QUARRYING

TR16_222_240

46. Considerations for quarry development.

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Whether the requirement is for the production of rock of a size required commercially or to create space for buildings or other developments the factors to be considered are similar. It is of great importance that the broken rock be produced economically.

The situation of the place where the blasting is to be done has a great influence on the method used. Where the quarrying to be done is adjacent to, or near buildings, highways and built-up areas the effect of ground and air vibrations is very important and modifications have to be made to the methods which would normally be used.

The factors which have to be considered are as follows:

(1) height of face
(2) burden and spacing of holes
(3) size of drill holes
(4) hade of holes
(5) subgrade drilling
(6) pattern of holes
(7) delay pattern
(8) type of explosive
(9) method of ignition
(10) position of primer
(11) stemming
(12) natural cleavage or shear planes

Height of Face

The height of a face being worked in a quarry is usually constant for faces other than top face once the floor horizon of each bench has been established, but the height of the top face is usually variable and would increase until a certain limit is reached.

The limits are usually based on the following:

(a) mining regulations
(b) type of loading equipment
(c) type of drilling equipment
(d) material being mined

Mining Regulations

MINES INSPECTION REGULATIONS 1969

20-(1) The batter of any open-cut or quarry shall be at such an angle as an inspector considers safe, taking into consideration the surrounding conditions.

(2) The height of any open-cut or quarry face shall be no more than twenty metres, unless otherwise permitted in writing by an inspector.

10-(1) Every owner shall provide safety belts and ropes for the use of men -

(a) in a precipitous place, pass or bin

(2) No person shall -

(a) be in a precipitous place, pass or bin; ... without using a secure safety belt and rope.

(3) No person shall, in a precipitous place or pass, fasten a safety rope or any other contrivance for support to drill steel.

Type of loading equipment

It has been found that the height the loading bucket can reach plus 1.5 m is the ideal operating height of face because it means that men are not required to climb over the face to scale it down as the loading bucket will do the lower part of the face and a man from the upper bench can do the top 1.5 m without having to climb on to the face.

Type of drilling equipment

The type of drill used depends on the diameter of the hole required by the owner. If it is a small diameter say 27 or 33 mm then the drill will probably be hand held but if the hole diameter is greater than 50 mm track-mounted drills would be used. The maximum depth of hand drilled holes having a diameter of 27 or 33 mm is normally about 6 m.

Track-mounted drills can go to much greater depths because of the number of lengths of drill rod that can be screwed together. The length of each rod may be 1.5, 1.8 or 2.4 m.

Experiments have shown that the rate of penetration of a drill when drilling hard rock, is relatively constant to a depth of 9 m but then decreases with increasing depth. As an example practice has shown that three 9 m holes can be drilled in the same time as one 18 m hole.

Rock drilling in quarries is done by:

(a) contract, or
(b) quarry owners' employees

Contract drilling can be done either of two ways:

(a) a fixed price per foot drilled, or
(b) on an hourly basis.

The method used would be determined by economic considerations at each quarry.

Burden and Spacing of Holes

These factors are dependent on each other.

Various formulae have been devised to calculate the burden but the one which seems to fit the blasting of dolerite is as follows:

(1) $B = Cd$ where B = burden (mm)
d = hole diameter (mm)
C = 14 to 49

It has been established for rock having a density of 2,560 kg/m^3 and using explosives having similar properties to AN 60 (S.G. of 1.3 and Ve 3,660 m/s) that a value of 30 for C is a reasonable mean to adopt.

Should the rock have a different density then a further factor can be introduced namely:

(2) $x = \left(\frac{2,560}{W}\right)^{\frac{1}{3}}$ where W = mass of 1 m^3 of the rock (kg)

Combining (1) and (2) gives an empirical formula for the calculation of the burden.

$$B = \left(\frac{2,560}{W}\right)^{\frac{1}{3}} Cd$$

where B = burden (mm)
W = density (kg/m^3)
C = 30
d = hole diameter (mm)

The spacing should be equal to the burden but some shotfirers prefer the spacing to be slightly greater whilst others prefer it to be slightly less.

Size of Drill Hole

The diameter of the drill depends to a large extent on the quantity of explosives that is required in each hole to blast down the face which in turn is dependent upon the spacing, burden and the amount of explosive needed to fragment the rock to the size required by the operator.

It has been established that to get a breakage of 90% -0.3 m in dolerite the mass of explosive (AN 60) per solid cubic metre should be about 0.55 kg.

The size of hole now generally used in quarrying is about 60 mm.

Hade of Hole

The angle of hade is 20-30°, mainly 20°.

The purpose of the hade is to:

(a) decrease the danger due to loose rock on the face
(b) enable a bigger proportion of the explosive energy to be used in fragmenting and moving rock from the face
(c) give the face a smoother appearance
(d) decrease the need for subgrade drilling, and
(e) ensure greater fragmentation.

If the face has pronounced shear planes or joints the angle of hade is varied so that the holes are drilled parallel to the shear or joint planes.

Subgrade Drilling

Subgrade drilling is the drilling of that part of the hole below the level of the floor (fig. 64), it is necessary particularly for vertical holes and where the rock is homogeneous, to ensure that humps and toes are not left along the face which create bad loading conditions and make the face difficult to blast.

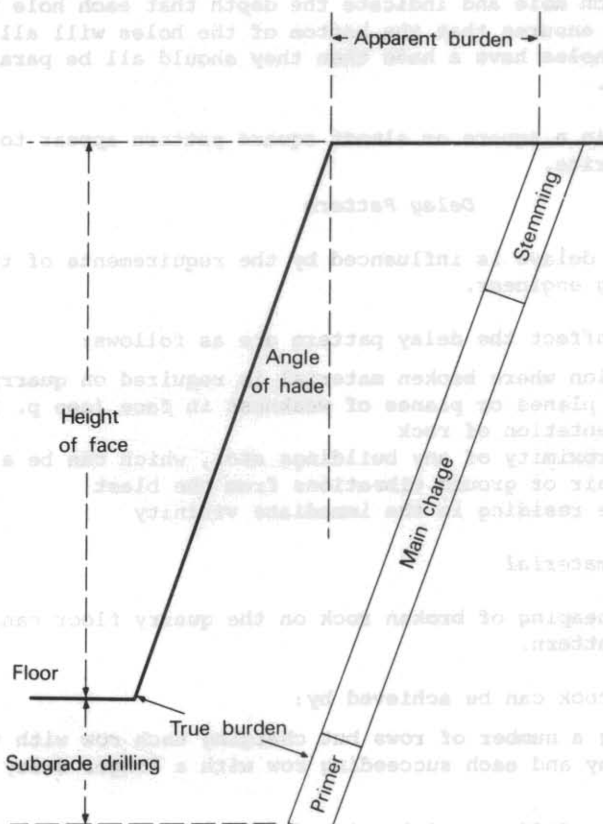

Figure 64. *Section through quarry face showing bottom priming.*

An empirical formula used to establish the amount of subgrade drilling for vertical holes is as follows:

$$J = 0.3\ B \quad \text{where } J \text{ is in metres}$$
$$B = \text{burden (m)}$$

The necessity for subgrade drilling decreases with increasing angle of hade; with a hade of 30° no subgrade drilling is required.

Another instance when the depth of subgrade drilling is varied is when the floor of quarry coincides with the pronounced structural discontinuity or parting: the holes are terminated at this level or a little below it (to take any drilled material which may not have been removed from the hole during drilling).

Pattern of Holes

When large blasts or frequent blasting is to take place it is good mining practice to lay out the positions of the holes in straight lines and each row behind parallel to the one near the face. This will result in improved contours and safer working conditions.

If the height of the face is irregular it is good practice to establish the level of each hole and indicate the depth that each hole will have to be drilled. This ensures that the bottom of the holes will all be on the same level. If the holes have a hade then they should all be parallel and dip towards the face.

Holes drilled in a square or almost square pattern appear to give the best results in dolerite.

Delay Pattern

The pattern of delays is influenced by the requirements of the quarry operators or blasting engineer.

Factors which affect the delay pattern are as follows:

(1) position where broken material is required on quarry floor
(2) shear planes or planes of weakness in face (see p. 229)
(3) fragmentation of rock
(4) the proximity of any buildings etc., which can be affected by air or ground vibrations from the blast
(5) people residing in the immediate vicinity

Placement of broken material

The spread or heaping of broken rock on the quarry floor can be achieved by the delay pattern.

The spread of rock can be achieved by:

(a) firing a number of rows but charging each row with the same delay and each succeeding row with a longer delay (fig. 65), or

(b) using a different delay in each hole and starting the delays at one end and finishing at the other (fig. 66).

2	2	2	2	2	2	2	2	2	2	2	2	2
+	+	+	+	+	+	+	+	+	+	+	+	+
1	1	1	1	1	1	1	1	1	1	1	1	1
+	+	+	+	+	+	+	+	+	+	+	+	+
0	0	0	0	0	0	0	0	0	0	0	0	0
+	+	+	+	+	+	+	+	+	+	+	+	+

Figure 65. *Quarry blast: electric delay detonator pattern, with delay detonator numbers.*

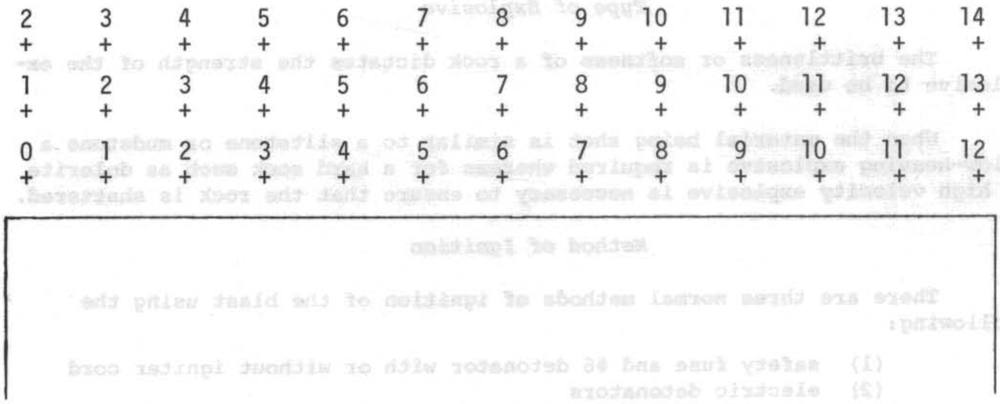

Figure 66. *Quarry blast: electric delay detonator pattern, with delay detonator numbers.*

Heaping of the broken material can be achieved by starting at a point with the odd number delays going in one direction and the even numbers in the other (fig. 67).

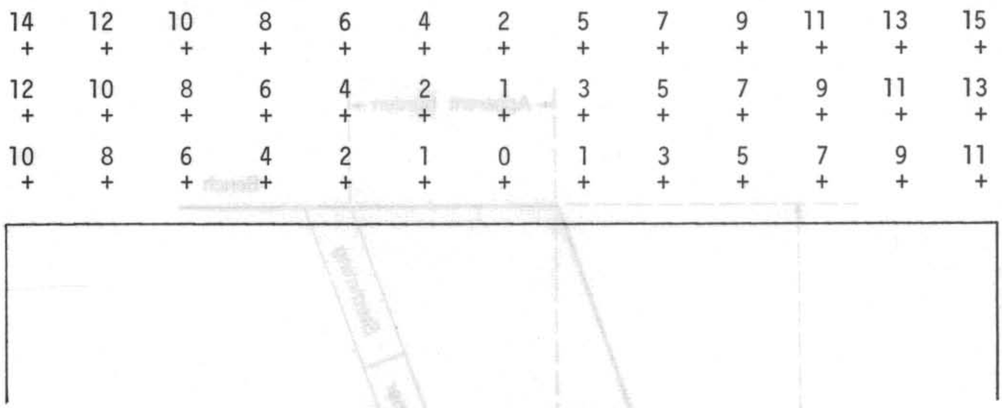

Figure 67. *Quarry blast: electric delay detonator pattern, with delay detonator numbers.*

Fragmentation

When a face is homogeneous and without pronounced shear planes the use of the delay pattern shown in Figure 67 will not only cause the material to be moved from the face but this will collide with material still in the air from the earlier blasted holes, resulting in further fragmentation.

Air and Ground Vibrations

If air and ground vibrations exceed certain values damage to buildings will occur.

The state of repair of a building influences the possibility of damage and an old, poorly built and maintained building is more prone to damage.

When subjected to air and ground vibrations the reactions from residents are as varied as the people themselves.

Type of Explosive

The brittleness or softness of a rock dictates the strength of the explosive to be used.

When the material being shot is similar to a siltstone or mudstone a slow-heaving explosive is required whereas for a hard rock such as dolerite a high velocity explosive is necessary to ensure that the rock is shattered.

Method of Ignition

There are three normal methods of ignition of the blast using the following:

(1) safety fuse and #6 detonator with or without igniter cord
(2) electric detonators
  (a) millisecond delays
  (b) ½ second delay
  (c) instantaneous
(3) Cordtex which can be initiated by any of the methods in (1) or (2).

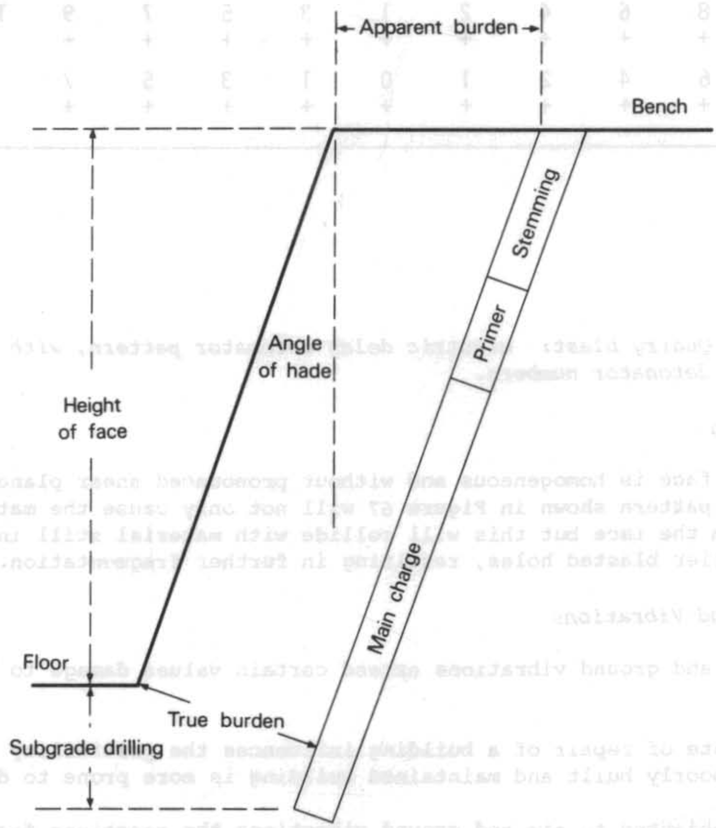

Figure 68. *Section through quarry face showing top priming.*

5 cm

Position of Primer

When using a safety fuse and safety detonator the primer is inserted at the top of the charge and this is called top priming (fig. 68).

Electric detonators permit either top or bottom priming and in some cases it may be expedient to use primers inserted within the charge. It is preferable to bottom prime as the shot firer can then be sure that no explosive is left in the bottom of the hole (fig. 64).

Stemming

Many materials can be used as stemming. The most commonly used, in descending order of preference, are as follows:

(1) water
(2) dry sand
(3) moist sand
(4) metal dust
(5) loam
(6) clay

It has been found that the length of stemming used at the top of the hole should be the same as the burden. When this is done the possibility of flyrock from the collar will be significantly reduced, if not eliminated but as the length of tamping is decreased the tendency for collar flyrock is markedly increased.

Natural Cleavage or Shear Planes

This is a factor which should be used by the quarry operator or blasting engineer to give the best results from the blast.

The blast pattern should be modified to suit the natural planes of weakness (fig. 69).

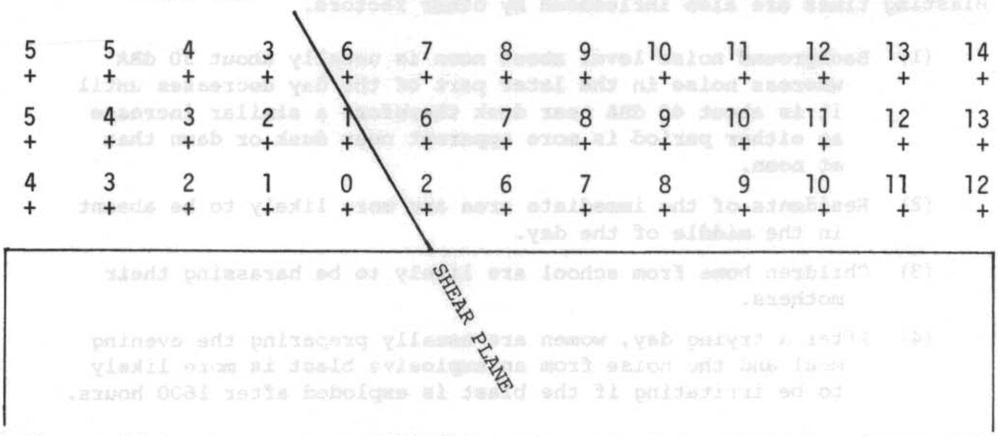

Figure 69. *Quarry blast: electric delay detonator pattern, with delay detonator numbers.*

TOES

In a majority of cases toes are caused by poor blasting techniques. They will be eliminated by careful adherence to the fundamentals of good blasting practice.

Should toes develop it is imperative that they be blasted and removed before any face blasts are done as toes cause deterioration of the face and create difficult quarrying conditions.

BLASTING COMPLAINTS

The majority of complaints received concerning blasting have proved to be from the air vibration due to secondary blasts even though the mass of explosive in the secondary blast seldom exceeds 10 kg compared with masses of up to 3 tonnes in the primary blast.

It is extremely doubtful if secondary blasts can create ground vibrations which could be recorded at a distance where buildings or people would normally be affected, however if any ground vibrations are felt it can be safely stated that they are due to a primary blast.

Air Blast

Temperature inversions alter the air pressure wave surrounding the blast and by refraction and, or, reflection, the pressure wave can be directed back to the surrounding countryside and focused on to an area causing a build-up of air pressure which may possibly create damaging or annoying conditions.

The worst period for temperature inversions is from sunrise to two hours thereafter and from two hours before sunset until sunset.

Inversions occurring above 1,500 m do not seem to create a condition where the air pressure waves are focused back to earth with sufficient amplitude to cause complaints.

It is therefore advisable to blast at times when temperature inversions are not present or when they are least likely.

Blasting times are also influenced by other factors.

(1) Background noise level about noon is usually about 50 dBA whereas noise in the later part of the day decreases until it is about 40 dBA near dusk therefore a similar increase at either period is more apparent near dusk or dawn than at noon.

(2) Residents of the immediate area are more likely to be absent in the middle of the day.

(3) Children home from school are likely to be harassing their mothers.

(4) After a trying day, women are usually preparing the evening meal and the noise from an explosive blast is more likely to be irritating if the blast is exploded after 1600 hours.

Most complaints are made because the complainants are convinced that the noise they hear from the detonation of explosives is damaging their property particularly if any windows rattle.

It has been determined that the number of complaints received is related to the noise produced.

A review of blasting complaints indicates that the noise propagation from some blasts was greater than others and the conclusion reached is that meteorological conditions were the cause. The findings of that review are as follows:

(1) Weather conditions can cause a variation in sound propagation.

(2) Weather conditions can be unfavourable to blasting from a sound propagation aspect.

(3) There is a reduction in the number of complaints by restricting blasting operations to those days having favourable weather conditions.

General rules can be established with regard to visible weather conditions and their effect on sound return.

These conditions can be interpreted as being favourable or unfavourable.

Favourable conditions:

(1) Clear to partly cloudy skies with fleecy clouds and relatively warm day temperatures.

(2) Cloudy days with rapidly changing winds, perhaps accompanied by brief showers.

Unfavourable conditions:

(1) The most unfavourable conditions occur when the air is relatively still. These days are usually foggy, hazy or smoky. An indication of unfavourable conditions may be drawn from the behaviour of smoke from a nearby smokestack. If the smoke fans out horizontally after the initial rise above the stack with little evidence of looping or vertical motion as the smoke moves away from the stack, then a poor dispersion condition exists and, very likely a temperature inversion.

(2) Clear, somewhat hazy days with fairly constant temperatures and possibly very light winds.

The difference in intensity of the noise from a blast is a function of the weather conditions at the time. These conditions determine the velocity of sound in different directions and at different altitudes. Noise from normal commercial blasting operations is not significantly affected by conditions at altitudes of more than 1,500 m above ground level. The factors that influence sound propagation are wind velocity and temperature.

Normally air temperatures decrease with increasing altitude, the temperature drop being usually 1°C for 150 m.

Should the air temperature be constant over a range of altitudes then an isotherm is said to exist, but if the air becomes warmer with increasing altitude then an inversion occurs.

The following sets of conditions occur and are described below:

(1) Atmosphere perfectly still and isothermal
(2) Sound speed increases with altitude
(3) Sound speed decreases with altitude
(4) Temperature and sound speed variations with altitude

(a) increase and then decrease,
(b) decrease, increase and then decrease,
(c) increase, decrease, increase at a greater rate and finally decrease.

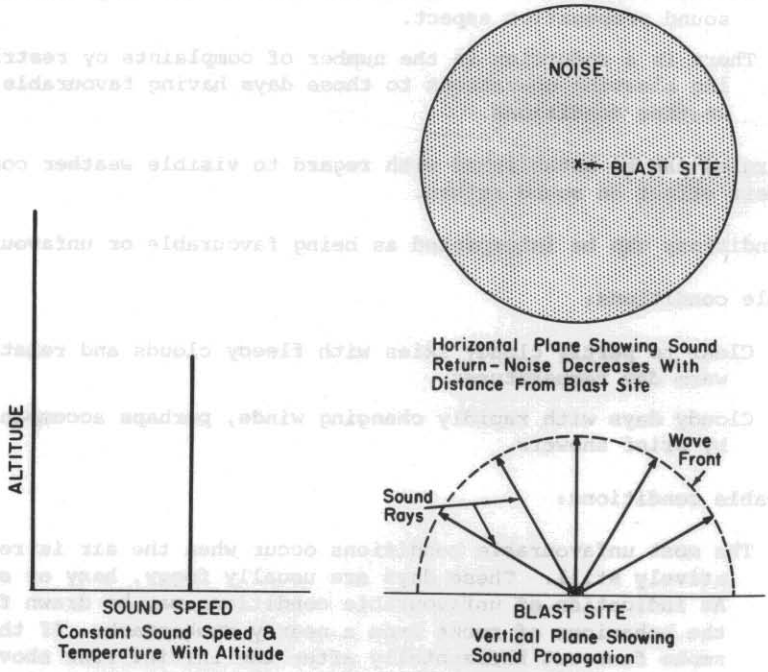

Figure 70. *Sound propagation from blast site.*

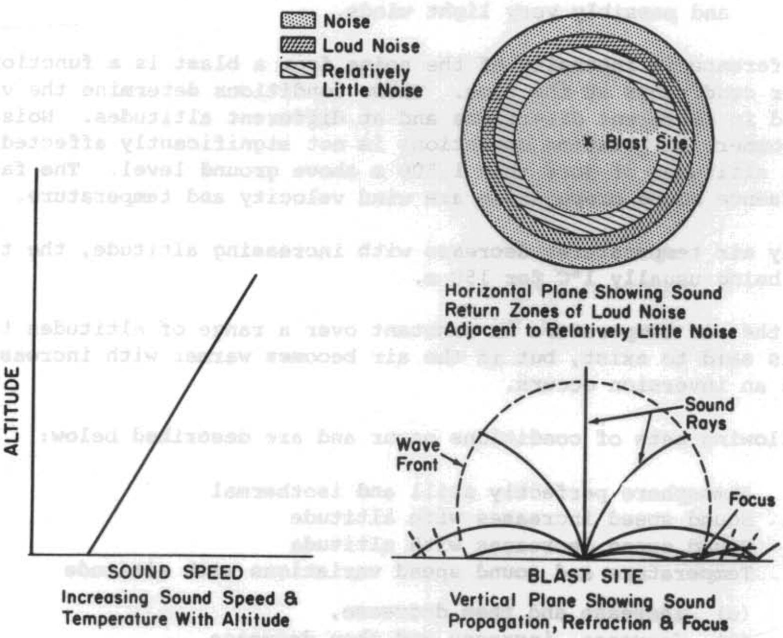

Figure 71. *Sound propagation from blast site.*

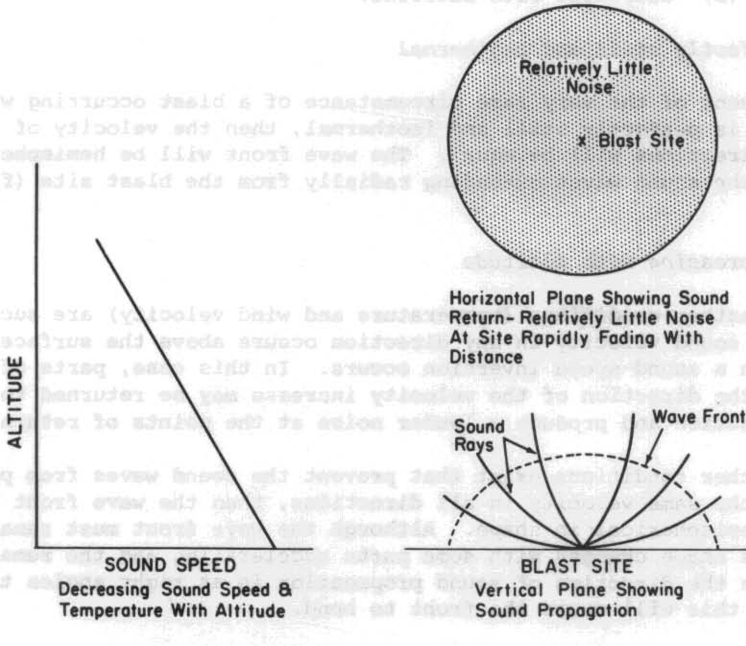

Figure 72. *Sound propagation from blast site.*

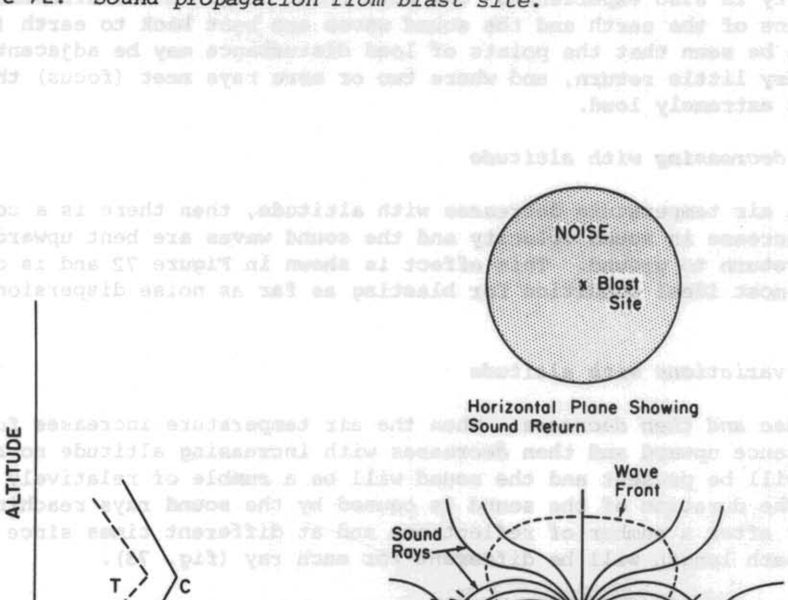

Figure 73. *Sound propagation from blast site.*

(5) Wind speed and sound speed

(a) increases with altitude,
(b) decreases with altitude.

Atmosphere perfectly still and isothermal

In the event of the very rare circumstance of a blast occurring when the atmosphere is perfectly still and isothermal, then the velocity of the sound in all directions will be equal. The wave front will be hemispherical in shape with the sound waves extending radially from the blast site (fig. 70).

Sound speed increasing with altitude

If the weather conditions (temperature and wind velocity) are such that a greater sound velocity in any direction occurs above the surface of the earth, then a sound-speed inversion occurs. In this case, parts of the sound wave in the direction of the velocity increase may be returned to the ground by refraction and produce a louder noise at the points of return.

When weather conditions exist that prevent the sound waves from progressing with the same velocity in all directions, then the wave front can no longer be hemispherical in shape. Although the wave front must remain continuous, the shape changes with some parts accelerating and the remainder lagging. Since the direction of sound propagation is at right angles to the wave front this will cause the front to bend.

When the temperature increases with altitude (a resultant increase in sound velocity is also experienced) the wave front drags in the direction of the surface of the earth and the sound waves are bent back to earth (fig. 71). It can be seen that the points of loud disturbance may be adjacent to points of very little return, and where two or more rays meet (focus) then the noise is extremely loud.

Sound speed decreasing with altitude

If the air temperature decreases with altitude, then there is a corresponding decrease in sound velocity and the sound waves are bent upwards and do not return to ground. This effect is shown in Figure 72 and is obviously the most ideal condition for blasting as far as noise dispersion is concerned.

Temperature variations with altitude

Increase and then decrease. When the air temperature increases for a short distance upward and then decreases with increasing altitude no zones of silence will be present and the sound will be a rumble of relatively long duration. The duration of the sound is caused by the sound rays reaching the listener after a number of reflections and at different times since the reflection path length will be different for each ray (fig. 73).

Decreases, increases and then decreases. When the air temperature decreases in the lower altitudes, then increases for a similar distance and finally decreases again within the altitude of influence a zone of relatively little noise exists near the blasting location with loud noise disturbance at more distant locations. A narrow zone in which the sound return is especially loud and sharp and occurs outside the relatively quiet zone. This is the result of a bundle of rays returning to the ground at these points at exactly the same time. Beyond this zone of very loud noise, other sound

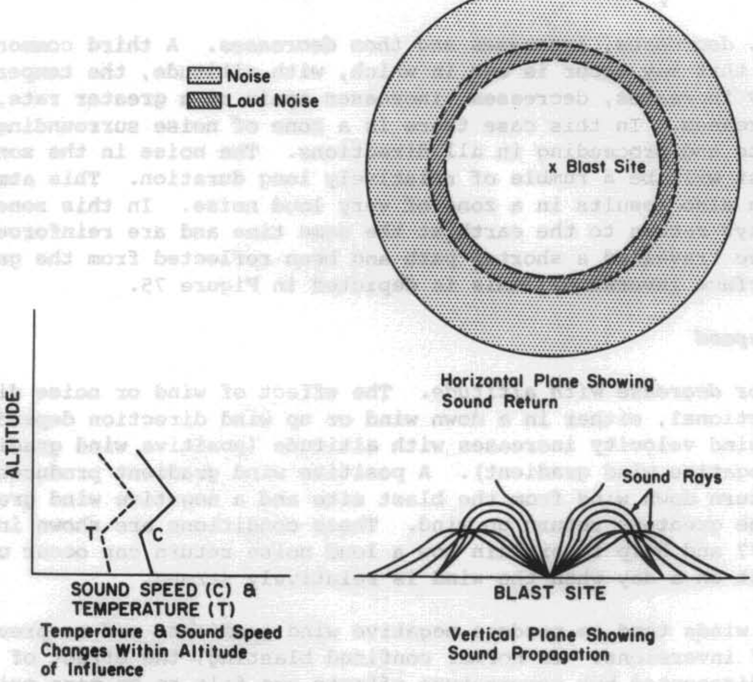

Figure 74. *Sound propagation from blast site.*

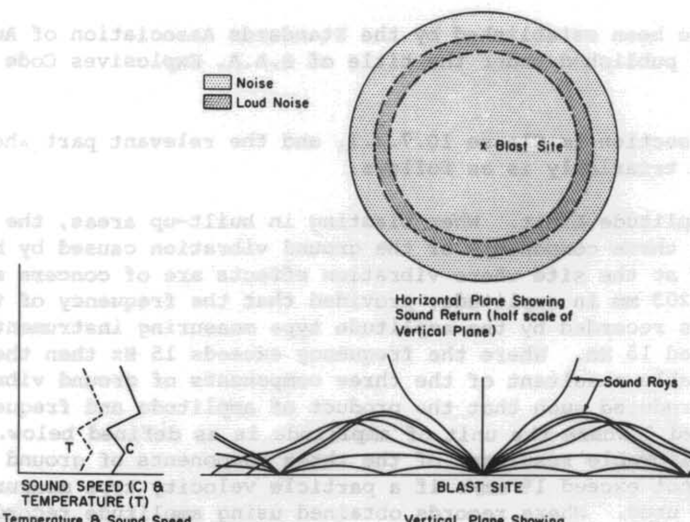

Figure 75. *Sound propagation from blast site.*

rays are returning to the surface, but are lower in intensity and sharpness (fig. 74).

Increases, decreases, increases and then decreases. A third common speed inversion that may occur is one in which, with altitude, the temperature successively increases, decreases, increases again at a greater rate, and finally decreases. In this case there is a zone of noise surrounding the blasting site and proceeding in all directions. The noise in the zone nearest the blast will be a rumble of relatively long duration. This atmospheric condition also results in a zone of very loud noise. In this zone several sound rays return to the earth at the same time and are reinforced by rays that have travelled a shorter path and been reflected from the ground (returned by surface inversion); this is depicted in Figure 75.

Wind and sound speed

Increase or decrease with altitude. The effect of wind or noise disturbance is directional, either in a down wind or up wind direction depending on whether the wind velocity increases with altitude (positive wind gradient) or decreases (negative wind gradient). A positive wind gradient produces the greatest return down wind from the blast site and a negative wind gradient produces the greatest return up wind. These conditions are shown in Figures 76 and 77 and help to explain how a loud noise return can occur up wind from a blast on a day when the wind is relatively strong.

Generally winds tend to produce negative wind gradients and so prevent the formation of inversions. In normal confined blasting, the effect of wind cannot be discounted but temperature effects are felt to be more critical.

GROUND VIBRATIONS

Experimental work has established that buildings and other structures can withstand ground wave intensities many times greater than a human being will tolerate without complaints being received.

Standards have been established by the Standards Association of Australie and have been published under the title of S.A.A. Explosives Code AS CA23-1967*.

The relevant section is Clause 10.7.4.1. and the relevant part when recordings are made triaxially is as follows:

> 10.7.4.1. Amplitude Limit. When blasting in built-up areas, the resultant of the three components of the ground vibration caused by blasting, measured at the site where vibration effects are of concern shall not exceed 0.203 mm in amplitude, provided that the frequency of the shock wave, as recorded by the amplitude type measuring instrument does not exceed 15 Hz. Where the frequency exceeds 15 Hz then the maximum allowable resultant of the three components of ground vibration shall be reduced such that the product of amplitude and frequency does not exceed 3 where the unit of amplitude is as defined below. The maximum allowable resultant of the three components of ground vibration shall not exceed 19 mm/s if a particle velocity type measuring instrument is used. Where records obtained using amplitude recording instruments do not allow the frequency to be readily interpreted, then direct particle velocity type instrumentation should be used.

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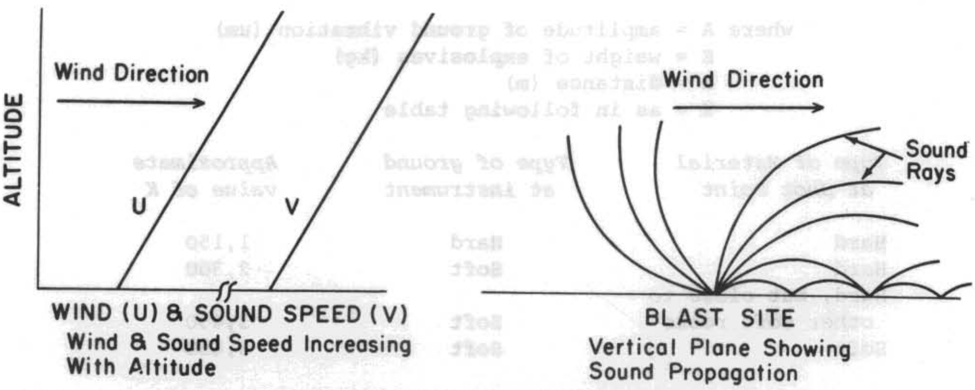
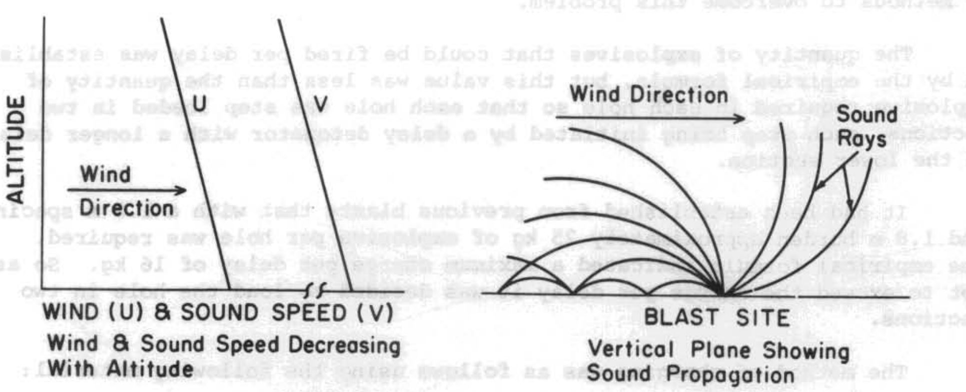
*Imperial units have been directly converted to metric units in anticipation of metrication of the code.



Sound propagation from a positive wind gradient showing greatest sound return down wind from blast site.

Figure 76. *Sound propagation from blast site.*



Sound propagation from a negative wind gradient showing greatest return up wind from blast site.

Figure 77. *Sound propagation from blast site.*

The above recommended limits are a compromise between safety and comfort, but are heavily biased towards comfort. The above recommendation gives a factor of safety for light damage of about 6 when considering a building in good condition.

Even though the recommended limit of the particle velocity is 19 mm/s in practice the aim has been to reduce the limit to 10 mm/s.

$$A = \frac{K\sqrt{E}}{d}$$

where A = amplitude of ground vibration (μm)
E = weight of explosives (kg)
d = distance (m)
K = as in following table

Type of Material at Shot Point	*Type of ground at instrument*	*Approximate value of K*
Hard	Hard	1,150
Hard	Soft	2,300
Hard, but close to other soft rocks	Soft	3,450
Soft	Soft	3,450

The weight of explosive that can be used per delay is then established by using the following assumption that A = 50 μm. This has been one of the methods used to design blasts and results recorded have indicated that it has been able to maintain a particle velocity of $\leqslant$10 mm/s. As a result the number of complaints has dramatically fallen.

An example of the use of this method of approach was at the Public Works Department quarry at Lutana.

The quarry was situated on the edge of a closely settled area with a row of houses as close as 90 m.

Complaints from these houses were very common, and in fact were so frequent that the Public Works Department asked if we could suggest a method or methods to overcome this problem.

The quantity of explosives that could be fired per delay was established by the empirical formula, but this value was less than the quantity of explosive required in each hole so that each hole was step loaded in two sections, each step being initiated by a delay detonator with a longer delay in the lower section.

It had been established from previous blasts that with a 1.8 m spacing and 1.8 m burden approximately 25 kg of explosive per hole was required. The empirical formula indicated a maximum charge per delay of 16 kg. So as not to exceed the charge per delay it was decided to load the hole in two sections.

The method of charging was as follows using the following material:

(1) Millisecond delay electric detonators
(2) A 51 mm diameter plug of Anzite weighing 1.42 kg.
(3) ANFO
(4) Rock dust for tamping.

Diagrammatic sketch of the method of loading is shown in Figure 78.

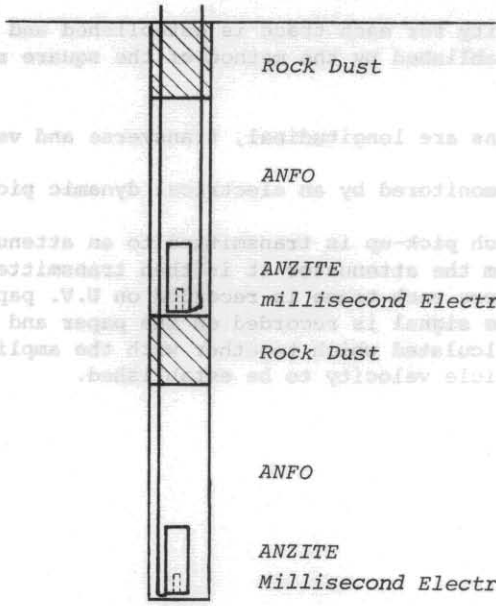


Figure 78. *Method of loading charge in two sections.*

A typical loading was to use a No. 1 millisecond delay electric detonator with a 51 mm diameter plug of Anzite weighing 1.42 kg to make a primer and place at the bottom of the hole and then to load half of the total charge of ANFO for the hole (about 11 kg) to form the lower step. Sufficient rock dust is then poured in to create a plug approximately one metre long. Another primer, having a No. 0 millisecond delay electric detonator, is then lowered on to the rock dust plug and the remainder of the ANFO poured in. The hole is then tamped with rock dust until the hole is completely filled.

The next hole is then treated similarly except that the two detonators used are No. 3 and No. 2 respectively and so on until the series of detonators is exhausted.

When the face was exploded the resultant ground vibration at the nearest home was 9.7 mm/s, and there were no complaints about the blast.

This method of blasting had other effects.

(1) Larger blasts were possible.
(2) Rock was broken into smaller fragments.
(3) Less secondary blasting was needed.
(4) Back break on the quarry face was reduced.
(5) Less scaling of the face was required.
(6) Face contours became more regular.
(7) The appearance of quarry was considerably improved.
(8) Production increased, due to ready accessibility to broken rock of the correct size for the crushing plant.

Method of recording

The ground vibrations are picked up triaxially and each trace is recorded separately.

The particle velocity for each trace is established and the resultant particle velocity is established by the method of the square root of the sum of the squares.

The three directions are longitudinal, transverse and vertical.

Each direction is monitored by an electrical dynamic pick-up.

The signal from each pick-up is transmitted to an attenuator by means of a coaxial cable. From the attenuator it is then transmitted to a multi-channel U.V. recorder where each trace is recorded on U.V. paper. In addition to the trace a time signal is recorded on the paper and from this trace the frequency (Hz) is calculated which together with the amplitude of the ½ trace enables the particle velocity to be established.