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By
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PRODUCTION BLASTING AND THE DEVELOPMENT OF OPEN PIT SLOPES

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ABSTRACT

Mine production blasting is a process of destruction of rock masses in order that ore may be extracted. Many open pit operations are faced with the apparently conflicting requirements of providing large quantities of fragmented rock for the processing plant and of minimizing the damage inflicted upon the surrounding pit slopes. A reasonable compromise between these two conflicting demands may often be found by means of simple engineering of production blasts.

Many operations tend to rely too heavily upon traditional wall control techniques to alleviate a problem already created by the production blasts.

Various production trends including use of larger blastholes and patterns have tended to aggravate the situation. These practices only serve to emphasize the need for engineered improvements.

Central to blasting engineering is the process of systematic trial and evaluation. Changes to the blasting system should be made singly, starting with the simplest.

This paper discusses simple changes involving drill pattern control, effective use of blastholes and explosives, adequate delaying including use of down-the-hole sequential techniques, effective utilization of free faces, and avoidance of "choked" situations. By directing explosive effort where it is needed, such changes generally result in a significant improvement of slope conditions and of production blasting cost and performance.

INTRODUCTION

Blasting is, by its very nature, a destructive process. The open pit blaster is often faced with the apparently conflicting demands of providing large quantities of well fragmented rock and of minimizing the amount of damage inflicted upon the rock slopes that remain.

Lack of attention to blasting adjacent to pit slopes can lead to difficult digging and pit walls that are psychologically uncomfortable and even dangerous to work beneath. There is evidence to suggest that a substantial number of slope failures have been aggravated and some even precipitated by poor blasting practice.

At the very outset of being confronted with the problem of development of pit slopes, many blasters will consider the use of traditional controlled blasting techniques such as presplitting. They may test out the technique, often with marginal success, and then conclude that the technique is too expensive, too demanding of drilling capacity, or just unsatisfactory. In many cases, the reason poor results are obtained is that the damage has already been caused by previous blasting in front of the wall control shot. For this reason, the author considers that wall control blasting (in the strict sense) should be used as the last and optional step in a process requiring careful production blasting. This paper discusses those changes that can sometimes be made to the production drilling and blasting system that result in improvement of the wall conditions. Most of these changes can be made with minor effort and little extra cost and invariably result in generally improved fragmentation. These modifications are often necessary, merely for the development of good blasting technique.

SYSTEMATIC MODIFICATION OF THE DRILLING AND BLASTING SYSTEM

Any changes that are made to the drilling and blasting system may significantly affect other aspects of the operation, to its benefit or detriment. Therefore, the first step in rationalizing a blasting system should be to ensure good record keeping of each blast and the results of that blast.

Unfortunately, precise measurements of the effect of blasting changes upon the operation are difficult and time-consuming. However, honest evaluation can be achieved by observation of the results in the field. Successful blasting can often be identified by observing the conditions of the muckpile after the shot. Figure 1 illustrates some important features to look for.

Once the blast is excavated to pit wall limits, it is necessary to evaluate the wall conditions. Table 1 can be used to classify blasting damage levels commonly observed on bench faces.

TABLE 1 LEVELS OF BLASTING DAMAGE COMMONLY OBSERVED ON PIT WALLS

	Observed Conditions of the Wall		
Arbitrary Damage Level	Joints & Blocks	Dip Angle Appearance and Condition of Face	Digging Condition at Face (Electric Shovel)
1 Slight	Joints closed, infilling still welded.	>75° circular sections of wall control holes seen.	Scars of shovel teeth seen in softer formation, further digging not practical.
2 Moderate	Weak joint infilling is broken, occasional blocks and joints slightly displaced.	>65° Face is smooth, some hole sections seen. Minor cracks.	Some free digging possible, but teeth "chatter."
3 Heavy	Some joints dislocated and displaced.	>65° Minor spalls from face. Radial cracking seen.	Free digging possible for <1.5m (<5 ft) with some effort.
4 Severe	Face shattered, joints dislocated. Some blocks	>55° Face irregular, some spalls, some backbreak cracks.	Free digging possible for <3m (<10 ft).
5 Extreme	Blocks dislocated and disoriented. Blast-induced fines or crushing observed.	55°>37° Face highly irregular, heavy spalling from face. Large backbreak cracks.	Extensive free digging possible for >3m (>10 ft).

Successful drilling and blasting involves the complex interaction of many factors. Therefore, when making modifications, the blaster should endeavor to change only one thing at a time, with the simplest change being made first. Side-by-side evaluation of a change in the same ground is the most affective test of a modification.

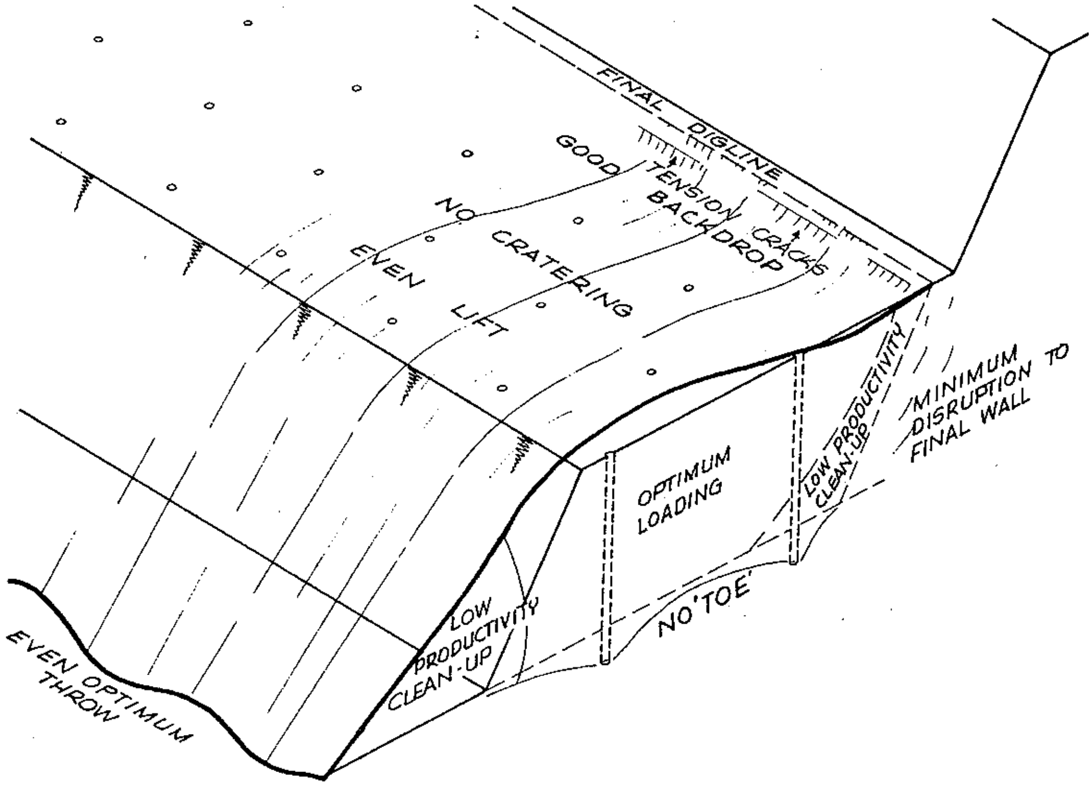


Fig. 1. Features of a satisfactory production blast.

MODIFICATIONS TO THE DRILLING AND BLASTING SYSTEM

Modifications that may lead to improvement of pit wall conditions and overall blasting efficiency are described under the following headings in this paper.

- Blasthole Pattern
- Explosive Types
- Charging Policy
- Front Row Control
- Delaying Practice
- Production Blasting and Excavation Adjacent to Pit Walls
- Controlled Wall Blasting (in the Strict Sense).

Upon study, many of the components of a particular drilling and blasting system will be found to be in order. However, the following portion of this paper describes some of the important components of mining systems that are frequently found to be deficient.

Blasthole Pattern

- Blasthole patterns should be carefully planned, pegged, and drilled. Pacing-out of patterns should be avoided in favor of more accurate methods such as use of tape or survey.

- Use of square or staggered patterns seems to be a matter of personal preference. Use of staggered patterns leads to improved charge distribution. However, square patterns are easier to lay out and are therefore more precise.

- Spacing should be selected to ensure effective hole utilization and adequate stemming. When selecting hole spacing, particular consideration should be given to the problems of charging of the front row holes adjacent to the free bench face (Figure 2A).

- Patterns should be designed with particular attention to the free bench face. Excessive front row burden is a common problem and can be overcome by reduction of pattern spacing. Locally, problems of excessive front row burden can be overcome by the drilling of fill-in or "easer" holes (Figure 2A). It is the opinion of the author that many problems encountered, particularly within or behind a blast, are a function of inadequate attention to front row control.

- Hole depths should be controlled to yield optimum design sub-grade. Hole depths, as drilled, should be measured and, if overdrilled, should be backfilled to optimum depth. In certain situations, subdrilling can be avoided altogether.

Explosive Types

- Selection of explosive type is generally made on the basis of availability, cost, personal preference, and what products have traditionally been used at the particular operation. Although the methods of comparison of the energy output of explosives is a contentious issue, cost comparisons of different explosives should always be made on an energy equivalent basis. Explosives having higher weight strengths may appear excessively expensive until they are compared on an energy-equivalent basis with cheaper but weaker products.

- High-strength explosives such as those containing aluminum, TNT or other promising nitrated fuels such as nitromethane are useful as a bottom load in operations where drilling costs are high and in situation where locally tough ground conditions are met. High-strength explosives are also valuable where the drillhole spacing or burden are too large, such as a heavily burdened front row hole, a short hole, or where an error in the blasthole pattern has been made.

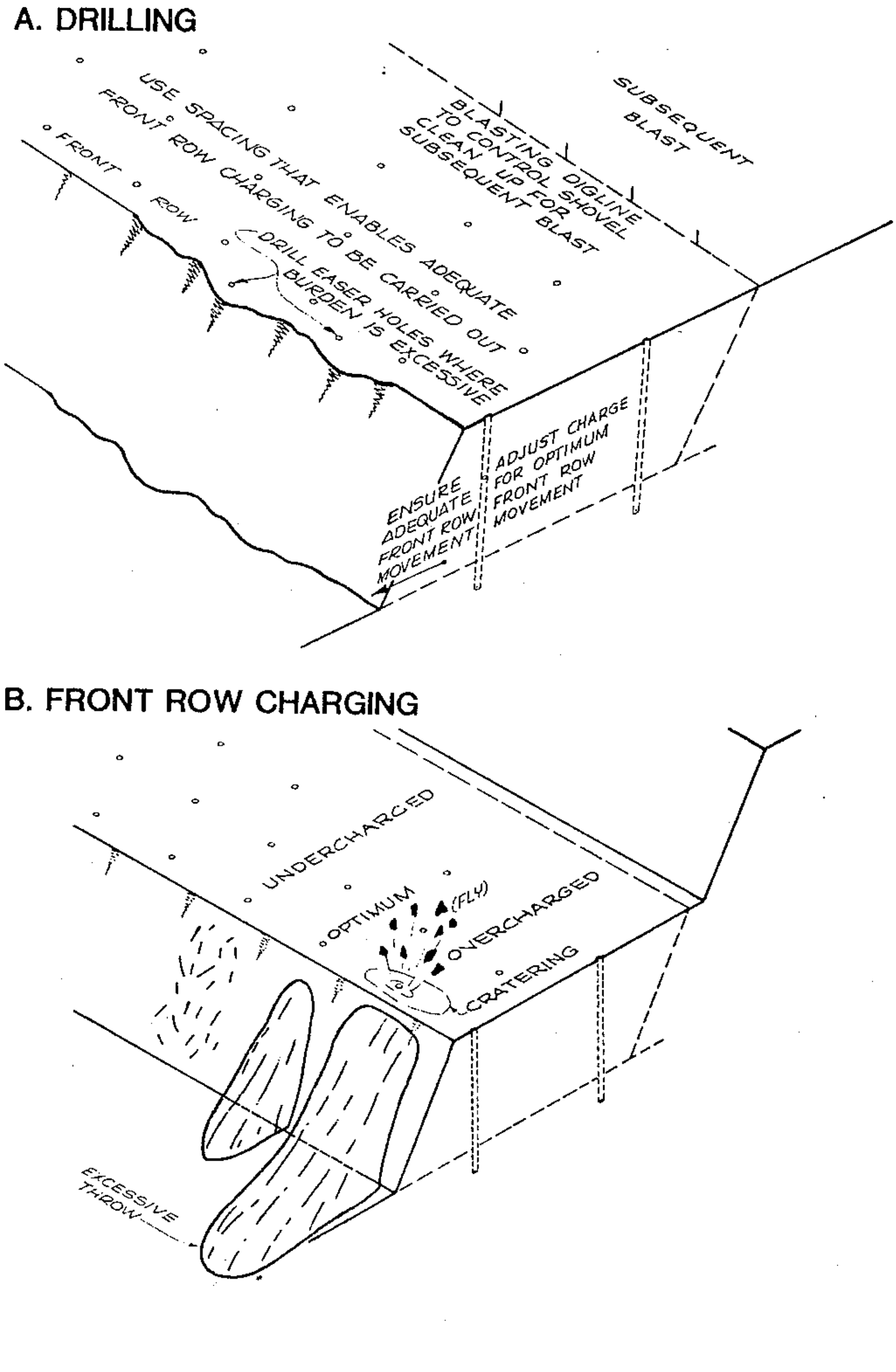


Fig. 2. Front row control.

- Low-strength explosives are particularly useful where improved charge distribution is required. Therefore, use of low strength explosives should always be considered adjacent to a pit wall where good charge distribution is so critical.

- From experience in slope engineering, the author has found that very few open pits are "dry," especially in proximity to the pit walls. Care should always be taken when using explosives such as ANFO that are susceptible to moisture attack. Such explosives should be fired as soon as possible after loading. Holes in low-permeability ground that appear dry during drilling may become wet with time. Holes should always be checked for standing water prior to loading. Explosives susceptible to moisture attack should always be used with caution, since a reduction of ANFO efficiency by only 20 percent is often all that is needed before it may prove more economical to use a more expensive, water-resistant explosive.

- The advent of continuous, coiled, cap-sensitive explosives such as Iremite has simplified the job of charging large-diameter wall control holes. Where such explosives are unavailable, stick explosives can be "strung" together with detonating cord using continuous "socks" of plastic netting. Such a product, used for vegetable packaging is marketed under the name "Vexar" craft netting.

- Use of explosives that produce predictable results is essential to the engineering of any blast and particularly blasts adjacent to pit walls.

Charging Policy

The reader may ask why production blasting patterns and hole-charging policy should be mentioned in a paper on pit wall control. First, it is the author's belief that good wall control blasting requires careful design, planning and placement of explosive charges. Second, there is a natural tendency to try to solve blasting problems by using more explosive to be on the "safe side." Obviously, quite apart from being wasteful, for a given blasting system, more explosive produces more pit wall damage.

Properly designed charge weights are fundamental to the success of a blast. A method of design of charges using powder factor, preferred by the author, is described in the following section and by Hoek and Bray, 1977.

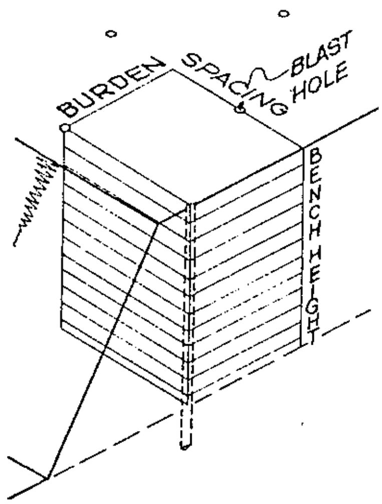
The Use of Powder Factor as a Simple Design Tool

Many operations treat powder factor (specific charge or energy factor) as an accounting tool, either for cost prediction or for reporting purposes. Fewer operations use powder factor to design patterns and charges, and those that do not, often manage well without. However, for efficient use of explosive and to produce consistent results, the author has found the technique useful for producing a controlled product.

In the main text of this paper, the importance of control over the production blast has been stressed. Efficient use of explosives to produce a consistently good product is the key, not only for good economical fragmentation but also for control of wall damage.

Selection of Design Powder Factor

The term "design powder factor" as used in this paper is the charge weight of a particular explosive divided by the burden volume (i.e., burden X spacing X bench height) (Figure 3).



Burden Volume=Burden X Spacing X Bench Height
Charge Weight=Burden Volume X Powder Factor

Fig. 3. Burden volume and the design of production charge.

Powder factors should always be adjusted to account for the differences in weight strength of the explosives used. Unfortunately, reliable relationships between powder or energy factor, rock type, and style of blasting do not appear to exist and must always be evaluated at the blast site. Trial, evaluation, and recording of the results are the most valuable tools for blasting control.

From the author's work in rock slope design and blasting engineering, an intersting empirical relationship has been developed (Figure 4). The relationship was derived by the recording and optimization of several hundred blasts in a porphyry copper pit that exhibited a wide range of natural fracturing. The relationship has since been evaluated in a wide range of geological conditions with fair success. This relationship indicates that "natural" fragmentation or block size of the rock mass and the surface characteristics of the blocks may significantly influence the amount of explosive effort required in blasting. The relationship is included in this appendix to stimulate thought and criticism but is not intended to be used without site specific evaluation.

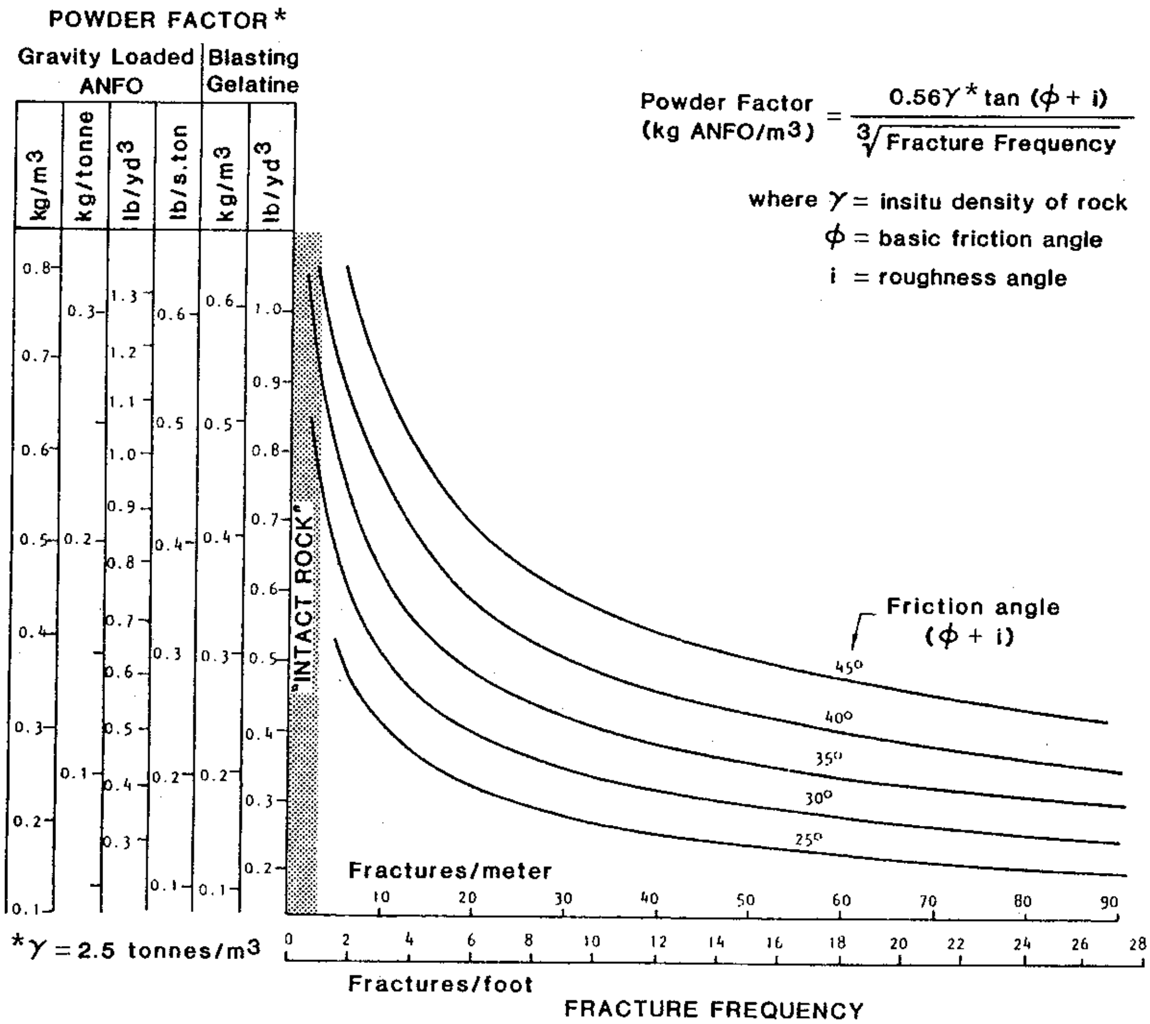


Fig. 4. Empirical relationship between powder factor, fracture frequency and joint shear strength developed at Bougainville Copper Mine.

Determination of Charge Weights

The first step is to select an appropriate powder factor for the rock conditions encountered in drilling the pattern. In an operating mine, this can be done by referring to the records of practice in similar ground, often from the bench level above. The blasthole pattern and the bench height are measured and the charge weight for each hole is calculated or determined by using tables. The process assures consistent charging, especially where pattern irregularities or variation in rock type occurs.

Error in selection of an appropriate front row charge weight may result in a "choked" blast or excessive throw. Some experienced blasters can successfully "eyeball" front row burdens and estimate charge weights. However, measurement at the crest, calculation of front row burden volumes, and the use of the powder factor, usually provide much more consistent results (Figure 5).

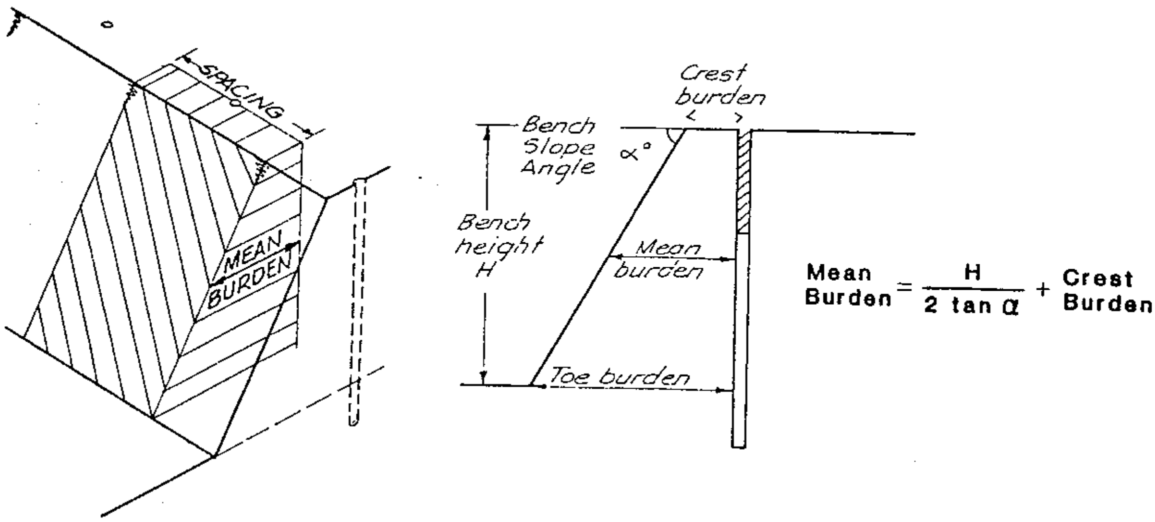
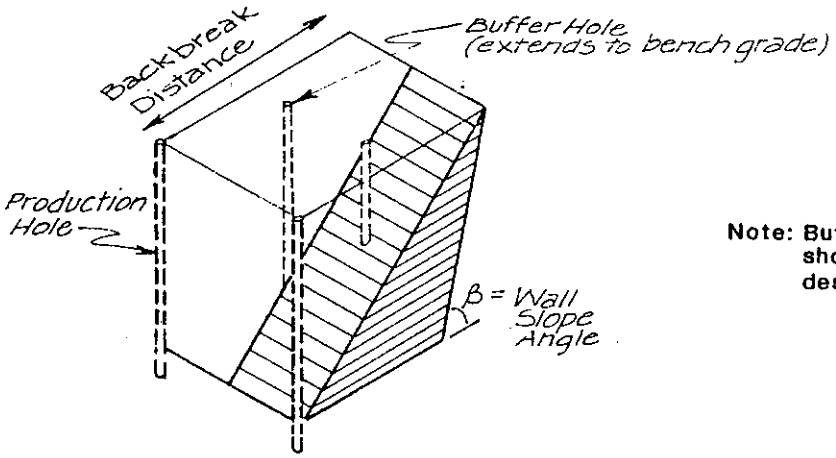


Fig. 5. Design of front row charges.

A method of estimating buffer charge weight is illustrated in Figure 6. The method requires the calculation of the volume of the wedge of relatively unbroken ground that occurs beneath the backbreak zone and in front of the pit slope.



Note: Buffer powder factors should be less than design powder factors

$$\text{Average "Buffer Burden"} \approx \frac{\left(\text{Backbreak Distance} - H \cot \beta\right)}{2}$$

Fig. 6. Design of buffer charges.

Front Row Control

The front row is perhaps the most cirtical portion of the blast (Figure 2). When the front row burden moves out adquately, there is an excellent chance that the remainder of the shot will succeed. Good forward movement of the blast is only possible with an adequately charged front row and a good free face to move to.

Provided that front row holes are not excessively over- or under-burdened, adequate front row charging can be achieved (Figure 6B). Measurement and calculation is the most reliable method of determining front row charge weights. One such method is described in the previous section.

- Because the result is wastage of explosives and eventual wall damage, "choked" situations (i.e., blasting into broken or unbroken muck piles) should be avoided whenever possible.

- Shovel cleanup of a good free face should be encouraged over as great a length of the blast as possible. Blasting diglines placed by visual evlauation of the shot are excellent for controlling shovel development of the subsequent free faces and for preventing over-excavation of subsequent blasthole patterns (Figure 2A).

Delaying Practice

Proper initiation and delaying of a blast is of critical importance in ensuring optimum movement of the muck pile, good fragmentation, optimum explosive utilization, comfort of the neighbor, and maintained integrity of the pit slopes.

- Correct use of delays of a suitable length ensures adequate movement of burden. By this means, the tendency for "choking" of that portion of the shot adjacent to the pit walls can be minimized. One of the most promising developments in this area is the development of practical sequential blasting techniques (illustrated in Figure 7). The technique was perfected with the development of the sequential electric system which has in turn been followed by non-electric methods (Tansey, 1979). The advantages of the method are that only a limited range of down-the-hole delays are needed. Shorter delays are potentially more accurate than the longer delays that must be used when blasting with conventional delaying methods (Winzer et al., 1979). In many sequential blasting situations, the risk of trunkline cutoff tends to be reduced, and hence longer delays can be used than would be possible with conventional delaying.

- Careful delaying can also be used to avoid certain choked situations by breaking ground from awkward patterns toward free bench faces.

- The common use of delays to divide the blast energy into smaller "packets" in order to reduce ground vibration and noise is also of particular importance in controlling damage to pit walls. The empirical relationships between maximum "instantaneous" charge weight per delay interval, distance, and the resulting peak particle velocity are well known. However, what happens to the pit wall in close proximity to a blast? A crude estimate can be made using the method shown in Figure 8. A rather better estimate can be made by use of BLAST, a computer program developed by Golder Associates. The program utilizes an empirical relationship developed by Korman et al., 1971 and can be used to predict peak particle velocity at any point on a planar grid or to print out a simulated seismogram at a specified location. The program was used to estimate peak particle velocities within a pit wall for an actual blast (Figure 9A). For comparison and to illustrate use of an improved delaying technique. Figure 9B was derived by modification of firing sequence and it illustrates the reduction of particle velocities behind the blast.

Although the prediction of vibration and damage to rock masses is in its infancy, it is obvously prudent to be considerate to the pit wall as well as the neighbor by careful use of delayed blasting.

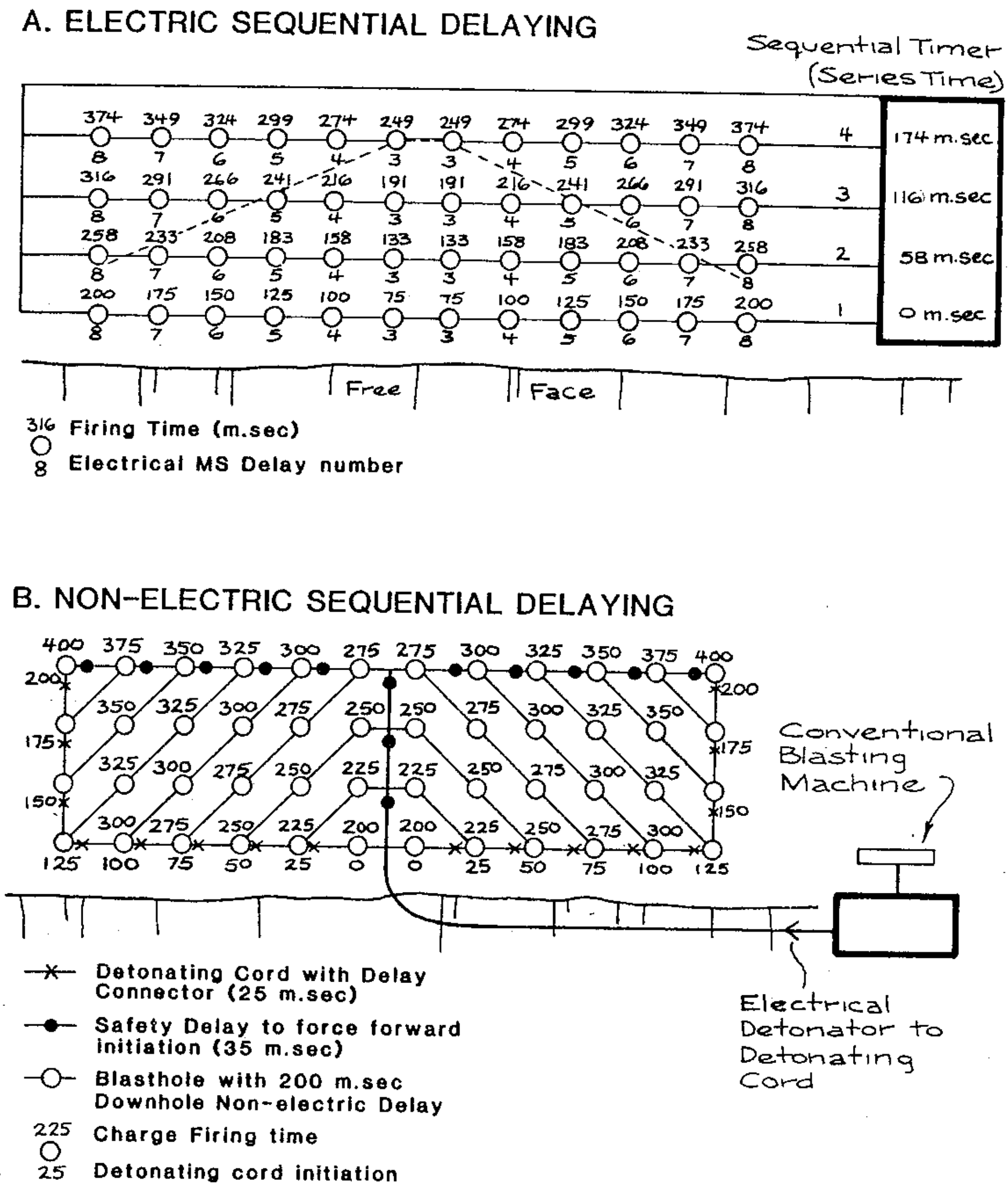


Fig. 7. Sequential delaying.

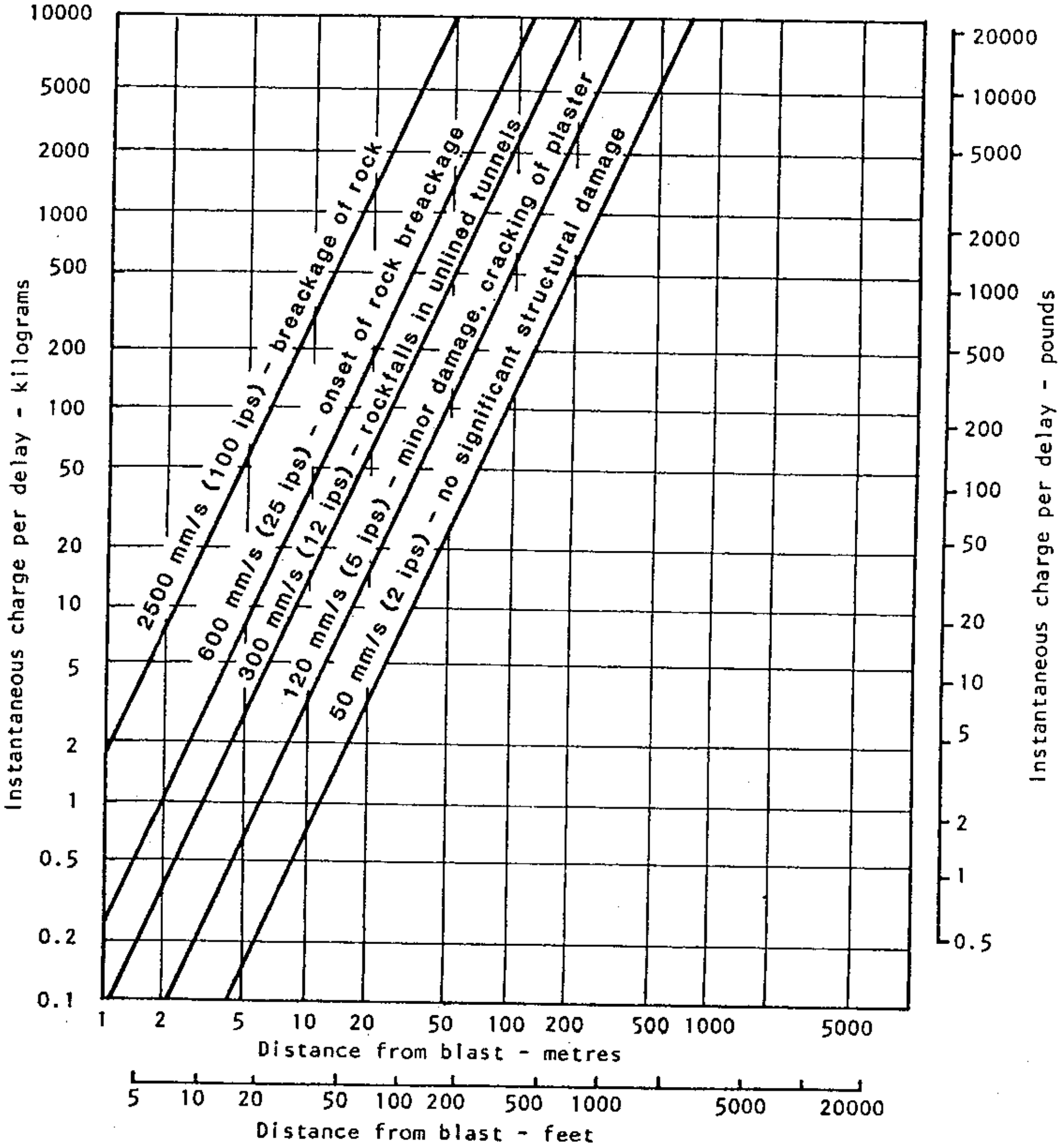


Fig. 8. Relationship between maximum charge weight per delay, distance and peak particle velocity. (After Langefors and Kihlstrom, 1973).

Production Blasting and Excavation Adjacent to Pit Walls

Close interaction between drilling, blasting, and excavation exists in any hard rock mining situation. When approaching pit walls, the need for careful blast engineering must be emphasized. Some of the common errors made when blasting adjacent to pit walls are illustrated in Figure 10A. More difficult digging can, and perhaps should, be tolerated adjacent to critical walls than would be accepted in the main production areas.

One common method of attaining steeper slopes is to develop multiple bench slopes by pushing back the benches to leave a large safety berm on every second or third bench. This method involves mining at normal bench height, but it does not leave the small, often inadequate safety berms typical of single benching methods. The multiple bench configuration must obviously be stable and especially during initial trial and excavation it should be monitored for any sign of slope failure. In addition, the bench faces should be developed and cleaned with special care if troublesome ravel is to be avoided. In certain extreme situations, scaling of slopes by means of a crane is used as an additional safety measure.

The following factors should be considered when blasting and excavating near interim or final pit walls:

- Careful shovel cleaning of pit walls is usually justified, especially when developing steep slopes or multiple benches.

- Considerable success has been reported from Bougainville Copper Mine where excavation or trimming to slope limits has been achieved by means of bulldozers working towards the shovels. In soft or fractured rock masses the method may achieve a smooth, sound bench face without overhangs, enable a reduction in powder factor and inefficient shovel clean up operations, and may in such circumstances eliminate the need for wall control blasting. Trial and economic evaluation would be necessary to determine the feasibility of dozer trimming at other operations.

- Backbreak or overbreak beyond the final wall limit is one of the major causes of wall damage and is obviously a wasteful activity. One of the simplest modifications that can lead to improvement in wall conditions is that involving adequate allowance for backbreak behind the final wall blasts. The backbreak distance behind a blast is a function of the blast and the rock mass conditions. Once an appropriate level of blasting control has been achieved, variation of backbreak will be a function of rock type and structure. Diggable backbreak should be reserved for each set of geological conditions. Diggable backbreak distance can be used as a design parameter in determining the distance that the back of the blasthole pattern should be offset from the final wall. In view of the importance of "back row" design adjacent to the pit walls, design of the blasthole pattern from the back to the front of the shot may be justified, provided that front row control can be maintained.

- In most production blasting and particularly when blasting adjacent to pit walls, multiple-row blasts should be avoided. Multiple-row or deep shots tend to "choke", fire irregularly and cause overbreak. Approximately three rows are optimum and the author feels that more than five rows should be avoided. Figure 11 illustrates how, subject to operating width constraints, a pit expansion can be mined-out in a series of relatively small steps involving drilling, blasting, and excavation back to ultimate pit limits. The sequence does require slightly more shovel mobilization than is necessary for "single" pass mining, but the results generally justify use of the method.

- Sub-drill should be minimized and in many cases can be completely eliminated when drilling holes adjacent to pit walls. When loading holes adjacent to pit walls, maintenance of optimum explosive rise and proper hole depths is at least as important as loading normal production patterns. To maintain adequate charge distribution and powder factor control, use of low-strength, low-density explosives is favored.

- Good charge distribution is also achieved by using smaller-diameter buffer charges than for the main production pattern. To maximize charge distribution and blasthole utilization, smaller-diameter holes are drilled on a closer spacing. At many operations, the drilling of one or more rows of buffer holes placed between the back of the main production pattern and the wall provides a significant improvement in wall condition. Buffer charges are fired in delayed sequence with the main production pattern and have the major advantage over traditional perimeter wall control because the rock is actually blasted rather than trimmed or split.

- A major problem facing many operations that are confronted with the need for wall control work is that of flexibility and capacity of the drilling system. Drilling using large, high productivity rigs such as the Bucyrus Erie 60R and Gardner-Denver 120 and hole sizes ranging from 250 mm (9-7/8 in) to 380 mm (15 in) is commonplace at many open pit mines. Drilling of smaller holes than are used for normal production is often inconvenient, time-consuming, and expensive and for scheduling reasons, almost impossible.

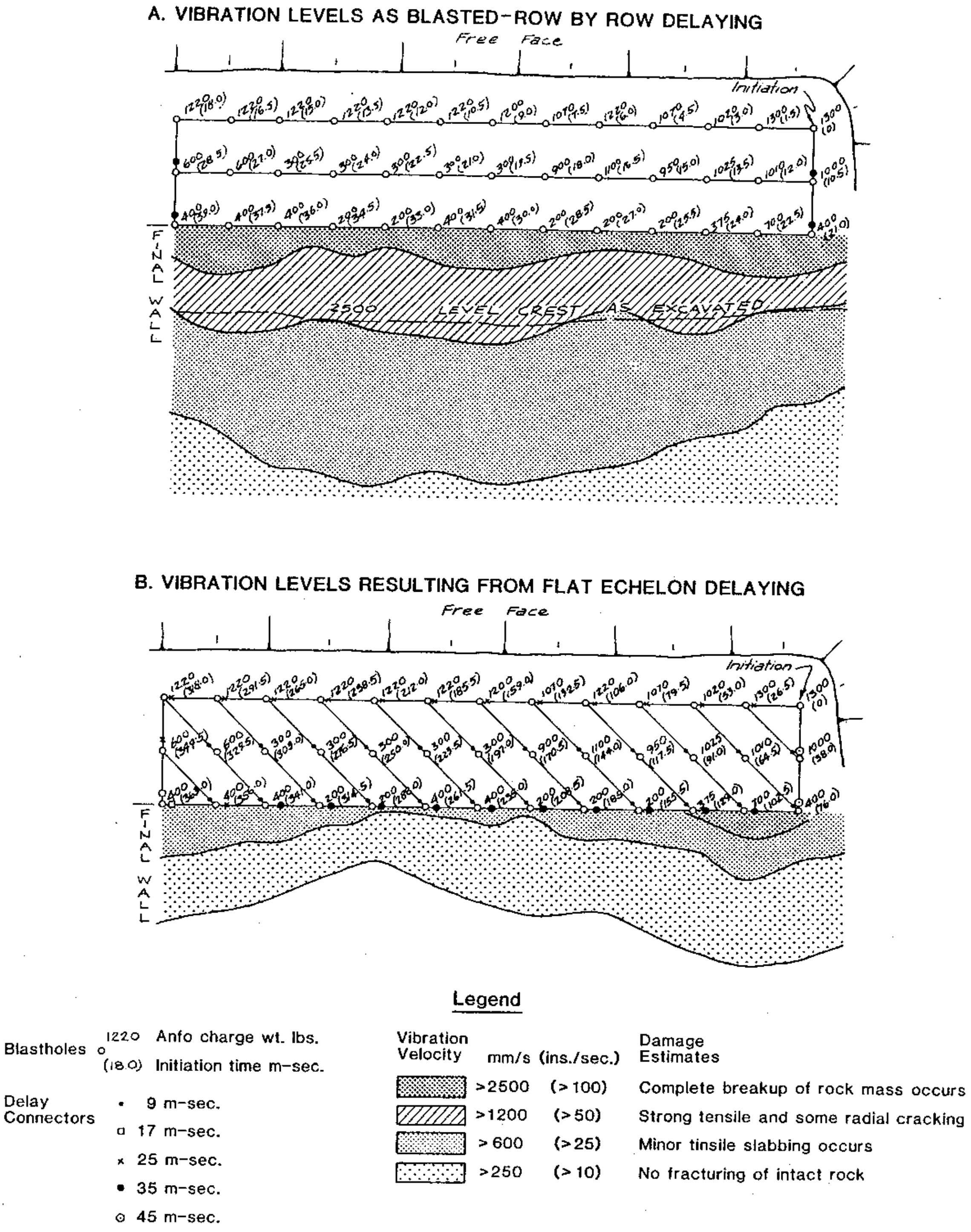


Fig. 9. Comparison of peak particle velocities generated behind a pit wall by different delaying techniques.

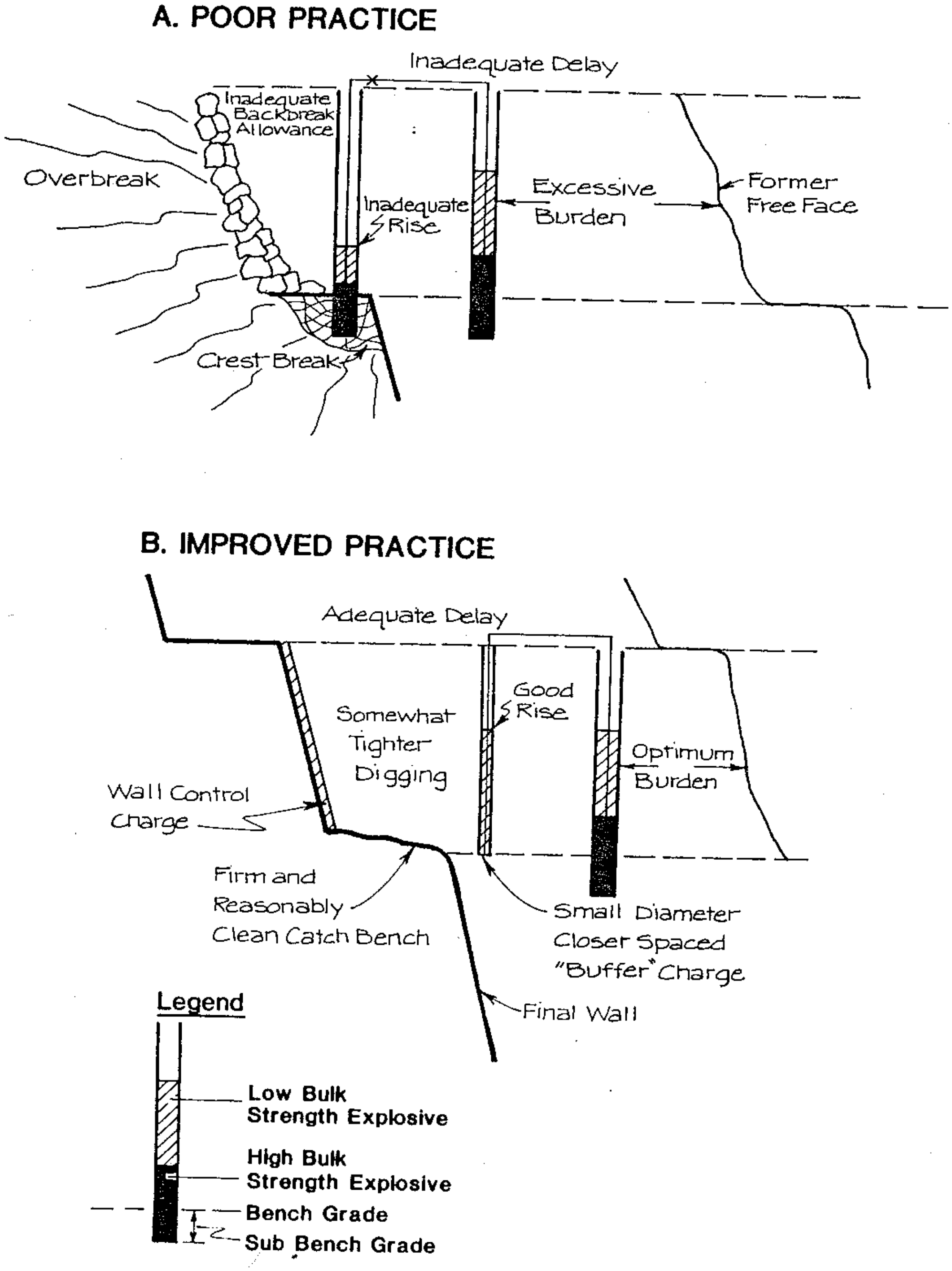


Fig. 10. Pit slope damage from production blasting and suggested remedies.

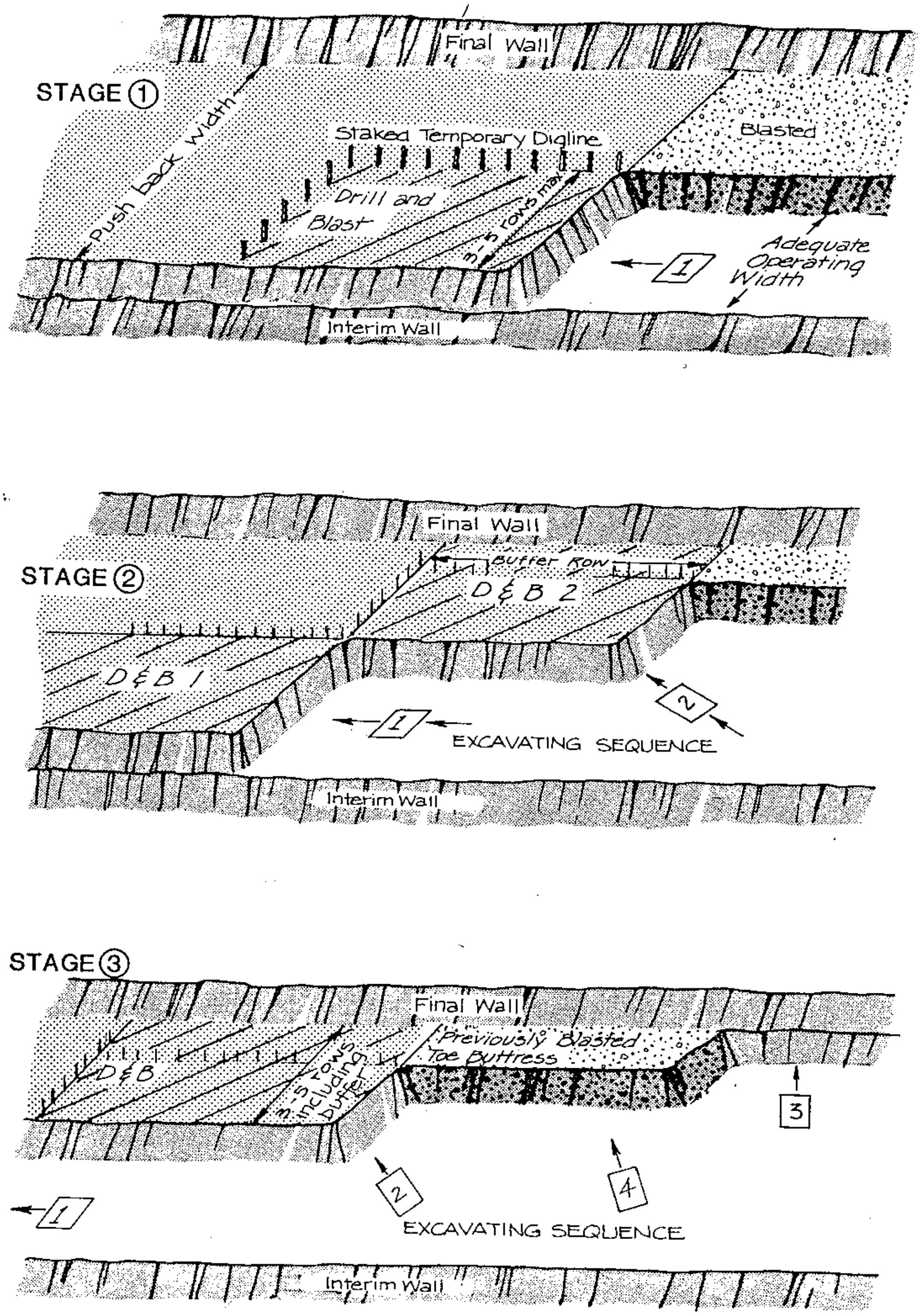


Fig. 11. Preferred drilling/blasting/excavating sequence during mining to final slope limits.

- Small decoupled buffer charges can be placed in the larger holes as a matter of expediency and for trial purposes. The advent of small-diameter, continuously coiled, cap-sensitive explosives such as Iremite has simplified loading of such holes. However, apart from cost and storage considerations, the process has a major drawback--it makes poor use of the blasthole volume!

- Once a functioning operation has demonstrated the benefits of wall control blasting, modification of existing equipment or purchase of new drill rigs should be considered. One promising technique that has been tried at a few operations and is available as an option from at least one major manufacturer. The technique involves minor modification of drill pipe racks and handling tools that enable the driller to easily switch from, say, 310 mm (12-1/4 in) to 250 mm (9-7/8 in) diameter holes adjacent to pit walls.

- New operations and those planning steep wall mining should give serious consideration to purchase of drilling equipment that is flexible enough to cope with the job of wall control as well as production blasting. The advantages of reduced stripping ratios or additional ore exposure can usually justify the expense.

- Slope failure is a time-dependent phenomenon and is frequently precipitated by removal of benches at the toe of a critical slope. Slope monitoring by survey and visual means will usually provide warning of impending failure, provided that the rate of failure is fairly gradual.

  To improve the safety of shovel operations beneath critical faces, progressive excavation back to final configuration is recommended. Stage 3 of an excavation sequence illustrated in Figure 11 includes the provision of a temporary toe buttress. The purpose of such a buttress is as follows:

  - To allow time and partial relief of the toe of a failure to occur so that the failure can be identified by monitoring and remedial action taken

  - To afford maximum protection to the equipment working on the bench

  - To provide maximum space for the excavation equipment to operate

  - To aid in equipment retrieval by assuring adequate operating space around a failure should it occur.

Wall Control Blasting (in the Strict Sense)

In the strict sense, the term "wall control blasting" or "perimeter blasting" is used to describe techniques such as presplitting which was developed for relatively small trial excavations. Ample references exist on the subject of perimeter blasting including those by Canmet 1977, Holmberg and Persson 1978, Kihlstrom 1972, and Langefors and Kihlstrom 1973.

The techniques of perimeter blasting have been applied to large-scale blasting in open pits, often with mixed success. The reasons for this limited success often lie in the scale and nature of the production blasting process (often the damage has been done before the perimeter blast has been fired). Once the open pit blaster is satisfied that the production and buffer blasting system is "engineered" and functioning well, smooth-wall or presplit trials may be evaluated using established methods of design. In many production situations, smooth-wall blasting, in which the perimeter charges are fired in delayed sequence towards free faces created by the main blast, appears to hold more promise than the presplit technique.

ACKNOWLEGEMENTS

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