FLYROCK ISSUES IN BLASTING

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ABSTRACT

Blasting operations are an essential element in the recovery of our Nation's mineral resources. The mining industry uses billions of pounds of explosives annually. The majority of blasting occurs in surface mining operations. Blasting results in the fragmentation and often the projection of rocks. Frequently, the rocks are thrown beyond the expected limits. Flyrock and failure to secure the blasting area dominate blasting-related accidents in mining, especially in surface mining.

Blasting accidents in the mining industry tend to result in critical injuries or fatalities. Accident reports and information collected from the Mine Safety and Health Administration (MSHA) and other government agencies provide supporting evidence. According to the data collected, blasting-related accidents (in mining) were 11 times more severe than all other types of mining accidents. Blasting accidents are not unique to mining operations - the same situation exists in the construction field.

In this paper the authors have compiled a list of the primary causes of flyrock and the failure to secure the blast area. In the next phase of this project, typical blasting scenarios will be reviewed which will highlight the main reasons flyrock and/or lack of blast area security occur. This will alert miners and construction workers to the current problems/hazards associated with blasting and to identify other safety measures to protect personnel.

INTRODUCTION

Annually, the United States uses billions of pounds of explosives in the mining and construction industries where rock fragmentation is an essential part of the project. A survey by the U.S. Geological Survey [2000] indicates that the United States used 2.12 million metric tons (Mt) of explosives in 1999. Mining operations and the construction industry accounted for the majority of the domestic explosive consumption.

Even though blasting presents numerous hazards, these industries consider blasting to be essential for the success of their operations. A review of Mine Safety and Health Administration (MSHA) accident reports indicates that the mining industry has improved its blasting safety record during the past five years. Many factors contributed to this improvement, including: novel explosive formulations produced by explosive manufacturers; enhanced blaster's training developed by academia, professional societies, and industry; and the meaningful roles played by local, state and federal agencies.

An analysis by Siskind and Kopp [1995] indicated that lack of blast area security, flyrock, premature blasts, and misfires were the four major causes of blasting-related injuries in surface mining operations between 1978-1993. During this period 356 injuries were attributed to surface blasting operations. Flyrock accounted for 28.3% of the injuries; lack of blast area security 41.2%; premature blast 15.7%; misfires 7.8%; and all other causes 7%. During this period, 39 fatal injuries (2.4 per year) and 317 nonfatal injuries (an average of 19.8/year) were reported. Siskind's study showed that, although blasting accidents declined from 1990 to 1993, they continue to occur. Siskind used MSHA's injury database as his primary source of information.

The authors extended Siskind's study to determine the current trend in blasting-related fatal and nonfatal injuries in surface mining. Between 1994 and 1997, six fatal injuries (an average of 1.5 per year) and 40 nonfatal injuries (10 per year) were reported. During this 4-year period, flyrock and lack of blast area security accounted for 58.7% of all surface blasting injuries.

Flyrock and lack of blast area security issues continue to pose problems for blasters. In 1999, three fatal injuries were attributed to blasting in surface mining operations. Flyrock and lack of blast area security issues accounted for two fatalities. This confirms the authors contention that problems associated with flyrock and lack of blast area security still exist.

BLASTING INJURIES - MINING

Tables 1 and 2 list fatal and nonfatal blasting injuries respectively from 1978 to 1998. These tables list injuries related to surface and underground mining for coal and metal/nonmetal (including stone, and sand and gravel) operations. A total of 104 fatalities occurred during the entire (1978-98) period, an average of five fatalities per year. Underground operations accounted for 56.7% of the fatalities; surface operations, 43.3%. Coal mining accounted for 48% of the fatalities; metal/nonmetal, 52%.

In table 1, the numbers within the parenthesis indicate four (4) year totals. Overall, fatalities have declined since 1978. However, fatalities involving surface mining operations in the metal/nonmetal sector have not changed substantially.

Table 2 shows that a total of 1,008 nonfatal blasting injuries occurred between 1978-98, an average of 48 injuries per year. Underground operations accounted for 63.6% of the nonfatal injuries; surface operations, 36.4%. Coal mining accounted for 54.7% of the nonfatal injuries; metal/nonmetal, 45.3%. Again the numbers within the parenthesis indicate four (4) year totals. Note that nonfatal injuries related to coal mining have decreased significantly.

However, injuries related to surface metal/nonmetal mining still persist. Twenty-six nonfatal injuries occurred between 1994-1997, while 33 nonfatal injuries occurred during 1981-1985 interval. In other words, no significant improvement has occurred in the 4-year injury rate in surface metal/nonmetal mining operations.

These numbers are still of concern because of the severity of the injuries associated with explosives. The average days lost (ADL) involved in an explosive incident is much greater than the ADL associated with other classes of incidents in mining. An examination of accident statistics (1992-1996) provided in table A2 of Phase I Strategic Planning document [NIOSH 1998] indicates that the ADL for explosive (all mining, all locations) incidents is 549.7 compared to an ADL of 46.4 for other (all mining, all locations, all class) incidents. This demonstrates the severe nature of the blasting incidents. The ADL caused by explosive incidents in surface stone mining operations was reported as 1524. This statistic emphasizes the need for more research into surface stone blasting procedures.

FLYROCK AND BLAST AREA SECURITY - MINING

Table 3 represents the contribution of flyrock and blast area security to the overall blasting scene. Out of 1,112 blasting injuries (surface and underground combined), flyrock and blast area security accounted for 281 injuries (25.3%). However, flyrock and blast area security issues represent 68.2% of all surface blasting injuries during the 1978-1998 time period. From table 3, it is apparent that the contribution of flyrock and blast area security ranged from 58.7% to 77.4% of all surface blasting injuries. Again, the data accentuates the need for continued research in these areas.

BLASTING INJURIES - CONSTRUCTION

- OSHA REVIEW

A review of the Occupational Safety and Health Administration (OSHA) data was conducted as a means for determining the extent of flyrock accidents, injuries, and fatalities in non-mining blasting operations. The Code of Federal Regulations, OSHA citation history, and the OSHA Technical Manual on blasting or the use of explosives were examined.

In reviewing the Code of Federal Regulations, which is a codification of the general and permanent rules published in the Federal Register by the Executive departments and agencies of the Federal government, it was determined that the flyrock concerns would best be identified under OSHA Code of Federal Regulations Title 29, part 1926: Safety and Health Regulations for Construction, subpart U: Blasting and the Use of Explosives, sections 1926.900 - 1926.914. However, in overview, the only standards which applies to either flyrock or blast area security are: 29CFR1926.909; 29CFR1910.109 (e)(1)(iii) and (iv); and

29CFR1910.109 (e)(5).

A thorough investigation was conducted of OSHA's data base on issued citations and inspection reports for the time period of October 1997 through 1998. It was determined that flyrock is classified under North American Industry Classification System (NAICS) 1629, Division C: Construction, Major Group 16: Heavy Construction, Not Elsewhere Classified, Blasting except building demolition-contractors. In overview of the citations issued, there are four (4) citations standards that are related to blasting or use of explosives. During this period there were nine (9) citations issued with penalties totaling $4525.00. This dollar amount is relatively low and therefore, the authors assume that the citations were not issued for injuries or fatalities.

OSHA's Technical Manual provides technical information and guidance on occupational safety and health topics. However, there are no specific topics here which address the prevention of flyrock injuries or blast area limits. The sections that may address flyrock issues are generalized but do not specifically deal with flyrock.

BUREAU OF LABOR STATISTICS

The authors next reviewed the publically available yearly information provided by the U.S. Department of Labor, Bureau of Labor Statistics (BLS) on their web site at www.bls.gov. Note that the statistics include the private sector only and not government workers or those self-employed. Table R59 lists the number of nonfatal occupational injuries involving days away from work by source of injury and industry division. For the period from 1992 to 1997, there were a total of 422 nonfatal injuries in the construction industry (including transportation and public utilities) included in the category of "Explosives, blasting agents" or an average of approximately 84 per year. While the data does not appear to be consistently classified from year to year, this does indicate that workers are being injured in accidents involving explosives and blasting agents. The BLS data is not broken down sufficiently to determine what proportion of the explosive/blasting agent accidents are related to flyrock and blast area security.

INTERNET/NEWSPAPER SEARCH

Since OSHA's Standards, citations history, and Safety Technical Manuals did not supply significant data and because of our concern with the reliability and the consistency of accident classification by BLS, we directed our attention to newspaper articles and to the internet. A Lexis-Nexis search was conducted for the period of 1994-1997 and the Institute of Makers of Explosives (IME) provided articles from their newspaper clipping service. The authors are currently in the process of reviewing 208 articles to determine if the accidents resulted from flyrock or blast area security issues. A sampling of articles related to the flyrock and blast area security issues in construction are briefly described below.

> 1994, McGregor, TX "Explosion rocks local dealership" - A dynamite explosion to excavate a city sewer system lift station proved stronger than expected. Fortunately, despite the extensive damage done to the car body shop including breaking windows and damaging several vehicles, no one was injured. [McGregor Mirror, McGregor, TX]

1995, Stuarts Draft, VA "Construction Worker Hurt in Blasting Accident Dies" A worker suffered a head injury when other workers were blasting at a Target Distribution Center construction project. A 10 to 15-pound rock propelled by the blast struck the worker who was then taken to an Intensive Care Unit via helicopter. He died the next day after undergoing surgery. Other workers said he ran for cover and was behind a van when the rock struck him, piercing his hard hat. [The Richmond Times Dispatch, Richmond, VA]

1997, Antonia, MO "Blast Catapults Mud, Rocks into Buildings; State Revokes Road Construction Permit" An ammonium nitrate blast sent mud and rock flying for 600 feet on a road construction project on Highway M. It damaged four buildings and two cars. No one was injured. The blaster claimed the accident occurred because they hit a mud seam. A softball-sized rock was recovered after it crashed through the roof of a steel fabrication business. [St Louis Post-Dispatch, St. Louis, MO]

1998, Douglasville, GA "Judge Halts Blasting at Arbor Place Mall" The blasting contractor was excavating rock at a construction site of a new mall, when a blast sent debris flying, damaging several homes. The company was fined $7500 and required to provide more safety measures. [The Atlanta Journal and Constitution, Atlanta, GA]

1999, Brentwood, TN "Explosion at Construction Site Damages Homes" Workers were setting off dynamite to lay a sewer line. A piece of rock fell through the roof of a home of a 72-year-old man who was at home with his wife and daughter. Several other homes were also damaged. Fortunately no one was hurt. [Associated Press]

1999, Braintree, MA "Hitting too Close to Home - Rocks from Blasting Rattle Neighbors" Blasting was being done at a cemetery to create more space for graves. Some rocks from the blast flew nearly 800 feet, reaching some private property near the cemetery. A rock, the size of a softball, struck the roof of one of the neighbors' houses. No one was injured. [Patriot Ledger Quincy, MA]

It is plainly evident that the construction industry does not have as detailed and accurate reporting system in place compared with the Mine Safety and Health Administration (MSHA) for the mining industry. However, it appears that flyrock and blast area security problems exists in both industries.

FLYROCK

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 these factors:

(1) Geology or material to be blasted,
(2) Blast pattern,
(3) Burden, depth, diameter, and angle of the holes,
(4) Blasting experience of the mine personnel,
(5) Delay systems, powder factor, and pounds per delay,
(6) Type and amount of explosive material,

(7) Type and amount of stemming.

Flyrock is generally perceived as the rock propelled beyond the blast area. IME [1997] has defined flyrock as the rock(s) propelled from the blast area by the force of an explosion.

PRIMARY CAUSES OF FLYROCK

Generally, flyrock is caused by a mismatch of the explosive energy with the geomechanical strength of the rock mass surrounding the explosive charge. Factors responsible for this mismatch include:

- Abrupt decrease in rock resistance due to joint systems, bedding layers, fracture planes, geological faults, mud seams, voids, localized weakness of rock mass, etc.
- High explosive concentration leading to localized high energy density,
- Inadequate delay between the holes in the same row, or between the rows,
- Inappropriate blast design,
- Deviation of blast holes from its intended directions,
- Improper loading and firing practice, including secondary blasting of boulders and toe holes.

a) BURDEN: Insufficient burden is a primary cause of flyrock from a highwall face. Highwall faces are irregular and therefore do not provide uniform burden from each point of the loaded borehole. Following the laws of physics, high-pressure gases generated during blasting will vent out and therefore pose the greatest hazards at the weakest point in the highwall. Blasters need to visually examine or laser profile the highwall face and search for zones of weakness, backbreak, concavity, unusual jointing and overhang.

b) BLAST HOLE LAYOUT AND LOADING: Any deviation in the direction of a blast hole can reduce or increase the burden. This becomes a significant factor for deep holes. A slight deviation from vertical toward the highwall can drastically reduce the burden at the bottom of the hole.

Blasters must prime and load their holes as planned. While loading a hole, blasters must frequently check the rise of the powder column to prevent overloading due to the loss of powder in voids, cracks, or other unknown reservoirs. Such overloading will generate excessive release of energy.

c) GEOLOGY AND ROCK STRUCTURE: Sudden change in geology or rock structure can cause a mismatch between the explosive energy and the resistance of the rock. It is prudent to try to detect such changes in advance and adjust accordingly. Sedimentary rocks often change their geomechanical properties due to abrupt changes in the direction of laminations or bedding planes, inclusion of zones of weakness, and voids. Geological intrusions can compromise the strength of the parent rock. Presence of mud seams, voids, caverns should cause a concern for the blaster. Inadvertently loading these areas will produce a high energy concentration.

d) STEMMING**:** Stemming provides confinement and prevents the escape of high-pressure gases from the borehole. The stemming should provide resistance to the escape of high-pressure gases comparable for that of the burden. Konya and Walter [1990] recommend a stemming length of about 0.7 times the burden. Improper or inadequate stemming can result in stemming ejections. Insufficient stemming also causes violent fragmentation of the collar zone resulting in flyrock and airblast.

e) DETONATOR FIRING DELAY**:** Critical elements of any blast design are firing delays between adjacent holes in a row and also those between successive rows. The firing delay is a function of the burden, spacing, hole depth, rock type, and the quantity of charge fired per delay. Proper firing delay helps to achieve good fragmentation of the blasted material. It also reduces ground vibration, air blast, and flyrock. The rock fragmented by the previous hole must be given a chance to move out prior to firing subsequent holes

f) LACK OF BLAST AREA SECURITY: An analysis of blasting injuries indicates that several factors are involved in causing injuries due to lack of blast area security. These factors are: (a) failure to evacuate the blast area by employees and visitors; (b) failure to understand the instructions of the blaster or supervisors; (c) inadequate guarding of the access roads leading to the blast area, or the secured area; (d) taking shelter at an unsafe location, or inside a weak structure. Blast area security issues could be addressed by providing adequate training and refresher courses (class room and hands-on type) to the blaster and other involved employees.

CONCLUSIONS

1. Domestic consumption of explosives has grown considerably in the recent years. Surface blasting operations related to recovery of coal, minerals, and construction activity account for a major part of this consumption. Even though blasting presents numerous hazards, the mining and construction industries consider blasting as an essential ingredient for the success of their operation. Injury analysis indicates that lack of blast area security and flyrock account for the majority of blasting-related injuries in surface mining operations. This calls for strengthening of training activities.

2. The ADL (average days lost) due to an explosive incident is much greater than the ADL caused by other class of incidents. An examination of accident statistics reveals that the ADL for explosive (all mining, all locations) incidents is 549.7 compared to an ADL of 46.4 for all other (all mining, all locations, all classes) incidents. This demonstrates the severe nature of the blasting accidents. The ADL caused by explosive incidents in surface stone mining operations was reported as 1524. The authors recommend more research emphasis on surface stone blasting operations.

3. Blast area has been defined as the area in which concussion (shock wave), flying material, or gases from an explosion may cause injury to persons. The blast area shall be determined by considering these factors: geology or material to be blasted; blast pattern; burden; depth, diameter, and angle of the holes; blasting experience of the mine; delay systems, powder factor, and pounds per delay; type and amount of explosive material; type and amount of stemming. These factors should be addressed in training session for blasters.

4. The rock mass surrounding the borehole experiences a very high degree of mechanical stress from the products of detonation. Any irregularity in the geological structure or confinement will cause an uneven stress field which may result in flyrock. Development of excessive or disproportionate gas pressure may propel rocks a great distance. Geological anomalies and lack of proper confinement are considered contributory factors for the creation of flyrock. The techniques to predict anomalies or compensate for its effects in blast design merit further study.

5. The factors involved in causing injuries due to lack of blast area security are: (a) failure to evacuate the

blast area by employees and visitors; (b) failure to understand the instructions of the blaster or supervisors; (c) inadequate guarding of the access roads leading to the blast area, or the secured area; (d) taking shelter at an unsafe location, or inside a weak structure. These accidents are preventable with good training and communications.

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Table 1. Fatal blasting injuries, 1978-98

Year	Coal		Metal/nonmetal		Total	4-year average
	Underground	Surface	Underground	Surface		
1978	3	0	5	2	10	11.25
1979	0	2	5	0	7	
1980	7	1	5	2	15	
1981	3(13)[1]	2 (5)	5 (20)	3 (7)	13	
1982	3	1	2	2	8	5.00
1983	0	0	0	0	0	
1984	1	1	1	3	6	
1985	6 (10)	0 (2)	0 (3)	0 (5)	6	
1986	0	3	1	0	4	3.25
1987	0	1	0	0	1	
1988	2	0	0	0	2	
1989	0 (2)	2 (6)	1 (2)	3 (3)	6	
1990	3	2	0	3	8	4.75
1991	2	1	2	0	5	
1992	0	1	0	3	4	
1993	0 (5)	1 (5)	1 (3)	0 (6)	2	
1994	0	1	0	2	3	1.75
1995	0	0	0	1	1	
1996	0	0	0	1	1	
1997	1 (1)	0 (1)	0 (0)	1 (5)	2	
1998	0	0	0	0	0	—
Total	31	19	28	26	104	—
Average	1.5	0.9	1.3	1.2	5.0	—

[1] Numbers within the parenthesis indicate 4 years totals

Source: Siskind and Kopp [1995] and MSHA Database

Table 2. Nonfatal blasting injuries, 1978-98

Year	Coal		Metal/nonmetal		Total	4-year average
	Underground	Surface	Underground	Surface		
1978	51	19	39	21	130	107
1979	49	14	34	12	109	
1980	48	14	33	16	111	
1981	28 (176)[1]	10 (57)	32 (138)	8 (57)	78	
1982	19	5	9	6	39	45.5
1983	17	7	10	5	39	
1984	16	16	4	18	54	
1985	32 (84)	3 (31)	11 (34)	4 (33)	50	
1986	17	9	9	8	43	50.5
1987	22	9	9	14	54	
1988	21	11	13	9	54	
1989	15 (75)	13 (42)	12 (43)	11(42)	51	
1990	13	6	6	13	38	27
1991	9	5	5	11	30	
1992	2	8	6	3	19	
1993	10 (34)	2 (21)	2 (19)	7 (34)	21	
1994	5	7	2	8	22	18
1995	1	2	4	7	14	
1996	4	4	6	6	20	
1997	1 (11)	1 (14)	9 (21)	5 (26)	16	
1998	4	2	2	8	16	—
Total	384	167	257	200	1,008	—
Average	18.3	8.0	12.2	9.5	48.0	—

[1] Numbers within the parenthesis indicate 4 year totals

Source: Siskind and Kopp [1995] and MSHA Database

Table 3. Trends in flyrock injuries (surface mining), 1978-98

Activity or cause	Fatal plus nonfatal injuries						
	1978-81	1982-85	1986-89	1990-93	1994-97	1998	Total
Blast area security	51	28	43	25	17	3	167
Flyrock projected beyond blast area	26	22	29	24	10	3	114
Total of above	**77**	**50**	**72**	**49**	**27**	**6**	**281**
Total of above (as a percent of all surface blasting injuries)	**61.1**	**70.4**	**77.4**	**74.2**	**58.7**	**60**	**68.2**
Total of above (as a percent of all blasting injuries)	**16.3**	**24.8**	**33.5**	**38.6**	**34.2**	**37.5**	**25.3**
All surface blasting injuries	126	71	93	66	46	10	412
All blasting injuries	473	202	215	127	79	16	1,112

Source: Siskind and Kopp [1995] and MSHA Database