# FATAL ACCIDENTS DUE TO FLYROCK AND LACK OF BLAST AREA SECURITY AND WORKING PRACTICES IN MINING

**T. S. Bajpayee**
**Mining Engineer**

**Suresh K. Bhatt**
**Mining Engineer**

**Timothy R. Rehak**
**General Engineer**

**Gary L. Mowrey**
**Electrical Engineer**

**David K. Ingram**
**Research Geologist**

**National Institute for Occupational Safety and Health**
**Pittsburgh, Pennsylvania, USA**

Coal and nonmetal mining used about 4.3 billion pounds of explosives and blasting agents during 2001 in the United States. A major part of this consumption was related to surface mining. Mine Safety and Health Administration accident data indicate that flyrock and lack of blast area security were the primary causes of blasting-related injuries in surface mining.

Fatal injuries due to lack of blast area security were primarily caused by failure to clear blast area or inadequate access control to the blast area. At a coal mine, a neighbor walked into the blast area and was fatally injured. The blaster could not see the victim entering the blast area from the firing station. In another case, a passenger in a vehicle was fatally injured by flyrock because highway traffic was not monitored during the blast. In another example, a dozer operator entered a blast area due to lack of access control.

Several fatalities resulted from using inadequate or no blasting shelter. A crane operator was fatally injured while standing in the open about 120 ft from the blast site. In another instance, a helper, standing about 150 ft away from the edge of a blast, was fatally injured by flyrock. In a limestone mine an equipment operator was fatally injured while guarding access roads in a pickup truck.

This paper briefly describes six representative fatalities due to flyrock and lack of blast area security in coal and nonmetal mines. Several mines were visited to collect information relative

to working practices aimed at mitigating blasting hazards. Salient information obtained through these visits is presented.

## INTRODUCTION

Explosive and blasting agents are used in mining, quarrying, construction, and other activities where rock fragmentation is essential for the success of the project. About 5.25 billion pounds of explosives were used in the United States during 2001. Out of this, coal and nonmetal mining consumed about 4.29 billion pounds [USGS, 2003]. A major part of this consumption was related to surface mining. Although blasting presents numerous hazards, the mining industry considers blasting an indispensable element of rock excavation. Although mechanical excavators can be successfully used in topsoil and clay, blasting is considered an inevitable technique for excavating hard rock. Manufacturers and users are consistently trying to enhance blasting safety. The mining industry has improved its blasting safety record during the past five years [Rehak et al. 2001]. Flyrock, lack of blast area security, premature blast, misfire, and disposal were major causes of blasting-related injuries in surface mines. Out of these flyrock and lack of blast area security accounted for 68% of the injuries [Verakis and Lobb, 2001]. Miners and personnel employed by the mining industry still continue to suffer fatal and disabling injuries from blasting accidents.

Blasting generally has two purposes: rock fragmentation, and displacement of the broken rock. The movement of the blasted rock (also known as muckpile) depends on the shot-design parameters, geological conditions, and mining constraints. In some mining practices, it is desirable to throw or cast as much rock as possible to the spoil heap. Cast blasting has helped mine operators uncover mineral deposits at a reduced cost.

Fragmented rock is not expected to travel beyond the limits of the blast area. All employees must be removed to a safe location away from the blast area during shot firing. If anyone, such as the blaster, is required to stay in the blast area, blasting shelters must be used for protection from flying debris. All entrances to the blast area must be securely guarded or barricaded to prevent inadvertent entry of employees, visitors, and neighbors. The blaster determines the bounds of the blast area. The blaster is responsible for complying with safety laws. Langefors and Kishlstrom [1963], Roth [1979], and Persson et al. [1994] have each developed models to predict flyrock range.

Flyrock is generally perceived as the rock propelled beyond the blast area. Institute of Makers of Explosives (IME) has defined flyrock as the rock(s) propelled from the blast area by the force of an explosion [IME, 1997]. The U. S. Code of Federal Regulations [CFR], Title 30 defines ‘Blast Area’ as the area in which concussion (shock wave), flying material, or gases from an explosion may cause injury to persons. The CFR also states that the blast area shall be determined by considering the following factors:

- geology or material to be blasted,

- blast pattern,
- burden, depth, diameter, and angle of the holes,
- blasting experience of the mine personnel,
- delay systems, powder factor, and pounds per delay,
- type and amount of explosive material, and
- type and amount of stemming.

The above CFR defines 'Blast Site' as the area where explosive material is handled during loading, including the perimeter formed by the loaded blastholes and 50 feet (15.2 meters) in all directions from loaded holes. A minimum distance of 30 feet (9.1 meters) may replace the 50-foot (15.2-meter) requirement if the perimeter of loaded holes is demarcated with a barrier. The 50-foot (15.2-meter) and alternative 30-foot (9.1-meter) requirements also apply in all directions along the full depth of the hole.

The energy released by an explosive charge in a blasthole crushes the rock near the immediate vicinity of the blasthole, fractures the rock beyond the crushed zone, generates seismic waves, creates airblast, and moves the fractured rock away from the bench. Any mismatch between the distribution of the explosive energy, geomechanical strength of rock mass, and confinement creates a potential for flyrock. Flyrock originates from the vertical highwall face and bench top. Schneider [1997] emphasized the role of excessive powder factor, insufficient burden, inaccurate timing, ineffective stemming, and overloading a blasthole in flyrock control.

An injury due to flyrock is sustained when it travels beyond the blast area and injures someone. Flyrock is generally caused by:

- insufficient burden,
- improper blasthole layout and loading,
- anomaly in the geology and rock structure,
- insufficient stemming, and
- inadequate firing delays.

An injury due to lack of blast area security occurs when a person fails to stay inside a blast shelter or in a protected location. Accidents due to lack of blast area security were caused by:

- failure to evacuate the blast area by employees and visitors,
- failure to understand the instructions of the blaster or supervisor,
- inadequate guarding of the access roads leading to the blast area, and
- taking shelter at an unsafe location or inside a weak structure.

Six fatalities due to flyrock and lack of blast area security were reported in surface coal mines and six in nonmetal mines during the period 1989 to 1999. Information related to three fatalities in coal mines and three in nonmetal mines is presented in this paper.

## CASE STUDIES

Reporting requirements for injuries, illness, and workplace exposures are stipulated in the Federal Coal Mine Health and Safety Act of 1969 and the Federal Mine Safety and Health Amendments Act of 1977. Mine Safety and Health Administration (MSHA) accident investigation reports were used to gather information about most of the fatal injuries listed below. Figure 1 relates to a fatal injury due to flyrock at a limestone mine in Lancaster County, Pennsylvania [MSHA, 1999b]. Case study No. 6 contains information relative to this fatal accident.

1. Fatal injury due to flyrock at a limestone mine in Pennsylvania (Case Study No.6)
Source: MSHA, 1999b

**1. Coal Mine, Webster County, WV:** On August 29, 1989, a drill operator sustained minor injuries and a 41-year-old dozer operator was fatally injured by flyrock in a surface coal mine [MSHA, 1989]. They were transported by an ambulance to a nearby hospital. The drill operator was treated for minor injuries and released, but the dozer operator was pronounced dead. The dozer operator had 13 years mining experience, including 15 months as a dozer operator. The mine produced about 8,400 tons of coal per day and employed 73 persons on two production shifts and a maintenance shift.

A total of 144, 7-7/8-in diameter holes, 19 ft deep, were loaded with emulsion explosive. Each hole contained about 221 lb of explosive. The blasting crew notified the foreman of an impending blast and the foreman cleared all employees from the pit area. An employee was guarding the access road to the pit. About two minutes before the blast the employee left his post and went to the mine office for a brief visit. No barricade or notice of blasting was posted at the entrance to the access road. In the mean time, the drill operator and the dozer operator, unaware of the imminent blasting, entered the pit area in a pickup truck. Since the blaster’s vision was obstructed by a large pile of dirt, he could not see the pickup truck in the pit area. Upon firing the shot the dozer operator was fatally injured and the drill operator sustained minor injuries.

This incident underscores the importance of blast area security. Such incidents could be avoided by adopting effective blast area security protocol, proper communication, and miner training.

**2. Nonmetal Mine, Luna County, NM:** On October 12, 1990, a visitor sustained severe injuries and a 32-year-old drill/blast helper was fatally injured by flyrock in a surface silica flux mine [MSHA, 1990]. They were transported by an ambulance to a nearby hospital. The visitor was hospitalized for treatment of broken ribs and internal injuries but the drill/blast helper was pronounced dead. The drill/blast helper had three days mining experience. The visitor wanted to take a photograph of the blast.

The mine employed four persons, working one 8-hour shift a day, five days a week. The mine produced silica flux for copper smelting. The ore was mined by drilling and blasting from shallow multiple benches. The mining company used a blasting contractor for loading and firing the shots.

The blast round consisted of 49 holes, 3-in diameter, 12 ft deep, on a 6-ft spacing. Each hole was bottom primed with a stick of 60-percent gelatin dynamite taped to detonating cord. Another stick of dynamite taped to detonating cord was placed three to four feet below the collar. Some of the holes were stemmed with two feet of drill cuttings. Several holes were completely filled with ammonium nitrate fuel oil (ANFO). A detonating cord trunk line was used to tie each hole without any firing delay. The trunk line was initiated by a cap and fuse assembly.

The visitor and the drill/blast helper were about 150 ft from the edge of the blast. Upon firing the shot, the drill/blast helper was fatally injured. The investigation report indicated that poor blasting practice (such as, overcharging blastholes, lack of stemming, and absence of delays) was exhibited during this shot. This incident signifies the importance of blasting shelters, proper blast design, and training of miners.

**3. Coal Mine, Campbell County, TN:** On June 4, 1993, a 16-year-old passenger, in a car driven by his parent on interstate 75 (I-75), was fatally injured by flyrock originating from an overburden blast in a nearby coal mine [Shea and Clark, 1998]. The closest blasthole was within 75 ft of the Right of Way (RoW) and 225 ft from the I-75 pavement.

Twenty-eight blastholes, in four rows, on an 18- by 18-ft pattern, 7-1/4 in diameter, were loaded with ANFO. Each hole contained 573 lb of explosive charge and was stemmed with 11 ft of drill cuttings. The length of the explosive column in each hole was about 32 ft. Unlike previous blasts, explosive charges were not decked during this blast.

This blast was not designed according to the specifications approved in the permit document [Shea and Clark, 1998]. Instead of decking explosive charges in two columns and priming separately, the entire charge was loaded in one column. Hole diameter and blast pattern used in this blast were also different from the approved plan. The stemming was insufficient, and the I-75 traffic was not monitored. An 8-ft thick layer of clay on the top of the sandstone overburden was considered a contributory factor.

**4. Nonmetal Mine, Madison County, IL:** On May 23, 1994, a 21-year-old crane operator was fatally injured by flyrock that struck him in the back [MSHA, 1994]. He had 1-1/2 months mining experience at this mine. On the day of the accident, the victim helped the blaster in stemming the holes, and placing mats over the holes. He and the blaster then moved to a top bench behind the blast and were standing at a distance of about 120 ft from the nearest blasthole.

Upon initiation of the blast, one of the holes threw flyrock toward the victim, fatally striking him in the back.

This limestone quarry operated in multiple benches. The quarry was about 160 ft deep and accessed by an inclined haul road across the benches. The haul road extended to the floor of the bottom bench. This mine employed 13 persons, working one 9-hour shift a day, five days a week.

Forty-one holes, 3-1/2 in diameter, 12 ft deep, were loaded with ANFO. Each hole contained a 500-ms down-hole delay. The delay between the adjacent holes was 25 ms. The bench height was 11 ft. Stemming consisted of 3 ft of crushed limestone. The stemmed holes were covered with blasting mats of 3- by 3-ft size. Five-gallon pails containing crushed stone were placed over the mats for additional protection.

This incident underscores the need to remove all employees from the blast area and to provide blasting shelter for employees whose presence is required in the blast area.

**5. Coal Mine, Pike County, KY:** On February 15, 1999, a 55-year-old area resident rode an all-terrain vehicle (ATV) from his residence to an access trail leading to the blast area [MSHA, 1999a]. He parked his ATV about 100 ft from the edge of the blast area and started walking to the blast area. Shortly after he started walking, a blast was detonated. Later, his body was found close to the perimeter of the blast area.

Mining was conducted on privately-owned land including land owned by the victim. It was reported that the deceased often visited the mine site and some of his visits were unannounced. The mine produced about 3,000 tons of coal per day and employed 46 persons on two 8-hour shifts. The mine operated 5 or 6 days a week.

A total of 212 holes, 6-3/4-in diameter, loaded with 13,000 lb of explosive, were detonated. Of these, 164 holes were 13 ft deep, and 48 holes were 23 ft deep. The blastholes were drilled on a 13- by 15-ft pattern. The blast area and the access road leading to the blast area were examined about five minutes before the blast. Guards were not posted at the access road, and the blaster did not have a clear view of the access road from the firing station. A Ford F-250 pickup truck was equipped with two electro-mechanical horns, and on the day of the incident only the low-pitch horn was operational. The high-pitch horn was found to be disconnected. The access road was in a valley, and probably the victim could not hear the blast warning signal or ignored the signal. This incident underscores the need for effective blast area security.

**6. Nonmetal Mine, Lancaster County, PA:** On December 21, 1999, a 32-year-old equipment operator was in a pickup truck while guarding an access road leading to the blast site [MSHA, 1999b]. The pickup truck was about 800 ft from the blast site. Flyrock entered the cab through the windshield and fatally struck the victim (Figure 1). The victim had seven years mining experience as an equipment operator at this mine.

The mine normally operated two 8-10 hour shifts a day, five days a week, and had 22 employees. The mining company used a drilling contractor to drill the holes, and a blasting contractor for loading and blasting. 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. Approximately 9,595 lb of explosives were used in this round and the length of stemming varied from 9 to 36 ft. The weight of explosive used in each blasthole was not recorded. Some of the holes were slanted up to 25° toward the highwall to compensate for irregularities in the highwall face. The investigation report indicated that at least one of the blastholes blew-out causing a massive amount of flyrock. This incident emphasizes several factors, such as excessive powder loading, voids, discontinuities, break in the rock strata, and blasthole inaccuracy.

## MINE VISITS

Several surface mines were visited to obtain information relative to blast design, flyrock safety, and blast-area-security protocol. Drilling, loading and blasting operations at several sites were observed. Blasting plans at most of the mines were also examined. Generally, blasting plans addressed safety-related issues pertaining to ground vibration, airblast, flyrock, blast warning, and access control, among others.

During the mine visits it was observed that blasts were laid out by the blaster based on the blasting plan. The mitigating techniques to prevent injuries due to flyrock and lack of blast area security were generally similar and recognized the importance of proper blast design and local geology, and also relied heavily on pre-drilling inspection, driller-blaster communication, pre-loading inspection, and guarding and access control. The salient points of observations during the mine visits are listed below.

- Blasting plan: During the mine visits several blasters emphasized the importance of following a good blasting plan that optimized the balance between energy distribution, energy confinement, and rock properties. Blasting plans were prepared based on local conditions such as geology, rock properties, equipment and explosives used, distance to nearest structures, and other environmental constraints. Proper blast design was the single most important tool to prevent blasting problems. Burden, spacing, hole diameter, stemming, subdrilling, initiation system, and type of explosive used matched the characteristics of the rock formation.

- Highwall and bench inspection: During field visit at a surface mine in Ohio, it was noticed that the blaster was inspecting the bench top and the highwall face. The highwall was inspected for the presence of cavity, backbreak, overhang, softer strata, slip planes, faults, and other geological irregularities. While the blaster conducted the inspection from the quarry floor, a helper on the bench-top used a pole and a tape measure to identify the location of trouble spots. The team was working in unison and all observations were recorded. It was also noticed during the field visits that blastholes were checked for depth, obstruction, and water.

Laser profiling of the highwall face was done at one limestone mine. The highwall profile indicated some areas of excessive burden and other areas of too little burden. This critical information helped the blaster to adjust explosive loading in a blasthole to compensate for the variations in the burden.

• Loading and firing: The driller's log was examined by the blaster before loading the blastholes. The blastholes were next loaded either by the blaster or under the supervision of the blaster. Before loading began all unnecessary personnel and equipment were removed from the blast site. Generally, the sequence of loading the blastholes matched the firing sequence. The blaster or a helper checked for the rise of explosive column in a blasthole during the loading process. Loading an explosive charge close to the collar zone often causes insufficient stemming resulting in bench-top flyrock.

At a surface mine a blasting shelter (Figure 2) was readily available for use. No one was allowed in the blast area after blastholes were loaded and lead-in line connected. The blasting shelter was available for the blaster to stay inside the blast area during any scheduled blasting. In general, access to the blast area was controlled by signs, barricades, and ground supervision. The blaster removed all unused explosives, communicated with the guards, and visually inspected the bench top prior to firing the shot. Radio communication was used by personnel involved in these activities.

2. Blasting shelter

• Post- firing inspection: The blaster inspected the muckpile and the newly created highwall from a safe distance before approaching the area. If no problems were detected, the blaster would then 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 would then sound an all-clear signal.

• Blasting log: Before leaving the blast site the blaster completes filling out a 'blasting log' and signs it affirming that all the information pertaining to the blast has been properly documented in the blasting log. This blasting log becomes an official document available for regulatory, legal, and/or public review, if required. In typical blasting log information relative to depth, diameter, burden, stemming, explosive distribution in the blastholes, delay sequence, sketch of delay pattern, distance to nearest structure or dwelling, seismographic data for ground vibration, and airblast are recorded. Appendix A shows an example of a blasting log.

## CONCLUSIONS

- Lack of blast area security, flyrock, premature blast, misfire, and disposal were major causes of blasting-related injuries in surface mines. Flyrock and lack of blast area security accounted for 68% of the injuries.

- Flyrock is caused by a mismatch of the distribution of the explosive energy, geomechanical strength of rock mass, and confinement. Flyrock usually originates from the vertical highwall face and bench top.

- 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, blasting shelters must be used.

- All entrances to the blast area should be securely guarded to prevent inadvertent entry of employees or visitors.

- Knowledge of local geology and site-specific blasting plan are helpful in reducing flyrock injuries.

- Good communication between the driller, blaster, access control guard, and miners is the key to a safe blasting operation.

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**APPENDIX A**

**BLASTING LOG**

## General Information

1. Company Name ______________________Permit No. __________________
2. Location of Blast _____________________Date/Time ___________________
3. Nearest Protected Structure __________________________________________
   Direction and Distance (feet) _____________________
4. Weather Conditions ___Dry____Foggy____Clear____Cloudy____Rain____Snow
5. Type(s) of material blasted ______Sandstone______Slate______Shale______Dirt
6. Mats or other protection used

## Blast Information

7. Type(s) of explosives used: Powder _____________Primers ________________
8. Total weight of explosives used: Powder _______ + Primers ________ = ________ lbs.
9. Blasthole Data: Number _________ Diameter _________ Depth ________
   Burden _________ Spacing ________________
10. Stemming Data: Type of Material _______________________________
    Length ________________________________________
11. Types of Delays used and Delay Period ____________________________
12. Maximum Weight of Explosive *Allowed* per Delay Period (Show appropriate formula and answer)
    ____________________________________________________________________
    ____________________________________________________________________
13. Maximum Weight of Explosives *Used* per Delay Period _______________
14. Weight of Explosives used per hole _________________________________
15. Method of Firing and Type(s) of Circuits _____________________________

**Seismograph Data**

16. Date and Time of Recording ______________________________________
17. Type of instrument ______________________________________________
18. Sensitivity ____________________________________________________
19. Calibration Signal or Certificate of Annual Calibration (Attachment) _____
20. Name of Person taking Reading ___________________________________
21. Location of Seismograph (*including distance from blast*) _______________

22. Vibrations Recorded: Longitudinal: _____________________________

Transverse: _______________________________

Vertical: _________________________________

Vector sum: _______________________________

Air Blast: _________________________________

23. Name of Person and Firm Analyzing Readings: ____________________

**Sketch of Delay Pattern**

24.

Note: Show Direction to Nearest Protected Structure on Sketch.

*25. Include any special design features, such as decking. Include reasons and conditions for unscheduled blasts.*

Name of Blaster (Print or Type) ____________________________________

Signature of Blaster _____________________________________________

Certification Number of Blaster ____________________________________