Chapter 23

Hazards to and from blasting

23.1 INTRODUCTION

The purpose of blasting in mines is not only to somehow fragment the rock mass, but to fragment the rock mass in such a way that

a It yields breakage of maximum volume of rock mass.
b The fragments formed by blasting are of such size that even the largest piece formed by blasting can easily be lifted by loading equipment and carried by the hauling equipment.

Further, while achieving the above objectives the blast must not cause damage or unbearable disturbances to the surroundings.

In this context the word hazard has so far been looked upon to mean the exposure to danger. This can be considered in two ways. The first is the risk to which the process of blasting is exposed to, by some external factors. The second is the risk to which the external entities are subjected to, as a result of blasting operations.

This chapter deals with blasting hazards from both the meanings.

23.2 HAZARDS TO BLASTING PROCESS

Many conditions make it difficult to engineer a blast in appropriate manner and so must be considered to be hazardous to the blasting process. Some of these conditions are as under.

1 Presence of some ground structures such as hard rock boulders, voids etc.
2 Heavy seepage of ground water into the blastholes
3 Blastholes that have high temperature within them
4 Deviation in drilling of blastholes

Details of these are given below.

23.2.1 Presence of ground structure

Ground structures such as boulders, voids, beds of soft formation do affect the process of blasting and efficiency of a blast. This topic is discussed in detail in chapter 24.

23.2.2 Seepage of ground water

The presence of ground water in a blasthole is undesirable. This is particularly so in large surface mines because in these mines the most commonly used explosive is ANFO and the AN component of the explosive dissolves in water. In such an event the blast may occur very feebly or many not occur at all.

In such situations the alternatives are:

1 Dewatering the blasthole and then using a thin (usually 0.5 mm thickness) plastic tube inside the blasthole. When such a tube extends from the bottom of the blasthole to ground surface the explosives filled inside the tube do not come in contact with water. It can therefore be safely blasted.
2 Using water resistant explosives such as slurry or emulsion. These explosives are much costlier than ANFO, resulting in increased cost of blasting.
3 When the location of the bench is such that water seeps into many blastholes, one or more deep waterwells can be drilled at appropriate locations and ground water is pumped from such wells. This results in decreasing the ground water table in the area and the flow of water in the blasthole stops or reduces.

23.2.3 Hot blastholes

On many occasions blastholes have relatively high temperatures within them. This can result from the inflow of steam or a layer of burning coal or some similar phenomenon.

Depending upon the temperature prevailing inside the hole and the temperature gradient, certain explosives can deflagrate or even detonate either immediately or after some time. For this reason it is very essential to find out if the blasthole is hot.

The likelihood of the presence of a hot blasthole is very high in coal mines, where the coal layers may actually be burning. In such circumstances it is compulsory to lower the hot hole meter and determine the temperature gradient in every blasthole.

23.2.4 Hole deviation

In designing a blast it is always presumed that the blastholes will be drilled exactly at the intended collaring point and they will lie perfectly along their intended path.

In actual practice the position and the alignment of the blastholes deviates from the ideal for many reasons described earlier in this book.

Situations of hole deviation like this can be dealt with by using a higher quantity of explosive or using more powerful explosive in the blasthole in proportion to the hole deviation.

23.3 HAZARDS OF BLASTING PROCESS

Hazards caused by blasting process can be due to many factors as under.

1 Misfires
2 Ground vibrations

3 Air blast
4 Fly rocks
5 Air pollution
6 Environmental changes

All these are of great importance because they cannot be totally wiped out. Corrective measures to ensure that their effect is on an acceptably reduced level, are required to be taken from time to time.

23.3.1 Misfires

Misfire means missed fire. When a charged blasthole does not explode or when a part of explosive column in a blasthole has not exploded along with other blastholes in the round, a misfire is said to have occurred.

If the danger of misfire is neglected and further mining activities are allowed the explosive in the blasthole can suddenly explode during such activity. This can prove disastrous to the surroundings and can lead to huge monetary loss as well as fatalities. Therefore, in every blast a blaster must take utmost care to ensure that no misfire occurs. After the blast, he must also verify that no misfire has actually occurred and if it has occurred he must take corrective measures before further activities in the mining sequence are allowed.

Misfires can occur in one of the following ways.

23.3.1.1 Faulty safety fuse installation

In safety fuse blasting circuits a misfire occurs when an improperly cut safety fuse has been inserted and crimped to a detonator, or when a safety fuse is not sufficiently inserted into a detonator before crimping. These are shown in Figure 23.1.

Loose crimping may separate the fuse and the detonator while they are being lowered into the blasthole.

Misfire can also occur if a safety fuse that does not have sufficient water resistance, or a fuse that has a puncture within it, is used in watery condition.

23.3.1.2 Faulty electric blasting circuits

In electric blasting circuits a misfire occurs when the detonator is not properly connected to the lead wires, or when the lead wires are not properly connected to the

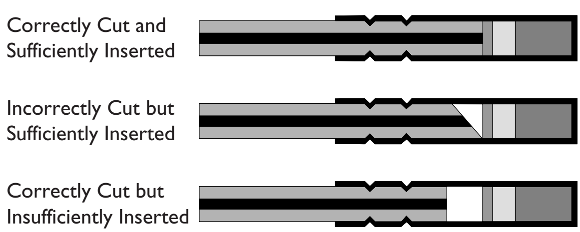

Figure 23.1 Faulty safety fuse installation.

main wires on the ground, or due to use of internally damaged/short circuited wire or current leakage.

Sometimes the sheathing of the lead wire gets punctured or damaged during the process of filling the stemming length of the blasthole by drill cuttings. This can lead to a misfire.

If the exploder chosen for the initiation is of insufficient capacity, inadequate current reaches the detonator and becomes a cause of misfire.

23.3.1.3 Faulty detonating cord circuits

Misfires in detonating cord circuits can occur by improper joint, branch line failure, use of a detonator with a very long delay interval, or incorrect sequence of firing.

Besides these, incorrect method of limiting the detonating fuse, loop cross-over, and approach of a different branch of detonating fuse can also cause a misfire.

23.3.1.4 Faults of exploder or faulty operation

More often than not, misfires are caused by a faulty exploder or its improper use. The following are the ways in which misfires are caused for this reason.

Choosing an exploder of inadequate capacity
Exhausted batteries
Faulty indicators of the battery status
Faulty cranking mechanism
Defective generator.

These factors are greatly reduced by proper maintenance of the exploders.

23.3.1.5 Unnoticed ground water inflow

The likelihood of sudden inflow of ground water into the blasthole is unlikely if the blasthole is in a solid intact rock mass because water always percolates through cracks and joints in the rock mass.

It is always necessary to check the inflow of water into the blasthole before charging. For such observation a blasthole camera is ideal but even a plexi mirror or a beam of searchlight is sufficient.

If it is noticed that there is no or negligible flow of water inside the blasthole, it is reasonable to assume that such sudden water flow will not take place after the blasthole is filled with explosive. In any case to reduce the chance of such an unexpected occurrence, blasting should be carried out as quickly as possible after the blasthole is charged.

Finally, a misfire can still occur. Very careful on-site investigation about misfires must be made by the blaster about half an hour after the blast. This time must lapse because if an explosion of the explosive in the blasthole is to take place, it will take place within this time period and the blaster will not be exposed to danger.

If the blaster notices the misfire there are different ways to deal with the situation as under.

After removing the stemming material from the blasthole with utmost care a detonator can be put to a certain depth inside the blasthole. After filling the stemming material again the explosive column can be blasted.

One or more blastholes can be drilled around the misfired blast. These newly drilled holes can be charged and blasted.

It may perhaps be worthwhile to remove the stemming material and then circulating water inside the blasthole so as to wash out the explosive or make the explosive totally insensitive.

Appropriate guidelines to deal with such situations are often given by the Governing Authorities through their publications. A blaster must proceed according the recommendations.

23.3.2 Ground vibrations

When an explosive is blasted in a blasthole, the chemical reaction evolves a huge quantity of energy. This energy starts propagating away in a radial direction. Initially the intensity of the energy is so high that matter near the walls of the blasthole gets crushed and displaced radially. When the intensity of energy decreases the energy continues to travel through the rock as an elastic ground vibration.

While the ground vibration radiates out from the blasthole, the intensity continues to reduces and at long distance it becomes too low to be perceived. At nearby distances the ground vibrations have sufficiently high energy to shatter many structures firmly embedded into ground. Such shattering of the structure can cause damage to the structure which can be very extensive as well. Human beings or other things not firmly fixed to the ground also experience these vibrations but adjust and usually do not experience any permanent damage.

Since it is essential to reduce the likely damage to structures by blasting, it is essential to study the nature of these waves, how they propagate and decay in their intensity, and what structures are damaged at what intensity.

23.3.2.1 Nature of ground vibration waves

There are three distinct types of vibration waves. They are compression wave, shear wave and Rayleigh wave. They are usually recognized by their shortened name, P wave, S wave and R wave respectively.

When the waves travel radially the particles of the ground matter move in different ways.

The P wave is a compression wave. Here the particles of the matter move back and forth in the radial direction. Before the wave generates, the particles of the matter are in steady state. As the wave begins, the particles swiftly move in a radial direction and push the particles on the front side in a radial direction. This gives rise to compression. Immediately upon passing the energy to the next particles, the particles rebound back again in the radial direction and create a tension wave. This is elucidated through Figure 23.2.

In the shear wave the movement of the particles is at right angles to the direction of wave propagation, as shown in Figure 23.3.

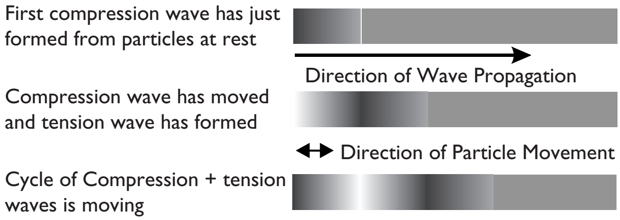

Figure 23.2 P wave propagation.

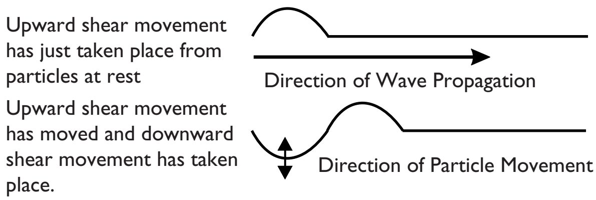

Figure 23.3 S wave propagation.

In the Rayleigh wave the direction of wave propagation is radial but the movement of the particles is in an elliptical manner in a plane that is perpendicular to the direction of wave propagation.

The P wave is robust and travels over a very long distance at a speed that is dependent upon the medium in which it travels.

Vibrations are measured in terms of amplitude and frequency. Amplitude relates to the movement of particles in either direction from the stable position. It is measured in mm. Frequency is the number of repetitions of the movement pattern. It is measured in number of cycles per second. Excessively high ground vibration levels are known to damage structures. Moderate to low levels of ground vibration are irritating.

Seismographs are used to record the ground vibration waves experienced at a place. The recordings are called a wavetrace.

Figure 23.4 shows the wavetrace at a point approximately 1800 meters from a single hole blast of 1000 kg of explosives fired in the overburden in the Hunter Valley coal mine.

The P wave arrives first followed by the various reflected and refracted vibrations associated with the P wave. This vibration gradually reduces until approximately 800 ms later, when the S wave arrives with its associated reflected and refracted waves. Approximately 900 ms later, the R wave arrives with its associated reflections and refractions. The vibration gradually decreases and returns to zero sometime after the 4 second time window.

Actually the waveform recorded by the seismograph is the combination of many waveforms each having a different frequency. Studies have shown that high frequency wave energy is absorbed more readily than low-frequency wave energy so that the energy content of stress waves at large distances is concentrated at low frequencies. The velocity is referred to as particle velocity in order to distinguish this quantity from

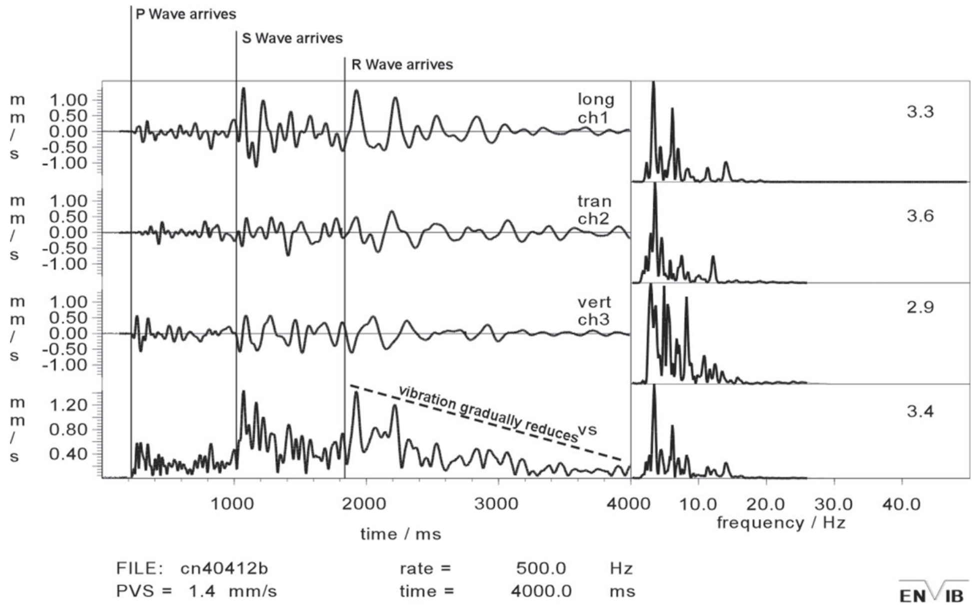

Figure 23.4 Ground vibration wavetrace of a blast in single blasthole.

propagation velocity. The peak particle velocity of ground vibration depends on the maximum weight of the charge per delay of eight milliseconds or more and not on the total charge weight of the blast. The most significant ground motion parameter is the maximum radial particle velocity, commonly referred to as peak particle velocity which is usually the maximum of the three components.

The amplitude of ground vibrations arising out of a mine blast increases with the energy released by the explosion, the confinement of explosive in the ground and to a small extent the density of rock.

Ground movement induced by blasting has some important characteristics. Usually the frequencies of vibration are in excess of 100 Hz in the close surroundings of the blast area. The vibrational frequencies and the maximum particle velocity decrease with increasing distance. If the rock mass is very hard more energy is absorbed in the vicinity of the blast.

23.3.2.2 Prediction of ground vibration levels

Research on accurate prediction of ground vibration levels through mathematical formulae has been carried out by many researchers. Some of the better known formulae are given here below.

23.3.2.2.1 Langefors formula

The formula proposed by Langefors is as under:

$$v = k * (Q/D^{1.5})^{0.5}$$

where

v = Peak particle velocity in mm/s
K = Rock transmission factor
Q = Instantaneous charge mass in kg
D = Distance from blast point in m

Langefors and Kihlstrom in their research in Sweden found that for the Swedish granite rock in which the research was carried out the rock transmission factor K was 400.

Specific attention must be given to the value Q i.e. instantaneous charge. Instantaneous charge is the charge that has blasted within a time period of 8 milliseconds.

For example, in a blast of 96 blastholes each containing 300 kg of explosive, if the timings of the delay interval were as given in Table 23.1, then the value of q will be

$$26 * 300 = 7800$$

because within a time span of 8 milliseconds (from firing time 30 to 35) 7 + 19 = 26 blastholes have been fired.

23.3.2.2.2 Scaled distance formula

For prediction of peak particle velocity, the scaled distance formulae are used more often than the Langefors formula. The general form of these formulae is as follows.

$$v = k * (D/Q^{(1/x)})^{-e}$$

where

v = Peak particle velocity in mm/s
k = Constant related to site conditions
Q = Instantaneous charge mass in kg
D = Distance from blast point in m
e = Exponent related to site conditions

In the above formula the term $(D/Q^{(1/x)})$ is called the scaled distance.

Table 23.1 Timings for a mine blast.

Firing time in milliseconds	*No of blastholes fired*
0	5
25	12
30	7
35	19
75	20
100	18
125	15

For x = 2 the scaled distance equals ($D/\sqrt{Q}$) and is called the square root scaled distance. This value was recognized through the investigations carried under USBM. This value is also adopted by US and Australian Standards.

For x = 3 the scaled distance equals ($D/\sqrt[3]{Q}$) and is called the cube root scaled distance. This value was recognized through the research carried out by Ambraseys, Hendron and Oriand.

The square root scaled distance is most commonly used and is based on the observation that the charge is distributed in a long cylinder (the blasthole), therefore the diameter of the hole is proportional to the square root of the charge weight. However, it can be argued that as the hole length shortens in relation to the diameter, the charge mass approaches a spherical shape, in which case the diameter is proportional to the cube root of the charge weight.

For estimation of the vibration level the value of k is taken as 1140 and the value of e is taken as = 1.6.

With these values the peak particles can be easily found, for different instantaneous charge masses and different distances, from the chart in Figure 23.5.

The site condition constant will differ depending upon the conditions. Values of this constant are:

for highly structured or hard rock k = 500,
for average conditions k = 1140,
for heavily confined blasting near field k = 5000.

The values of exponent e for different rock masses are as given in Table 23.2.

23.3.2.3 Damage by ground vibrations

Ground vibrations affect every living and nonliving entity.

Damage directly caused to human beings or other living entities by ground vibrations is virtually unheard of. This is because they are very loosely connected to the ground mass. More importantly they have inherent capability of responding to different vibrational frequencies by internal adjustments. However, human response to ground vibrations can be perceptible, unpleasant or intolerable depending upon the peak particle velocity and the frequency of vibrations. The chart in Figure 23.6 gives a fair idea of the human response to peak particle velocities and frequencies of ground vibrations.

Structures that are firmly fixed in the ground have only one natural frequency, which depends upon their structural properties. Natural frequencies of different types of structures are given in Table 23.3.

Damage to structures occurs due to differential particle movement as shown by Figure 23.7. It can be divided into three categories as stated in Table 23.4.

The significance of natural frequencies lies in the fact that when the ground vibration frequencies match with the natural frequencies of the structures, a phenomenon called resonance takes place. In such circumstances the amplitude of the vibrations keeps on increasing and the structure absorbs a higher quantum of energy. Eventually the stresses at certain points in the structure exceed the strength limit and the structure fails.

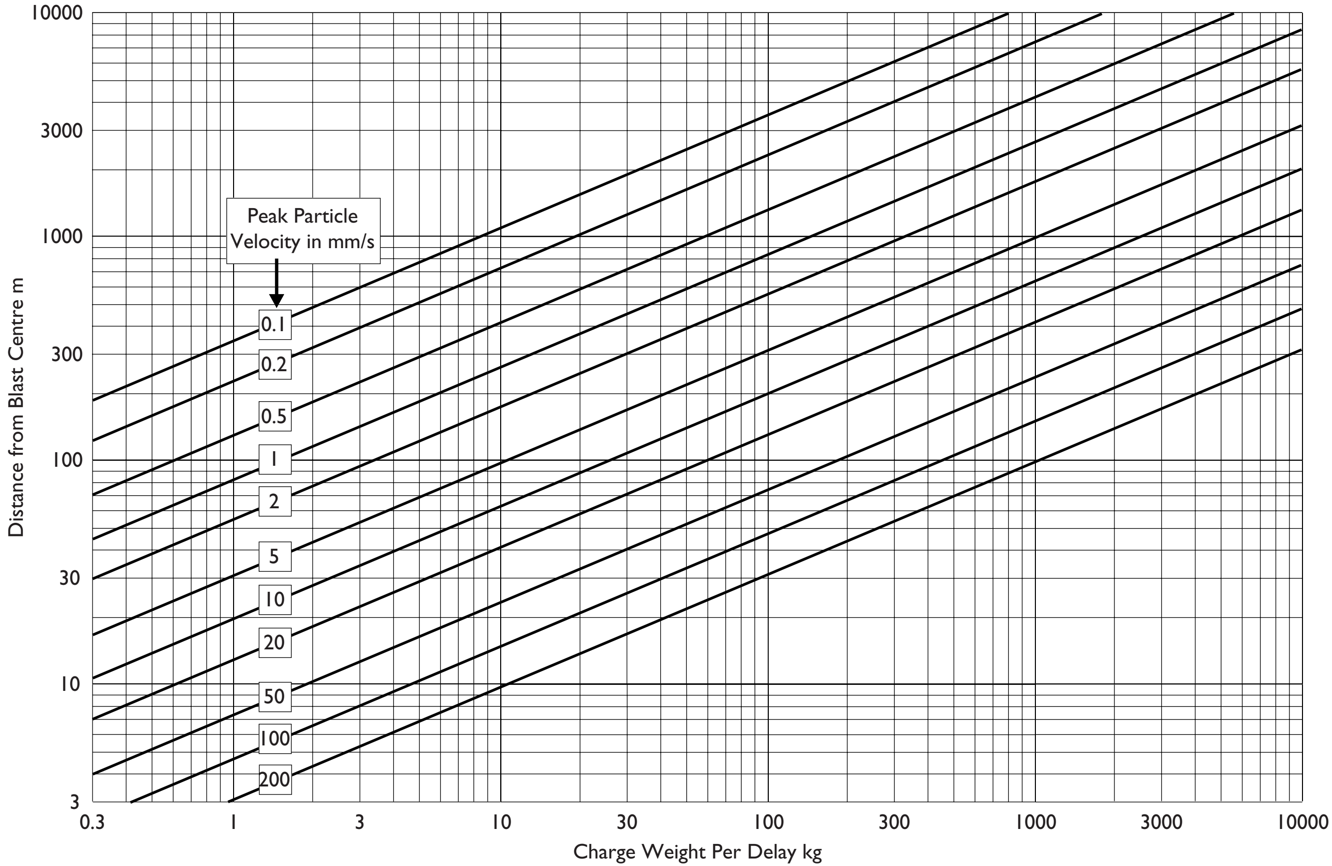

Figure 23.5 Chart for estimation of ground vibration level.

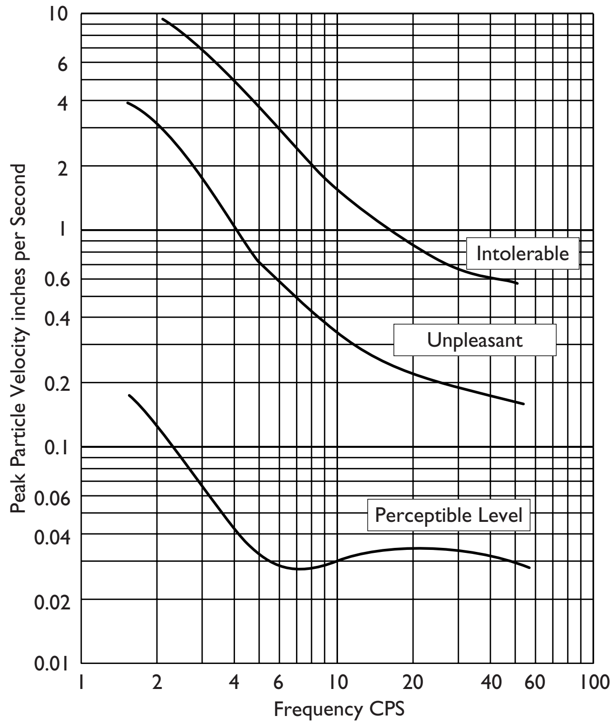

Figure 23.6 Response of humans to levels of ground vibration.

Table 23.2 Values of exponent e for different rock masses.

Rock mass type	*Value of exponent e*
Rhyolite	2.2–2.5
Granite	2.1–2.4
Limestone	2.1
Ordovician Sediments	2.8
Overburden in Coal Mines	1.5–1.8
Massive Basalt	1.9–3.0

Table 23.3 Natural frequencies of some typical structures.

Structure or element	*Natural frequencies (NF) in Hz*
Multistory Building	NF = 0.1N (N = Number of Stories)
Radio Towers 100 ft Tall	3.8
Petroleum Distillation Towers 65 ft Tall	1.2
Coal Silo, 200 ft Tall	0.6
Building Walls	12–20
Wood Frame Residences	7.0 (Standard Deviation 2.2)

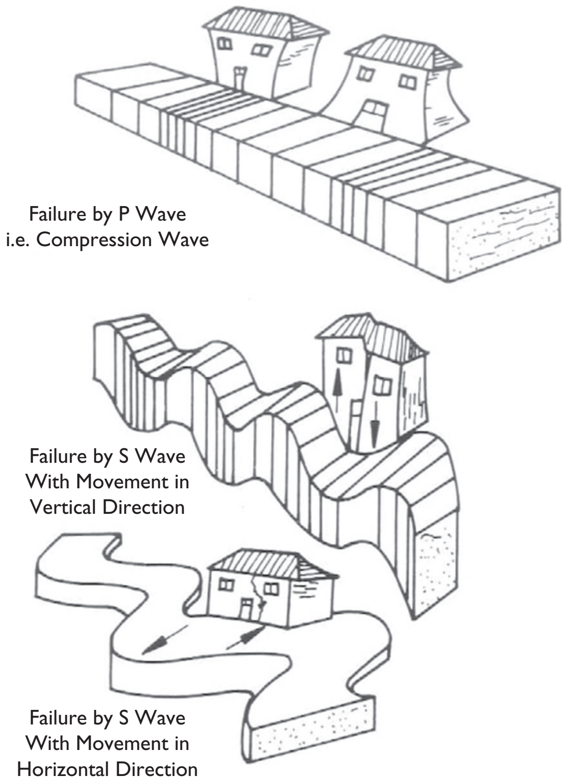

Figure 23.7 Effect of different types of ground vibration waves on structures.

Table 23.4 Three categories of damage to structures by ground vibrations.

Category	*Description of damage*
Threshold	Formation of new minor cracks in plaster or at joints in wallboard, opening of old cracks and dislodging loose objects.
Minor	Superficial, not affecting the strength of the structure; for example, loosened or fallen plaster, broken windows, significant cracks in plaster, hairline cracks in masonry.
Major	A significant weakening of the structure, large cracks, shifts of the foundation, permanent movement of bearing walls, settlements which cause distortion of the structure or walls out of plumb.

On the basis of research carried out, mainly in the USA, the maximum limits set for ground vibrations are as shown in Figure 23.8.

A maximum limit of peak particle velocity of 2 in/sec. was suggested by the U.S. Army Corps of Engineers, whereas a maximum limit of 1 in/sec. was suggested by USBM in 1977. Both these values were independent of the frequencies.

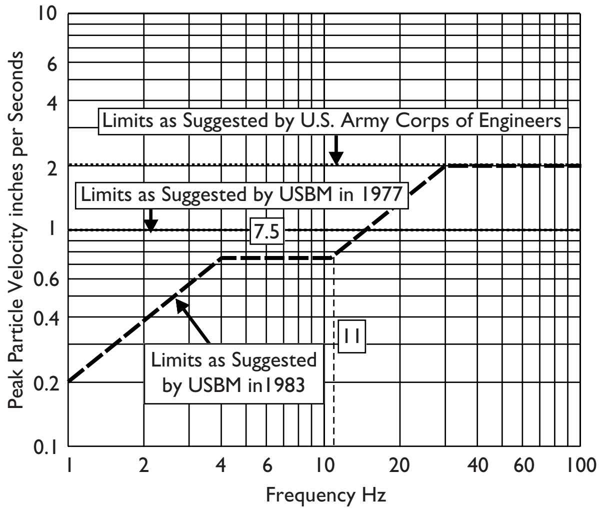

Figure 23.8 Limits of ground vibration levels to avoid damage to structures.

The latest limiting values as applicable from 1983 are based on more rational research by USBM and are dependent on ground vibration frequencies. This need arose because the tall structures are very vulnerable to ground vibrations with frequencies less than 10 Hz. This is quite evident from the values of natural frequencies given in Table 23.3.

It is usually possible to design the blasts by adjusting the mass of instantaneous charge in such a way that the peak particle velocities lie below these limits.

More detailed description can be found in many research papers and books.

23.3.3 Air blast

Air blast is often called air overpressure because the rapid movement of rock mass, and the ejection of gases under extremely high pressure, cause pressure waves by successively increasing and decreasing the pressure of atmospheric air.

The pressure waveform recorded from the blast of a single blasthole is shown in Figure 23.9.

Air pressure waves are essentially compression waves. Like ground vibration waves they also have amplitude and frequency. Higher amplitude means louder sound. High and low frequency sound waves form sharp or coarse sounds.

Human beings are not able to hear sounds of all frequencies. A few individuals may have the ability of hearing sounds of frequencies as low as 20 Hz and as high as 20 kHz, but for most persons the frequency of audible sound is limited to 60 Hz to 15 kHz.

The absolute air pressure that can be barely heard by a human with sharp ears is measured to be about 0.00002 i.e. $2 * 10^{-5}$ Pa. Similarly the air pressure at the point of blast has been estimated at 20000 Pa. Thus the range of pressure in the spectrum

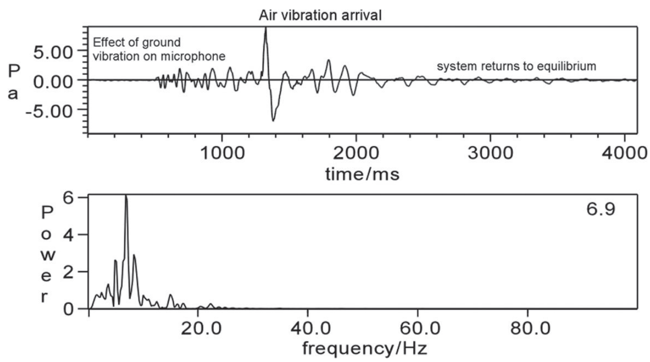

Figure 23.9 Air vibration wavetrace of a blast in single blasthole.

is very high. Therefore, air pressures are most usually described in terms of decibel, shortened to dB. The relation between actual pressures and dB is

$$dB = 20 * \log_{10} (P/P_0)$$

where
dB = Sound level value
P = Pressure as measured in Pa
P_0 = Reference pressure in Pa

23.3.3.1 Prediction of air blast pressure

The formula used for calculation of pressure of an air vibration wave is

$$P = A * (D/W^{0.33})^a$$

where
P = Peak air pressure in kPa
A = First site constant
a = Second site constant
D = Distance from blast in m
W = Instantaneous charge mass in kg

As per ICI "Handbook of Blasting Tables", airblast overpressure for an unconfined charge may be estimated through the following equation:

$$P = 185 * (D/W^{0.33})^{-1.2}$$

Extensive tests carried out by Terrock Pty Ltd. at a military firing range confirmed the above equation with slight variation as under.

$P = 182.5 * (D/W^{0.33})^{-1.2}$

For fully confined blasthole charges, the formula set forth by ICI is

$P = 3.3 * (D/W^{0.33})^{-1.2}$

However, as per tests carried out by Terrock this changes to

$P = 12.7 * (D/W^{0.33})^{-1.2}$

The above formulae can be used for the purpose of estimation of airblast pressures.

Air pressure of a blast diminishes as the pressure wave travels away from the blasthole.

Tests carried out by Terrock revealed that when the distance from the blasthole was doubled, a pressure drop of about 7 to 10 dB was experienced. The most common value was 8.6 dB.

On the basis of data collected, the graph as shown in Figure 23.10 was constructed.

It is to be noted that air blast pressure waves travel from the blastholes towards the bench face and then away in the same direction without much pressure drop. However, the pressure drop towards the rear side is much higher.

23.3.3.2 Damage by air blast pressure

For quick apprehension of the levels of sound i.e. air blast pressure waves, Table 23.5 mentions different sound levels and the corresponding sound commonly heard.

Usually below sound pressure level of 90 dB no hearing loss occurs even if it is heard for 8 hrs per day. Above this level hearing loss occurs. The hearing loss is greater when sound pressure is higher and/or duration of hearing is longer.

When sound pressure level is about 100 dB, to avoid significant hearing loss the maximum duration should not exceed 2 hrs in a day.

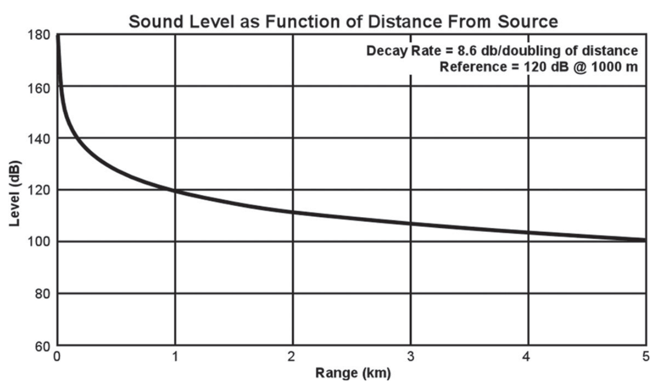

Figure 23.10 Reduction in air blast pressure with distance.

Table 23.5 Air blast pressure wave examples.

Pressure level dB	*Value of exponent e*
180	Most Structures Severely Damaged
176	Plaster of Walls Crack
171	Most Windows Break
155	Space Rocket
151	Some Windows May Break
133	Most Commonly Adopted Maximum Allowable Value
130	Jet Airliner
110	Large Orchestra with Electric Amplification
100	Pneumatic Rock Drill without Silencer
90	Loud Noise by Human
60	Conversational speech
40	Normal Conversation
25	Whisper
5	Rustling Leaves
0	Threshold of Hearing

When sound pressure level is about 115 dB to avoid significant hearing loss the maximum duration should not exceed 15 minutes in a day.

Ear plugs or ear muffs are required to be worn to reduce hearing loss in conditions of harsh and loud sound. These devices have been found to be useful in reducing sound levels entering the ear by about 20 dB.

Sound pressure level of 133 dB is the maximum allowed even for a very short period of time. Beyond this level the air blast pressure wave causes pain to the ears. Injury may occur to the ears even with protection.

Damage to structures starts at about 133 dB and increases as indicated in Table 23.6.

There are many means by which damage from air blast can be minimized. Some of them are as under.

1 Ensure that all blastholes are adequately stemmed with appropriate stemming material. To prevent blowouts from blastholes a stemming length of 30 times the diameter of the blasthole should be used
2 Ensure that the front row has adequate burden. Adjust the charge according to the available burden
3 Adopt appropriate timing delays and sequence
4 Keep the rate of detonation across the face less than the speed of sound
5 Ensure that all explosive materials like detonating cords etc. are buried at least one foot in the ground
6 Do not carelessly leave any unused pieces of detonating cord or other explosive items on the bench top
7 Do not use more explosive in a delay than permitted
8 When possible, delay the blast to direct movement away from critical areas

Table 23.6 Damaging effect of air blast pressure waves.

Pressure level dB	*Value of exponent e*
<153	Severe shaking of windows and doors but no damage
165	One out of twenty properly mounted window glass may just break
166–173	Most of the window glass break depending upon the pressure
<173	All glass will break and additionally intact plaster of the wall may also break

9 Avoid adverse environmental conditions such as blasting when wind is blowing toward residential areas, or under an atmospheric temperature inversion
10 Do not blast more often than necessary
11 Time blasts to coincide with peak ambient noise levels
12 Give adequate warning messages about a blast in the offing to all those who are likely to be within 3 to 5 km distance from the blast bench. Use a warning horn, loudspeaker messages etc.

23.3.4 Fly rocks

In a mine blast the build up of excessive pressure within the blasthole exerts a propelling force on the pieces of rock and makes them fly like a projectile. These are called flyrocks. The throw of flyrocks is very unpredictable as far as their precise direction is concerned. However, it can be said that flyrocks usually move from the blastholes in the first row towards the free face as shown in Figure 23.11. Flyrock can be attributed to many reasons. Some of them are as under.

1 Inadequate burden
2 Use of high quantity of explosives charge
3 Insufficient stemming height
4 Improper firing sequence
5 Use of heavily loaded snake holes.

Flyrock studies have been conducted only recently on a large scale when high speed cameras became easily available. Their use in the field enabled visual tracking of the trajectories of the flyrocks.

It has been observed that when the specific charge in the blasthole is less than about 0.2 kg/m^3, there is hardly any throw of flyrocks. As the specific charge becomes higher, the distance to which flyrocks fly becomes greater. An empirical relation between different associated variables is

$$L = 5.63 * d * (q - 0.2)$$

where
L = Maximum throw of flyrocks in m
q = Specific charge of the blast in kg/m^3
d = Diameter of blasthole in mm

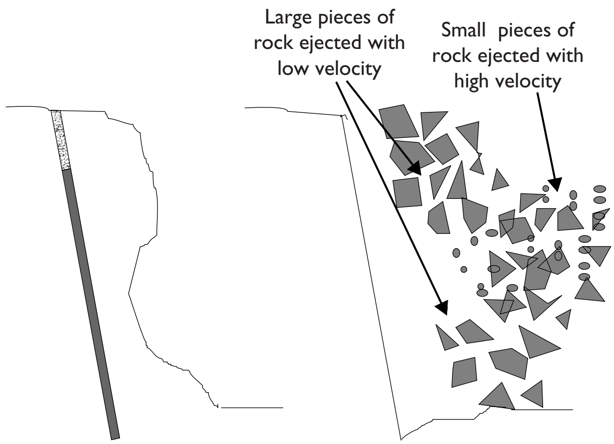

Figure 23.11 Flyrocks at the position of reduced burden.

Thus for a typical value of 0.5 kg/m^3, the equation becomes

$L = 1.689 * d$

From this a flyrock throw distance of 525 m can be estimated for a 311 mm dia. blasthole.

Two more empirical equations have been set forth after analyzing the problem with the help of computer simulations. They are as under.

$L = 260 * d^{0.66}$
$\phi = 0.1 * d^{0.66}$

where
L = Maximum throw or flyrocks in m
d = Diameter of blasthole in inches
ϕ = Diameter of boulder in m

From this equation for a 10 inch diameter blasthole, the throw distance of 1188 m can be calculated for a boulder of diameter 0.47 m.

More research is needed in respect of flyrocks so as to formulate safe limits.

Till then blasters have to rely on the factors stated above and more importantly their experience in blasting.

23.3.5 Air pollution

Air pollution is probably the most devastating hazard of mining. Unfortunately it is never considered so because effects of air pollution are not immediate like air blast, fly rocks or ground vibrations.

Following are some of the happenings during or after the blast.

The formation of toxic fumes in chemical reactions that take place during blasting was described in chapter 18 of this book.

The noxious gases formed in the process, viz. carbon monoxide, nitrogen oxide and nitrogen dioxide, mix with air. Their concentration quickly reduces below the danger levels. Sometimes they remain entrapped below the heap of broken rock and can make their presence felt even after some days but they too eventually mix with atmospheric air and their concentration reduces below danger level.

If someone has to be in the midst of a blasted bench immediately after the blast he must wear an oxygen mask and special suit.

In a mine blast more serious pollution of the atmospheric air is caused not by noxious gases but by other factors.

The first of these factors is the dust. Rational guesswork in this regard indicates that at least 500 g of dust is being mixed with the atmospheric air for each m^3 of blasted material in a mine blast.

Silicates being the most abundant minerals in the earth's crust, a very large part of the dust is siliceous. Millions of microscopic silica particles go into the lungs with every breath. As they do not have any role in the body they are not absorbed into the blood. They remain glued to the alveoli through mucus and are not excreted with exhalation. This way silica particles accumulate in the lungs. Over time scar tissue develops in the lungs, which damages the lungs' ability to work properly.

The inhalation of silica particles has also been linked with lung cancer, bronchitis and tuberculosis. The silicosis itself may lead to other conditions including lung fibrosis and emphysema. The disease is also linked to a fatal pulmonary tuberculosis actually called silico-tuberculosis. As the disease progresses, the person experiences increasing difficulty in breathing and may die. Workers working near the points of pollution are at greater risk.

The medical community considers that these diseases are incurable and irreversible and may progress even after the exposure ends. This is not entirely true.

Silicosis kills thousands of people around the world every year.

Variants of silicosis are only a part of the story.

Apart from silica, every blast mixes several million metallic free radicals with atmospheric air. These metallic free radicals are mainly of lead, mercury, aluminum and copper. Depending upon the mine, nickel, beryllium, uranium, cadmium, iron etc. are also mixed in atmospheric air. Molecular or atomic size particles of these elements are very active because they are deficient in their electronic balance. They lack one electron and hence are termed free radicals. When they enter into the human body, they try to grab electrons from the atoms in their contact. This proves very harmful to human body as it accelerates ageing. Persons exposed to such an environment succumb to several degenerative diseases in their forties or fifties rather than eighties.

High blood pressure, coronary artery disease, Alzheimer's disease and Wilson's disease are some examples of such diseases.

These diseases are also considered to be incurable, irreversible and progressive. This is also not entirely true.

If not curable, these diseases are reversible to a very great extent with appropriate medical treatments. I have studied these aspects and later given treatments to some patients and verified this.

In any case the treatments for these diseases are very long drawn if not very expensive.

23.3.6 Environmental changes

Hazards of drilling and particularly blasting have very long term effects on the surroundings. They not only affect the human population in the vicinity but also affect all types of animals and plants.

When a mining project is to be started, a large area is acquired by the authorities. It runs into several thousand hectares. Such a large area is required for the actual mining site and also the processing plants, township of mine workers etc. The area is often a forest land where trees and shrubs have grown for centuries. Several generations of animals have spent their entire lifespan there. Birds have sang morning and evening songs. Reptiles have hissed.

As the mining project progresses greenery reduces when trees and shrubs are cut. Birds fly away as they have no place to make their dwelling. Animals run away when their food resources have dried up. Reptiles come out of their underground holes and are often killed on the makeshift roads.

In a typical mine scenario, the work site is almost invariably situated far away from the locality. Even the workshop is located a few kilometers away. As the mine starts, the burning sun and movement of heavy equipment on the dry ground make the atmosphere so dusty that the color of the surroundings gets rapidly converted into the color of dust layers deposited on such surroundings. Harsh rattling noise of the machines often becomes unbearable. Visitors unaware of such surroundings get frustrated. Their frustration turns into annoyance when they realize that even for a glass of water they have to tread a kilometer of uneven dusty road.

In the last few decades the grave consequences of such changes in scenario have been noticed, and now every mining project, whether government-owned or private, has to take necessary steps towards preserving or restoring the environment.