution can be calculated by running a particle distribution on the muckpile. Computer software exists to aid in making distribution calculations.

Velocity of detonation in any borehole can be calculated by placing a gage inside the borehole. This gage is wired to an oscilloscope that logs the speed of the detonation wave in the borehole.

Blast-Pattern Parameters



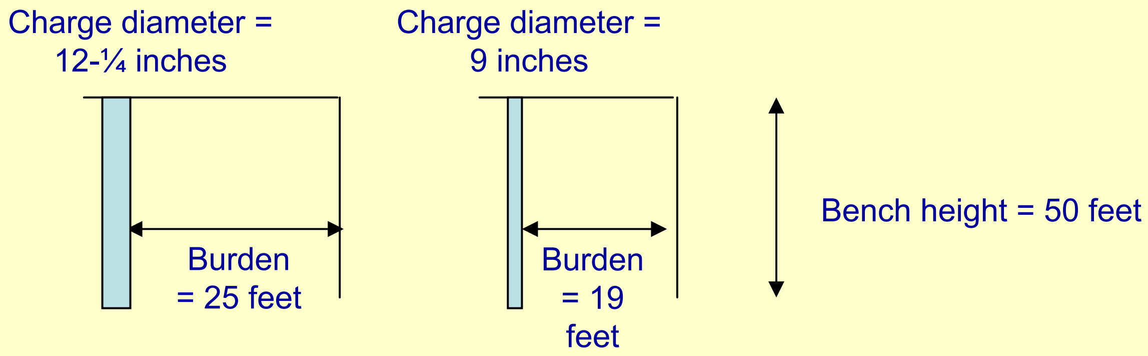
Blast Design

Burden

The proper burden dimension to use in any given individual blast can be calculated by taking into account hole diameter, relative rock density, and the explosive that will be used in the blast. Too small a burden can result in excessive airblast and flyrock; on the other hand, too large a burden can result in improper fragmentation, toe problems, and excessive ground vibrations. The burden, in turn, is the basis for calculating spacing, stemming, and subdriling.

Field testing gives a better idea of the exact burden to use in an operation; however, lower burden-to-charge diameter ratios should be used as a first approximation when the blasthole diameter is large in comparison to the bench height.

The assumption of 25 times the charge diameter is a good starting point for determining the burden dimension to use when shooting with ANFO (0.85 g/cm^3) in rock with a density of near 2.7 g/cm^3. When shooting with a denser emulsion or blend product (1.2 g/cm^3), the burden can be increased to from 30 to 35 times the charge diameter. Thus, if an operation plans to shoot ANFO in 9-inch holes in a 50-foot bench, a good starting point would be a 19-foot burden. In a hole with a 12-¼-inch diameter, the burden can be increased to 25 feet.*



ANFO shot.

*Note that both these assumptions with respect to charge diameter are first approximations. A blaster can modify the charge diameter:burden ratio based upon his or her experience and knowledge of the explosive being used, the rock type, and the specifics of the operation.

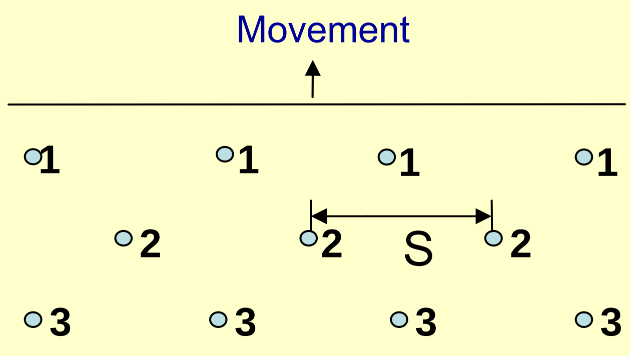
Blast Design

Spacing

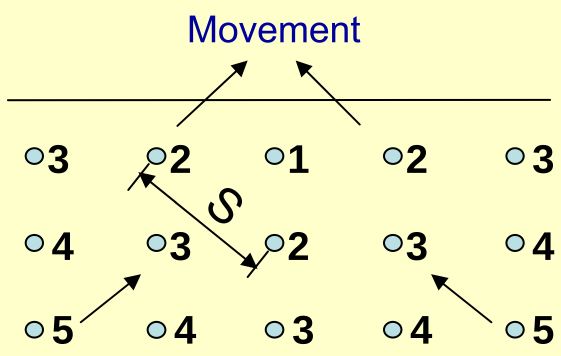
Spacing is the distance between adjacent blastholes in a row, measured perpendicular to the burden. In row-to-row shooting, spacing is measured between holes in a row; when the shot progresses at an angle to the free face, the spacing is measured at that angle.

Spacing may be somewhat dependent on the timing, but is most often a function of the burden. Close spacings cause crushing and cratering between holes, boulders, and toe problems. Holes spaced too far apart will result in inadequate fragmentation.

The assumption of from 1.8 to 2 times the burden is a good starting point for determining the spacing of a blast to be initiated simultaneously in holes in the same row. When shooting sequentially down the row in a box cut or "V" pattern, spacing should be from 1 to 1.2 times the burden (or close to a square pattern).



Spacing ≈ 2 x burden



Spacing ≈ burden

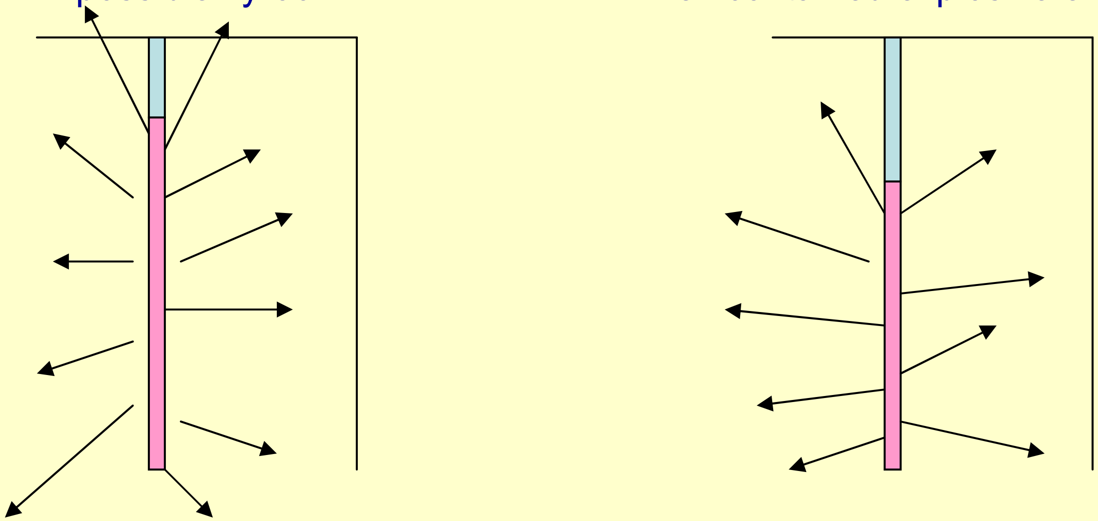
Blast Design

Stemming

Stemming contains explosive energy within a blasthole, so that it will break and move the rock without generating flyrock. Sized crushed stone or drill cuttings should be used as stemming.

Inadequate stemming = possible flyrock

Adequate stemming = well-contained explosive energy

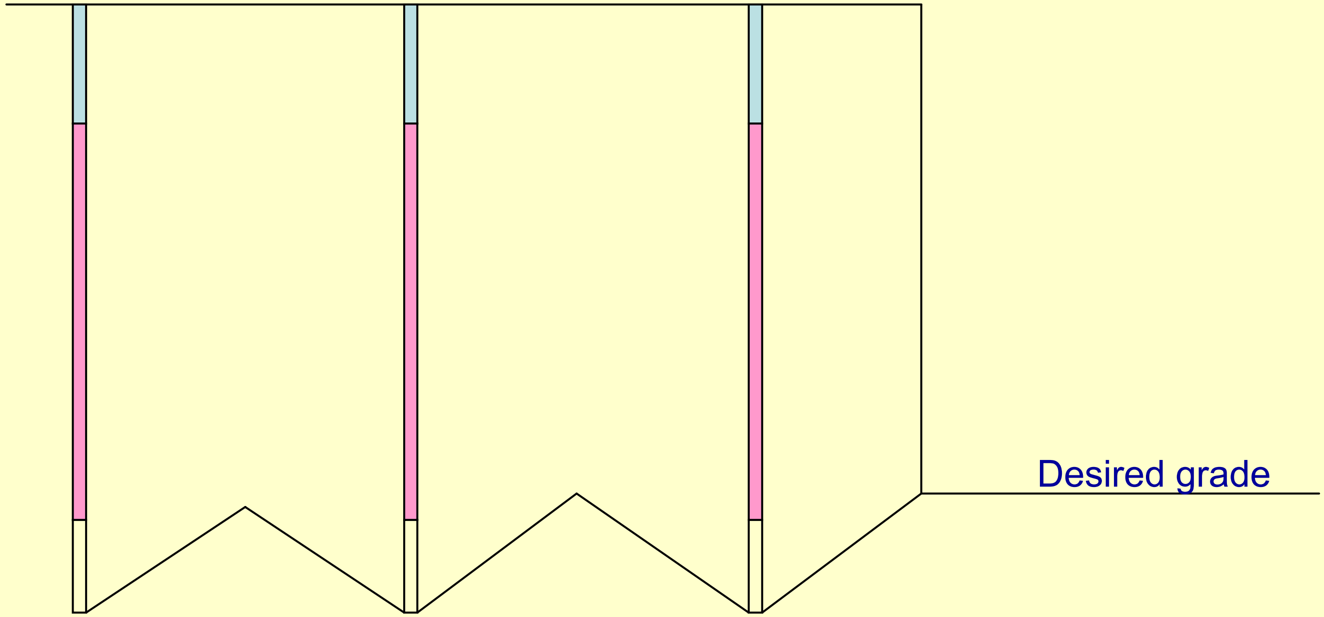


Stemming columns are generally 0.5 to 1.3 times the burden. A good first approximation for stemming column height is 0.7 x burden.

Blast Design

Subdrilling

"Subdrilling" is the distance drilled below the floor level (or actual required blast depth), in order to ensure that the full face of the rock is capable of being removed to the desired excavation limit. Subdrilling may be required to achieve a smooth pit floor. The subdrill portion of a borehole is generally backfilled with drill cuttings or other stemming material. ***DO NOT LOAD EXPLOSIVES INTO THE SUBDRILL!*** Excessive confinement will lead to high peak particle velocity ground vibrations.



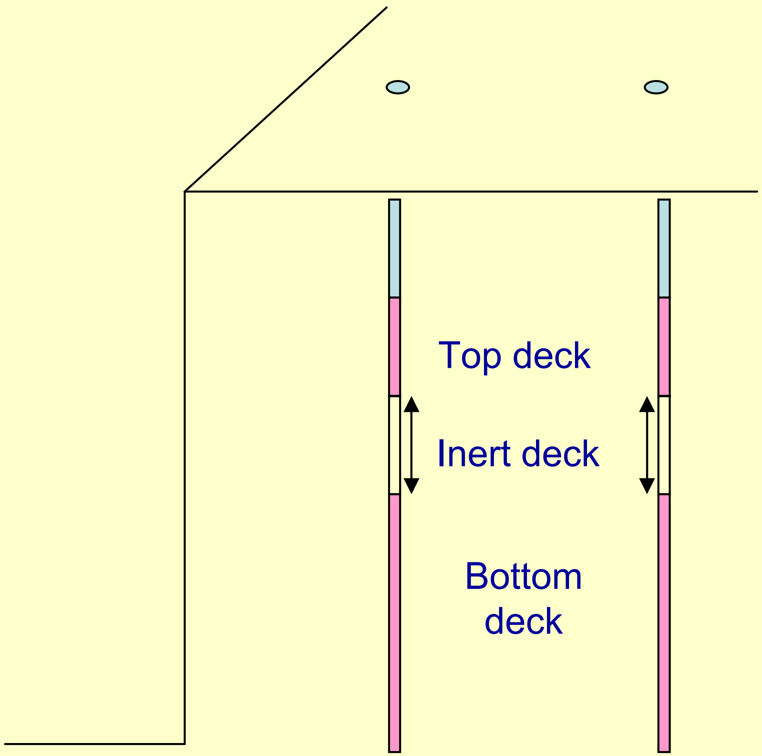
Blast Design

Decking

A process called "decking" is often used to reduce either the charge load per hole, the amount of explosives detonated per delay, or both. Decking is also used to get explosives into harder rock zones or to keep them out of weak zones such as mud seams.

Using the decking process, the top deck in a blasthole is normally shot one delay period after the bottom deck in the hole. The idea is to keep the explosives in the bottom deck from propagating through and detonating the top deck. To achieve this, an air deck or deck of inert stemming is inserted between the top and bottom decks. The length of the inert deck will vary depending upon borehole conditions. Increase the deck length in wet holes to reduce the chances of propagation between decks.*

There are many types of hole plugs commercially available for creating decked charges.



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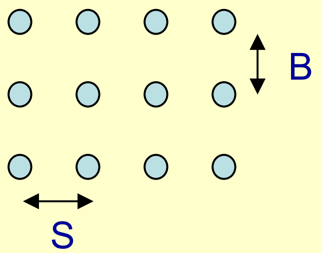
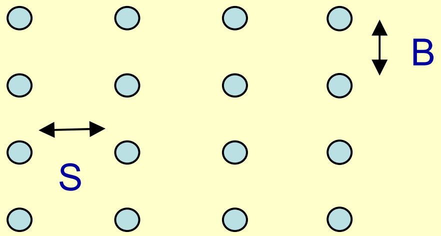
*The minimum stemming between explosive decks should be six times the borehole diameter, and, in wet holes, this amount should be doubled.

Blast Patterns

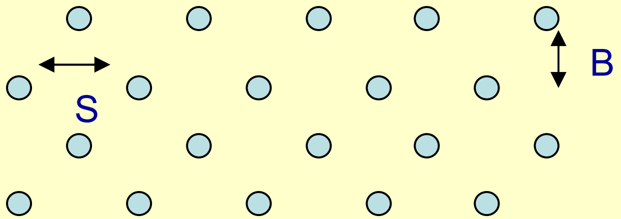
A **square blast pattern** has drilled spacings that are equal to drilled burdens.



A **rectangular blast pattern** has drilled spacings that are larger than drilled burdens.



In a **staggered blast pattern**, the drilled spacings of each row are offset such that the holes in one row are positioned in the middle of the spacings of the holes in the preceding row. In addition, the drilled spacings are larger than the drilled burdens.



A staggered blast pattern is used for row firing, where the holes in one row are fired before the holes in the row immediately behind them. The square and rectangular blast patterns are used for firing “V” (chevron) or echelon rounds.

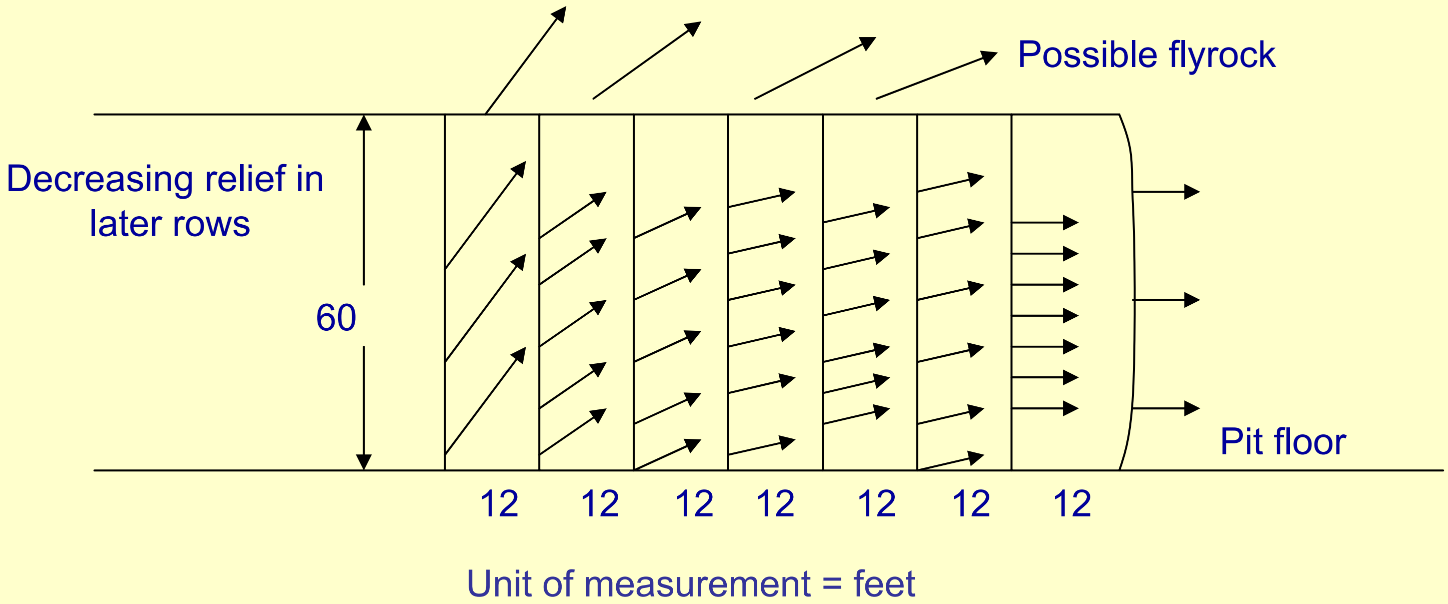
Millisecond Delay Blasting

The timing between holes in a row and between rows in a shot both (1) dictates the movement and fragmentation of the shot and (2) helps prevent cut-offs in the explosive column that are owing to shifting rock. Larger diameter holes on large burdens and spacings require greater delay time to ensure correct movement and to reduce the "dead-pressing" effects of adjacent boreholes (dead-pressing can lead to the emission of nitrogen dioxides).

Rock fragmentation occurs within 5 to 15 milliseconds after detonation. The gas pressure created by a blast moves the rock out from the blast face at velocities of from 50 to 100 feet per second. This broken rock is only moving 0.5 to 1 foot in 10 milliseconds. The movement of rock is important with respect to designing a blast that obtains optimal fragmentation.

The general (conservative) rule of thumb is "2 milliseconds per foot of burden" for designing delay times required for maximum fragmentation.

As the number of rows increases, the low velocity of the moving rock causes a reduction in relief toward the free face, leading to more vertical rock movement.



Blast Design

High-Energy Bottom Charges

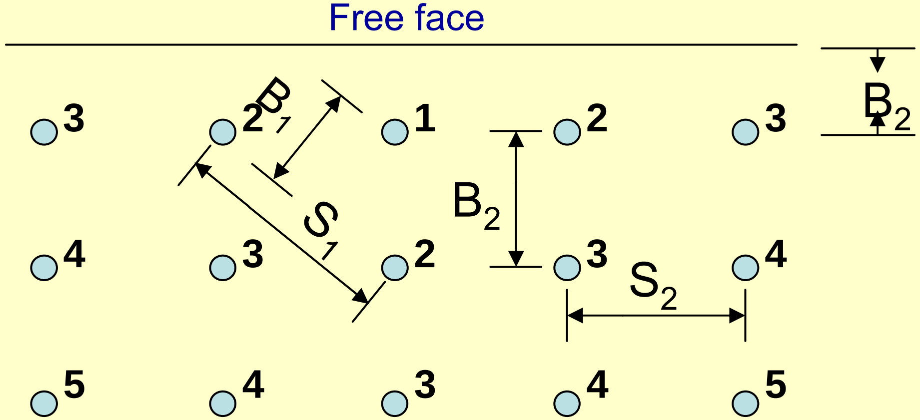
The rock at the bottom of a vertical hole requires more energy to break than does the rock at the top of the same hole. This is the primary reason why most blastholes are bottom-primed. High-density explosive charges may be added to the bottom of a hole to increase fragmentation at the toe or to improve the final pit-floor grade.

Click on the image above to play a quarry-shot blasting clip.

Blast Timing

A **"V"-pattern, or chevron, firing round** is appropriate for most square or rectangular blast patterns; it is not as practical for staggered-pattern loading.

Under any square or rectangular blast scenario that uses a "V"-pattern, actual burden and spacing (both of them dependent upon the timing of the shot) will be different from drilled, or apparent, burden and spacing.* When a "V"-pattern firing round is used under a square-pattern loading scenario, the rock movement is 45 degrees to the open face. "V"-pattern firing rounds are quite common at surface coal mines that use larger diameter blastholes.



Numbers indicate firing sequence (B_1 = true burden; B_2 = apparent burden; S_1 = true spacing; S_2 = apparent spacing).

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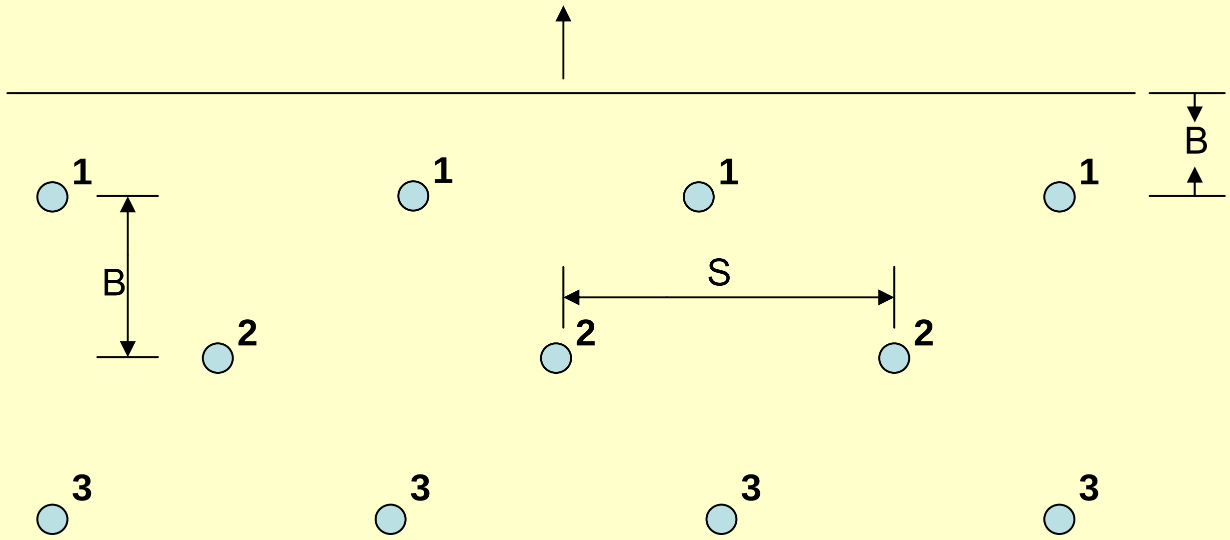
*Under any "V"-pattern blast scenario, a distinction is made between "apparent burden" and "true burden," such that apparent burden is defined as both the distance between the shot's first row and the highwall or free face and the distance between all subsequent rows running parallel to the face. True burden, on the other hand, is defined as the distance between rows as these are delineated by the drill pattern and the delay timing associated with it. (Note as well that, as the example here shows, a comparable distinction is also made between "apparent spacing" and "true spacing.")

Blast Design



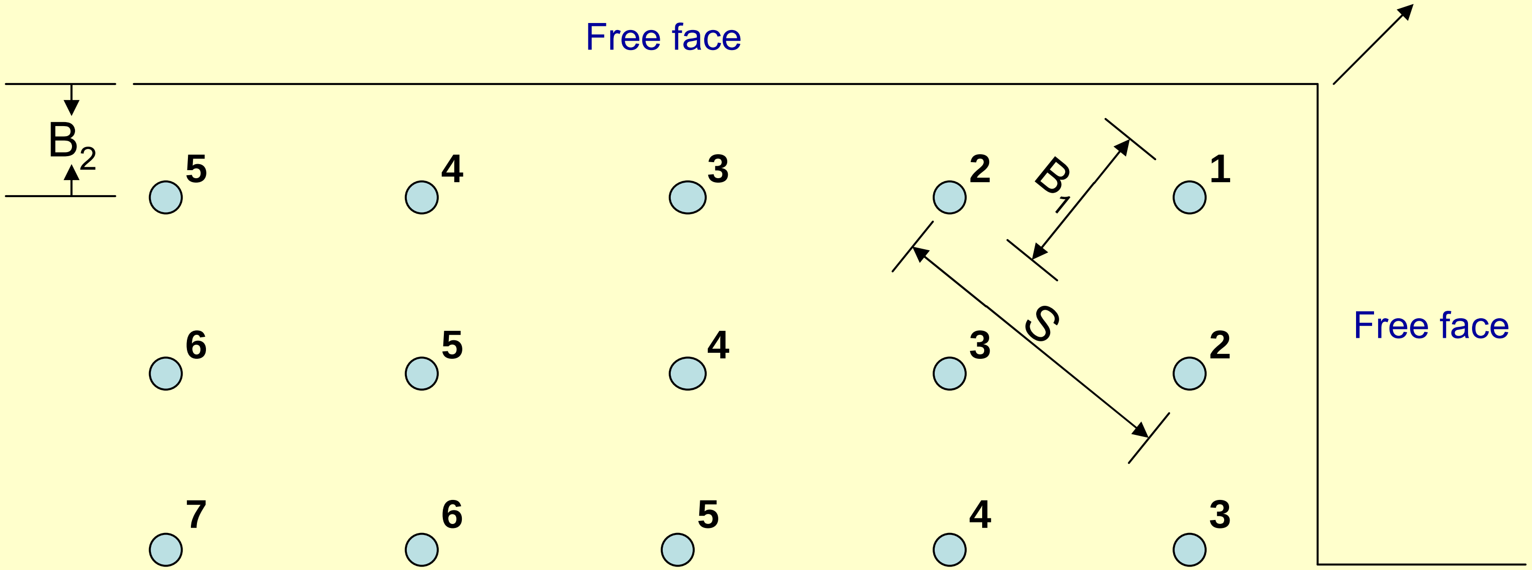
QUARRY, ROW-BY-ROW.

Numbers indicate firing sequence (S = true spacing; B = true burden).*

*****Note that a quarry, row-by-row blast pattern is shot row by row, the rows shooting parallel to the highwall or free face; that is, the timing of the blast is not defined by a delay pattern (whether a "V," a chevron, or an echelon). Accordingly, there is no distinction in this type of shot between the "apparent burden" of the shot and its "true burden." There is only the "burden" of the shot, which is defined as both the distance between the shot's first row and the highwall or free face and the distance between all subsequent rows running parallel to the face.

Blast Timing

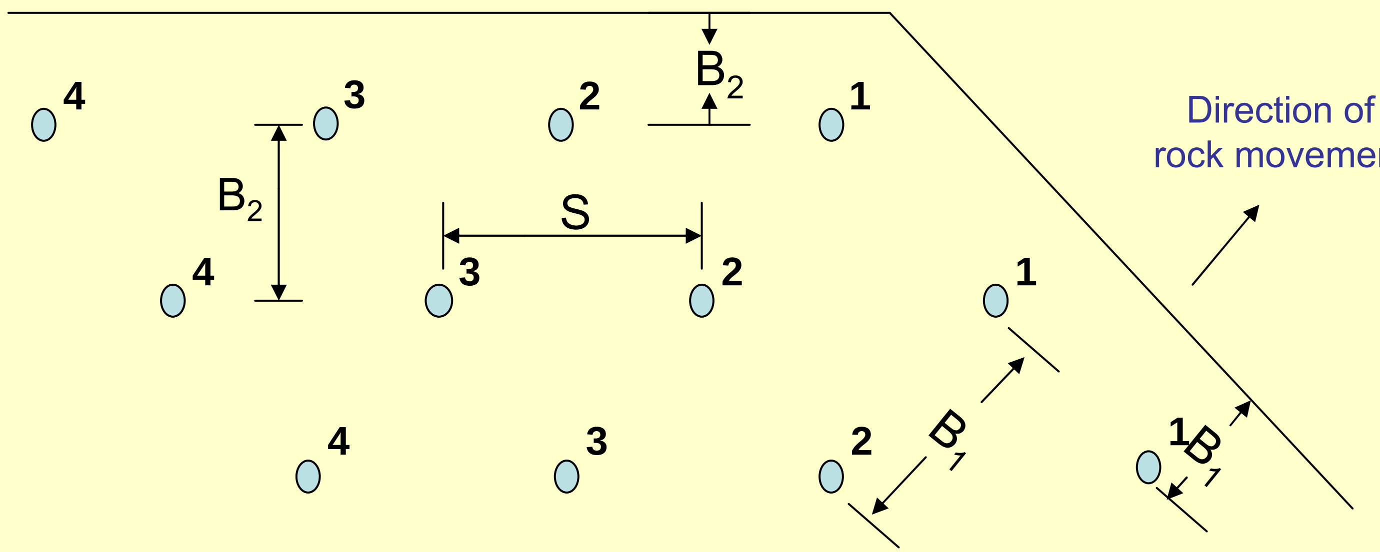
Echelon patterns are normally designed to take advantage of two free faces; they are typically used in large overburden shots (that is, in blastholes with diameters greater than 8 inches), casting operations, and interburden shooting.



Numbers indicate firing sequence (B_1 = true burden; B_2 = apparent burden).*

*Under any echelon-pattern blast scenario, a distinction is made between "apparent burden" and "true burden." (See footnote regarding "V-"pattern blast scenarios.)

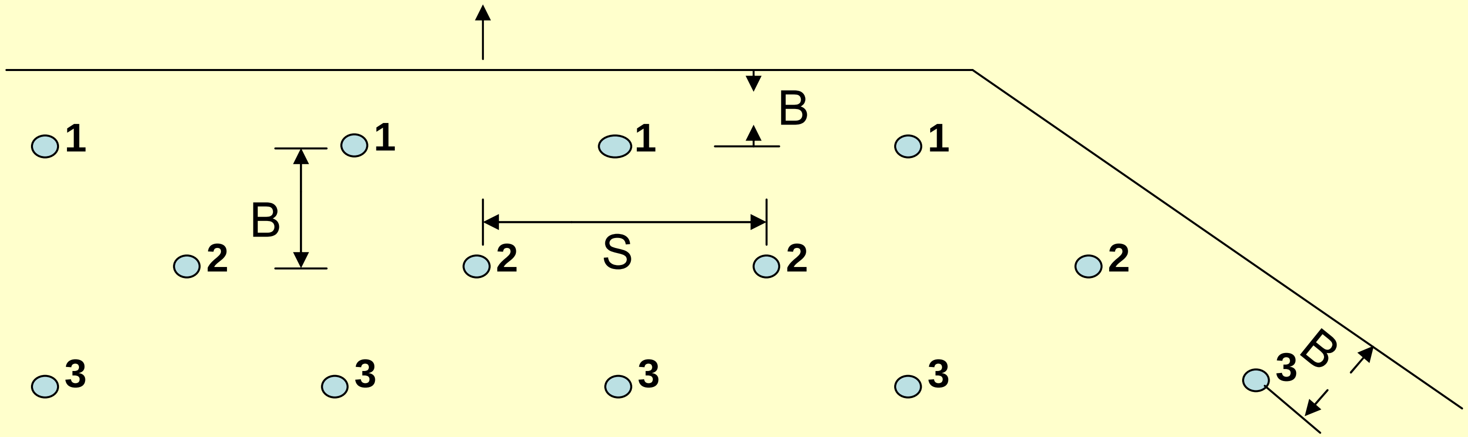
Blast Design



CORNER CUT, STAGGERED PATTERN, ECHELON.

Numbers indicate firing sequence
(S = true spacing; B_1 = true burden; B_2 = apparent burden).

Blast Design



CORNER CUT, ROW-BY-ROW.

Numbers indicate firing sequence
(S = true spacing; B = true burden).

Review Questions and Discussion

1. Why should you avoid loading explosives into a subdrill?
   a. Excessive confinement will lead to high peak particle velocity ground vibrations
   b. Over-confinement could generate toxic fumes
   c. Loading the subdrill could result in poor highwall stability
   d. All of the above

2. How does increasing the fragmentation of blasted rock decrease downstream costs related to it?
   a. Increased fragmentation reduces shovel digging time
   b. Increased fragmentation reduces the wear on haul equipment
   c. Increased fragmentation increases the crushed throughput
   d. All of the above

3. What is a way to reduce the explosive energy adjacent to a highwall on a production blast to ensure the integrity of the highwall?
   a. Reduce the total shot time, thereby reducing the amount of time the highwall is subjected to vibrations
   b. Use a controlled blasting technique (for example, pre-splitting)
   c. Drill on an angle to keep the explosive energy away from the toe

4. What is the purpose of using a decked charge?
   a. To lower the powder factor
   b. To reduce the amount of explosives detonated per delay
   c. To avoid loading a weak seam or to bypass a void in the rock
   d. All of the above

Review Questions and Discussion—continued

5. What are some general rules for designing the stemming for blastholes?
   a. Use crushed stone or drill cuttings as the stemming material
   b. Stem at a ratio of from 0.5 to 1.3 times the amount of burden
   c. Design stemming so that it contains explosive energy without generating flyrock
   d. All of the above

6. What is the most important objective(s) of any blasting program?
   a. Fragmentation
   b. Lowering costs
   c. Ensuring the safety of all workers in and around the blast site
   d. a and c

Answers

1. a. is correct.
2. d. is correct.
3. b. is correct.
4. d. is correct.
5. d. is correct.
6. d. is correct.