CHAPTER 27

Initiation sequence and delay timing

7.1 INTRODUCTION

he group of controllable parameters least known by ıgineers and operators is the one that comprises the itiation sequences and the delay timings between the ıarges of a blast. The nominal drilling patterns with a ırden B and spacing S are radically modified with the itiation sequence, changing to other values B_e and S_e ılled *effective* values.

The parameters indicated do not only have influence ɔon the fragmentation, but also upon other basic aspects ıch as displacement and swelling of the rock, overbreak ıd intensity of vibrations. Therefore, the small extra cost ̄ using more complex initiation sequences is well worth ıe expense, as the global economy of the whole opera-ɔn benefits.

A large part of the theories exposed here are offered by ıe specialists T.N. Hagan and A.B. Andrews, who have ɜdicated their efforts over several years to study and ɔtimize blastings.

7.2 SINGLE-ROW DELAYED BLAST

or constant conditions of bench height, powder factor, ʼpe of rock and blasthole diameter, and if the charges are red instantaneously, there is a relationship S/B in which ıe displacement and the fragmentation are optimum. he ratio S/B in homogeneous materials oscilates be-veen 2 and 4 (Langefors, 1966) but, due to the fact that ıe excavated volume per blasthole starts to decrease ʼhen $S > 3B$, the optimum values of S/B are near 2.4.

If the spacing is under 2.4 B, as the charges act in nison, the radial cracks between blastholes intersect ɜfore any others reach the free face, creating a splitting ı the plane of the blastholes, through which the gases ʂcape prematurely to the atmosphere. This then pro-uces a simultaneous pushing of the rock mass in front of ıe charges, with a pronounced horizontal shearing, ɜgatively affecting fragmentation not only because the ropagation of the cracks is interrupted due to gas infiltra-on, but because there is almost no in flight collisions of ıe projected rock and the breakage caused by shearing ccurs only along pit floor level and in the lateral planes .B and CD, Fig. 27.1.

When very fine fragmentation is not necessary or when ıe rock is intensly fractured and its displacement is nough to provoke the desired fragmentation, the blast can be fired instantaneously with a ratio S/B = 0.8 to 2.4, and with a burden dimension of 25 to 30% more than in sequenced blastings (Ash, 1969).

In pronounced bedding or joints parallel to the free face the ratio S/B can be above 2.4; on the other hand, if the orientation is normal to the face, the S/B value should be under 2.4. In homogeneous rock, if the relation S/B is larger than 2.4, the face will be very irregular as the cooperation between charges will not exist.

When the single-row blastholes are fired at intervals, the fragmentation increases considerably with respect to the instantaneous blasts, because the radial cracks that develop around each explosive column are almost totally formed before the next charge is detonated. In these situations, the charges create aditional free faces which means that each blasthole shoots to two faces, JK and KL, Fig. 27.2.

Fragmentation is better than in instantaneous blastings, because the heave energy is used in vertically shearing the burden and extending the cracks and the strain wave has a larger field of action.

When the interval of delay between adjacent blastholes is long, so that each charge can fragment and displace its corresponding share of the burden, the optimum spacing S_o is equal to 2.79 B_o, Fig. 27.3.

The value of the spacing is ample enough so that the cracks in the blastholes 0 and 1 develop totally without intersecting. When S diminishes to under 2.79 B_o, the effective burden B_e is somewhat less than optimum B_o and the fragmentation is poor, elevating the excavation costs, Fig. 27.4

If S = 2.79 B is maintained, and B exceeds B_o, Fig. 27.5, the crater angle is considerably less than 138° and the blasthole with delay nunber 1 will break towards face BD which is nearer than DC, resulting in a deficient fragmentation in the central region X. For this reason, the spacing should be less than 2.79 B. If, on the other hand, B is made less than B_o and S = 2.79 B, the hole 1 will break equally towards the faces DC and BD and the crater angle will remain at 138°, the fragmentation will be finer than required and, as the pattern is more closed, the drilling and blasting costs will be higher.

When B is considerably less than B_o, and S increases to above 2.79 B, in an effort to compensate the relatively small burden, the spacing becomes so great that the rock between the holes is not adequately displaced or frag-mented.

Even so, in practice the most common values of S

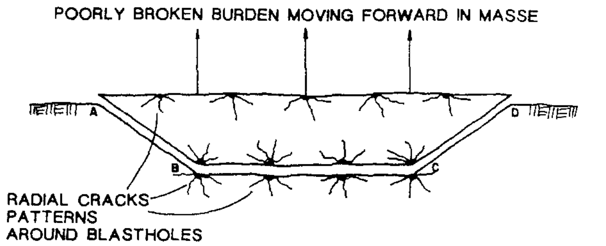


Fig. 27.1. Rock displacement in a single-row instantaneous blast.

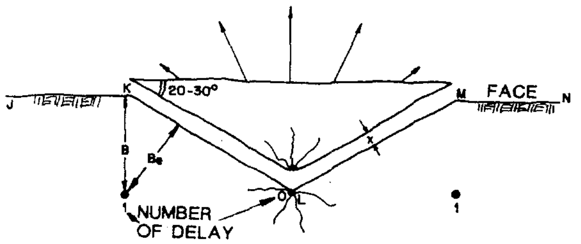


Fig. 27.2. Effective burden B_e in a sequenced single-row blast (Hagan, 1975).

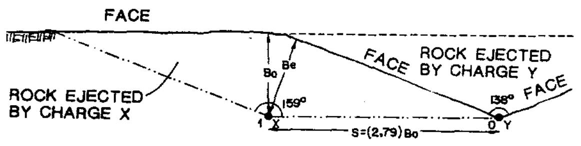


Fig. 27.3. Short delay blast with optimum burden and spacing (Hagan, 1975).

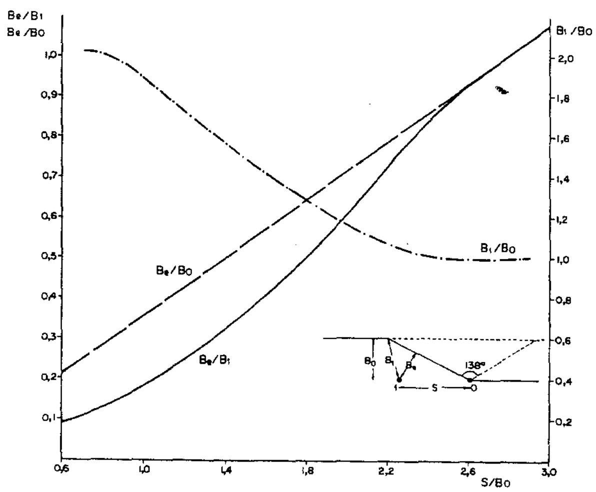


Fig. 27.4. Variations in the relationship of the burden with the spacing between blastholes.

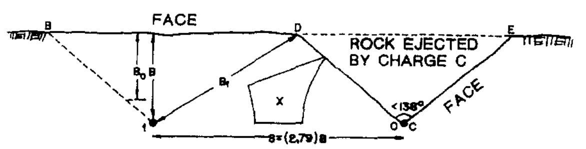


Fig. 27.5. Short delay blast with both burden and spacing more than optimum (Hagan, 1975).

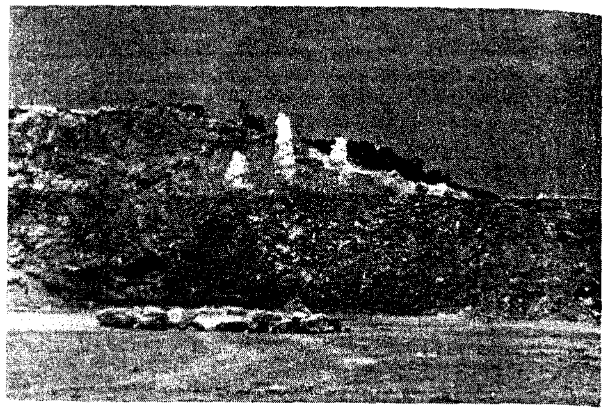


Photo 27.1. Sequenced row blast in a 20 m high bench.

oscillate between 1.1 and 1.4 B, with a mean value of 1.25 B. It seems, then, logical to think that the burden dimensions that are used are larger than the theoretically optimum.

27.3 MULTI-ROW SEQUENCED BENCH BLASTINGS

Except in those rock formations where single-row blasts produce a large overbreak with positive effects on the breakage costs, multi-row rounds are recommended as they give better fragmentation.

27.3.1 *Blasts with a free face*

The criteria to be followed in this type of blasts are:

– Each charge should have a free face at the moment of detonation.

– The relation S_e/B_e should be between 3 and 8, and preferably between 4 and 7.

– The blastholes should be on a staggered pattern with a high degree of equilibrium $v/w \approx 1$.

– The rows with the same delay should form an angle θ of between 90 and 160°, and preferably between 120 and 140°.

– The angles β and γ, which form the principal direction of rock movement and the side(s) and rear excavation boundaries, should be as large as possible to minimize disruption of the new faces.

In Fig. 27.6, the different initiation sequences available for multiple blasts with square or staggered patterns are indicated.

In this group of sequences the following can be observed:

– In the square patterns in line (a) in V (b) and staggered in V (d), some blastholes have very limited free faces. In the last one cited the charges C, D, G, and H have only the vertex of the V of the cut as the closest free face.

– The sequences in the square $V2$ (g) and the staggered $V2$ (h) show a high grade of unbalance and a S_e/B_e value that is too large.

– The square $V1$ (e) pattern and above all the stag-

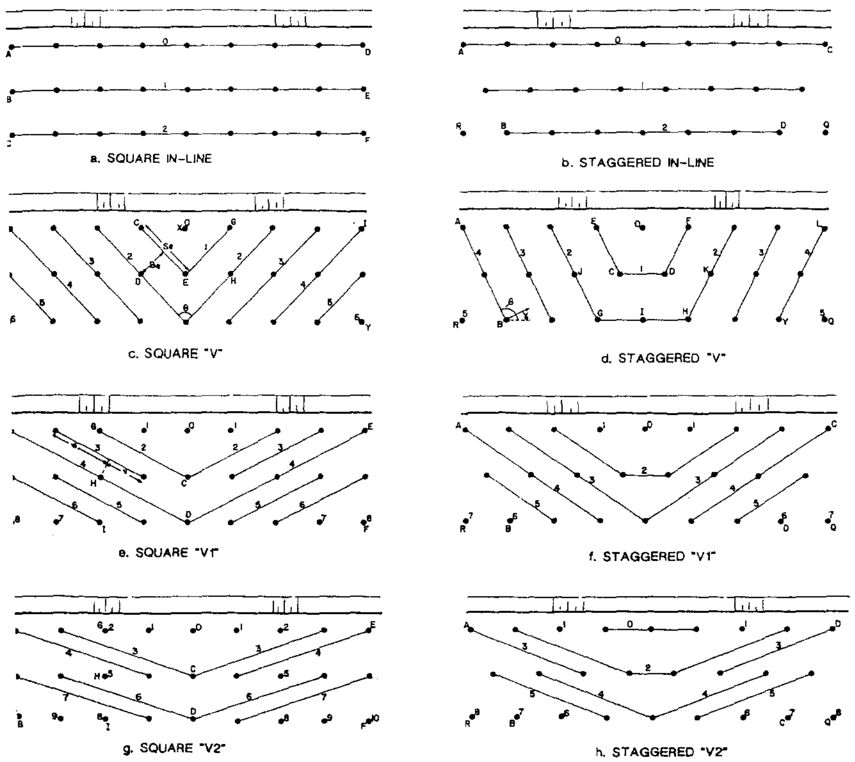
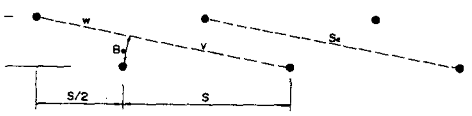
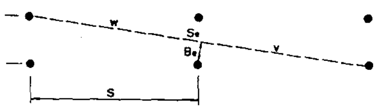


Fig. 27.6. Blasthole/initiation pattern with $B = S$ for shots fired to an open face (Hagan, 1975).



$S_\bullet = \sqrt{B^2 + 2{,}25 \cdot S^2}$ $\qquad S_\bullet / B_\bullet = (B^2 + 2{,}25 \cdot S^2)/B \cdot S$

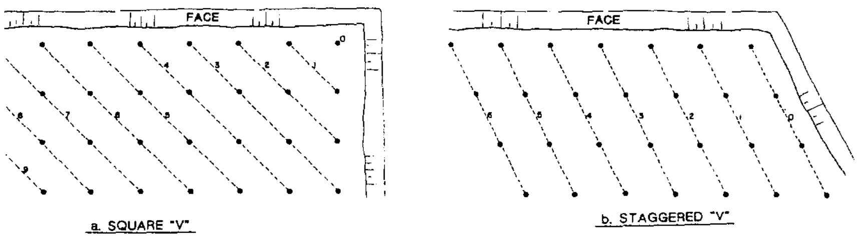
$B_\bullet = B \cdot S / S_\bullet$ $\qquad v/w = 1{,}5 \cdot S^2/(B^2 + 0{,}75 \cdot S^2)$



$S_\bullet = \sqrt{B^2 + 4 \cdot S^2}$ $\qquad S_\bullet / B_\bullet = (B^2 + 4 \cdot S^2)/B \cdot S$

$B_\bullet = B \cdot S / S_\bullet$ $\qquad v/w = 2 \cdot S^2/(B^2 + 2 \cdot S^2)$

Fig. 27.7. Calculation of the geometric relationships in rectangular *V*1 and staggered *V*1 patterns.



g. 27.8. Blasting with two free faces.

gered $V1$ have S_e/B_e and v/w values that are acceptable.

– The staggered sequence in line (b) gives the largest displacement of blasted rock.

The blasts with spacings that are larger than the burden $S > B$ are usually more favorable as the following has been observed:

– The rectangular pattern $V1$ improves by increasing S/B from 1 to 1.8, where S_e/B_e and v/w are optimum for S/B = 1.3 to 1.7 B with a mean value of 1.5 B.

– In the staggered sequence $V1$, the yield increases if the S/B value is maintained between 1.1 and 1.3.

– In the rectangular and staggered patterns V and $V2$ the results cannot be improved by increasing or decreasing of S/B value with respect to 1.

– The square and staggered sequences in $V1$ leaves excavation perimeters that are quite stable, Fig. 27.7.

The general rules for increasing rock displacement in all the indicated patterns are:

– Decrease S_e

– Increase the angle θ, and

– Increase the number of blastholes with an adequate effective face.

Finally, to acheive faces in acceptable condition for each blast the following should be carried out:

– Increase the angles β and γ.

– Increase the surfaces of the effective faces in the perimetral blastholes.

– Lower the values of B_e in the contour holes.

27.3.2 *Blasting with two faces*

Blasting with two free faces, Fig. 27.8, is the most frequent geometric configuration in mining.

The planes of the slopes form angles between themselves that oscilate between 90 and 150°.

Generally, all the charges have an adequate free face and for this reason the displacement is greater.

To the contrary of blasts with one free face, the blastholes can be drilled in the positions that give optimum values to S_e/B_e and v/w. This is acheived with a certain lateral displacement of the rows of holes, Fig. 27.9.

The curves corresponding to the values S_e/B_e = 4, 6 and 8 are shown in Fig. 27.10, from which the S/B relations can be determined for the patterns that have an acceptable degree of balance v/w = 0.85 to 1.15.

Photo 27.2. Bench blastings with initiation sequence in $V1$.

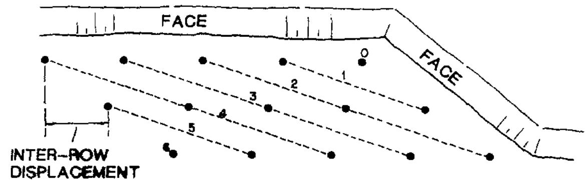


Fig. 27.9. Skewed rectangular V pattern fired to a free end to give a perfectly balanced effective stagger (Hagan, 1975).

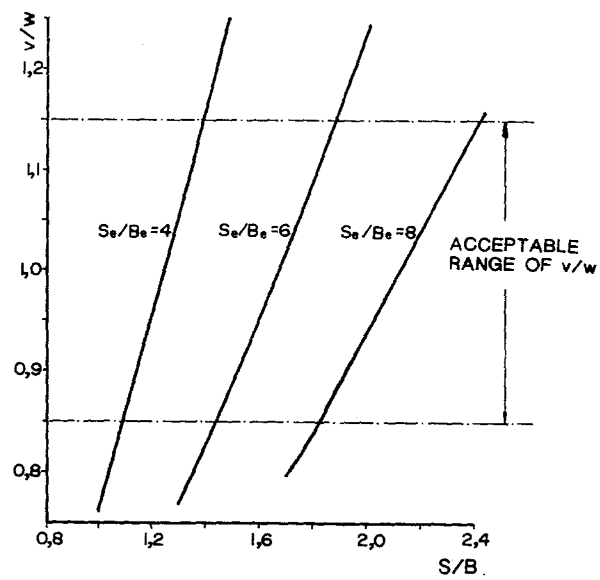


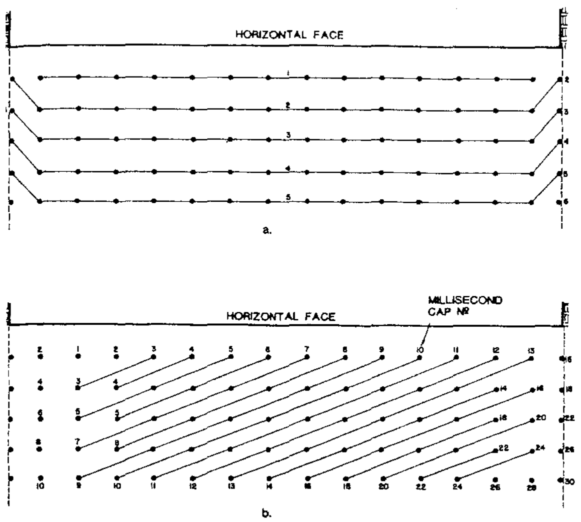
Fig. 27.10. Skewed rectangular V patterns which, when fired to a free end, have S_e/B_e values of 4, 6 and 8 (Hagan, 1975).

27.4 BENCH BLASTING SEQUENCES FOR UNDERGROUND STOPES

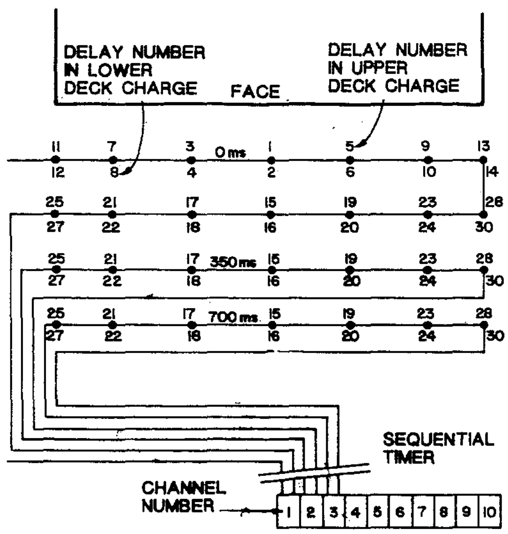
In horizontal benching for underground stopes, when there is a sufficient number of millisecond delay detonators or a sequential blasting machine, the initiation of the blasts should commence near the end of the upper row, although not exactly at the end, Fig. 27.11. By doing this, the following will result:

1. An increase of the total blast time and the delay timing with respect to the burden.
2. Fewer operating charges, as the number is lowered from 16 simultaneous detonations to 7.
3. Reduction in overbreak from the perimiter blastholes as a consequence of double the delay timing between charges adjactent to these, and
4. Improved fragmentation.

When, due to imperatives of economy, the lower vertical benches are drilled with diameters between 76 and 89 mm, and a reduction of overbreak and vibration level is desired, the charges can be decked and secuential blasting machines used to initiate the blasts, Fig. 27.12.



ig. 27.11. Horizontal bench blast that produces (a) considerable and b) little overbreak (Hagan, 1982).



ig. 27.12. Use of individually-delayed deck charges in large diameter ownholes (Hagan, 1982).

hoto 27.3. Multirow sequenced bench blasting (Courtesy of IRECO anada Inc.).

27.5 DELAY TIMINGS

The optimum blasting has the following objectives:

- Adequate rock fragmentation, swelling and displacement.
- Control over the flyrock and overbreak.
- Minimum level of vibrations and airblast.

The delay timings play a fundamental role in the fulfillment of these objectives. The influence of this parameter on the first two groups indicated will be studied here, as the topic of vibrations and airblast has a chapter of its own, and the opportune design criteria will be established.

27.5.1 *Influence of the delay timing in fragmentation and displacement*

The delay timings, according to Lang and Favreau, should permit the succession of the following events:

- Propagation of the compression and tensile waves from the blasthole to the free face (approx. 0.58 ms/m).
- Readjustment of the initial field of tensions, due to the presence of radial cracks and the effect of the reflection of the shock wave on the free face. The readjustment time can be estimated between 10 to 20 ms after the initiation, depending on the type of rock and explosive.
- Acceleration of the fragmented rock by action of the gases, up to a velocity that assures an adequate horizontal displacement. The larger the delay timing, the better the movement, estimated between 30 and 50 ms after initiation.

As to the delay timing in between blastholes, it has been proven that the interaction of the first shock waves does not contribute in a significant way to the rock fragmentation. Therefore, in a bench blast with a row of sequenced blastholes, the fragmentation depends basically upon the total development of the cracks generated around each blasthole before the next one detonates.

Bergmann, after a series of experimental trials, recommends an interval of 3 to 6 ms per meter of burden. These values coincide with those indicated by Langefors, which were based upon cualitative observations in field blastings, Fig. 27.13. Andrews extablishes a low limit of 3 ms/m of burden and a high of 16.6 ms/m, the latter being adequate for massive or slightly fractured rocks, and finishes by stating that a delay of 10 ms/m gives good results in most rock.

Bauer, after observations with high speed cameras, determined that the minimum delay in blasts with holes of 38 to 311 mm diameter is of 3.2 to 4 ms/m of burden, which is the mean time needed to start movement of the face rock. Therefore, he recommends a delay timing of 5 to 7 ms/m, Fig. 27.14.

The same author analyzes which is the maximum delay timing admissable to avoid cut-offs in the initiation system as a consequence of the ground movement induced by the detonation of a blasthole charge over others, when a surface delay system is used. Fig. 27.15 shows the time that has passed before the onset of movement in

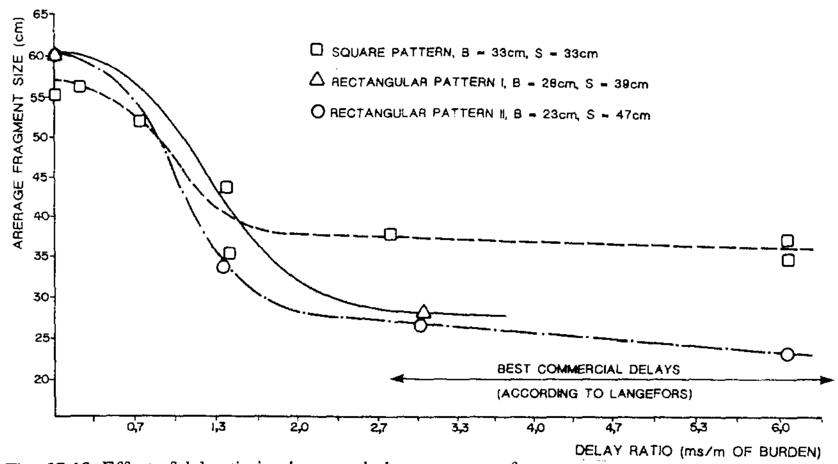


Fig. 27.13. Effect of delay timing between holes upon mean fragmentation, for the same powder factor (Bergmann, 1975)

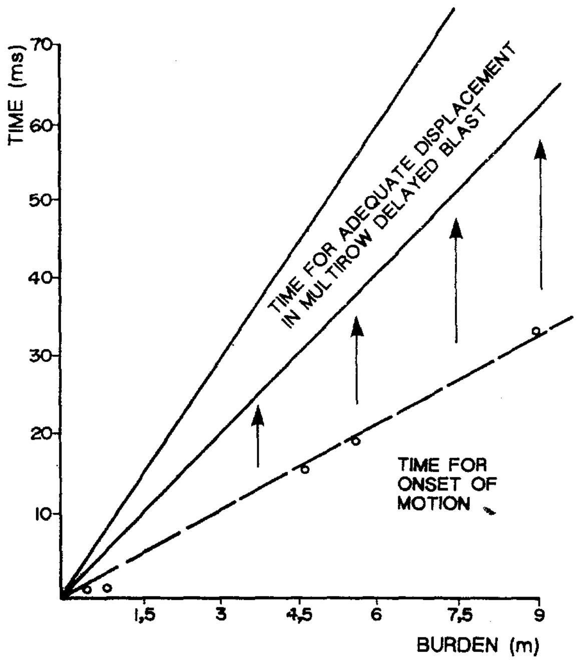


Fig. 27.14. Time for the onset of face movement and the time for adequate displacement for burdens of different size and adequately charged blasts in hard rock (Mining Resource Engineering Ltd.).

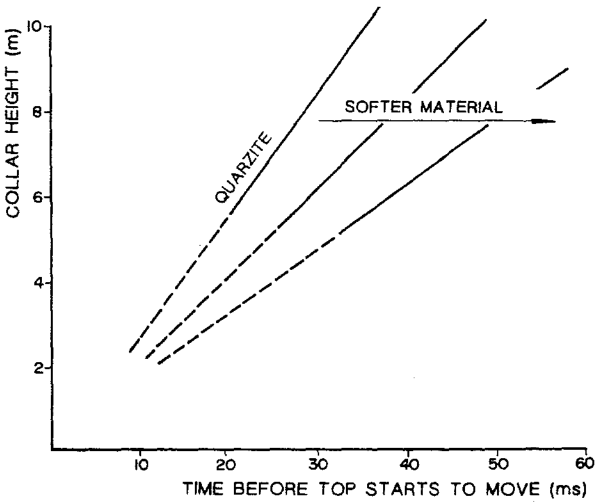


Fig. 27.15. Delay time prior to bench top motion for holes of 229-381 mm diameter.

function with the stemming height and the type of rock, with blastholes of 229 to 381 mm in diameter.

If the delay timing to achieve detachment of the burden is less than the time it takes to produce bench top movement, the initiation system can be on the surface.

However, in those cases where the stemming height, to achieve a good rock fragmentation, is smaller, and the times are inverted, a down-the-hole delay system should be used, or a mixed system, to avoid the possibility of misfires.

Winzer, in this field, also points out that the delays between charges should be over 3.3 ms/m, even reaching 12 ms/m.

On the other hand, Konya and Walter (1990) propose the values of Table 27.1 to calculate the delay times between blastholes, knowing the spacing between them and for different rock types.

Table 27.1.

Rock type	Delay times (ms/m of spacing)
Sandstones, marls, coals	6-7
Shales, salts and some limestones	5-6
Compact limestones and marbles, granites and basalts, quartzites, gneisses and gabbroe	4-5
Diabases, porphyrites, gneisses and micaschists, magnetites	3-4

Finally, Fadeev et al. suggest the following equation to calculate the delay time between blastholes:

$$TRB = 2\left(\frac{\rho_r}{CE}\right)^{1/2}$$

where: TRB = Delay time between blastholes (ms/m of

›urden), ρ_r = Rock density (t/m^3), *CE* = Powder factor kg/m^3).

This way, the first basic guideline for the Delay Time ›etween Blastholes *TRB* can be established:

TRB = 4-8 ms/m of burden

[o justify the delay between rows, it is interesting to :onsult the analysis that Andrews carried out on the two ›lasting patterns of Fig. 27.16.

In design a) the delay time between rows is equal to hat existing between blastholes in the same row. The ›last continues, having an effective face with a direction hat forms 45° in relation to the original.

The blastholes in a same row detonate simultaneously esulting in high lateral confinement and poor fragmenta-ion, even though S_e/B_e is equal to 2.

In the blasting b) the delay between rows is double the ›ne that exists between the holes in a single row and the ace forms an angle of 26.56° with respect to the ori-;inal.

The fragmentation produced is good and with a lower 'ibration level. The relationship S_e/B_e is equal to 5, which neans that the effective face will have a jagged :onfiguration and each charge will have two free faces.

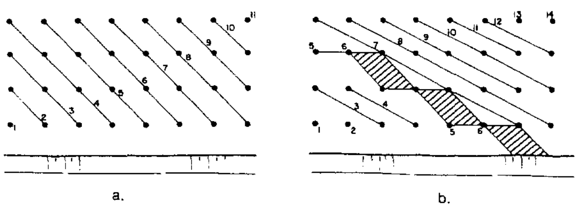
Therefore, the second basic guideline for the Delay ¯ime between Rows *TRF* is:

TRF = 2-3 *TRB*

The delay timing can also be used as a tool for control-ing rock displacement, its profile and swelling. If the lelay time between rows is large, the material of the first ow does not act as a screen nor does it exercise a onfining effect for the rest of the blast, Fig. 27.17 (a). On ıe other hand, if the delay time is short, a vertical omponent of displacement that becomes increasingly ırger enters into the back rows, obtaining a higher ›rofile.

By studying the two profiles, one can observe that the irst is the most adequate for front end loaders as it ›ermits a better penetration of the bucket and, therefore, nore efficient loading, while the second is more apt for ope or hydraulic shovels as the low productivity zone, or lack of height, is smaller and permits filling of the ıdle in finer and higher slices.

However, with this shooting sequence the swelling nay not be optimum, causing a longer loading time.



'ig. 27.16. Comparison of the two multi-blast patterns with different ıitiation sequences.

27.5.2 *Influence of the delay timing in flyrock and overbreak.*

When blasts of various rows of holes are fired, the delay time between these should allow horizontal movement of the fragmented rock, avoiding the following problems, Fig. 27.18:

– The increase in the vertical component of displacement as the number of rows increments towards the interior, and, as a consequence, the risk of flyrock.

– Toe problems as the confinement increases as well as resistance to the cut at floor level due to a larger burden.

– Overbreak problems in the last rows as the charges act with crater effect. According to the investigations carried out by Martin Marietta laboratories in blasts with 10 rows of blastholes, in order to nullify the vertical component of the movement it is necessary to have at least 60 ms/m delay between effective rows. However, times that are too long can produce airblast, cut-offs and even flyrock if the burden is small in the first rows. In Fig. 27.19, from studies with ultrarapid cameras, the minimum delay time necessary between effective rows that is needed to eliminate uncontrolled flyrock in a blasting can be deduced.

Konya and Walter show the expected results of the blasts for different delay times between rows, gathered in Table 27.2, expressed as a function of the burden value.

27.6 UNDERGROUND BLASTS IN TUNNELS AND DRIFTS

When parallel blasthole cuts are used, the first charges that are detonated are those closest to the relief holes. The burden value increases as the initiation sequence continues, Fig. 27.20.

The rock fragmented by the action of the first holes is projected laterally towards the small volume of available space. In blastholes with a length of more than 3 m, the time necessary for the complete expulsion of the fragments of rock in the zones of the cut is considerable, and usually more than 100 ms. Therefore, the delay time between consecutive blastholes should exceed 100 ms if sinterization and compressing of the rock in the zone of the cut is to be avoided, Fig. 27.21, and allow each charge a free effective face afterwards.

This has been demonstrated in practice by exper-

Table 27.2.

Delay times between rows (ms/m of burden)	Result
7	Intense airblast, overbreak, etc.
7-10	High, compressed muckpile, moderate airblast and overbreak.
13-20	Muckpile of medium height, moderate airblast and overbreak.
13-20	Disperse muckpile with minimum overbreak.
23-47	Blast with maximum displacement.

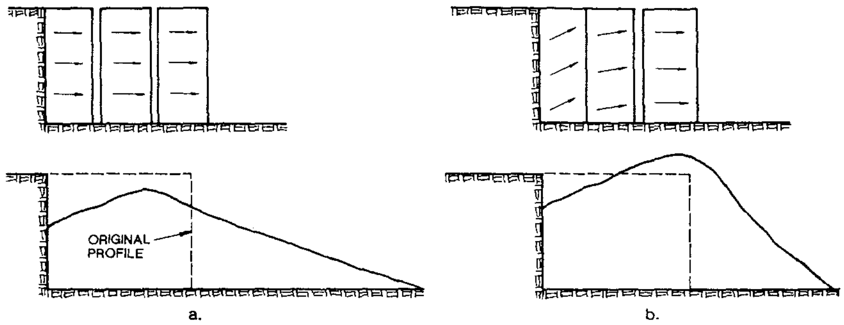


Fig. 27.17. Rock displacement as a funcion of timing.

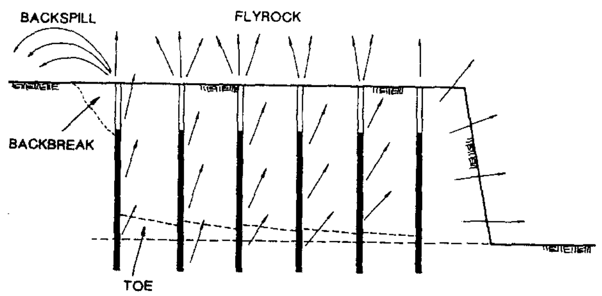


Fig. 27.18. Effects of restricted ground movement.

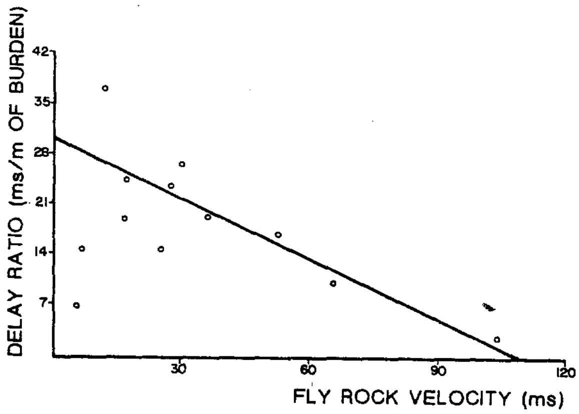


Fig. 27.19. Correlation of the mean delay between rows with the velocity of the projected rock fragments.

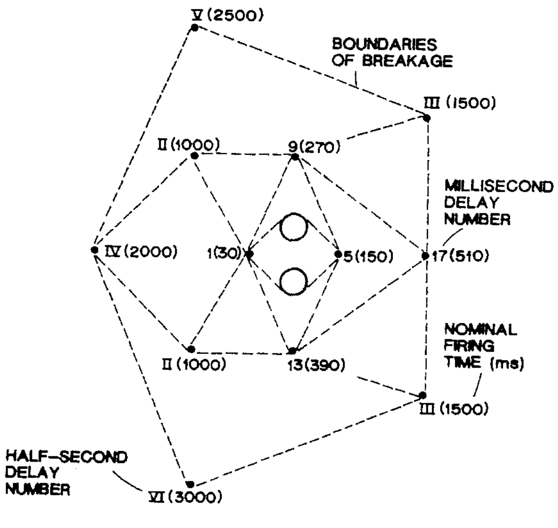


Fig. 27.20. Recommended use of millisecond delays in burn cut (Hagan, 1982).

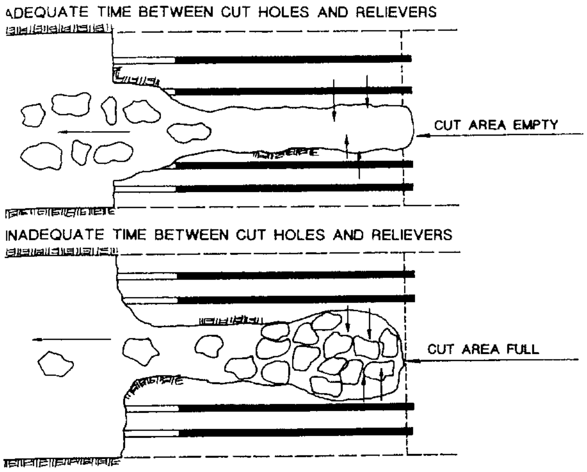


Fig. 27.21. Effect of delay interval in tunnel round performance.

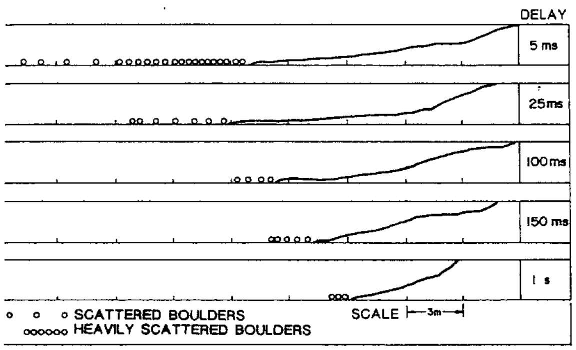


Fig. 27.22. Effect of delay interval on rock throw and muckpile shape in tunnels (Du Pont).

Table 27.3.

Nominal delay (ms)	Advance %	No. of boulders > 300 mm	Displacement (m)
5	88	15	23
25	97	26	20
100	96	27	15
150	97	26	12
1000	96	26	9

imental blasts as can be seen in Table 27.3, and Fig. 27.22.

These studies show that very small intervals give better fragmentation but at the same time reduce the advance of the round and increase rock throw, making the loading more difficult due to boulder dispersion.

In tunnels with medium and large sections, it is not possible to use initiation sequences with longer timing than 100 ms due to the available number of detonators. For this reason, it has become necessary to use millisecond delay detonators in the cut and half-second delay detonators in the rest of the sections.

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