13.1 INTRODUCTION
Blasting has less of an influence on pit-wall stability than geology and groundwater. Of course, the geology of a pit cannot be changed, yet a mine operator can usually exert more control over blasting than over groundwater. Although blasting is usually the third most influential factor, it is the factor that can be controlled most.

When one considers the immense power of explosive charges in normal production blasts, it is not surprising that the rock mass adjacent to the blast block is weakened. Rock-mass strength can be almost eliminated where a rock mass is very close to charges. New fractures and planes of weakness are created in the adjoining rock, and fissures (i.e., natural cracks) are opened and sometimes extended. New, dilated and extended cracks are manifested as overbreak.

Overbreak has a deleterious effect on the inclination of final bench faces and a lesser effect on the overall inclination of pit walls. If a blast is not well designed, overbreak can contribute to pit-wall instability. The extra effort, expense, and care required to produce a more stable and, consequently, safer pit wall usually cost less than the corrective measures that must be taken once a hazardous pit wall has been formed. Therefore, it is important to optimize (not minimize) overbreak, especially as blasts approach the designed wall of the pit. The successful application of overbreak-control blasting techniques reduces not only the quantity of rock to be removed, it lessens the hazard and cost of rock Falls and may reduce the need for pit-wall support. The predicted cost savings resulting from less damage help to determine the expenditure that can be allocated to improving blasting techniques.

Where ground vibration fails to produce new fractures or to extend fissures or blast-induced fractures significantly, its contribution to instability is usually less than that of overbreak.

Because the design, implementation, and effects of blasts can be controlled within wide limits, mine operators are able to promote stability by controlling blast-induced damage. To fully appreciate the relationship between damage and blasting, it is necessary to understand how the design of blasts affects overbreak and ground vibrations.

13.2 PIT-WALL BLASTING RATIONALE
As production blasts approach a designed pit wall, there is usually a distance within which mine operators should be concerned with protection rather than production. Accordingly, provided there is sufficient working area, blasts on a given bench should consist of production blasts that are relatively remote from the designed pit wall and pit-wall blasts that abut or are close to the designed pit wall. If overbreak by production blasts is minimized, the volume of pit-wall blasts can be reduced.

In pit-wall blasts, there is a strong economic incentive to achieve the required levels of soundness and smoothness at the lowest possible cost. The cardinal way to lower cost is to implement economies of scale into the design of pit-wall blasts. Economies of scale can be best achieved by utilizing blasting knowledge and expertise to control the adverse effects of using large-diameter production blastholes charged with bulk explosives as close as possible to the designed pit wall.

13.3 SELECTING PIT-WALL BLASTING TECHNIQUES
As a normal production blast is progressively modified to reduce overbreak and ground vibrations, it first becomes a production blast, then a cushion blast, then a postsplit blast, and finally a pit-wall blast that features both cushion blastholes and postsplit blastholes. Presplit blasts are often fired in association with cushion blasts as an alternative to postsplitting. Presplit blasts are different in that
- Presplit blastholes are fired before and immediately in front of the blastholes, sometimes in a separate blast.
- Where the height of a final face is to be two or three times the normal bench height, the depth of presplit blastholes is sometimes two or three times that of the blastholes in front of the presplit.

In this chapter, pit-wall blasts are divided into three categories
- Modified production blasts
- Smoothwall blasts
- Blasts that incorporate presplitting (see Table 13.1)

Smoothwall techniques and presplitting are often used to produce pit walls with great integrity and/or smoothness. The satisfactory (sometimes spectacular) results that are obtained tend to explain the popularity of such methods. However, the subject of damage control is greater than that of smoothwall blasting and presplitting.

The blasting technique selected to control damage must first be safe and then, very importantly, cost efficient. The aesthetic aspect of a presplit face should not bias judgment on the cost efficiency of this technique. If sufficient success can be achieved with modified production blasts, the need for smoothwall blasting or presplitting can be reduced or even eliminated.

13.4 MODIFIED PRODUCTION BLASTS
The overbreak caused by production blasts is reduced by lowering the concentration of explosive energy in the adjacent ground. Contrary to popular belief, the redesign of a production blast to reduce wall damage usually improves the fragmentation, displacement, and looseness of the muck pile.

A modified production blast is a blast that has been modified uniformly over its entire area, not just the back-row blastholes. A modified production blast should shoot to a free face and have only one charge detonating per delay.
Comparing with a normal production blast, a modified production blast should have fewer rows of blastholes and longer interrow delays. The blasthole pattern, charge weight, and powder factor should be the same as for normal production blasts. A stand-off distance should be allowed between the back-row blastholes and the designed final face (Figure 13.1). Digging equipment is required to dig back through the overbreak zone to form the final face. While the material in the overbreak zone may be considered bonus production, the digging rate normally decreases as the designed final face is approached.

The greatest challenge lies in optimizing the stand-off distance so that there is neither an excessive amount of damage nor excessively difficult digging back to the designed final face.

The optimum stand-off distance is larger for choke blasting (compared to free-face blasting) and increases with increases in blasthole diameter, effective burden distance, number of rows of blastholes, effective subdrilling, and bench height; it increases with decreases in rock-mass strength, powder factor, and the delay interval between dependent charges.

### 13.5 Smoothwall Blasting

The blasts that are located directly in front of postsplit or cushion blastholes should shoot to a free face rather than to a choked face and have:

- The minimum practicable number of rows of blastholes
- High powder factors and correspondingly small burden distances and blasthole spacings
- Interhole and interrow delays that ensure single-hole firing
- Interrow delays that result in good progressive relief of burden
- Zero or, preferably, negative subdrilling for the blastholes that are above a designed final berm or located just in front of a designed final crest

Usually the optimum powder factor for these blasts is expected to be low. However, low powder factors normally result in little forward displacement and overbreak from explosion.
gases jetting backward into fissures and blast-generated cracks. Overbreak is limited by using high powder factors, provided relatively small blasthole patterns are employed, not heavy charges.

Where the designed final face is steeply dipping (say >70°), a vertical back-row blasthole is usually satisfactory to form the final face. Where the designed inclination of a final face is flatter than 70°, the best solution is to angle the back-row blastholes, if possible, or add vertical stab blastholes to help fragment the increasingly large volume of rock behind the full-depth blastholes.

13.5.1 Cushion Blasts
Cushion blasting is the simplest and least expensive smoothwall-blasting technique. A cushion blast is a pit-wall blast in which back-row blastholes contain lighter charges and are drilled in a correspondingly smaller pattern (Figure 13.2). The diameter of cushion blastholes is usually the same as that of production blastholes in front of them. The charge weight for the cushion holes is commonly reduced by about 45% and both burden distance and blasthole spacing by about 25%. Therefore, the powder factor is similar throughout the pit wall blast. The lighter charges are better distributed within the blasthole by air decking and conventional decking, by using a lower-density explosive, or by decoupling. Because of the smaller burden and spacing for back-row blastholes, cushion blasting increases the costs of drilling, priming, initiation, and blast crew labor.

Cushion blastholes should detonate in a delayed sequence after the more heavily charged blastholes in front of them. Every cushion blasthole should be well relieved by the proper performance of adjacent earlier-firing blastholes. Due to the reduced spacing of cushion blastholes, it is often necessary to fire two adjacent blastholes with a short delay between them. Otherwise, the back-row production blastholes will detonate far enough ahead of the cushion blastholes to have sufficient time to displace their charge(s).

Cushion blasting is used without pre- or postsplitting where the rock is strong or only minor reductions in damage are required or for forming pit walls with relatively short lives. The use of smaller-diameter cushion blastholes reduces and may even eliminate the need for decked charges and correspondingly small pattern sizes. As the diameter of cushion blastholes decreases, cushion blasting merges into postsplitting.

13.5.2 Postsplit Blasts
Postsplitters consists of
1. Drilling a row of parallel, closely spaced blastholes with a suitable burden to spacing ratio (usually about 1.25:1) along the designed final face.
2. Loading every blasthole with a light, well-distributed charge.
3. Initiating these charges after the charges in front of them have detonated.
13.6 PRESLITTING

13.6.1 Background

Presplitting involves

1. Drilling a row of parallel, closely spaced blastholes along the designed final face.
2. Charging these blastholes very lightly.
3. Detonating these blastholes before the blastholes in front of them.

Firing of the presplit charges splits the rock along the designed final face, producing an internal surface to which the later-firing blastholes in front of them can break. The presplit plane acts as a pressure release vent for the explosion gases generated by charges in the back one or two rows of blastholes in front of the split. It also partially reflects the blast-generated strain waves and so reduces the strains that are experienced beyond the split. The result is a relatively undisturbed face with less shattering, rock movement, and damage.

13.6.2 Effect of Rock-Mass Properties on Presplitting

Presplitting rarely gives impressive results in closely fissured rock. When overcharged, presplitting can damage appreciable volumes of rock as explosion gases vent through the fissures. Under favorable geological conditions (massive rock of moderate to high strength), presplitting can provide improved results over postsplitting but is generally more costly. However, if the presplit blastholes are too close together or overcharged, they themselves will produce damage.

13.6.3 Limitations of Presplitting

The few limitations of presplitting are primarily restricted to the ground and air vibrations produced by firing the presplit blastholes. The levels of ground vibration per kilogram of explosive for these blast are usually much higher than those for production blasts because the rock that is remote from the bench face is relatively undisturbed.

In theory, there is no limit to the length of presplit that can be fired in a single blast. In practice, however, the possibility of rock properties changing and the charge either failing to produce the split or causing excessive damage is good reason not to fire presplits far in advance of the pit-wall blasts. By keeping the presplit about three regular spacings (see Figure 13.4) in advance, any knowledge of changes in rock properties gained from the results of pit-wall blasts can be promptly applied to subsequent presplit blasts. The risk of presplitting the entire length of the designed pit wall in a standard manner is high when rock properties vary frequently over short distances.

13.6.4 Diameter of Presplit Blastholes

There is no limit to the diameter of presplit blastholes; diameters of up to 406 mm have been used in large open pits. To achieve economies of scale, there is an incentive to use large-diameter rather than small-diameter presplit blastholes. Unfortunately, the diameter of angled presplit blastholes is limited by the drill that can drill angled blastholes beneath the body of the drill and/or at 90° to the drill's tracks. Most large rigs can only drill angled blastholes where there is sufficient bench width to provide tail room for the drill. Therefore, maximum economies of scale can often be achieved only where vertical presplit blastholes are geotechnically acceptable.

13.6.5 Length of Presplit Blastholes

Theoretically, there is no limit to the depth that can be presplit in a single blast. In common with other pit-wall blasting techniques, however, presplit results depend on good blasthole alignment. Blasthole deviation usually improves with increased hole diameter.
13.6.6 Blasthole Spacing and Charge Concentration

The spacing and charge load for presplit blastholes normally increase with the blasthole diameter, as shown in Table 13.2. But because rock properties have a dominant effect on blasthole spacing and charge load, these data, based largely on experience in average rocks, should be considered only as recommended starting values. The optimum spacing and charge load for a particular rock should be determined by field trials. The spacings shown in Table 13.2 are conservative, and satisfactory results could be achieved with spacings larger than those listed, especially where pronounced fissures are parallel or nearly parallel to the designed final face.

13.6.7 Charging Presplit Blastholes

Over the last several years, the labor-intensive task of attaching cartridges of explosive to a detonating cord downline has been changed by the development of continuous columns of small-diameter explosive for presplitting. Continuous charges are optimum from the energy distribution viewpoint. However, because their energy yield per meter of charge length is constant, their use does not allow small changes in powder factor, which are achievable with spaced cartridges on a downline. With continuous charges, the effective concentration of energy can be varied by:
- Taping two or more continuous charges (of equal or different diameter) alongside each other
- Doubling over different lengths of the charge at the base of the blasthole
- Changing the stemming length or (uncharged) collar length of the blasthole

Changing the blasthole diameter is a fourth but much less practical way to vary the effective energy concentration.

With large-diameter blastholes, presplitting can sometimes be carried out using a low-density bulk explosive. The energy concentrations of these explosives are too high for long, continuous, fully coupled presplit charges but are usually acceptable for fully coupled charges that have a long column of air above them. With these charges, the best presplit results are achieved by:
- Lowering the density and energy concentration of the explosive
- Top priming
- Avoiding the use of stemming

If stemming is necessary to control air vibrations, the air deck above the charge should be long enough to provide a sufficiently low mean energy concentration over the unstemmed part of the blasthole.

13.6.8 Stemming Presplit Blastholes

If there is no need to control air vibrations, presplit blastholes should not be stemmed, allowing the explosion gases to jet into the atmosphere very rapidly. Because they are not "bottled" up at high pressure below a stemming column, the explosion gases are less likely to jet into cracks that intersect the upper wall of the blasthole. This will reduce damage to the crests of final berms.

Where long, highly decoupled presplit charges are used in massive rock, every blasthole should generally be charged to within about 10 blasthole diameters of its collar. In closely fissured rock (rock in which the mechanical efficiency of presplitting is lower), the uncharged collar should be as long as about 15 diameters.

13.6.9 Firing Presplits

Firing Presplits as a Separate Blast. Presplit blasts should be fired separately and ahead of the adjacent pit-wall blast; the pit-wall blast is located where the total burden distance is so large that the presplit charges could not possibly push the entire block of rock to be broken by the adjacent pit-wall blast forward. In this situation, the presplit defines the designed final face before blastholes in the adjacent blast are drilled. Once satisfactory blasthole spacing and energy concentration have been determined in one or more trial blasts, presplitting can be carried out at any convenient time. Presplit planes should not be subjected to heavy rainfall or severe groundwater conditions for prolonged periods. The accumulation of water and silt in presplit fractures significantly reduces their ability to act as vents for backward-jetting explosion gases, as reflectors of strain waves, and hence, as damage barriers.
If optimum presplit results are to be achieved, charges should be initiated simultaneously. This is successfully achieved by joining all downlines from presplit blastholes to a detonating cord trunkline. Where ground vibrations are likely to cause damage or disturb residents, however, delays should be inserted into the trunkline at intervals to obtain the consecutive firing of groups of blastholes. The number of blastholes in each group should be sufficient to achieve a satisfactory splitting action while not exceeding the maximum charge weight that can be fired per delay. The major advantage of firing presplits separately is that it simplifies drilling and blasting operations. Where a pit-wall blast is already quite complex, the addition of presplit blastholes further increases the complexity. There is a greater probability of errors and, hence, suboptimum results with blasts that are more complex.

**Firing Presplit Blastholes with the Adjacent Pit-Wall Blast.**

Presplit blastholes should not be fired separately where the total burden distance is smaller than about 150 times the diameter of the presplit blastholes, since ground movement could cause drilling, charging, or cut-off problems. Where the total burden distance is inadequate, the presplit blastholes should be fired with the adjacent blast. Such ground movement could make the subsequent drilling of production (or cushion) blastholes difficult or impossible. If blastholes for the adjacent pit-wall blast have been drilled before firing the presplit, the blastholes just in front of the presplit could be damaged to the extent that they cannot be charged properly. Where these blastholes have been drilled and charged before the presplit, the downline could be severed before it has detonated.

Combining the presplit blast and adjacent pit-wall blast into a single firing is more complex but it eliminates a step in the drilling-and-blasting cycle. Composite blasts can be drilled, charged, and fired in a single cycle, thereby reducing labor requirements and the (unproductive) movement of personnel and equipment out of and back into the blast area.

As shown in Figure 13.5, a key requirement in firing a presplit with a pit-wall blast is to time the presplit to fire after the adjacent surface delays have fired to minimize the risk of a surface cut-off but before the in-hole delays fire to enable the presplit to develop completely. Allow at least 50 ms between the presplit and the earliest-firing production blastholes in their vicinity for the latter. In the above example, there is more than a 200-ms gap between all blastholes, allowing plenty of time for the presplit to form.

As many presplit charges as possible should detonate simultaneously as blast-generated vibrations or as the initiation timing will allow. The example in Figure 13.5 shows six to seven blastholes being fired together to reduce that risk.

If the time interval between the presplit detonation and the blastholes immediately in front of them is excessive, ground movement could cause cut-offs in the production or cushion blastholes. This is especially likely where

- Adverse fissures exist
- Presplit blastholes are overcharged
- An inadequate stand-off distance between the presplit blastholes and the row of blastholes immediately in front of them is used

The optimum delay interval between the presplit detonation and the blastholes immediately in front of them should be at least 50 ms and typically in the 100-ms to 200-ms range. For this reason, as illustrated in Figure 13.5, 200-ms delays were used to initiate the presplits to force a sub 200-ms gap between them and the adjacent production holes.

**13.6.10 Protecting Presplit Faces**

Presplit faces will be damaged or even destroyed if production or cushion blastholes are drilled too close to them. If the stand-off distance is excessive, a wedge of unbroken rock will be left at the base of the presplit face, possibly requiring re-blasting.

The back-row charges of the pit-wall blast, not the presplit charges, break the rock between these two rows of blastholes. Heavier toe charges in presplit blastholes do not assist in preventing large wedges or monuments of rock but, in most cases, damage the presplit face at its base. Although the stand-off distance is optimized by trials, it is typically 40 to 70% of the burden distance for the back-row production or cushion blastholes, depending on whether the rock mass is strong and massive or weak and closely fissured.

It is most important that back-row production or cushion blastholes be well relieved. The burden distance, energy factor, and delay allocation should be such that each back-row charge sees an effective free face that is reasonably near and as extensive as possible. Where such relief is achieved, back-row charges find it reasonably easy to break and heave their burdens laterally and, therefore, do not subject the presplit plane to prolonged back pressure.

**13.7 CONCLUSION**

Although blasting does not influence pit-wall stability as much as geological factors or groundwater, it is more easily controlled. The aim of pit-wall blasting is to achieve the optimum balance between damage control and cost effectiveness. The most effective and expensive technique is to use presplit holes in conjunction with cushion blastholes. The simplest technique is to modify production blast design adjacent to the pit wall. Whatever design is selected, it will require optimization using a series of engineered field trials.