

An Analysis and Prevention of Flyrock Accidents in Surface Blasting Operations

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Abstract

Blasting is a primary means of extracting minerals and ores at surface mining operations. The domestic consumption of explosives and blasting agents during the year 2002 was about 5.53 billion pounds.

Flyrock is always a major concern for the blaster. Flyrock from surface blasting operations has caused serious injury and death to employees and other persons. Injuries due to flyrock and the lack of blast area security accounted for over two-thirds of all blasting-related injuries in surface coal, metal, and nonmetal mines during the period 1978-2002. Selected accidents due to flyrock and lack of blast area security in surface mining are presented in this paper. Incidents related to construction blasting are also described.

Techniques to mitigate blasting accidents are discussed. These include proper blast design, driller-blaster communication, inspection prior to loading and firing the blast, removing employees from the blast area, controlling access to the blast area, and using a blasting shelter. An experienced driller could detect potential problem areas such as voids, mud seams, incompetent rocks, and other irregularities by observing the progress of drilling. The drill log should include the details of any unusual or exceptional circumstances noticed during drilling. A blaster may need to alter the loading configuration to alleviate potential problems.

Basic blast design is sometimes taken for granted and assumed to be proper for the conditions encountered, but one size does not fit all. It is known from the physics of blasting that the explosive energy takes the path of least resistance. The path of least resistance could generate flyrock, depending on the blast site conditions. A combination of 'borehole tracking' and 'laser profiling' can assist in improving the design of a blast. The blaster can use these tools to adjust borehole loading to match site conditions.

Introduction

Blasting is an essential component of surface mining. It serves as the leading role in fragmenting the overburden and exposing coal and other mineral deposits. Domestic consumption of explosives and blasting agents during the year 2002 was about 5.53 billion pounds. Out of this, about 3.79 billion pounds (68.5%) were used in coal mining, 1.17 billion pounds (21.1%) in metal and nonmetal mining, and 417 million pounds (7.5%) in construction blasting [USGS, 2003].

This paper presents a brief account of injuries due to flyrock and lack of blast area security in surface mines and elucidates mitigation techniques. Flyrock has caused serious injury and death to employees, visitors, and neighbors in the mining industry. Injuries due to flyrock and lack of blast area security account for 68% of all blasting related injuries in surface coal, metal, and nonmetal mines during the period 1978 - 2001 [Verakis & Lobb, 2003]. Construction blasting has encountered its share of flyrock problems. There are numerous examples of property damage by flyrock in construction blasting. Flyrock management and control has become an indispensable part of blast design.

The Institute of Makers of Explosives (IME) has defined flyrock as the rock propelled beyond the blast area by the force of an explosion (IME, 1997). Flyrock comes in different sizes and shapes, ranging in mass from few ounces to several tons. Persson et al. [1994] referenced flyrock weighing approximately three tons thrown to a distance of 980 ft.

The blaster determines the bounds of the blast area, and flyrock is not expected to travel beyond the blast area. During blasting, all employees should be removed from the blast area and all entrances to the blast area should be guarded. If anyone, such as the blaster, is required to stay inside the blast area, a proper blasting shelter should be used. Injuries within the blast area have been sustained when proper blasting shelters were not used.

Interaction of explosive charge with surrounding rock:

Upon initiation of an explosive charge in a blasthole, a detonation wave travels through the explosive charge column. The velocity of detonation is a function of explosive characteristics, confinement, and charge diameter. When an explosive charge is detonated in a blasthole, very high pressure is exerted on the wall. Konya & Walter [1991] reported maximum detonation pressures of 140, 90, and 60 kbars (1 kbar = 14,504 psi) for dynamites, emulsions, and ANFO type explosives, respectively. The wall of a blasthole could experience transient pressure of about 500,000 psi for emulsion-type explosives. This high pressure causes expansion of the blasthole, crushing of the rock in the immediate vicinity, growth of cracks beyond the crushed zone, and generation of a seismic wave and air blast.

Upon firing an explosive charge in a blasthole, a compression wave travels to the highwall face. Rocks such as sandstone, shale, limestone, dolomite, and granite are generally strong in compression and little damage is inflicted by the compression wave. However, upon arrival at the free face, the compression wave is reflected back as a tensile wave. The tensile wave initiates cracks and fractures because most of the rocks are weak in tension. The gases from the detonation products enter into the tensile-fractured spaces and resume their expansion work causing propagation of cracks. Gas pressurization then causes the fragmented rock mass to burst out from the bench. If there is excessive local gas pressurization, flyrock could be generated.

Flyrock is caused by a mismatch of the distribution of explosive energy, type of confinement of the explosive charge, and mechanical strength of the rock. Factors responsible for creating this mismatch include:

- Abrupt change in the rock resistance due to presence of joints; cracks; layers of mud, silt, or soft material in the host rock; differential weathering of rocks near an outcrop; faults and slip planes; back breaks, overhangs, and uneven highwall face;
- High explosive concentration leading to excessive localized energy density due to migration of explosive charge into fissures, caverns, voids, and mud seams;
- Deviation of blastholes from the intended direction causing a reduction in burden or spacing;
- Insufficient or improper stemming leading to stemming ejection and bench-top flyrock;
- Inappropriate or poor blast design.

Flyrock Incidents at Surface Mines

This section provides a brief description of selected incidents related to flyrock and lack of blast area security in surface mining. Most of the information was obtained from Mine Safety and Health Administration's (MSHA) accident investigation reports. Many of these incidents underscore the importance of blast design, local geology, removing employees from the blast area, guarding and controlling access to the blast area, and using blasting shelters. A few incidents related to construction blasting are also included.

- On July 5, 1990, a blaster standing on the top of a 200-ft highwall about 505 ft from the blast site was fatally injured by flyrock [MSHA, 1990a]. The highwall could not shield him from flyrock. The employee suffered a massive head injury. The flyrock originated from a toe blast. The toe round consisted of 23 holes ranging in depth from 3 to 5 ft. The holes were loaded with 2-1/2-in diameter packaged explosive product. Explosive energy takes the path of least resistance and blasting of small diameter angled toe holes requires special attention. The blaster failed to perceive that flyrock could strike him on the top of a highwall. This accident could have been prevented by using a proper blasting shelter or "matting" the holes.
- On October 12, 1990, a visitor sustained severe injuries and a miner was fatally injured by flyrock in a surface silica flux mine [MSHA, 1990b]. The mining company used a blasting contractor for loading and firing the shots. The visitor and the miner were about 150 ft from the edge of the blast. Upon firing the shot, the miner was fatally struck on the back of his head. This accident underscores the importance of identifying a proper blast distance and clearing the blast area.
- On February 1, 1992, a blaster was fatally injured in a surface coal mine [MSHA, 1992]. The blaster positioned himself under a Ford 9000, 2-1/2-ton truck while firing the shot. Flyrock traveled 750 ft

and fatally injured the blaster. This accident illustrates the importance of being in a protected location or using a proper blasting shelter.

- On April 25, 1994, a driller/loader was fatally injured by flyrock in a surface coal mine [MSHA, 1994]. The blaster notified the superintendent of an impending blast and cleared other employees from the pit area. The victim and another employee working under the direction of the blaster were about 236 ft from the nearest blasthole. Upon firing the blast, the driller/loader was fatally injured by flyrock. This accident emphasizes the significance of being in a protected location or using a proper blasting shelter for employees whose presence is required in the blast area.
- On December 21, 1999, an equipment operator in a pickup truck was guarding an access road to the blast site [MSHA, 1999]. The pickup truck was about 800 ft from the blast site. Flyrock entered the cab through the windshield and fatally struck the employee. The highwall face was about 50 ft high and the depth of holes ranged between 49 and 54 ft. The blast round consisted of 22 holes drilled on a 16- by 16-ft pattern. Some of the holes were angled up to 25° toward the highwall to compensate for irregularities in the highwall face. At least one of the holes blew out causing flyrock. This incident underscores the importance of being in a protected location.

Flyrock Incidents at Construction Sites

Construction blasting is often conducted close to population centers and requires special considerations for flyrock management. During the planning and design stage, possible environmental impacts due to flyrock, ground vibration, air blast, fume, and dust should be evaluated. A successful blast design is based on a thorough review of such items as rock properties, geology, specification of material to be blasted, and environmental constraints. Flyrock accidents in construction blasting are investigated by Occupational Safety and Health Administration (OSHA). Several incidents related to construction blasting are briefly described below.

- On March 24, 1992, an employee was standing next to a front-end loader when a blast was detonated. The blast consisted of 68 holes loaded with 2-in diameter by 16-in long cartridges of explosives. A dirt cover of 4- to 5-ft was used to confine the blast. The employee suffered trauma to his neck and lacerations to his face [OSHA, 1992]. This accident could have been prevented by using a proper blasting shelter or removing the employee from the blast area.
- On April 13, 1995, a blaster having 16 years experience was fatally injured by flyrock. He loaded the blastholes and took shelter behind a magazine of approximate size 4-ft high by 4-ft wide by 6-ft depth. Upon firing the shot, a single piece of rock struck the blaster on the head. He was about 150 ft from the blast site [OSHA, 1995]. This accident could have been prevented by using a proper blasting shelter.

Mitigating Techniques

Flyrock is caused by a mismatch of the distribution of explosive energy, confinement of the explosive charge, and mechanical strength of the rock. Proper blast design, knowledge of local geology, and use of blasting shelter play an important role in preventing flyrock accidents.

Blast design: Proper blast design is the single most important tool to prevent blasting problems, including flyrock. A blast designer optimizes the balance between rock properties, explosive energy distribution, and explosive energy confinement. A logical approach is to adjust energy distribution and confinement suitable for the rock properties, including geological abnormality. Such optimization would improve fragmentation and minimize flyrock, ground vibration, and air blast. Flyrock can originate from the highwall face, bench top, and toe. Today, with the expanded use of computers and electronic aids there are more tools to assist the blaster in designing a safe and efficient blast. Burden, spacing, hole diameter, stemming, subdrilling, initiation system, and type of explosive used should match the characteristics of the rock formation. For example, a closely jointed blocky limestone formation would require a tighter pattern (such as 8- by 8-ft, or less) with small diameter blastholes than a competent homogeneous sandstone formation.

Loading an explosive charge close to the collar zone causes insufficient stemming resulting in bench-top flyrock. Stemming ejection and poor fragmentation generally result from insufficient, or poor quality stemming. A cavity in a highwall face could reduce the effective burden and may cause flyrock. Proper subdrilling reduces the need for toe-holes, a common source of flyrock.

Geology: Geology plays an important role. Mud seams, voids, joints, extended cracks, and fissures may cause potential problems. A void within the rock could allow overcharging a portion of the blasthole, causing a blowout. Mud seams and voids are relatively weak compared to the surrounding rock and allow the explosive gases to vent from the face. Mud seams and voids are common sources for flyrock. Geological mapping of the highwall face helps in locating geological irregularities. Drills equipped with performance monitoring systems could provide useful information about mud seams, voids, incompetent rocks, and other geological irregularities. Shea & Clark [1998] reported a fatal accident where a layer of clay on the top of a sandstone overburden was a significant factor in propelling flyrock beyond the blast area. The clay layer reduced effective stemming. Explosive loading should be modified to compensate for any change in geology. Geology can set absolute limits and will dictate results [Wallace, 2001].

Pre-drilling inspection: The blaster should inspect the highwall face and bench top prior to marking the location of new blastholes. Explosive loading and/or blasthole location should be altered to compensate for any irregularities observed during the inspection. The highwall should be inspected for the presence of any cavity, backbreak, overhang, softer strata, slip planes, faults, or other irregularities. While the blaster conducts his inspection from the quarry floor, a helper on the bench top uses a pole and tape measure to identify the location of trouble spots. This information should be recorded and used when explosive loading occurs.

If laser profiling data is available, it should be utilized. Laser profiling indicates the areas of highwall where excessive burden is present and areas where too little burden exists [MSHA, 2002a]. Any extensive crack or dislocation of strata near a blasthole could provide a path for venting out the detonation products and cause flyrock. Burden, spacing, inclination, and explosive loading should be altered based on the results of pre-drilling inspection. The blaster should mark the location of the blastholes on the bench top and on the site map. Essential parameters such as diameter, depth, subdrilling, burden, spacing, and angle of holes should be clearly communicated to the driller.

Driller-Blaster communication: Driller's log should be completed during the drilling process and examined by the blaster prior to loading to locate any abnormality or irregularity. The log should indicate items such as the depth and angle of each hole, location of voids, competency of rock, loss of air, and/or lack of drill

cuttings [MSHA, 2002b]. Effective communication between the driller and the blaster is essential. In many operations, the drilling crew also loads the holes and keeps the blaster informed of any potential problems. In a large operation, two drilling technicians and two blasting technicians work under the supervision of a blaster. The technicians rotate their duty routinely. This arrangement helps to maintain effective communication between the drilling and blasting crews.

Pre-loading inspection: All blastholes should be checked for depth, inclination, and water prior to loading any explosive [Dick et al., 1983]. Blastholes should also be checked for any obstructions or caving. Any void or cavity should be filled or plugged. Small voids should be filled with stemming material and large voids should be plugged [Dick, et al., 1983]. This will prevent loading excessive explosive in a blasthole and thereby avoid adverse effects. Blastholes often deviate from the planned inclination, causing too much or too little burden. Borehole probes measure the location of the blasthole within the rock to be blasted and allow the blaster to adjust the explosive charge accordingly from hole-to-hole, or even within portions of the same hole [MSHA, 2002c].

Loading and firing: The loading should be done under the supervision of the blaster. Before loading begins all unnecessary personnel and equipments should leave the site. The sequence of loading the blastholes should match the approved firing sequence. The blaster or a designated employee should check for both the amount of explosive material and the rise of explosive column in the blasthole during the loading process. This is particularly important for incompetent rocks. Decking height and stemming length must be checked. Insufficient or poor quality stemming could lead to stemming ejection, fragmentation of the collar zone, and flyrock.

The use of a proper blasting shelter should be emphasized. The previously described flyrock injuries could have been prevented by using proper blasting shelters. Taking shelter under a pickup truck, explosive truck, or other equipment is not adequate because flyrock can travel horizontally. The accident referenced in MSHA [1992] resulted because the blaster positioned himself beneath a truck and fired the shot.

Lack of blast area security accounted for approximately 41% of all blasting related injuries in surface mining [Verakis & Lobb, 2003]. The blast area must be identified, cleared and entrances guarded prior to firing a shot. A blaster is often unable to see the entire blast area from the firing station due to the nature of the terrain or obstructions such as a pile of rock. A last minute check of the blast area and communication with guards could prevent such mishaps

Post- firing inspection: The blaster should inspect the muck pile for undetonated explosives and the newly created highwall from a safe distance before approaching the area. If no problems are detected, the blaster should approach the area carefully and examine for any abnormal fragmentation, back break, overhang, bootleg, cut-off charge, and misfire. Upon completion of a satisfactory examination, the blaster should send an all-clear signal, complete the blast report, and return all unused explosive material to the magazine.

Conclusions

- Flyrock is caused by a mismatch of the distribution of explosive energy, confinement of the explosive charge, and mechanical strength of the rock.

- All employees should be removed to a safe location away from the blast area during blasting. If anyone is required to stay in the blast area, proper blasting shelters should be used.
- All entrances to the blast area should be securely guarded to prevent inadvertent entry of employees or visitors.
- Proper blast design and an effective blasting plan will reduce the chances for flyrock.
- Good communication is a key to a safe blasting operation.

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