Rock Blasting Fundamentals

Course Review Notes

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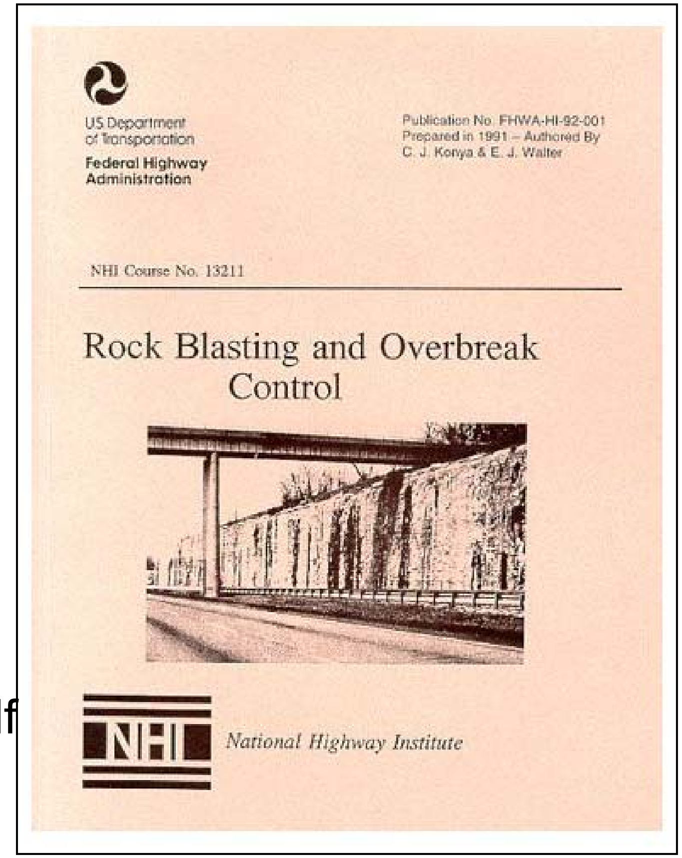
Course Reference

This course is based primarily upon the reference "Rock Blasting and Overbreak Control" (2nd edition) published by the Federal Highway Administration in 1992.

This reference may be obtained *free of charge* in Adobe Acrobat (PDF) format through the FHWA at the following website address:

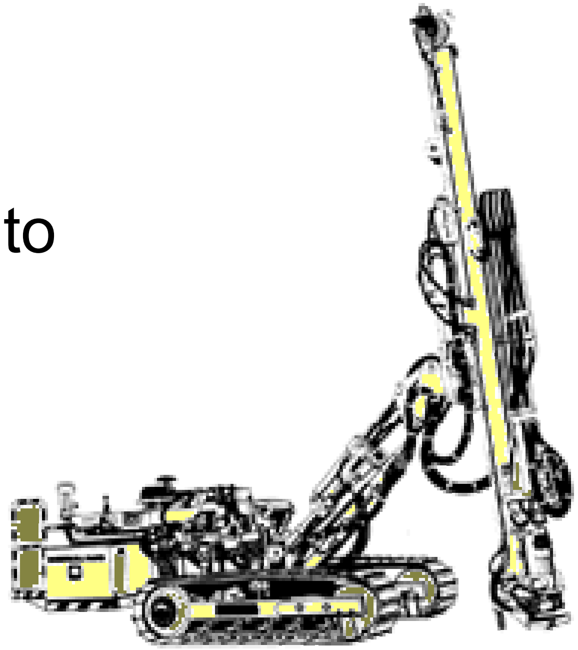
http://isddc.dot.gov/OLPFiles/FHWA/012844.pdf



Introduction

- Rock Blasting consists of drilling holes in a rock mass at depths, in diameters, and at spacing so that an explosive can fracture the rock in a controlled manner.

- The rock must fracture enough to displace it and break it down to the size of the intended use.



Introduction

Blasting of a rock slope for a road cut

Introduction

- Rock blasting is performed to fracture rock so that it may be excavated for construction or quarried for aggregate processing.

- Blasting is accomplished by discharging an explosive that has either been placed in as unconfined manner (such as mud capping) or confined in a borehole.

Introduction

- Blast design is *not* an exact science, but rather an iterative procedure of designing the blast hole layout and calculating the quantity of explosives required for blasting rock, based on substantial professional experience.

- By considering the rock formation, it is possible to produce the desired result.

Geologic Characterization of the Rock Mass

Photograph courtesy of Tectonic Engineering & Surveying Consultants P.C.

A geologist or geotechnical engineer should evaluate the geologic character and rock mass properties of the rock slope prior to blasting.

Geologic Characterization of the Rock Mass

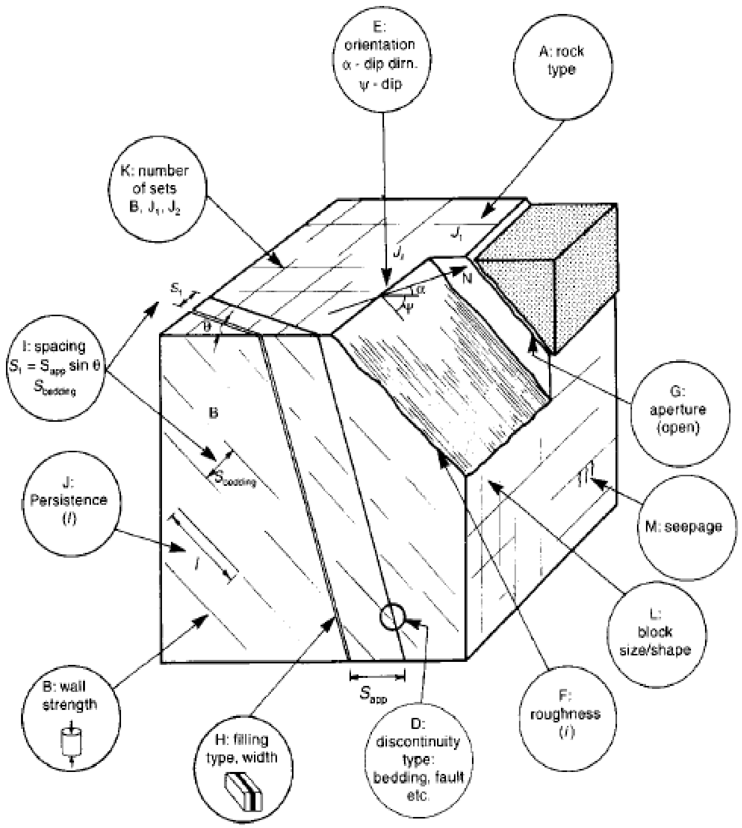


Image from Geotechnical Engineering Circular No. 5 - Evaluation of Soil and Rock Properties, FHWA, 2002.

Field observation and documentation of several rock mass parameters comprise a detailed geologic investigation to define the rock mass character and properties.

The characteristics of the rock mass will have an influence on the blast design.

See Section 9.1 in the reference for additional information.

Geologic Characterization of the Rock Mass

- Rock is not a homogeneous isotropic material. Structural features such as fracture planes, seams and changes in the burden must be considered.

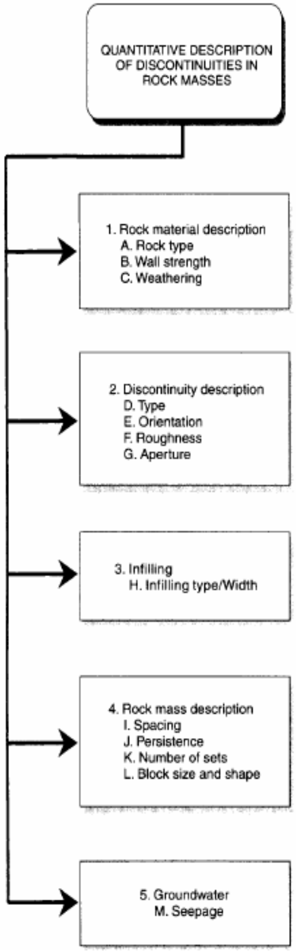
- As a result, wave propagation is faster in sound, competent rock in comparison to softer, highly weathered rock or soil.

- 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.

Geologic Characterization of the Rock Mass

- Standardized geologic mapping and logging procedures should be used for describing rock masses.
- The types of information collected will depend on site access, extent of rock outcrops, and the location of the proposed blasting relative to existing site features.
- A list of parameters and categories describing rock mass characteristics (after Wyllie, 1999) is shown.



Geologic Characterization of the Rock Mass

Description of Geologic Mapping Terms (FHWA, 2002)

Term	Description
Rock Type	The rock type is defined by the origin of the rock (i.e., sedimentary, metamorphic, igneous), color (including whether light or dark minerals predominate), texture or fabric ranging from crystalline, granular, or glassy, and grain size ranging from boulders to silt/clay size particles.
Wall Strength	The compressive strength of the rock forming the walls of discontinuities will influence shear strength and deformability. Rock compressive strength categories and grade vary from extremely strong (> 250 MPa grade R6) to extremely weak (0.25 to 1 MPa grade R0) (see table 37).
Weathering	Reduction of rock strength due to weathering will reduce the shear strength of discontinuities as well as reduce the shear strength of the rock mass due to the reduced strength of the intact rock. Weathering categories and grades are summarized in table 38.
Discontinuity Type	The discontinuity type range from smooth tension joints of limited length to faults containing several centimeters of clay gouge and lengths of many kilometers. Discontinuity types include faults, bedding, foliation, joints, cleavage, and schistosity.
Discontinuity Orientation	The orientation of discontinuities is expressed as the dip and dip direction of the surface. Alternatively, the discontinuity can be represented by strike and dip. The dip of the discontinuity is the maximum angle of the plane to the horizontal (angle ψ in figure 92) and the dip direction is the direction of the horizontal trace of the line of dip, measured clockwise from north (angle α in figure 92).
Roughness	Roughness should be measured in the field on exposed surfaces with lengths of at least 2 m. The degree of roughness can be quantified in terms of the Joint Roughness Coefficient (JRC) as described in section 6.5.2.3. Wall roughness is an important component of shear strength, especially in the case of undisplaced and interlocked features (e.g., unfilled joints).

Geologic Characterization of the Rock Mass

Description of Geologic Mapping Terms (FHWA, 2002)

Aperture	Aperture is the perpendicular distance separating the adjacent rock walls of an open discontinuity (thereby distinguishing it from the width of a filled discontinuity), in which the space is air or is water filled. Categories of aperture range from cavernous (> 1 m) to very tight (< 0.1 mm).
Infilling Type and Width	Infilling is the term for material separating the adjacent walls of discontinuities such as fault gouge; the perpendicular distance between adjacent rock walls is termed the width of the filled discontinuity. Filled discontinuities can demonstrate a wide range of behavior and thus their affect on shear strength and deformability can vary widely.
Spacing	Discontinuity spacing can be mapped in rock faces and in drill core; spacing categories range from extremely wide (> 6000 mm) to very narrow (< 6 mm). The spacing of individual discontinuities has a strong influence on the mass permeability and seepage characteristics of the rock mass.
Persistence	Persistence is the measure of the continuous length or area of the discontinuity; persistence categories range from very high (> 20 m) to very low (< 1 m). This parameter is used to define the size of blocks and the length of potential sliding surfaces. Persistence is important in the evaluation of tension crack development behind the crest of a slope.
Number of Sets	The number of sets of discontinuities that intersect one another will influence the extent to which the rock mass can deform without failure of the intact rock. As the number of sets increases and the block sizes reduce, the greater the likelihood for blocks to rotate, translate, and crush under applied loads.
Block Size and Shape	The block size and shape are determined from the discontinuity spacing, persistence, and number of sets. Block shapes include blocky, tabular, shattered and columnar, while block size ranges from very large (> 8 m^3) to very small (< 0.0002 m^3).
Seepage	Observations of the seepage from discontinuities should be provided. Seepage quantities in unfilled discontinuities range from very tight and dry to continuous flow. Seepage quantities in filled discontinuities range from dry in heavily consolidated infillings to filling materials that are washed out completely and very high water pressures are experienced.

Geologic Characterization of the Rock Mass

Rock Material Strengths (FHWA, 2002)

Grade	Description	Field Identification	Range of Uniaxial Compressive Strength (MPa)
R0	Extremely weak rock	Indented by thumbnail	0.25 – 1.0
R1	Very weak rock	Crumbles under firm blows with point of geological hammer; can be peeled by a pocket knife	1.0 – 5.0
R2	Weak rock	Can be peeled by a pocket knife with difficulty; shallow indentations made by firm blow with point of geological hammer	5.0 – 25
R3	Medium strong rock	Cannot be scraped or peeled with a pocket knife; specimen can be fractured with single firm blow of geological hammer	25 – 50
R4	Strong rock	Specimen requires more than one blow of geological hammer to cause fracture	50 – 100
R5	Very strong rock	Specimen requires many blows of geological hammer to cause fracture	100 – 250
R6	Extremely strong rock	Specimen can only be chipped with geological hammer	> 250

Geologic Characterization of the Rock Mass

Weathering Grades (FHWA, 2002)

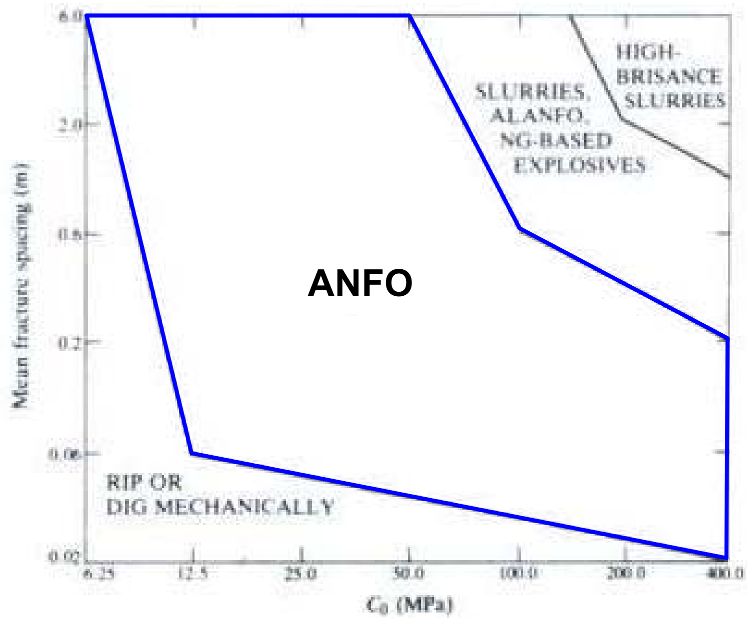
Term	Description	Grade
Fresh	No visible sign of rock material weathering; slight discoloration on major discontinuity surfaces is possible	I
Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering and the external surface may be somewhat weaker than in its fresh condition.	II
Moderately weathered	Less than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones.	III
Highly weathered	More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones.	IV
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed but the apparent structure remains intact. There may be a large change in volume, but the soil has not been significantly transported.	VI

Explosives Engineering

- There are two forms of energy released when high explosives are detonated, shock and gas.
- An unconfined charge works primarily be shock energy, whereas a confined charge yields a higher gas energy output.
- There are several physical attributes which are critical to the selection of explosives for a project. These are:
  - Temperature resistance,
  - Sensitiveness,
  - Water pressure tolerance,
  - water pressure resistance, and
  - fumes

Explosives Engineering

An empirical matching of explosives and rock mass properties is presented from Brady and Brown (1992).



A significant observation from the figure is that ANFO (ammonium nitrate and fuel oil) is a suitable explosive for use in a wide range of rock mass conditions.

Explosives Engineering

- ANFO is blasting agent that is produced by mixing prilled ammonium nitrate and fuel oil.
- ANFO is used extensively on construction projects and represents approximately 80 percent of all explosives used in the United States.
- ANFO is generally considered to be the cheapest and safest among explosive types.

Explosives Engineering

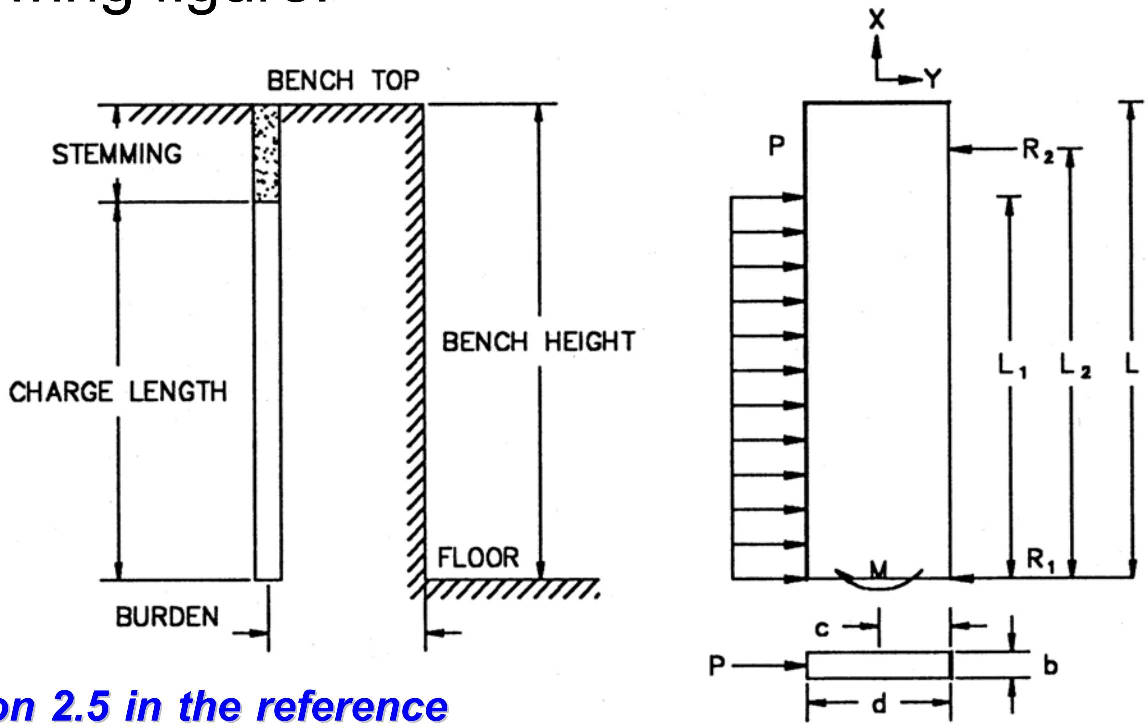
- An initiation system transfers the detonation signal from hole to hole at precise times. The order and timing of the detonation of the individual blast holes is regulated by the initiation system.
- Plastic shock tubes or electric caps using a timing system are generally employed.
- A shock tube is non-electric, instantaneous, and has a thin reactive powder that propagates the shock wave signal.

Photograph courtesy of Mining Services International , Inc.

See Section 4.2 in the reference for additional information.

Blasting Free Body Diagram

- The basic geometry of rock blasting is shown in the following figure:



The basic geometry of rock blasting.

A free body diagram illustrating the explosive pressure P and moment M from the blast.

Image from Rock Blasting and Overbreak Control, FHWA, 1992.

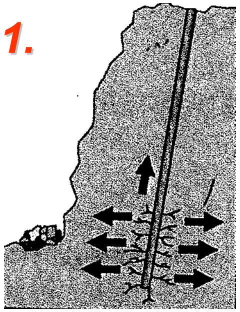
See Section 2.5 in the reference for additional information.

Rock Breakage Mechanism

Konya's Breakage Theory:

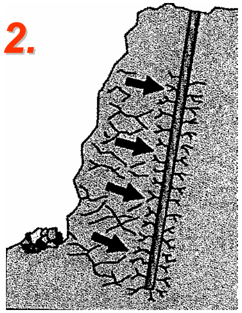
(Konya and Walter, 1990)

1.



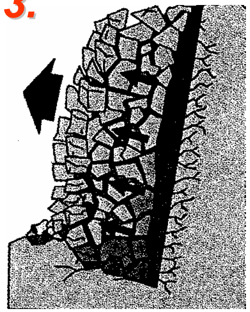
After detonation, the stress wave causes microfractures at the borehole walls. Normal resistance causes cracking to concentrate toward the face.

2.



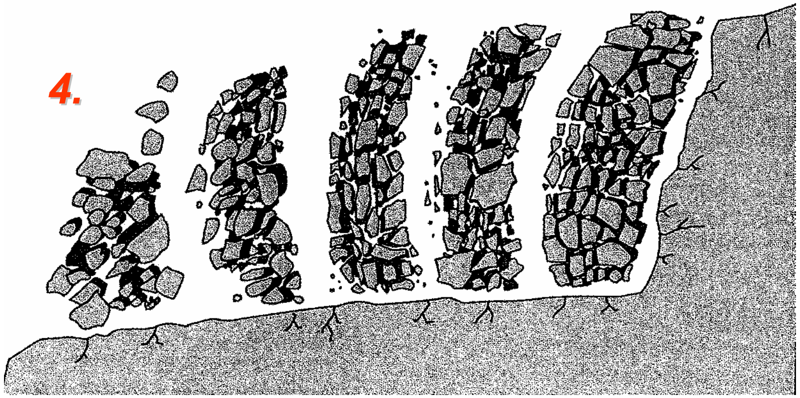
After the stress wave has passed, the expanding gasses causes pressurization of the blasthole, producing radial cracking on the borehole walls.

3.



After the radial cracks form, the high-pressure gasses penetrate the radial crack network. Face movement begins and flexural failure occurs as a result of the bending of the rock mass.

4.



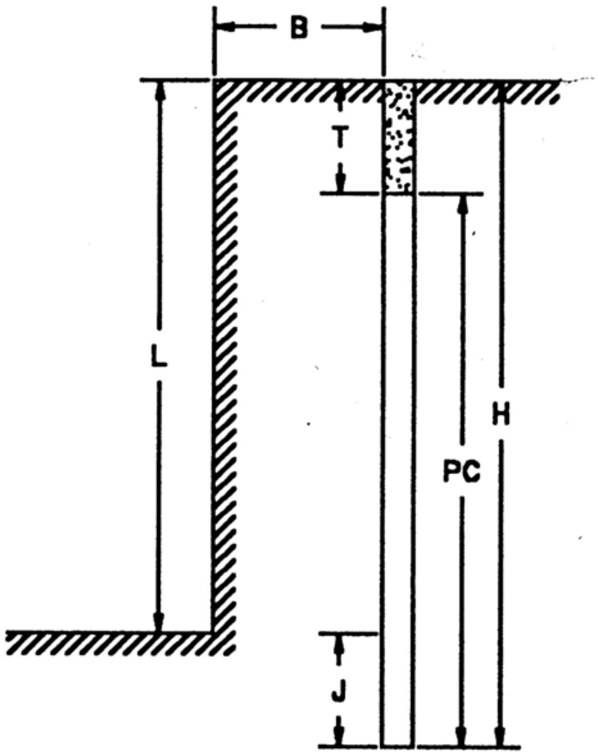
Cantilevered outward bending action.

Rock Blasting Basics

- Holes are drilled to the required depth to remove the rock, and filled with ANFO (charge length). The charge is topped off with stemming that helps hold the blast down.

- The blaster and blasting consultant can arrange the geometry of the blast for optimal breakage. This is done so that P and M do not exceed the amount needed to break the rock. Excessive P and M causes ‘Fly-Rock’ and excessive ‘Airblast’ and ‘Vibration’ that can cause damage and injury.

Blasting Geometry and Symbols



B = Burden (distance between the free face and the first hole)

T = Stemming (the inert material in the hole)

L = Length of the bench height

H = Hole depth

PC = Powder Column Length. (ANFO)

Two main parameters to remember are the L/B ratio and the stemming height.

See Section 6.1 in the reference for additional information.

Rock Blasting Basics

- The burden distance, **B**, (as illustrated on Slide No. 22 is the most critical dimension in the blast design.
- The burden distance is the shortest distance to stress relief at the time of the blast detonation.
- It is generally the distance to the free face of an excavation or rock cut.
- When the burden distance is insufficient, rock will be violently thrown from the face (often excessive distances), rock fragmentation and air blast levels will be high.

Rock Blasting Basics

- An approximate rule of thumb in order to verify that the Blaster is using the proper burden is as follows:

Burden is usually 24 to 30 times the production hole diameter.

For example:

If the production holes are 0.5 feet (6 inches) the burden should be

24 x 0.5' = 12' or 30 x 0.5' = 15'

The burden for the shot should be between 12 and 15 feet.

Rock Blasting Basics

- An empirical formula for a first-order approximation of the burden distance for a first trial shot is:

$$B = \left(2 \cdot \frac{SG_{ex}}{SG_{rock}} + 1.5 \right) D_e$$

Where,

B = Burden, *feet*

SG_{ex} = specific gravity of the explosive

SG_{rock} = specific gravity of the rock mass

D_e = diameter of the explosive, *inches*

Rock Blasting Basics

Rock Classification	Specific Gravity	Density Broken ton/cu. Yd)
Basalt	1.8 – 3.0	2.36 – 2.53
Diabase	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

Source: Construction Planning, Equipment and Methods, 6th ed., McGraw Hill

Rock Blasting Basics

- A contractor has planned a blasting program in slightly weathered Gneiss having a specific gravity of 2.6. The contractor intends to use poured ANFO having a specific gravity of 0.85. The drill hole is 3-inches in diameter.

  What is the recommended burden distance for the trial shot?

$$B = \left(2 \cdot \frac{SG_{ex}}{SG_{rock}} + 1.5\right) D_e = \left(2 \cdot \frac{0.85}{2.6} + 1.5\right) \cdot 3\ in = 6.5 \cdot ft$$

  Does the rule of thumb (on Slide No. 24) provide a reasonable estimate?

Rock Blasting Basics

- The corrected burden distance may be computed by considering the rock mass conditions:

$$B_{corrected} = B \cdot K_d \cdot K_s$$

Where,

K_d = correction factor for rock deposition

K_s = correction factor for rock structure

Rock Blasting Basics

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

Source: Construction Planning, Equipment and Methods, 6th ed., McGraw Hill

Rock Blasting Basics

- A contractor has planned a blasting program in slightly weathered, moderately fractured Gneiss having a specific gravity of 2.6. The rock bedding was measured to dip steeply into the cut.

- The contractor intends to use poured ANFO having a specific gravity of 0.85. The drill hole in 3-inches in diameter.

What is the corrected burden distance for the blast?

$$B_{corrected} = B \cdot K_d \cdot K_s = 6.5 \cdot (1.18) \cdot (1.30) = 10\text{ft}$$

Drilling Multiple Blast Holes

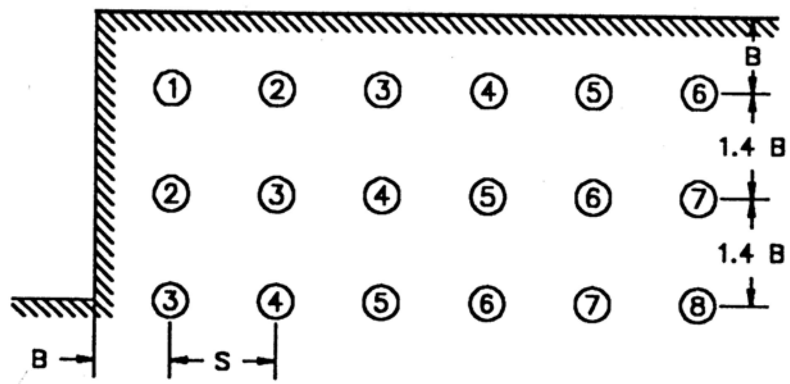
Photograph courtesy of Tectonic Engineering & Surveying Consultants P.C.

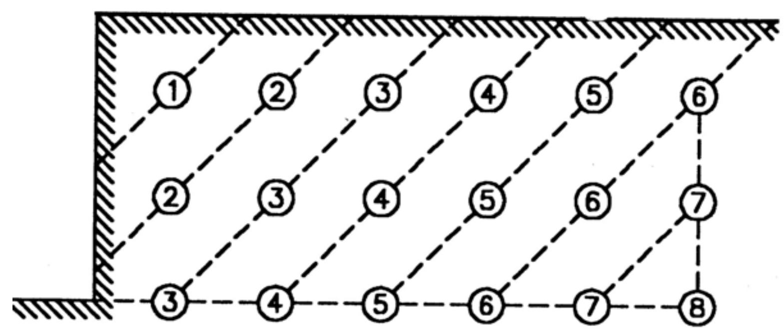
Hole Spacing and Timing

The distance, **S**, or spacing of the holes, is a function of the burden. The burden distance, **B**, is still the distance to the free face.

The spacing of the holes and the timing (or delay) of the holes are part of the blasting design.

The blast delay is illustrated by the sequencing numbers. Each hole may be blasted milliseconds apart to control the blast. The row-to-row shots are certainly time delayed.





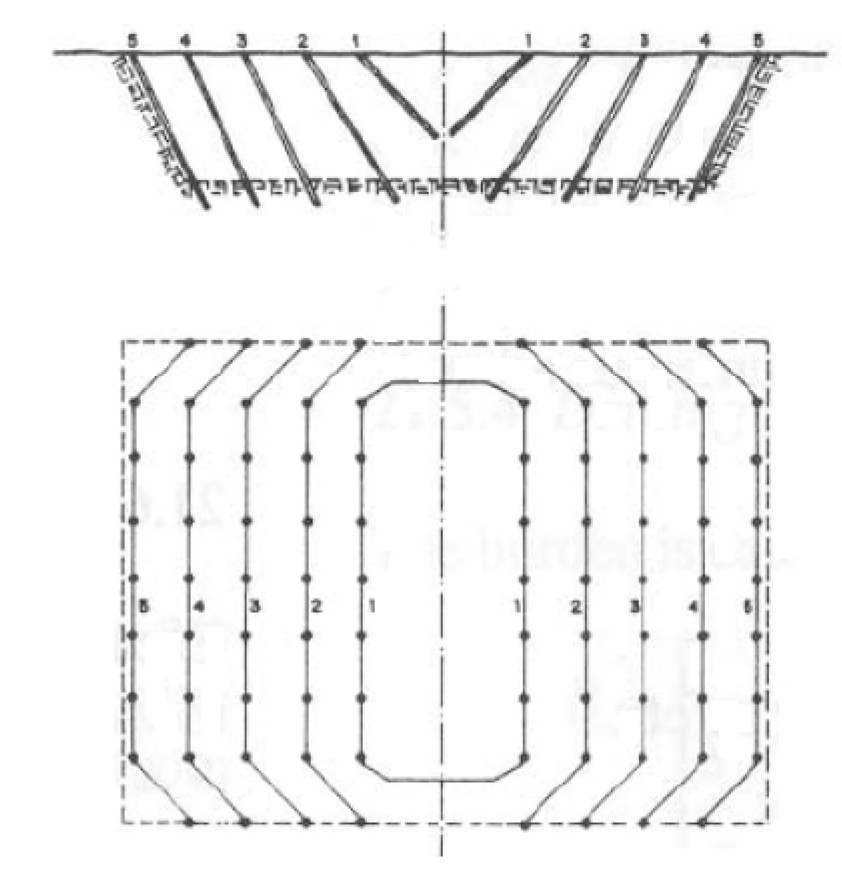
See Section 7.3 in the reference for additional information.

Hole Spacing and Timing

Drilling Blast Pattern

Photograph courtesy of Tectonic Engineering & Surveying Consultants P.C.

Hole Spacing and Timing



Trench blasting is similar to highway cuts, but on a much smaller scale and generally with more precision. Trenches are routinely excavated for water pipelines, sewer lines, drains, and electrical conduits, among other applications.

Trench blasting also varies because it is often conducted within urban areas, and thus is more often subjected to smaller vibration criteria.

There are two types of trenching: conventional and smoothwall, which is used when there is concern about overbreak of the surrounding rock.

Affects of Stiffness Ratio

When the ratio between the distance L (Bench Height) and the Burden (B) is changed, potential blasting problems are decreased as the ratio is increased.

Stiffness Ratio (L/B)	1	2	3	4
Fragmentation	Poor	Fair	Good	Excellent
Air Blast	Severe	Fair	Good	Excellent
Fly-Rock	Severe	Fair	Good	Excellent
Ground Vibration	Severe	Fair	Good	Excellent
Comments	Severe backbreak & toe problems. Do not shoot REDESIGN!	Redesign if possible	Good control and fragmentation	No increased benefit by increasing stiffness ratio above 4

As this ratio is decreased, these problems are increased.

See Section 6.4 in the reference for additional information.

Affects of Stiffness Ratio

- Generally, a ratio near one maximizes the rock blasting production. The main problem with designing a ratio that is near one is that the rock generally fractures in large chunks. This can pose problems for Contractors when trying to use the material for fill.

- When the ratio is increased, it can decrease the particle size of the rock. This allows the material to be used as fill easier.

Affects of Blast Timing

Timing the blast is another important parameter in the blast design.

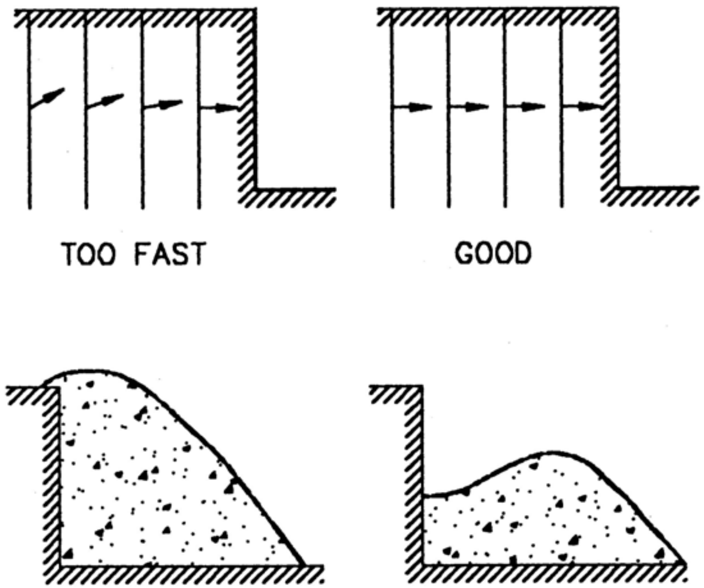


Image from Surface Blast Design, 1990.

With correct timing, the blast has a distinct lateral movement.
With poor timing, the movement is more upright and has potential problems.

See Section 6.5 in the reference for additional information.

Rock Blasting Basics

- The timing or delay minimizes the pounds of explosive per delay period.
- This can significantly control noise and vibration effects. It would be a disaster if all the holes went off at the same time.
- The design variables of burden, stemming, subdrill, spacing, and timing are selected to maximize fragmentation and to minimize excessive vibration, airblast, and fly-rock.

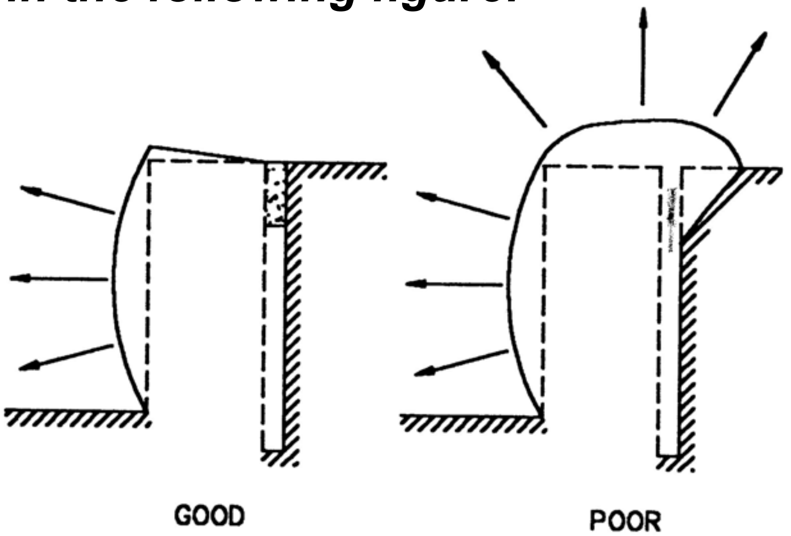
Affects of Stemming

Many specifications require that the stemming Depth (T) of inert material be at least 0.75 times the burden (B). This helps control the airblast.

The effects of stemming are depicted in the following figure:

If effective, the blast direction is lateral. If the stemming is ineffective, the blast can blow upward and cause excessive airblast.

Notice that in the example, the blast cuts back into the cut slope. This is an obvious problem.



See Section 6.2 in the reference for additional information.

Affects of Stemming

- Drill cuttings are normally used for stemming. However, when blasting in water filled production holes, or when blasting within 200 feet of a structure (*this is a general guideline – check with your local jurisdiction*), the stemming material is changed to prevent problems.

- For holes less than 4 inches, a fine processed crushed gravel, 1/4” to 3/8” is generally used. For holes 4 inches or more, a 3/8” to 3/4” gravel is commonly used. This helps hold the blast down better.

Affects of Stemming

- If the stemming distance is too great, poor top breakage may result in an increased backbreak distance.
- An approximate rule of thumb in order to estimate the stemming distance, ***T***, is to consider 0.7 times the burden distance.

$$T = 0.7 \times B$$

Powder Factor

The **powder factor** is the quantity of explosive used per unit of rock blasted, measured in lb/yd^3 of rock. An ideal condition of straight rock surfaces and straight drilled holes is an oversimplification of field conditions. It is a common assumption that the rock properties are uniform within the rock mass and that the blasthole contains a uniform charge.

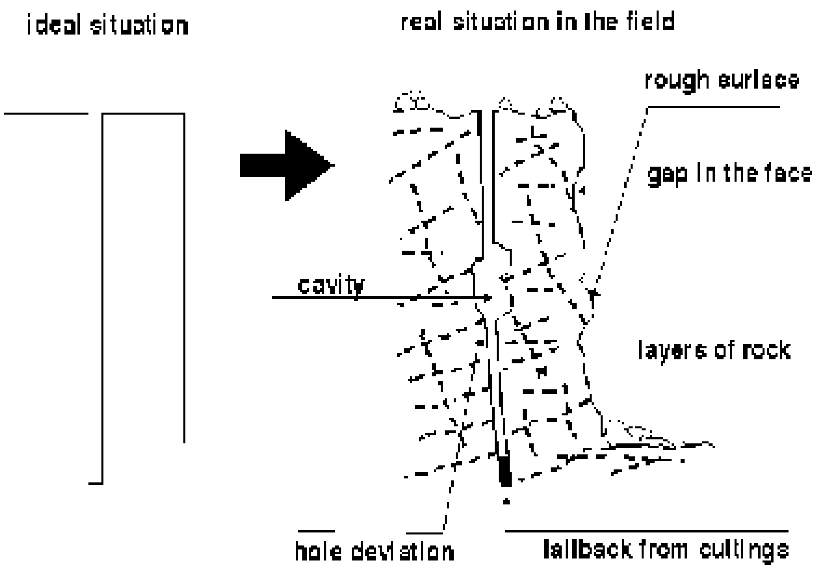


Image courtesy of Green Mountain Explosives Inc., Auburn, NH, 2007.

As the blast design must eventually be taken to the field, the design must take this variability into account.

The powder factor is usually between 0.3 and 0.8 kg/m^3 for an ANFO type of explosive.

Smooth Blasting and Presplitting

- Presplitting is an effective method of controlling the final appearance of steep slopes; it can result in a clean sheared face. Presplitting is generally required when the slope is steeper than 1H:1V and deeper than 5 feet.

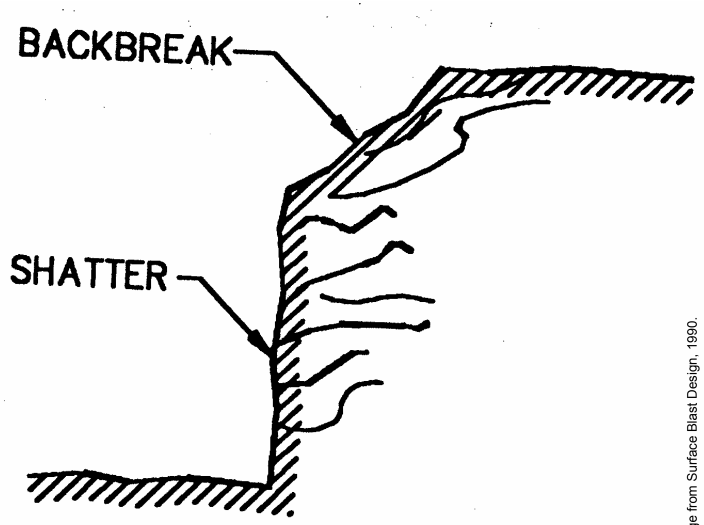


Image from Surface Blast Design, 1990.

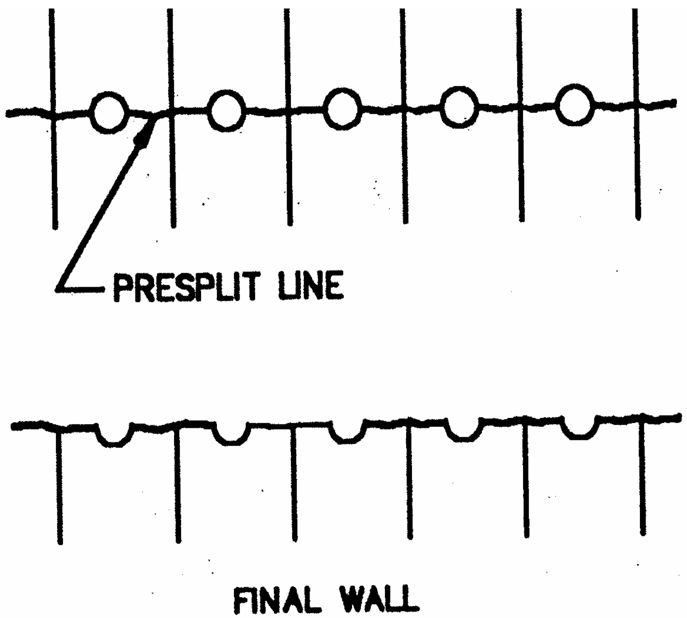
See Section 8.1 in the reference for additional information.

- If presplitting is not performed (or performed improperly) the resulting slope face will result in overbreakage and will have a rough and irregular rock face.

- Additionally, back-breakage may occur, governed by the geologic character of the rock mass.

Smooth Blasting and Presplitting

Presplit with joints at 90° angle



See Section 8.1 in the reference for additional information.

- Specialized presplit blasting explosives are used.
- Hole diameters are generally smaller than production blasting holes (about 3"), and the presplit holes are blasted prior to the production blast.
- The presplit hole spacing generally ranges from 18 to 36 inches. This is adjusted to obtain a good shear face of the rock, depending on the geologic character and rock mass properties.

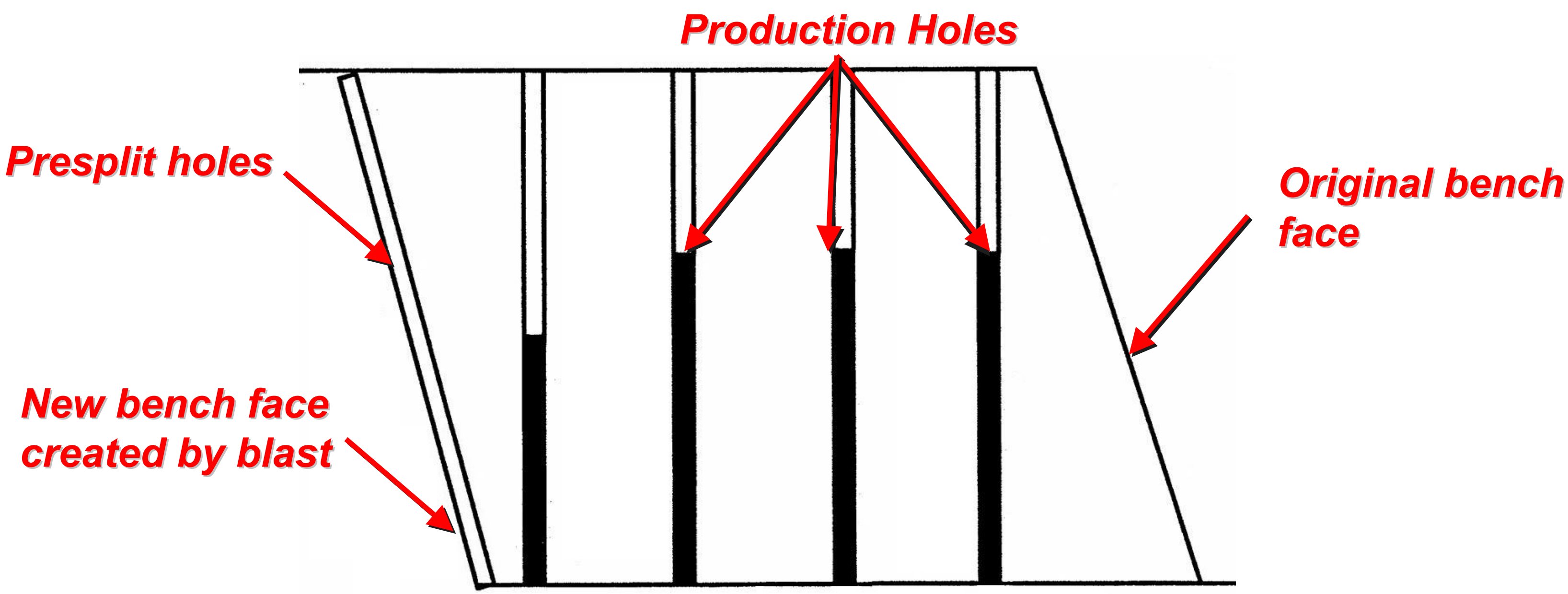
Smooth Blasting and Presplitting

Photograph courtesy of Tectonic Engineering & Surveying Consultants P.C.

Verify the presplit hole spacing along the slope face.

Smooth Blasting and Presplitting

Production blasting performs the primary fracturing of the rock.



Presplitting consists of lightly loaded, closely spaced holes, fired prior to the production blast which forms a fracture plane across which the production blast cannot travel.

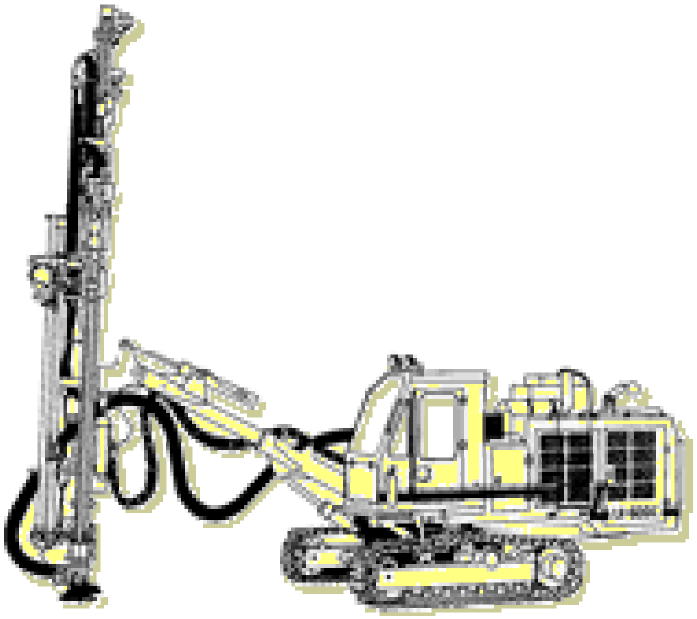
Smooth Blasting and Presplitting


Source: E. Hoek (2007) Practical Rock Engineering available at www.rocscience.com

Comparison between the results achieved by pre-split blasting (on the left) and normal bulk blasting for a surface excavation in gneiss as presented in Dr. Evert Hoek's Practical Rock Engineering (2007 ed.)

Environmental Impacts from Blasting

- Ground Vibrations
- Airblasts
- Noise
- Fly Rock
- Dust and Fume



Ground Vibrations from Blasting

A competent blaster will design the blast so the maximum amount of energy released by the explosive goes into breaking and displacing the rock. The noise and vibrations associated with blasting is a result of excess energy that escapes.

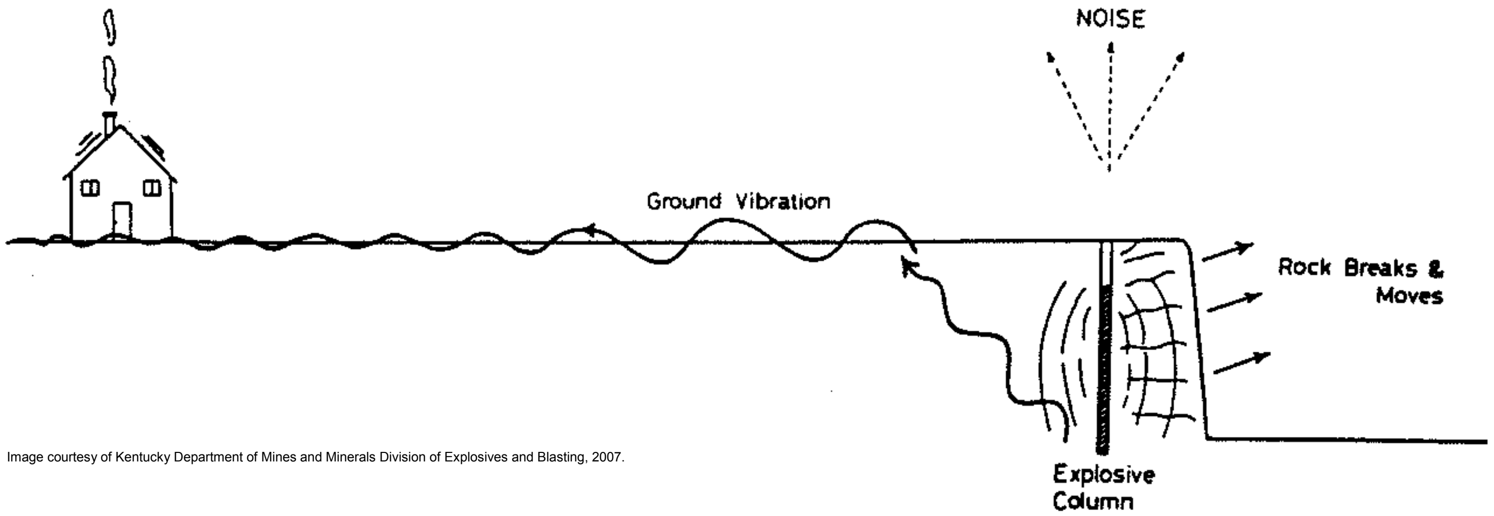


Image courtesy of Kentucky Department of Mines and Minerals Division of Explosives and Blasting, 2007.

There is no way to design or detonate a blast that will use 100% of its energy in useful work. There will always be a small amount that will cause the undesirable effects of noise and vibration.

Ground Vibrations from Blasting

There are many factors such as geology, type of explosives, and the placement of the boreholes that can affect the intensity of the ground vibrations. However, the two primary factors affecting the strength of the vibrations are:

1. The amount of explosives set off at one time.
2. The distance from the actual blast site.

All explosives in a blast are not detonated simultaneously; they are fired in sequence with small time delays separating the charges. These time delays are only a few thousandths of a second but they are critical in controlling a blast.

The distance from the blast site to the location where the ground vibrations are felt or measured is important simply because vibrations will die out as they propagate away from the source. The waves radiate in all directions and gradually decrease as the distance from the source increases. Eventually at large distances, the vibrations completely die out.

Common Vibration Thresholds

10.00 in/sec	Cracks in solid concrete slabs or wall may appear
4.50 in/sec	Cracks in masonry may begin to appear
3.00 in/sec	Cracking may begin in motar joints in Concrete block foundations
2.00 in/sec	Above this level, there is a possibility of structural damage occurring
1.00 in/sec	New cracks in drywall may appear
0.75 in/sec	Existing cracks in drywall may extend
0.50 in/sec	Cracks in old plaster may appear, existing cracks in plaster may extend
0.03 in/sec	Vibrations are easily detectable by people
0.00 in/sec	No Vibrations

Ground Vibrations from Blasting

The peak particle velocity (ppv) can be calculated based upon several variables using the following equation:

$$V = K\,(R/(Q)^{0.50})^{B}$$

Where,

V = Peak particle velocity (*in units of distance per unit of time*)
K = Site and rock factor constant
Q = Maximum instantaneous charge per delay (*in units of mass*)
B = Constant related to the rock and site
(usually -1.6)
R = Distance from charge (*in units of length*)
$(R/(Q)^{0.50}$ is defined as a scaled distance

Ground Vibrations from Blasting

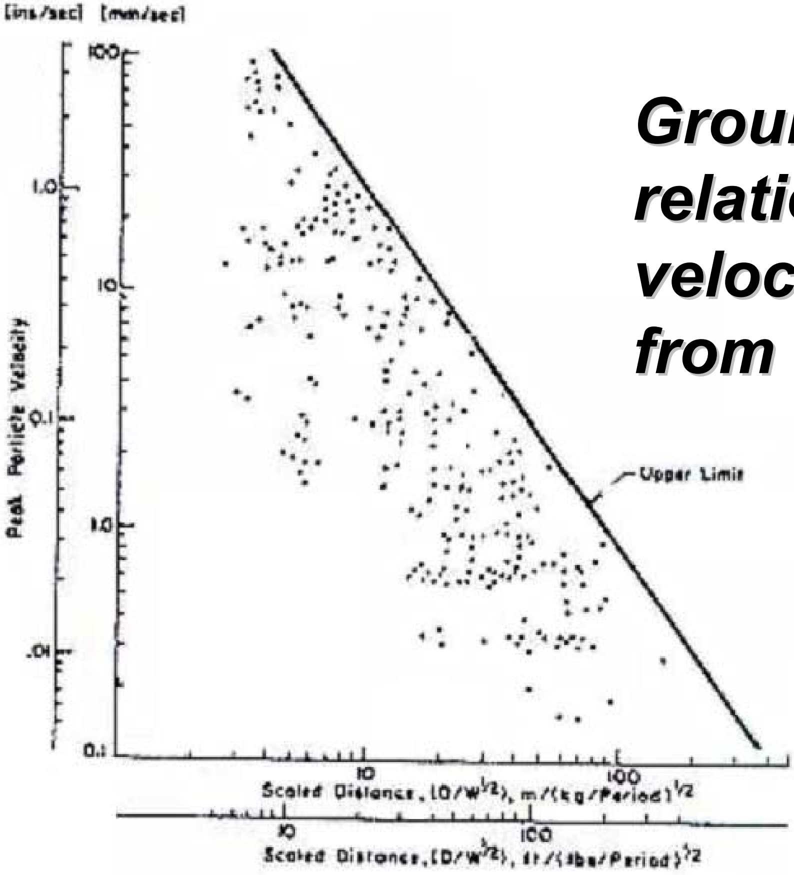
Typical K Factors – English system

(Under confined) -hard or highly structured rock	=	24
Free face average rock (Normal confinement)	=	160
Heavily (Over) confined	=	600

Typical K Factors – Metric system

(Under confined) -hard or highly structured rock	=	500
Free face average rock (Normal confinement)	=	1,140
Heavily (Over) confined	=	5,000

Ground Vibrations from Blasting



Ground vibration measurement relationship of peak particle velocity (ppv) and distance from blast for several sites.

See Section 10.4 in the reference for additional information.

Ground Vibrations from Blasting

- It is impossible to accurately estimate the strength of vibrations based upon a person's sensations alone. Most people are capable of detecting vibrations at very low levels and the vibrations feel severe before they actually reach the point of causing structural damage.

- Even people who work around blasting everyday cannot accurately judge the intensity of a vibration. How a blast feels depends upon many factors not related to the vibration strength. Things such as the person's sensitivity to vibration, whether they are in a basement or upstairs, and the characteristic frequency of the blast all have some bearing on how the vibrations feel.

Ground Vibrations from Blasting

- A blast will always feel more severe when it is unexpected and it startles a person. However, when the same person has been warned to expect a blast and is prepared for the vibration, it almost always feels less intense.

- The blaster is required to design the burden, stemming, subdrill, spacing, and timing to minimize excessive vibration, airblast, and fly rock. The blaster must monitor the airblast and vibration for every shot at the nearest structure(s). Seismographs are used to monitor the vibration.

- To lower the vibration everything needs checked. This would include the blast design and layout of the blast holes.

Ground Vibrations from Blasting

To control ground vibrations …

- Minimize charge per delay of explosive
- Optimize the amount of explosives in blasting
- Exercise strict control over spacing and orienting all blast drill holes
- Make sure the order of firing is correct
- Minimize degree of confinement by using the minimum practicable sub-drilling
- Use smaller diameter of blast hole
- Interrupt the continuity of rock mass
- Minimize frequency of blast
- Increase distance from reception area
- Investigate alternative rock-breaking techniques

Ground Vibrations and Airblasts

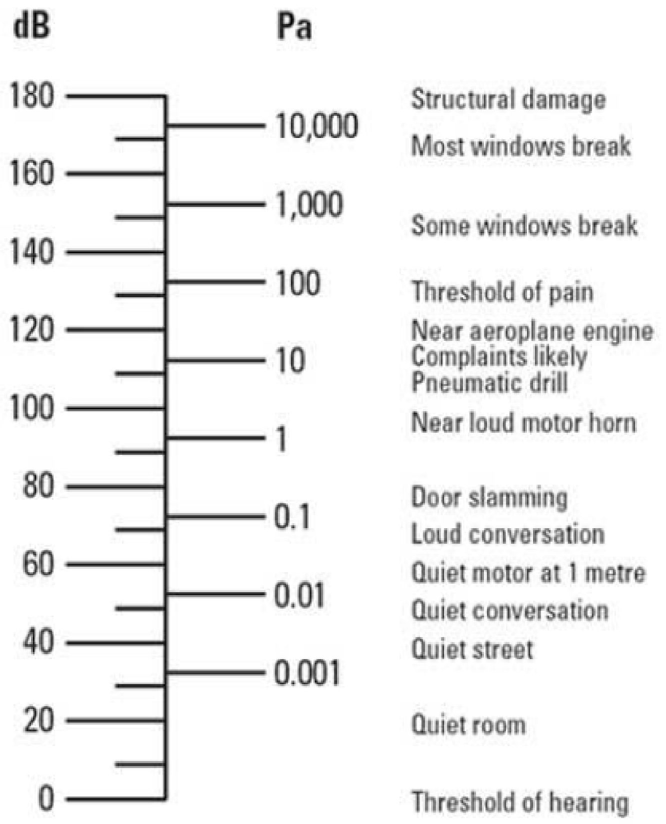
- Vibration and airblast from blasting can lead to community concern primarily due to the fear of structural damage.

- This fear occurs because people are able to detect vibration at levels which are well below those which result in even superficial (apparent rather than actual) damage to buildings and items of heritage value.

Airblasts

Noise from blasting is a common source of community concern because operational noise emissions frequently occur on a continuous basis.

This can interfere unreasonably with day to day activities, particularly concentration, recreation and sleep, and result in an adverse impact on residential amenity.



Airblast Pressure

The airblast pressure can be calculated based upon several variables using the following equation:

$$P = K\,(R/(Q)^{0.33})^{B}$$

Where,

P = Pressure, kPa (*in units of pressure*)
K = State of Confinement
Q = Maximum instantaneous charge per delay (*in units of mass*)
B = Constant related to the rock and site (usually -1.2)
R = Distance from charge (*in units of length*)
$(R/(Q)^{0.33}$ is defined as a scaled distance

Airblasts

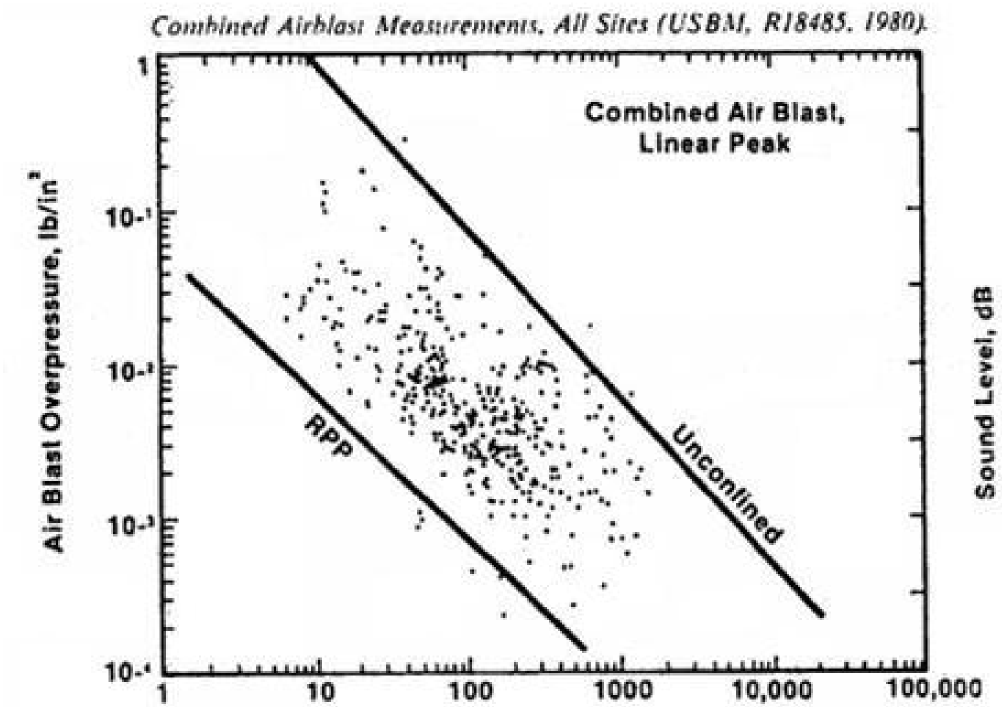
- To lower the air blast check the stemming height and type of material used for the stemming.
- Thin or thick areas of the burden may create excess air blast and even fly rock.
- Read the burden of the free face to ensure of a uniform burden face.

Typical K Factors

• Unconfined	=	185
• Fully confined	=	3.3

Airblasts

Airblast measurements from mining blasts, adapted from U.S. Bureau of Mines RI 88485, 1980. Unconfined line is from Perkins and Jackson, 1964 and RPP line (total confinement) is from Wiss and Linehan, 1978.



"Most significant is the wide range of measured values resulting in variation in confinement and undocumented weather influences."

(Siskind, 2000)

Airblasts

To control noise and airblasts …

- Minimize charge per delay of explosive
- Use a hole spacing and burden which will ensure that the explosive force is just sufficient to break the rock to the required size (re-check the explosive factor)
- Ensure stemming depth and type is adequate
- Restrict blasts to favorable weather conditions
- Eliminate exposed detonating cord, shallow blasting and secondary blasting. In the event that an explosive detonating cord is used to detonate the blast holes, it should be covered with a suitable aggregate material.
- Minimize frequency of blast
- Use barrier between blast area and reception points

Flyrock

- One of the greatest challenges a blaster (and blasting consultant) must consider in mining and construction blasting, is to accurately determine the bounds of the blast area.

- Most fatal injuries due to lack of blast area security were primarily caused by failure to clear blast area or inadequate access control to the blast area.

Flyrock

- The U.S. Code of Federal Regulations (CFR), Title 30, Part 57.6000, defines the 'blast area' as the area in which concussion (shock wave), flying material, or gases from an explosion may cause injury to persons.

- The U.S. Federal Office of Surface Mining regulations [30 CFR §816.67 and 817.67] help to characterize the bounds of the blast area by specifying that flyrock shall not be cast from the blasting site.

Flyrock

The primary factors resulting in flyrock are:

- **insufficient burden or use of blast mats,**
- **improper blast-hole layout, loading, (excessive) powder factor,**
- **anomaly in the geology and rock structure,**
- **insufficient stemming, and**
- **inadequate delay time (hole to hole or row to row).**

Flyrock: Case History

A blaster was firing charges inside two water well holes. When the shot was fired a piece of flyrock traveled approximately 210 feet, striking the blaster on the head, fatally injuring him because he was not wearing a hard hat.

At the time of the blast, he was standing in the clear, and had no protection from flyrock.

Flyrock: Case History

- At a limestone mine, a neighbor walked into the blast area and was fatally injured. The blaster could not see the victim entering the blast area from the firing station.
- In another case, a passenger in a vehicle was fatally injured by flyrock because road traffic was not monitored during the blast.
- In another example, a dozer operator entered a blast area due to lack of access control.

1. Fatal injury due to flyrock at a limestone mine in Pennsylvania (Case Study No.6)
Source: MSHA, 1999b

Flyrock

Recommended methods to control flyrock:

- Cover the rock to be blasted with suitable material, to control flyrock
- Ensure stemming depth and type is adequate
- Choose a burden of sufficient magnitude to reduce the possibility of blast through
- Avoid shallow blasting that is generally less than 3 feet
- Select the direction of blasting face so as to place any person or buildings at the rear of the face
- Take special care when carrying out secondary blasting to avoid overcharging
- Make sure that the order of firing is correct

Blasting Mats to Control Flyrock

- Blast mats are often used to control flyrock, permitting blasting adjacent to roadways and rail lines, as well as residential areas.
- Blast mats help to redirect the concussion force of the blast back to the origin resulting in noise (acoustic level) reduction.
- Additionally, a greater quantity of explosive can be used to shatter the rock, resulting in greater fragmentation permitting the rock to be excavated, loaded and hauled out more quickly and efficiently.

Blasting Mat Placement

Photograph courtesy of Tectonic Engineering & Surveying Consultants P.C.

Close-up View of Blasting Mats

Photograph courtesy of Tectonic Engineering & Surveying Consultants P.C.

Construction Blasting

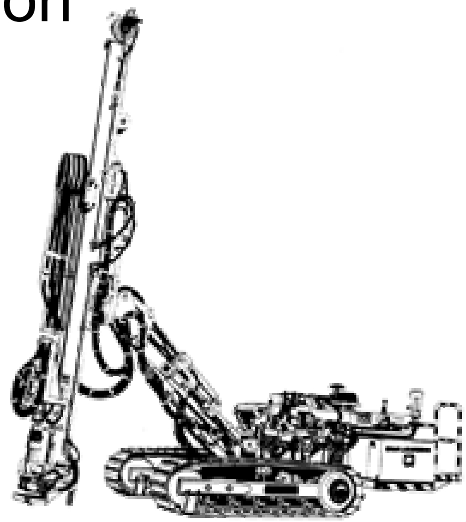
Photograph courtesy of Tectonic Engineering & Surveying Consultants P.C.

Construction Blasting

Vibration and Airblast Criteria

Three criterion are generally applied to limit peak particle velocities from blasting for a given site. They are:

- Limiting Particle Velocity Criterion
- Scaled Distance Equation Criterion
- Blast Level Chart Criterion



Vibration and Airblast Criteria

Limiting Particle Velocity Criterion:

DISTANCE FROM BLAST SITE (FEET)	MAXIMUM ALLOWABLE PEAK PARTICLE VELOCITY (IN./SEC.)
0 – 300	1.25
301 – 5,000	1.00
> 5,001	0.75

See Section 10.5 in the reference for additional information.

Vibration and Airblast Criteria

Scaled Distance Equation Criterion:

DISTANCE FROM BLAST SITE (FEET)	SCALED DISTANCE FACTORS TO BE USED WITHOUT SEISMIC MONITORING (FT/(lb)$^{0.5}$)
0 – 300	50
301 – 5,000	55
> 5,001	65

See Section 10.5 in the reference for additional information.

Vibration and Airblast Criteria

Blast Level Chart Criterion:

APPENDIX B.—ALTERNATIVE BLASTING LEVEL CRITERIA

Safe blasting vibration criteria were developed for residential structures, having two frequency ranges and a sharp discontinuity at 40 Hz (table 13). There are blasts that represent an intermediate frequency case, being higher than the structure resonances (4 to 12 Hz) and lower than 40 Hz. The criteria of table 13 apply equally to a 35-Hz and a 10-Hz ground vibration, although the responses and damage potentials are very much different.

Using both the measured structure amplifications (fig. 39) and damage summaries (figs. 52 and 54), a smoother set of criteria was developed. These criteria have more severe measuring requirements, involving both displacement and velocity (fig. B–1).

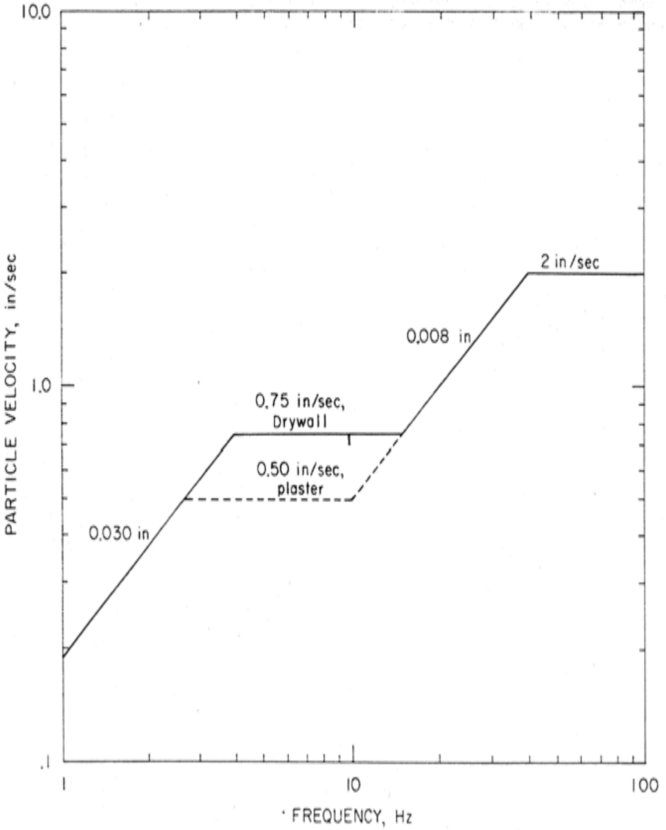


Figure B–1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.

See Section 10.5 in the reference for additional information.

Blasting Safety

- Follow all applicable federal, state, local and safety laws and regulations
- Specify the transportation, storage, handling and use of explosive
- Require the blaster to check every cap before using
- Make sure the order of firing is correct
- Use only blasting machine designed for firing the blast
- Use only device designed for checking cap
- Make sure all persons and equipment are safe before firing
- Do not attempt to investigate a misfire too soon

Blasting Safety

- Use electric caps made by the same manufacturers in the same circuit
- Always keep the electric cap wires as short-circuited
- Be sure that all wire ends are clean before connecting
- Recognize the possibility of static electrical hazards and stray current
- Do not handle explosives during an electrical storm
- Do not expose explosive materials to impact, excessive heat from flame-producing devices, friction, or electrical impulses

Construction Blasting

Photograph courtesy of Tectonic Engineering & Surveying Consultants P.C.

Notice the contractor's drill rig is very close to the Shot

Blasted Rock After Excavation

Blasting Inspection Guidelines

- Review the preblast survey
- Verify the experience of the Blasting Specialists
- Review and verify the blasting plan
- Production blasting is for widely spaced production holes in the main excavation
- Review the detailed blasting plan of test shots
- Document test sections and drilling patterns
- Document safety procedures
- Witness all shots
- Check vibration, air-blast and fly rock for all blasts
- Check monitoring wells with Hydrologist (if applicable)
- Verify presplit requirement
- Measure presplit areas
- Review contractor’s record keeping for explosives and blasting logs
- Review blasting summary reports

Blasting Inspection Guidelines

USGS
science for a changing world

Sample Blasting Plan

1. Blast officer:
   Other personnel who will be present:
2. Site & location of planned blasting:
   Date of planned blasting:
3. Explosives
   Type:
   Quantity:
   Detonator device:
4. Means of transporting explosives:
   Provisions for storing and securing explosives on site:
5. Minimum acceptable weather conditions:
   If electrical initiation to be used – considerations for stray radio frequency energy and electrical currents:
6. Procedures:
   Handling explosive charges:
   Setting explosive charges:
   Wiring explosive charges:
   Firing explosive charges:
7. Required PPE:
8. Minimum standoff distances:
   Procedures for clearing and controlling access to blast danger:
9. Procedures for handling misfires or other unusual occurrences:
10. Emergency action plan:
    Phone numbers: Ambulance ________________
    Fire department ______________
    Police ______________________

    Location and phone number of nearest medical services facility:
    Actions to be taken when a person is injured:
11. Attach a copy of material safety data sheet for each explosive or other hazardous material expected to be used.

U.S. Geological Survey WRD/OGW/Branch of Geophysics
11 Sherman Place, U-5015, Storrs Mansfield, CT 06269
phone (860) 487-7402/fax (860) 487-8802
http://water.usgs.gov/ogw/bgas/

The blaster or blasting consultant will routinely prepare a detailed blasting plan prior to blasting operations.

A sample blasting plan outline developed by the U.S. Geological Survey is shown. This outline has been provided in Adobe Acrobat (PDF) format as part of the supplemental course documents for future reference.

Vibration and Airblast Monitoring

- A seismograph is a sensitive electronic instrument designed to measure and record the intensity of ground vibrations.
- The seismographs used in blasting operations operate on the same principle as earthquake monitors, but are also portable and manufactured specifically to measure the type of ground vibrations generated by blasting.
- A seismograph placed near a home will detect the vibration of the ground around the house caused by blasting or any other disturbance.

Photograph courtesy of Malcolm Pirnie, Inc.

See Sections 10.2 and 10.7 in the reference for additional information.

Vibration and Airblast Monitoring

Portable seismic and acoustic monitoring station

Microphone stand

Acoustic microphone

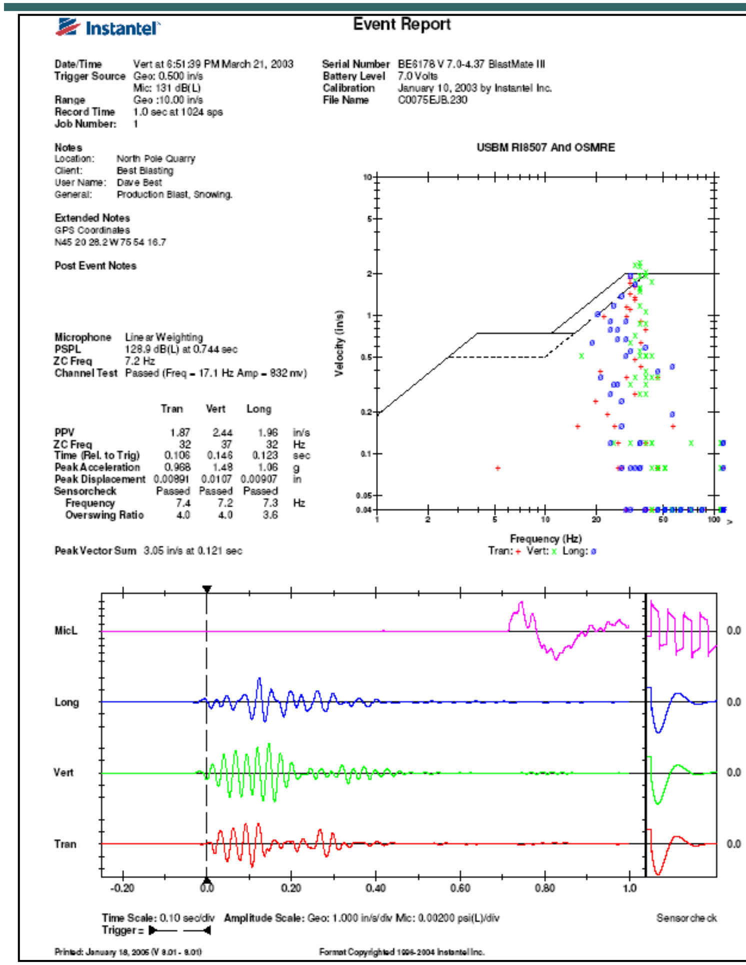
Geophone receiver

Paper print-out of data

Key pad for project data entry

GeoSonics Inc. seismograph

Vibration and Airblast Monitoring



Instantel

Event Report

Date/Time	Vert at 6:51:39 PM March 21, 2003	Serial Number	BE6178 V 7.0-4.37 BlastMate III
Trigger Source	Geo: 0.500 in/s	Battery Level	7.0 Volts
	Mic: 131 dB(L)	Calibration	January 10, 2003 by Instantel Inc.
Range	Geo :10.00 in/s	File Name	C0075EJB.230
Record Time	1.0 sec at 1024 sps		
Job Number:	1		

Notes
Location: North Pole Quarry
Client: Best Blasting
User Name: Dave Best
General: Production Blast, Snowing.

Extended Notes
GPS Coordinates
N45 20 28.2 W75 54 16.7

Post Event Notes

Microphone Linear Weighting
PSPL 128.9 dB(L) at 0.744 sec
ZC Freq 7.2 Hz
Channel Test Passed (Freq = 17.1 Hz Amp = 832 mv)

	Tran	Vert	Long	
PPV	1.87	2.44	1.96	in/s
ZC Freq	32	37	32	Hz
Time (Rel. to Trig)	0.106	0.146	0.123	sec
Peak Acceleration	0.968	1.48	1.06	g
Peak Displacement	0.00891	0.0107	0.00907	in
Sensorcheck	Passed	Passed	Passed	
Frequency	7.4	7.2	7.3	Hz
Overswing Ratio	4.0	4.0	3.6	

Peak Vector Sum 3.05 in/s at 0.121 sec

Time Scale: 0.10 sec/div Amplitude Scale: Geo: 1.000 in/s/div Mic: 0.00200 psi(L)/div Sensorcheck
Trigger =

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The blaster or blasting consultant will routinely prepare a report detailing the blast event upon completion of the blasting operations.

A sample vibration monitoring report prepared by Instantel is shown. Critical data such as the peak particle velocity (ppv) is recorded and data is plotted against the U.S. Bureau of Mines blast level chart criterion.

Instantel
The World's Most Trusted Vibration Monitors

Blasting Sequence

Scroll through the next series of slides quickly to see the progression of a controlled construction blast for a roadway widening.

Please observe that blast mats were used by the contractor; however, a small quantity of flyrock was generated (look above the construction sign – the arrow on the sign points to the flyrock).

However, the throw of the rock was relatively contained by the blast mats.


CONSTRUCTION
ZONE


CONSTRUCTION


CONSTRUCTION
CONSTRUCTION
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BEGINS


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Questions?

Please email questions to:

instructor@PDHonline.org

Please be sure to reference the course number and title in the subject line.

Parting Thoughts

"The use of field observations of the performance of structures is central to the general practice of geotechnical engineering in which it is known as the observational method."

Ralph Peck, 1969

Course Preparation and Delivery