INFLUENCE OF GEOLOGICAL DISCONTINUITIES UPON FRAGMENTATION BY BLASTING

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ABSTRACT: Discontinuities are an integral part of the rock masses and pose special problems in blasting operations in mining and civil industries resulting in high excavation cost due to underbreak and overbreak problems. Experience has shown that the excessive blast damage to the perimeters of underground and surface excavations due to presence of discontinuities can be controlled in an appreciable manner by careful blast design keeping in view the discontinuities present in the rock masses. This paper reviews the findings of different researchers on the influence of geological discontinuities upon rock fragmentation by blasting and discusses some methods proposed to control the overbreak problems in excavation.

INTRODUCTION

Blasting is an integral part of mining and civil construction activities and is inherently a destructive process. The quality of the rockmass in which an excavation is being driven has a strong influence on the level of dynamic forces to which the rock can be subjected and sustain damage. Generally all actual rock masses have different types of discontinuities spread throughout the rockmass. Joints, bedding planes, layering, foliation and faults are amongst the most common type of discontinuities. It has been reported by Persson *et al*. (1994) that blasting in a homogenous isotropic medium naturally does not result in the same fragmentation pattern as when the medium is permeated with discontinuities. In most rock materials, fissures occur, thus reducing the explosive induced stresses due to shock wave reflections. Radial cracks from the explosive charge are effectively arrested at the fissures when the stress concentration factor becomes too low and the explosive gas penetrates through already existing fissures. Bedding planes in sedimentary rocks and foliation in metamorphic rocks can result in the rock material properties which are dependent upon loading direction. The previous stress-time history in apparently homogenous sedimentary rocks and the differences between the principal stresses can very much change the explosive-induced fracture pattern and thereby affect the fragmentation.

Singh (2005) reports that rock formations often contain bedding planes and joints. These jointed rock formations cause a very serious problem in terms of safety &stability of the underground excavations. It is found that the underground controlled blasting techniques which work well in the massive deposits, yield poor results while adopted in jointed rock formations in controlling over break. This over break due to blasting is a serious problem for mining industry as it not only decreases the productivity but also is a big threat to the safety. In order to control this damage caused by blasting, it is very important to understand the effect of joints on blasting results. This paper will highlight the problems associated with the presence of discontinuities in the blasting operations and the remedial measures proposed by different researchers.

Rock Mass Features: Scoble *et al*. (1996) found that during designing of a blast, the rockmass is considered to be homogeneous. In reality rock contains features like joints and other discontinuities, which have a pronounced effect on the blasting results. In order to have a smooth and stable excavation perimeter, it is important to have good understanding of effects of these rockmass features on the blasting results.

Orientation of Discontinuities: From experiments, Worsey et al. (1981) found that the results of controlled blasting depend upon the angle between the designed perimeter line and discontinuities. If this angle is less than 60^0 the results of the controlled blast will become poor, while if the angle is less than 15^0,then controlled blasting will have no significance over normal blasting.

Hustrulid (1999) cites from Burkle (1979) and states that blasting results are affected by the orientation of the rock mass structures. Three cases which have to be considered arei) shooting with the dip, ii) shooting against the dip and iii) shooting along the strike. While shooting with the dip back break increases, toe problem decreases resulting in a smooth floor and throw of the blast increases resulting in scattered and low muck pile (Figure 1a). When shooing against the dip one finds less back break, more toe problems resulting in uneven floor and throw of the blast decreases resulting in higher muck pile profile (Figure 1b). Finally, when shooting along the strike (Figure 1c) one finds that the floor can be highly sawtoothed due to the different rock types intersecting the floor. For the same reasons the backbreak is irregular.

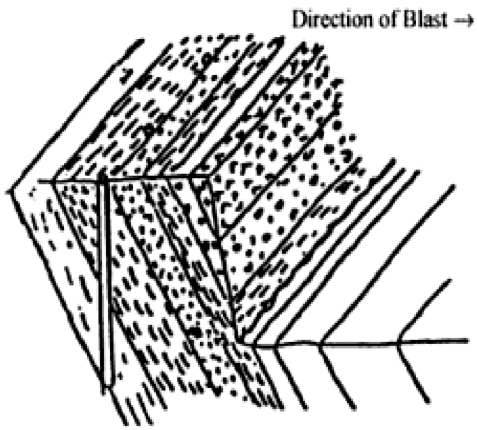

Figure 1a.Diagrammatic representation of shooting with dip (Burkle, 1979).

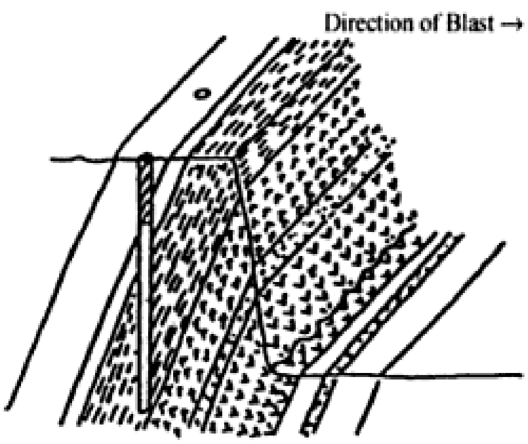

Figure 1b.Diagrammatic representation of shooting against the dip (Burkle, 1979).

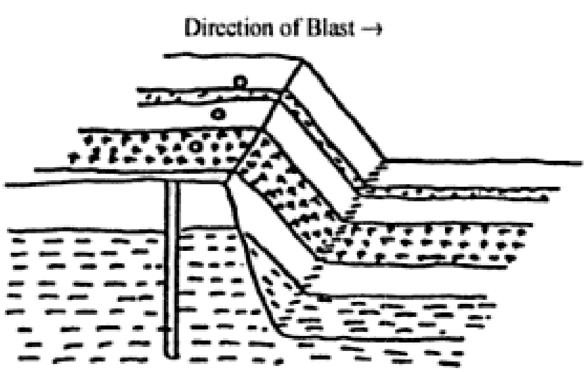

Figure 1c. Diagrammatic representation of shooting along strike (Burkle, 1979).

Singh and Xavier (2005) have cited from Cunningham and Goetzsche (1996) andwrote that joint's orientation plays a key role in the stability of the perimeter of the underground excavations. The intensity of the induced stress wave can be decreased (attenuated) by these joints. The degree of attenuation depends upon the angle of incidence between the surface of the joint and the wave passing through the joint. If this angle is perpendicular or parallel to the face then attenuation will be minimum, on the other hand if this angle is from 15^0 to 45^0 then attenuation is maximum (Lewandowski et al., 1996). It is therefore suggested thatperimeter control will be easy if angle between joints and perimeter line is nearly parallel, parallel or at 90^0as attenuation will be minimum, while for all other anglesattenuation will be increased resulting in poor perimeter control.

Singh and Narendrula (2007) investigated the relationship between orientation of joints and perimeter control. High strength concrete modelshaving different joint orientations were used for experiments. The blastholes with joint orientations at 45^0 produced the worst results,i.e. maximum overbreak(Figure 2), Whilefor the joints at an angle of 90° to the blastholes, the damage was insignificant (Figure 3).

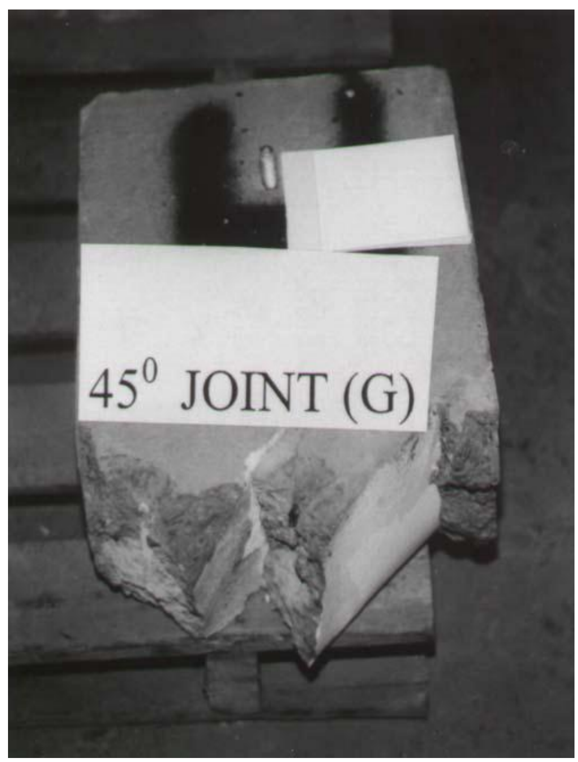

Figure 2. Overbreak for 45° orientation of joints (Singh and Narendrula, 2007).

Figure 3. Insignificant damage in case of a vertical joint (Singh and Narendrula, 2007).

Aperture of Discontinuities: Worsey and Qu (1987) reported that as joint surface separation increases, it becomes difficult to get a smooth excavation profile from blasting, as open joints hinder the crack propagation between the perimeter holes. On the other hand the chance of overbreak reduces if joints are tight and cemented.

Tariq and Worsey (1996) observed during small scale experiments that 3mm of joint opening reflects back the explosive energy just like a free face, thus no spit plane is produced. It was also found that joint opening & angle of cratering are directly proportional.

Frequency of Discontinuities: If discontinuities are present than the effective area of influence of a hole reduces, because the gaps of the joints will not only hinder the propagation of radial cracks but will also provide easy passage for the gases to escape, thus reducing the borehole pressure (Figure 4). The fragmentation and heave of blasted material will be reduced as a consequence. (Hustrulid, 1999).

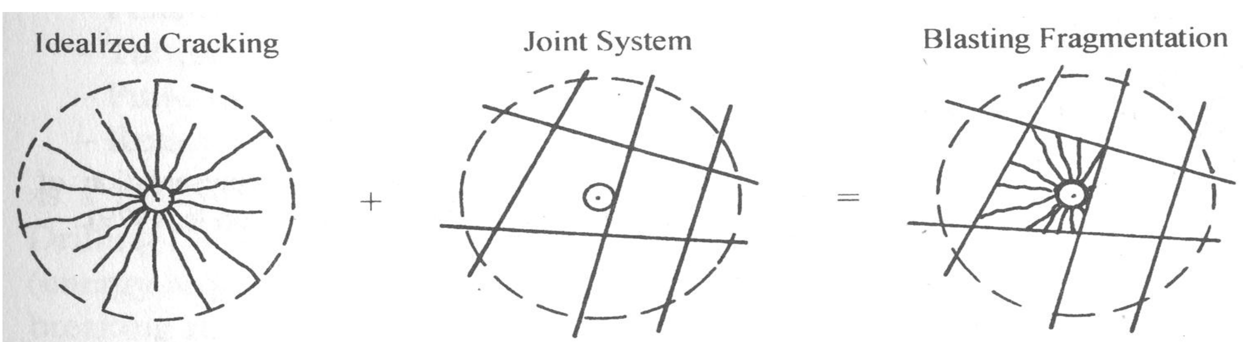

Figure 4.Effect of jointing on fragmentation (after Hustrulid, 1999).

It has been stated by Singh and Xavier (2005) and Singh and Narendrula (2007) that in order to have a smooth excavations profile the drilling pattern should be closer than the joint spacing. The frequency of 2-3 joint planes per spacing should be avoided to have good perimeter control.

Filling in the Joints: Singh and Xavier (2005) conducted blasting experiments on small scale concrete models (Figure 5), drift blasting and several operating mines. They have reported that wave transmission through the joint depends upon the width of the joint and the infilling material of the joint. If the width of infilling material is small and impedance of the infilling material is close to the medium than the wave transmission through the joint will be better. For the width of the joint it was observed that with increase in width of the joint, the energy loss into the joint increases, especially when joint is close to the face. The joints filled with clay material tend to produce uneven excavation profile due to the swelling potential and its thickness. If infilling material in the joint is stable and the joint aperture is small, than the magnitude of overbreak will be governed by the orientation of joints with respect to the blast holes' line.

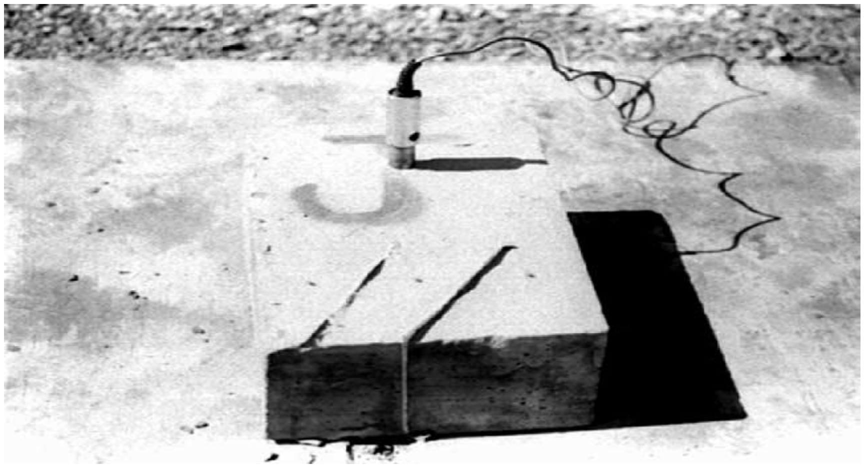

Figure 5.small scale model of concrete with joints between the holes (after Singh and Xavier (2005).

Persson *et al*. (1994) report a model experiment conducted by Seinov and Chevkin (1968) in which they simulated joints and filled fissures by using three glass plates (6 x 30 x 30 mm) separated by materials with different acoustic impedance and width. Air, water, kaolin and concrete were used (Figure 6). Results from these experiments indicated that, in a medium with open fissures, an increased amount of explosive may lead to improved fragmentation. When the fissures were filled with kaolin, energy was absorbed from the explosion and fragmentation did not significantly improve when the specific charge was increased. When the acoustic impedance between the plates was increased by using a cement mixture, an increase in the fragmentation was achieved. Fragmentation was slightly greater when water was used instead of air in the fissures.

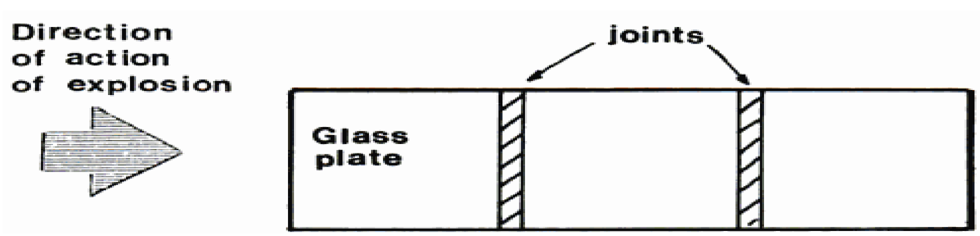

Figure 6. Model experiments in glass plates performed by Seinov and Chevkin (1968).

Rock Quality Designation (RQD): Rock mass quality can be designated by RQD which is defined as:
Length of cores greater than 100mm/total length of core x 100.
Singh and Xavier (2005) report that it is difficult to control blast damage in the rocks having RQD value less than 70%.The RQD values less than 50% would require close spacing, light loading and relief holes to produce acceptable results.

Condition of Joints: Joint condition also plays an important role in the final excavation profile .It has been observed that with increase in the joint roughness value, the perimeter walls stability increases. Same trend is observed for the discontinued joints.(Singh and Narendrula, 2007).

Watery Conditions: Singh and Xavier (2005) report the following hydrogeological conditions affect rocks and rock masses and hence the blasting operations:

a) As friction between particlesof rocks reduces, itsmechanical properties like tensile and compressive strengths also reduce (Obert and Duvall, 1967).

b) Breakage effects increase by the decrease in attenuation of the shock wave.

c) The cohesion and frictional properties of the joints are lowered.

d) There is no internal spalling in the joints filled with water as the passage of shock waves is allowed. But when the rockmass is in tension, the water is mobilized, forming a wedge, which may produce overbreak.

e) Water in the drill holes increases the degree of coupling as compared to the air. This results in more energy transferred to the rock mass and hence more vibrations.

Layers or Foliation: Rock masses generally contain layers of different rocks with varying strengths and characteristics. The presence of such layers interferes with the transmission and effectiveness of explosive energy and is responsible for the underbreak and overbreak. Singh and Narendrula (2007) studied this phenomenon and showed the effect of adjusted thickness of layers on the half cast factor, which is defined by the following equation:

Length of the half barrels after the blast/Initial length of the blast holes x100(Figure 7).

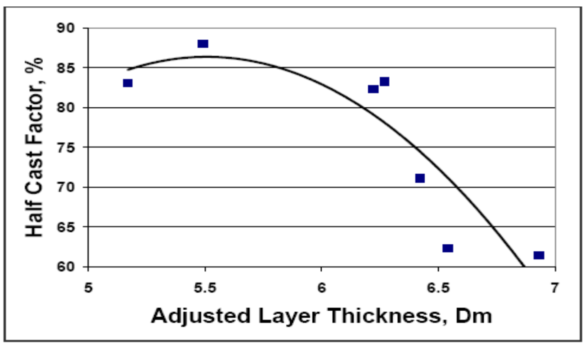

Figure 7.Adjusted thickness of layers vs half cast factor (Singh and Narendrula, 2007).

Rock Mass Rating: Various rock mass classification systems have been proposed and they are widely used in the design of the rock support system. Singh and Narendrula(2007) have plotted the RMR values for different test sites against the average half cast factor (HCF). This indicates that for rock masses with RMR values less than 47, it is difficult to retain half barrels (Figure 8).

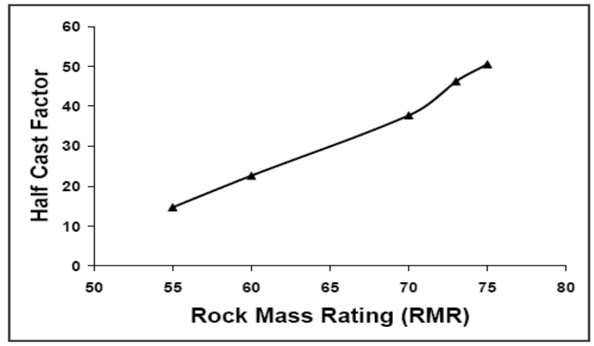

Figure 8. Rock mass rating vs average half cast factor (Singh and Narendrula, 2007).

Overbreak Control Measures: A number of researchers have proposed numerous remedial measures to control the overbreak caused by the geological discontinuities. All of these measures were site specific. Singh (2005) has proposed the following changes in the blast design to control the rock fragmentation process by blasting.

1. The overbreak depends upon the amount of explosive per unit length of blast hole and the spacing between the holes. To reduce overbreak in highly jointed rocks, it is suggested to increase number of holes by reducing spacing and to charge the holes lightly.
2. *Rock Mass Characterization*: The knowledge of the strength and geological features of a rock mass is necessary for proper designing of the blast. Figure 9 illustrates the criteria for controlling the blast damage based upon RMR values. For initiation of minor and major damage in rocks having different RMR values, the corresponding blast vibrations required are shown in figure 9.Blast vibrations can be kept under desired level, if blast is designed keeping in view the quality of the rock mass.

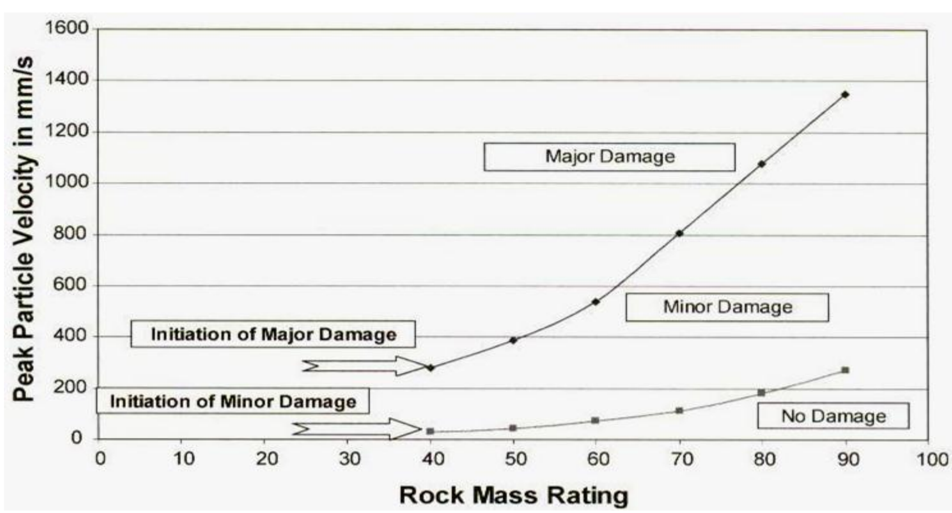

Figure 9. Magnitude of blast vibrations required for the initiation and propagation of minor and major damage in rocks with different RMR values (after Singh, 2005).

3. *Rock Quality Designation (RQD)*: A rock mass having RQD value of less than 70% has more chances of overbreak.Overbreak can be reduced in case of rock masses having RQD value less than 50% by decreasing the spacing, light charging of the holes and by uncharged guide holes.
4. In a rockmass having joints, the spacing between the blastholes should be kept lessthan two times the joint spacing.
5. In jointed rock masses the successful perimeter control can be achieved by reducing the holeburden and stemming.Both these steps will ensure the reduction of boreholepressure due to early release of gases.
6. It is suggested to ensure a burden to spacing ratio of 1.2 to 1.3 for perimeter holes and maximum relief to burden should also be ensured.
7. One way to control the overbreak is to have well designed firing sequence of the holes. It is suggested to fire the perimeter holeson the same delay and at the end of the round.
8. The more the holes are closer to the perimeter, the less the explosive concentration should be in them.
9. Long period delays do not let the superposition of the ground vibrations and also are useful in providing proper relief to the burden.
10. Blast should be designed and executed carefully, as the poor blast results are often due to improper blast designs or negligence in their execution.

Conclusions: Rock discontinuities have a major influence on damage caused by blasting and should therefore be given requisite importance while designing a blast. The damage due to blasting induced to a rock mass depends upon quality of the rock mass and the explosive energy transmitted to it.When the angle between the joints and line of blast holes is 45^0 or near to 45^0, the profile obtained will be irregular and shattered.Overbreak is increased in case of joints dipping away from the excavation.As the aperture of the joint increases, the cratering to the joint also increases, resulting in poor perimeter control. The quality of rock mass also depends upon the nature of filling in the joints. In case of weak filling in joints, its swelling potential and thickness plays its part in decreasing the quality of the rock mass. This poor rock mass quality increases the chances of extensive damage.

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