CHAPTER 6. MODIFYING BLASTING TECHNIQUES TO FIT GEOLOGICAL CONDITIONS

6-1. Exploratory Study.

a. Blasting techniques for rock removal, quarrying, and preparation of finished slopes usually should be modified to fit the geological conditions. Because of the extreme complexity of each setting, familiarity with blasting results in similar geological settings is beneficial.

b. Excavations in the vicinity of a job should be examined to observe results of blasting. These should include all highways, quarries, mines, and excavations for hydraulic and other structures. Careful note should be taken of the geological structure, charge geometry, and blasting results. If the results are considered satisfactory, the techniques used may serve as a starting point which can be further refined to fit local details.

c. The results of this exploratory study, conducted before excavation, should be presented as a short report of case examples for use in design. Concurrently with the study of blasting techniques in the vicinity, information on rock physical properties should be collected. Field seismic velocities may serve to classify the rock for blasting purposes, as explained below.

6-2. Rock Types. Rocks can sometimes be classified for blasting purposes according to their seismic velocity. This is, in turn, conveniently converted to characteristic impedance.

a. Seismic Velocity.

(1) The velocity with which stress waves propagate in the rock (usually equal to the sonic velocity) is important, because it affects the distribution in space and time of the stress imposed on the rock by the detonating explosives and is an indirect measure of the elasticity of the rock.[1] Seismic velocities should be measured in the field where the effects of joints and bedding will be included. Velocities of core samples tested in the laboratory usually run considerably higher than velocities measured in the field. Granite, massive limestone, and quartzite tend to have much higher velocities than porous rocks such as sandstone and volcanic rock. Field velocities for granite below the zone affected by surface weathering will average about 15,000 fps. Velocities in porous rock and medium hard to hard shales are of the order of 7,000 to 10,000 fps.

(2) A zone of mechanical and chemical weathering and attack by

surface elements is to be found almost everywhere. Seismic velocities vary accordingly (para 6-5). This zone usually exceeds 10 ft in thickness and should be carefully delineated. In this zone, natural joint frequency exceeds that in the firm rock below, and fractures have been opened up. In addition, the weathering products that fill spaces between rock blocks tend to be clayey and have the effect of attenuating seismic waves.

b. Impedance.

(1) Effective rock breakage depends not only on explosive and rock characteristics but also upon an efficient transfer of energy, known as coupling action, from the explosive to the rock. Effective energy transfer depends upon (a) depth of emplacement of charge in rock, (b) efficiency of confinement of charge, and (c) impedance characteristics of both explosive and rock.

(2) Characteristic impedance of an explosive is defined as the product of its mass density and detonation velocity. Characteristic impedance of rock on the other hand is the product of its mass density and seismic velocity. Fig. 6-1 shows a typical impedance calculation for granite.

Longitudinal wave velocity = 18,200 fps

Unit weight = 165 lb/ft^3

$$\text{Mass density} = \frac{165\ \text{lb/ft}^3}{32.2\ \text{ft/sec}^2}$$

$$\text{Characteristic impedance} = 18{,}200\ \text{fps}\left(\frac{165\ \text{lb/ft}^3}{32.2\ \text{ft/sec}^2}\right)$$

$$= 93{,}300\ \text{lb sec/ft}^3$$

$$\text{or} = 54\ \text{lb sec/in.}^3$$

Fig. 6-1. Typical impedance calculation for granite

(3) Explosives with impedance nearly matching the characteristic impedance of the rock transfer more energy to the rock. It follows that an explosive loosely placed in a blasthole loses a substantial percentage

of its blasting efficiency This results from the fact that both rock and explosives have velocities exceeding that of air in the hole by 10,000 fps and usable energy is reduced passing through this low-velocity medium. Table 6-1 shows physical and chemical properties of explosives and common rocks. Ammonium nitrate and shale have similar impedances

Table 6-1. Some Significant Properties of Explosives and Rock in Blasting Work (after Leet[25])

Properties of Some Explosives

Type of Explosive	Specific Gravity	Detonation Velocity fps	Characteristic Impedance lb/sec/in.^{3}
Nitroglycerin	1.6	26,250	47
Dynamite: 50% Nitroglycerin, 41% Ammonium nitrate, 5% Cellulose	1.5	22,650	38
80% Ammonium nitrate, 10% Nitroglycerin, 10% Cellulose	0.98	13,100	14
ANFO 93% Ammonium nitrate, 7% Fuel oil	1.0	13,900	15

Properties of Some Rocks

Rock Type	Longitudinal Wave Velocity fps	Characteristic Impedance lb/sec/in.^{3}
Granite	18,200	54
Marlstone	11,500	27
Sandstone	10,600	26
Chalk	9,100	22
Shale	6,400	15

(Courtesy of Harvard University Press)

and, therefore, good coupling possibilities. Nitroglycerin (impedance 47) and granite (impedance 54) also suggest an efficient transfer of explosive energy. Characteristic impedances are only one of the criteria needed for selecting the best explosives for the given job. Other factors such as rock structure, water, safety, and economics also play major roles.

c. Compressive and Tensile Strengths.

(1) Following Atchison,[1] "Compressive and tensile strength properties are sometimes used to classify rock with regard to ease of breaking with explosives. A common characteristic of rock that is crucial to the fragmentation process is the high ratio of compressive strength to tensile strength. This ratio ranges from 10 to 100, most rocks being very weak in tension." The ratio has been termed the blasting coefficient (para 2-3). Table 2-1 shows the compressive and tensile strengths for a selected group of rocks with divergent properties.

(2) Fig. 6-2 is an empirical chart useful for estimating blasthole spacing and size and powder factor for rocks of different strength. Actual hole diameter, which is usually the given parameter, must be corrected to effective diameter to compensate for stemming and other inert filling in the hole. Soft minerals, where abundant in rock, also tend to absorb blasting energy and make fragmentation more difficult.

d. Density and Porosity.

(1) Density of intact rock (laboratory measured) often indicates the difficulty to be expected in breaking rock (Fig. 4-3) with the denser material responding best to explosives with high detonation pressures. On the other hand, less dense, more porous rocks absorb energy in ways that make control of fragment size and gradation difficult.

(2) A linear relationship between porosity and in situ sonic (seismic) travel time is shown in Fig. 6-3. This relationship can be used where porosity is known to estimate seismic velocity and, in turn, impedance. Velocity must be corrected for pore fluid in saturated rocks as explained in reference 26.

6-3. Fractures and Fabric. The structural pattern of the rock exerts a major influence on fragmentation in many blasting situations. Blasting patterns should be designed to take advantage of rock structure where possible.

a. Joint Frequency.

(1) In rock removal blasting, closely spaced joints can mean a savings in blasting costs because it will not be necessary to use a sizable part of the energy in fracturing. A pattern and technique using

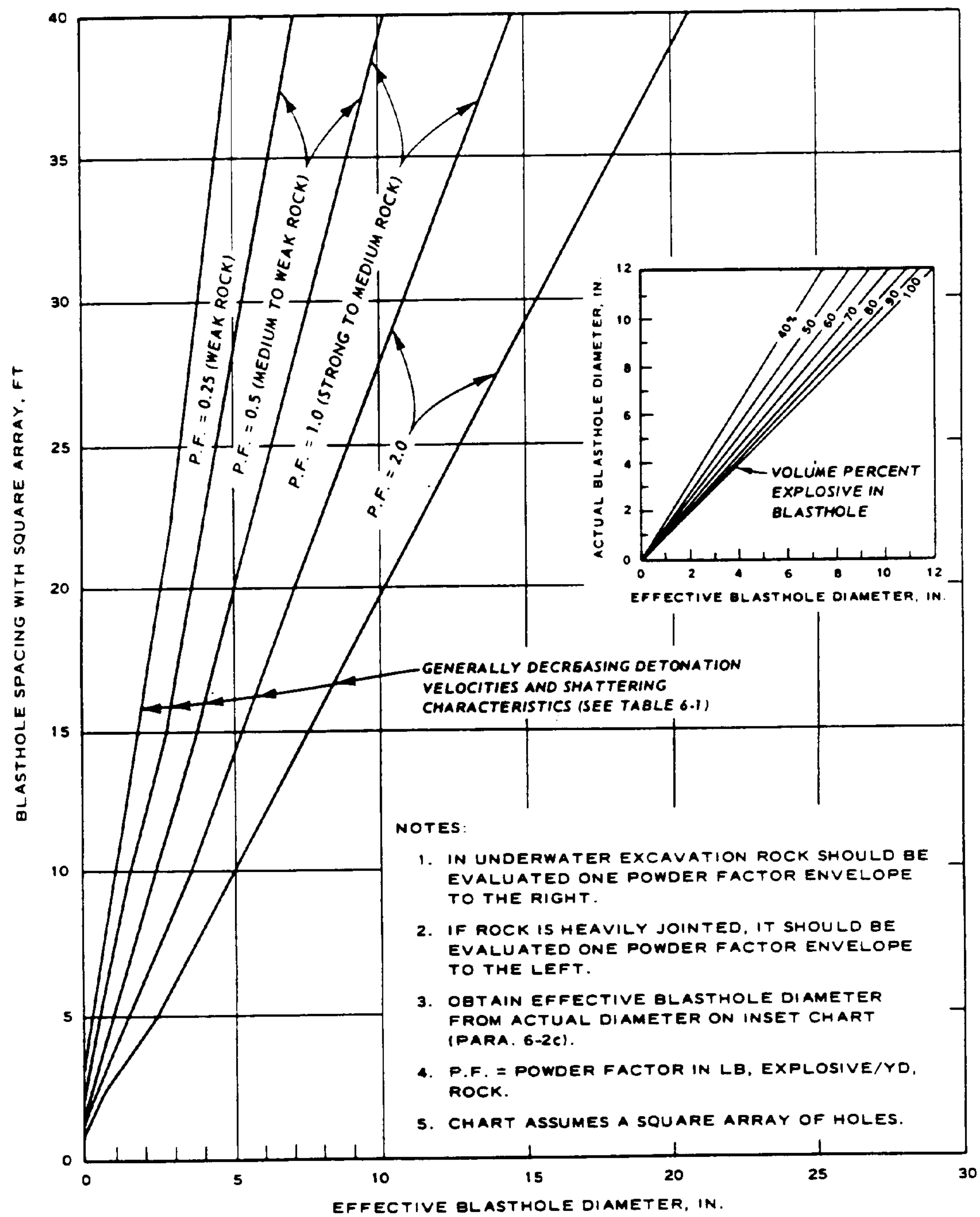
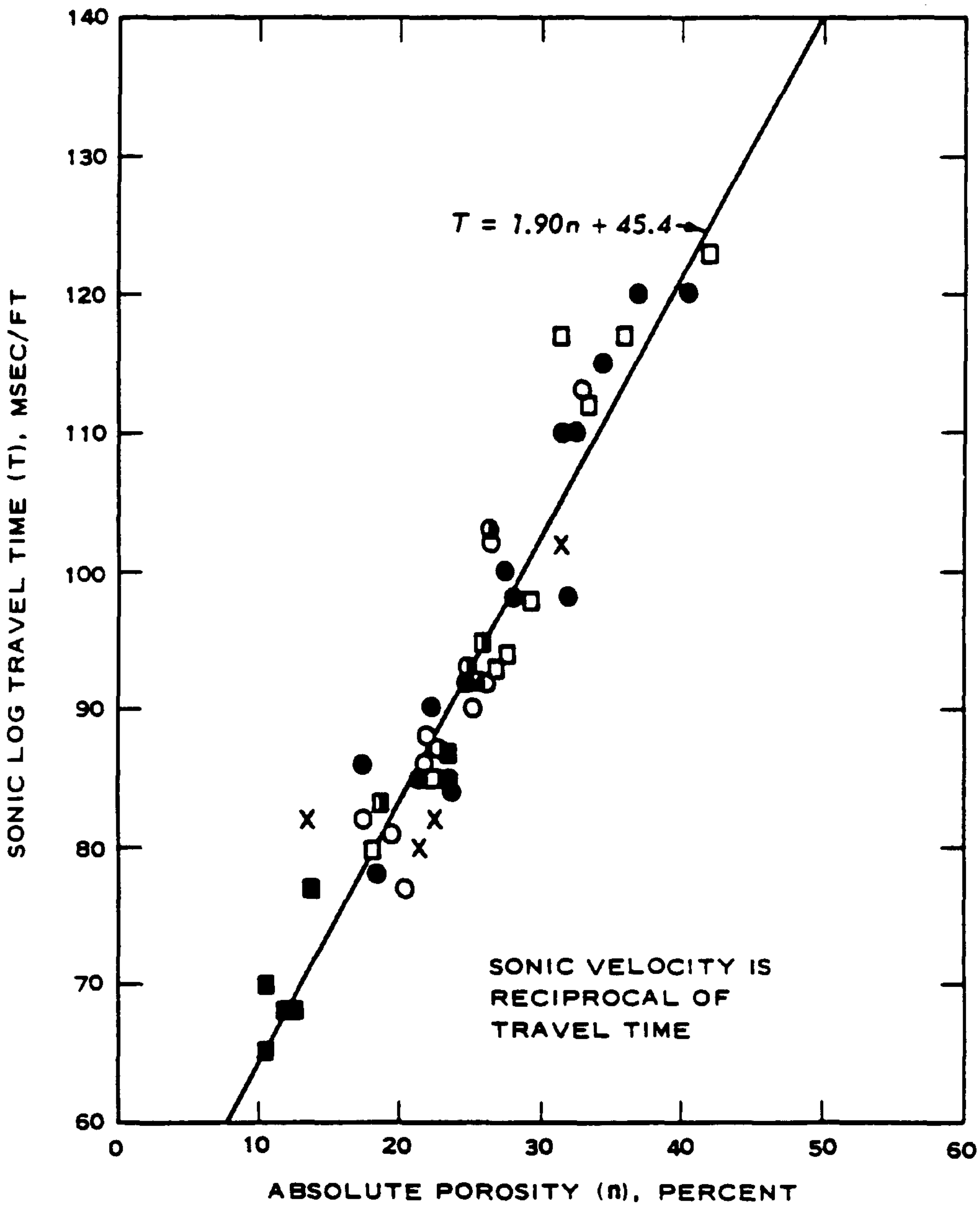


Fig. 6-2. Empirical relation: blasthole spacing and diameter and powder factor for multiple-row blast pattern in rocks of different strengths



(Courtesy of American Society of Civil Engineers)

Fig. 6-3. Sonic log travel time as a function of porosity for a suite of volcanic sedimentary rocks and lava (after Carroll[26]) less powder may suffice. Normally, the seismic velccity in a highly fractured rock will be significantly lower than the velocity in similar rock with fewer fractures. It follows that the characteristic impedance will also be lower, and a highly fractured rock can be matched with an explosive or blasting agent with a lower characteristic impedance. Such an explosive has reduced shocking power for fracturing but greater heaving effect for loosening and moving material.

(2) Presplit blasting for a finished rock surface may be more difficult in highly fractured rock depending partly on the nature and attitude of the fractures. Careless presplitting may damage highly fractured rock because liberated gas tends to migrate along these fractures and loosen the mass. This can be minimized by reducing the hole depth and spacing and by stemming carefully.

(3) More effective fragmentation is accomplished where explosive charges lie within the solid blocks bounded by joints.[1] In quarrying highly fractured material, the fragment size of the product will approximate that of the natural fragment, and of course, no quarrying should be attempted where the natural fragment size falls below that desired. Where the natural block size is suitable, a minimal amount of additional fracturing can be tolerated, and energy of the blast should be used for heaving. Again, an explosive with a low detonation velocity may prove best.

b. Cushioning Joint Coatings.

(1) Some joint coatings consist of crystalline material such as quartz and calcite. The properties of these minerals are similar to those of the adjacent rock, so the coatings have little effect. Elsewhere, clayey minerals occurring along fractures can have significant effect. They hold moisture and have plastic rather than elastic properties, so they tend to attenuate the seismic waves. A list of some of these minerals and the usual host rock is presented in Table 6-2.

(2) In rocks where a rapid attenuation of the seismic wave is expected, a heavier charge may give better results. The decision to use heavier charges should, of course, be tempered with the realization that greater crushing will result in the vicinity of the charge. Closer blasthole spacing is a possible alternative modification of the technique. In this manner, adjacent blast-fractured zones can be made to overlap and the seismic zone will be relegated to lesser importance.

c. Orientation of Joints. Blasting technique may need modifications to fit joint orientations. Stability of the excavation is of utmost importance and will take priority over questions of economics, such as are involved in blasting. With this in mind, the long-range stability of

Table 6-2. Clayey Fillings Occurring Along Rock Joints

Mineral or Mineral Mixture	Host Rock
Remolded clay (Same minerals as in host)	Shale
Kaolinite	Highly weathered rocks, hydrothermally altered rock
Montmorillonite	Tuff, shale
Chlorite	Tuff, andesite, and chlorite schist
Sericite	Hydrothermally altered rocks
Vermiculite	---

Note: Where one or more of the listed host rocks has in the geologically recent past overlain the rocks at the project site, the clayey fillings may have been washed downward along fractures into the new host.

an excavation slope should be a factor along with geological factors considered in designing or modifying a blasting technique. The change should of necessity be made at an early stage of construction.

(1) Orientation in Various Geological Settings.

(a) Idealized systems of fractures may sometimes be predicted for the more common geological settings expected on construction jobs. The simplest is an orthogonal system that can be expected in flat-lying sedimentary strata. This system consists of horizontal joints parallel to the bedding and one or two sets of vertical joints.

(b) The free face may be carried parallel rather than perpendicular to major vertical joints. Not only are large fractures already developed in the major direction, but it can also be expected to be a potentially weak direction in which additional blast fracturing will take place (see e below).

(c) Where this orientation is included in the design of the excavation as a final surface, overbreakage often may be minimized and the slope should be more stable. Conceivably a through-going natural joint surface might be substituted for a presplit surface.

(d) A favorably oriented system of prominent fractures that can be worked into construction design is not necessarily a panacea. It can be detrimental if not properly evaluated. For example, excessive charges can lead to excessive gas migration along these fractures and movement of a long block of rock into the excavation. This gross overbreakage would be manifested by the opening of fissures along natural joints parallel to the lip of the excavation.

(e) In inclined sedimentary or metamorphic strata, the joint system usually consists of joints inclined parallel to the bedding and one or two sets of joints perpendicular to bedding. Such a geological setting poses a more complicated problem for designing the blasting pattern and loads. Much of the breakage and a large part of the final surface may be along natural joints, so that excavation slopes and blasting patterns should be designed accordingly.

(f) Vertical strata prefer to break along preexisting vertical bedding joints; this plane may be susceptible to overbreakage and later progressive slope movement by stress relief aggravated by blasting. Therefore, a more permanent slope would be attained where oriented either perpendicular to or at a large oblique angle to the strike of the bedding or schistosity. In this case more fracturing would be necessarily done by the explosive so that a denser pattern or heavier charges might be needed.

(g) In massive unbedded rock such as granite, the fracture system is believed to have been determined by regional stresses in the remote geological past. It will commonly consist of nearly vertical joints in two sets striking at right angles. A third set of nearly horizontal sheeting joints may also be present. Such a mass can be treated like one of massive horizontal sedimentary strata. Excavation should be designed where possible to take advantage of the natural joint system, and due caution exercised for overbreakage on natural joints well back from the lip of the excavation. The frequency of fractures in massive rocks is low and consequently blasting problems usually are less acute.

(2) Adverse Orientations. The first and usually most critical adverse joint orientation occurs where a major set of joints is steeply inclined into the excavation. Shear stresses along these joints are high relative to joint shear strengths and disturbance during the blasting may lead to slope failure. Progressive failures can also result from such weakening. Fig. 6-4 shows adverse dip into an excavation in idealized form. As the excavation progresses to depth, the left wall will have considerable overbreakage.

d. Faults and Breccia.

(1) Fault zones may consist of a series of subparallel faults, anastomosing, and enclosing slabs of wall rock or lenses of breccia. Blasting conducted near faults will often break to the fault surface.

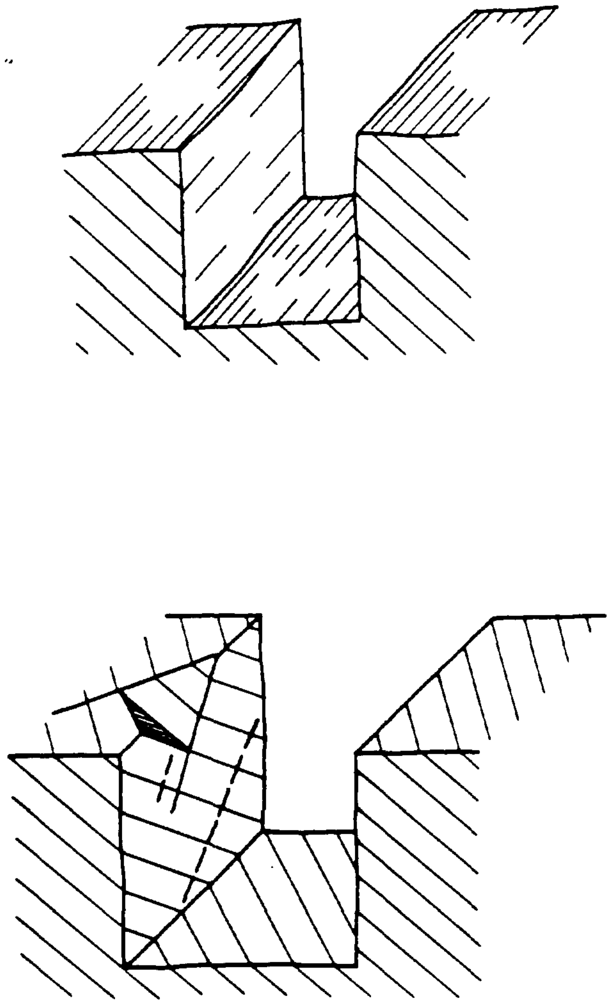


Fig. 6-4: Adverse dip of joints into excavation (left side)

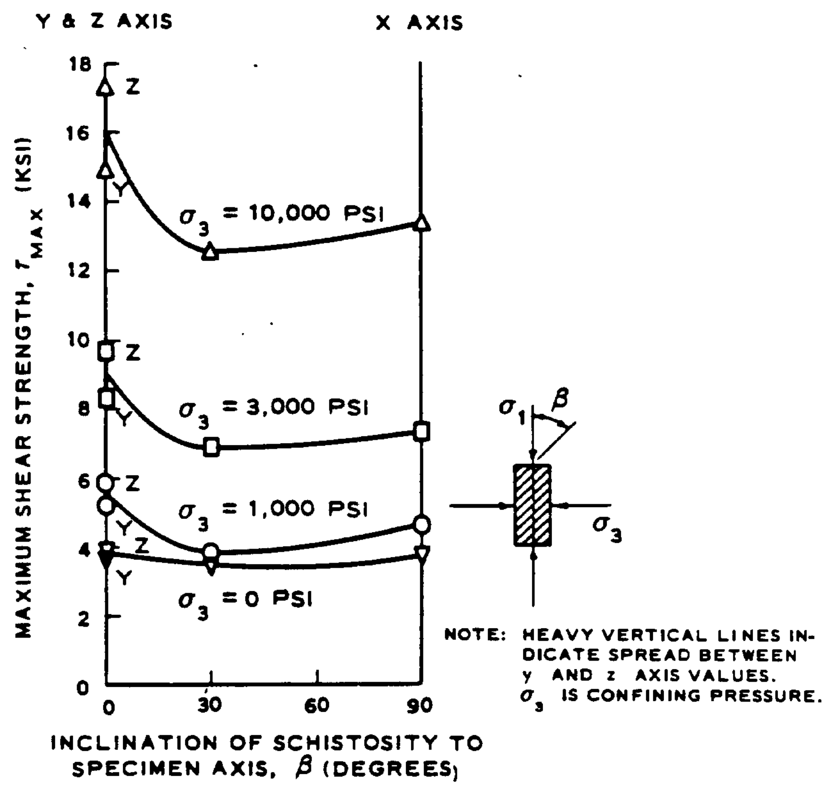
Venting of gases can also occur along permeable breccias or fault zones, causing a loss in the blasting energy and poor results unless deck loading is utilized.

(2) Fault zones and breccia by virtue of their high porosity can also have a cushioning effect on crushing and seismic waves. In such materials, the blasting technique might be modified to the extent that little seismic energy is provided. An explosive with a low detonation velocity might be most satisfactory.

(3) Porous faults and breccias constitute potentially weak zones that may be of utmost importance in stability consideration. Corps of Engineers experience in basalt breccia of the Columbia River Plateau indicates that such breccia can be presplit as easily as interbedded basalt and, in fact, stands more stably in some cases. Apparently the shock wave attenuates rapidly in volcanic breccia and the mass has sufficient cohesion to remain intact. Some of these slopes were presplit with every other hole left unloaded.

e. Fabric.

(1) The fabric of a rock, for blasting purposes, is the mineralogical or granular texture that may impart different physical properties in different directions. For instance, the compressive strength of schistose gneiss[27] for various orientations varies approximately as indicated in Fig. 6-5.



(Courtesy of Laboratório Nacional de Engenharia Civil)

Fig. 6-5. Variation of shear strength with inclination to schistosity (y-z plane) in fine-grained gneiss (after Deklotz, Brown, and Stemler[27])

(2) Fabric has been used effectively by the dimension stone industry, which recognized at an early date the difference between "grain," "hardway," and "rift." Fabric directions, particularly in granite, were used to the advantage of the quarryman as favorable or unfavorable planes for breaking out dimension stone. The same technique might be considered in quarrying for engineering materials. Blasting patterns might be designed to break rock preferentially along weak fabric directions so as to reduce powder factor or increase spacing provided the desired product is obtained.

(3) For presplitting, the fabric should be determined so that presplit surfaces may possibly be adjusted to utilize weak planes. Lines of presplit holes may even be adjusted in rare cases to parallel fabric directions. In such cases, the spacing of holes may be as much as doubled. It follows that the major value of knowing fabric is in determining optimum hole spacing and/or charge size.

(4) In conventional production blasting, the nearest free surface should, within reason, be kept parallel to the dominant weak plane in order to promote spalling, general breakage, and movement to that surface.

(5) The in situ stress field is rarely important in surface excavation blasting. The effect is much the same as for fabric to which in situ stress is often geometrically related. Presplitting is easier parallel to the maximum compressive stress.[28]

6-4. Bedding and Stratification. The dominant structure of many rocks is the bedding. In some igneous rocks which ordinarily do not have bedding, other structures, such as sheeting joints, may function in its place. Where advantageous, the blasting technique should be modified to fit the bedding.

a. Alternating Rock Types.

(1) Careful analysis of the stratigraphy of a site should reveal when a blasting round will lie in more than one rock type. The properties of each rock type are distinct, and the blasting technique may have to be modified for portions in each or the depths of the rounds changed to correspond to the stratigraphy. This applies not only to differences in the properties of the intact rock but also to the differences in properties of differently jointed masses. Ultimately, an array of blastholes passing from layer to layer might be divided vertically and loaded accordingly.

(2) It may be advisable to drill the blastholes to a stratum contact

and thereby outline excavation lifts to conform with the individual stratum. This would be feasible in rocks with well-defined bedding. A finely foliated rock sequence might be treated as one homogeneous unit since it would be unreasonable to divide the charge according to the adjacent wall rock.

(3) Certain geological settings are typified by contrasting rock types. Sandstones and shale are commonly associated in moderately to thinly bedded strata. Elsewhere, limestones and shale are interbedded. Porous tuff and tuff breccia are interbedded with hard lavas, such as basalt and andesite, in volcanic areas. Extremely hard basalts are sometimes separated by thin porous zones of basalt fragments and cinders.

b. Porous and Permeable Beds.

(1) Porous and permeable beds are particularly troublesome where they promote a tendency for the adjacent excavation wall to be lifted on gases migrating from the detonation. It may be necessary to divide the charge into two by decking this interval.

(2) Permeable and porous zones also have a cushioning effect and dissipate seismic energy. As with clayey joint coatings and fault breccia, these low seismic velocity zones may be matched with explosives with low detonation velocity, such as ANFO.

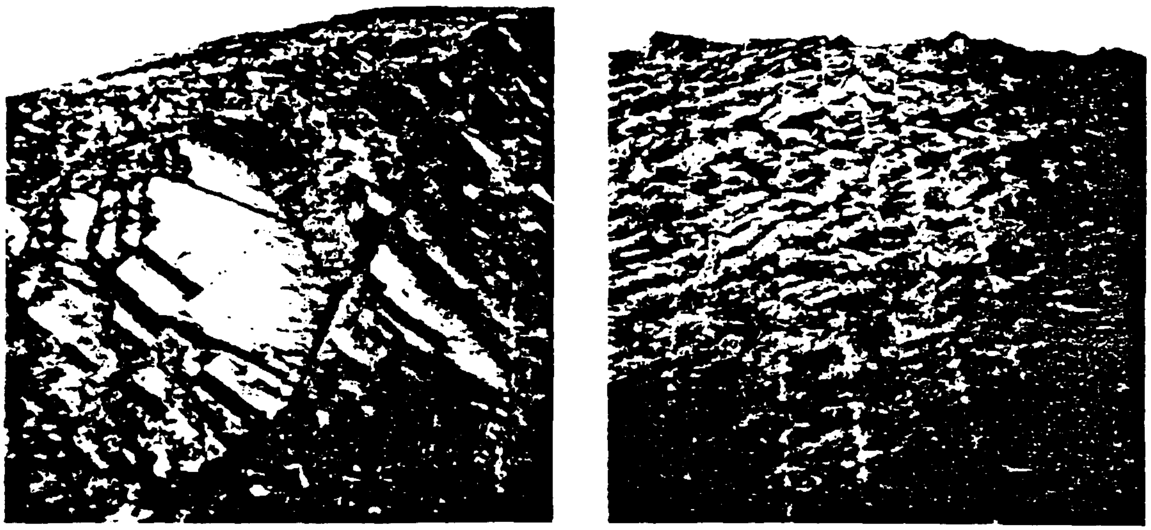
c. Weak Beds or Zones.

(1) It may be necessary to take special precautions where weak zones are indicated in the excavation, particularly pronounced bedding and joints across bedding. The resistance to sliding and slope failure along these surfaces may be divided into two components, an interlock strength and a residual strength. The residual strength may not be sufficient to preserve the slope so that during blasting, all precautions should be taken to avoid lowering the interlock strength by excessive vibration. Weak beds are problems only when they dip toward an excavation. Weak beds dipping steeply away from an excavation may lead to overbreakage and the formation of overhangs. Weak beds are used advantageously for the floor in many quarrying operations inasmuch as the toe tends to break out clean. Excavation walls containing weak zones may need to be redesigned so that the potentially unstable material may be removed. If the slope is designed to be held by rock bolts, exceptional precaution would still be advisable during blasting to avoid unnecessary damage.

(2) A carefully conceived blasting pattern will avoid development

of unstable conditions and may even take advantage of weak zones for rock removal.

d. Dipping Strata. A general rule in dealing with strata dipping toward an excavation is that they are potentially dangerous or unstable. Strata dipping away from an excavation, in contrast, are usually stable and present few problems (Fig. 6-6). However, see discussion of adversely dipping joints in paragraph 6-3c(2).



a. Cut in Strata Dipping Toward Excavation

b. Cut in Strata Dipping Away from Excavation

Fig. 6-6. Effect of dipping strata on stability of excavation. Views of opposite walls of a cut through argillite

e. Cavities.

(1) Cavities in an excavation site may have a marked effect on blasting. The air space may tend to decouple the explosive and rock and decrease the efficiency. Another adverse effect is that explosives, particularly in bulk or slurry form, can be lost into or through a cavity that intersects the hole. Also overloading will result in extra hazards of flyrock. For these reasons, a record of the volume of explosives loaded in each hole should be maintained by the contractor. When there is an indication of a loss of explosives in cavities, the zone should be located and corrective measures taken to seal it.

(2) The cavity may be sealed by filling with sand, by grouting, or by plugging off the hole above and below the cavity. Where the hole is plugged, a portion of the explosive charge should lie on either side and additional care will be required in priming and detonation. Although such measures may be expensive, they may be justified, for a misfire or inefficient round will be more costly.

6-5. Weathering.

a. The weathering effect is twofold. First, the properties of the rock are altered, and second, this change of properties is localized in a layer parallel to the ground surfaces so that crude stratification is developed.

b. Field seismic surveys together with available boring data will usually resolve the problem. They show the thickness of the weathered zones and the P-wave velocities of each material. Velocities in more fractured weathered zones are less than those in the fresh rock below, and blasting techniques should be adjusted. A weathering coefficient (Table 6-3) can be a useful guide for modifying blasting for the weathered zones. The characteristic impedance of the explosive recommended

Table 6-3. Classification of Laboratory Samples of Monzonites According to the Degree of Weathering (from Iliev[29])

(Courtesy of Laboratório Nacional de Engenharia Civil)

Degree of Weathering	Velocity of Ultrasonic Waves, m/s	Coefficient of Weathering, K
Fresh	>5,000	0
Slightly weathered	5,000-4,000	0 -0.2
Moderately weathered	4,000-3,000	0.2-0.4
Strongly weathered	3,000-2,000	0.4-0.6
Very strongly weathered	<2,000	0.6-1.0

Note: $K = \frac{\text{velocity fresh - velocity weathered}}{\text{velocity fresh}}$

m/s = meters per second

for use in weathered rock is found by multiplying the characteristic impedance of the explosive used in fresh rock by the factor, 1 - K. A more conventional method is to use the same explosive but to increase the powder factor when weathered material is absent.

c. One way of simplifying the handling of weathered material is to blast and excavate it in one or two lifts apart from material below. By partially excavating down to the lower limit of a weathered zone, the mass is simplified to one with uniform properties. Because of the decreased seismic velocity, upper lifts might respond to lower velocity explosives for best impedance matching and efficiency. In the transition zones and in the fresh rock below, detonation velocity might be increased farther.

d. Some weathered rocks are so decomposed that they can be treated as soil and excavated without blasting. A seismic velocity of about 4,000 fps is a routinely accepted upper limit for rock that can be loosened by ripping without blasting. With improvements in ripper design and techniques, material with seismic velocities as great as 7,000 fps can be ripped. However, there are other factors that may be involved in determining whether rock can be ripped economically.

e. In a few special types of weathering, the lower portion of the zone has material characterized by a greater strength, as in laterite and caliche.

6-6. Groundwater.

a. Zones of various degrees of saturation by groundwater form another type of crude stratification parallel to the ground surface, with properties varying accordingly. Saturated zones require explosives with greater water resistances and necessitate more care in stemming. Important distinctions must be made in the properties of the materials and the results to be expected. The filling of void space by water tends to increase the P-wave velocity in the mass and improves wave transmission. The coupling between the explosive and the rock is also improved.

b. Unsaturated material above the water table should be blasted separately from that in the capillary zone and below where reasonable. After removal of the unsaturated material, however, it should be verified that the material yet to be excavated is still saturated. Disturbance during excavation may have caused groundwater to migrate. Fluctuations from rainy to dry seasons should be considered also.

c. The results of blasting during removal of the unsaturated zones should be carefully evaluated for guidance in the blasting below the water table. Where these previous results are considered satisfactory, modifications might consist of the use of explosives with a higher detonation velocity for better coupling to the saturated rock, and/or the use of smaller loads and wider hole spacings.