Establishing blast exclusion zone at Huni Pit - a case study

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Abstract
During the early stage of open pit mining in the Huni Pit of Damang Gold Mine, the pit was shallow. The established distances to the public road on the west was 756 m and 646 m to the east and north respectively. The blast exclusion zone established was 959.80 m and 500 m radius expansion from the 960 m Reduced Level (RL) from the crest line of the pit to the north and east respectively for extra safety precautionary measure with nine (9) blast guard positions. A review of the blast exclusion zone was done on the 912 m RL with empirical models. From the computations, the maximum horizontal distance the flyrock could reach is 220 m and 277.45 m for blast hole diameters of 115 mm and 127 mm with the same stemming length of 2.0 m. These projected maximum horizontal distances are far less than the distances to the public road. Hence, the blast exclusion zone has been reduced to 500 m as recommended by Minerals Commission of Ghana. The revised blast exclusion zone has removed the inconvenience associated with travelling from Damang via Akyempim to Twifo Praso, Takoradi, Cape Coast and Accra during blasting times.

Keywords: Blast Exclusion Zone, Blasting Times, Flyrock, Safety, Mining

Introduction
Blasting operations in open-pit mining have long been associated with a hazardous by-product known as flyrock, which poses significant risks to both human safety and mining-related assets. Flyrock, as described by Akuinor et al. (2022), represents a perilous consequence of blasting, endangering not only individuals but also mining equipment, infrastructure, and nearby communities. Lundborg et al. (1975) have underscored the severity of this issue, emphasizing flyrock as one of the most treacherous outcomes in open pit blasting operations. The trajectory and projection of flyrock are intricately tied to the energy of the explosives used, as well as the effectiveness of stemming length and the quality of stemming material. Chiappetta et al. (1983) have demonstrated that flyrock follows a ballistic trajectory path, with maximum range achieved when the rocks are propelled at an initial angle of 45 degrees. This is because shallow pits have a higher tendency of flyrock throw accidents. Consequently, during blasting, the main road from Damang to Akyempim that leads to Takoradi, Cape Coast and Accra was always blocked from the southern part to the northern part of the pit thereby inconveniencing commuters. These established nine (9) exclusion blasting zones served the purpose for their establishment over time.

As mining progressed, the pit became deeper and there was the need to assess and determine useful and safe blast exclusion zones that will still be relevant. In the context of open-pit mining operations at the Huni Pit of the Damang Gold Mine, the issue at hand is the management of blast-induced hazards, specifically concerning flyrock, which poses a significant danger to personnel, mining equipment, infrastructure, and neighboring communities. Initially, safety protocols were established to mitigate the risk of flyrock throw accidents during blasting, including the definition of blast exclusion zones. These safety measures included defining exclusion blasting zones with a significant radius from the blast site (Minerals Commission of Ghana, 2012). However, these zones obstructed a major road (from Damang to Akyempim) that connected several important destinations such as Takoradi, Cape Coast, and Accra. This resulted in significant inconvenience for commuters, as the road was frequently blocked during blasting operations. As the pit deepened over time, there arose a need to reevaluate and adjust these exclusion zones to balance safety concerns with minimal disruption to road traffic.

This paper aims to address this challenge by establishing a revised blast exclusion zone that accounts for the pit's increased depth, thereby ensuring both safety and the smooth flow of road traffic (Health and Safety Executive, 2002; Regan, 2011a; International Society of Explosive Engineers (ISEE), 2011b; International Society of Explosive Engineers (ISEE), 2011c). The ultimate goal is to promote sustainable cities and communities while supporting industry, innovation, and infrastructure development, in alignment with Sustainable Development Goals 9 and 11. Consequently, blast guard positions were established based on the established blast exclusion zone.

Materials and Methods
Study location and site overview
The research was conducted at the Huni Pit within the Abosso Goldfields mine, situated near Damang Township approximately 300 km by road, west of Accra, at a latitude of 5° 11’ N and longitude of 1° 57’ W. An aerial view of the Damang Mine and its surrounding facilities is depicted in Figure 1.

The Huni Pit is flanked by waste dumps to the west, north, and east, with elevation levels of 1,050 m to the west and 1,020 m to the east of the pit, as indicated by coordinates 9,282.089 E, 26,998.231 N (West) to 10,956.589 E, 27,005.193 N (East). Figure 2 shows the initial blast exclusive zones with the blast guard positions. In the scenario described, the methods used to assess and determine the revised blast exclusive zone for open-pit mining in the Huni Pit of Damang Gold Mine involved empirical modeling and calculations.

Blast exclusion zone assessment
The assessment of the revised blast exclusion zone for open-pit mining at the Huni Pit involved the following methods:

i) Data collection: Gathering data on the pit’s depth, geological characteristics, historical blasting operations, blast hole dimensions, stemming lengths, and distances to

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potential impact zones, including public roads.

iii) **Empirical modeling**: Utilizing empirical models, which are mathematical equations derived from real-world observations, to predict flyrock behavior during blasting. This involved estimating the maximum horizontal distance that flyrock could travel from the blast site for various blast hole diameters from 115 mm to 200 mm (115 mm and 127 mm are in Tables 2 and 3), with a constant stemming length of 2.0 meters. Factors considered in this modeling included hole diameter, charge depth, charge weight, detonation sequences, flyrock trajectory, proximity to structures, historical data, site topography, and regulatory requirements. (Anon, 2002; Anon, 2011a; b; c).

iii) **Safety criteria comparison**: Comparing the calculated maximum horizontal flyrock distances with established safety criteria, such as those provided by the Minerals Commission of Ghana, to assess potential risks to public roads, mine infrastructure, and personnel.

iv) **Recommendations**: Based on the assessment, proposing a revised blast exclusion zone that prioritized safety, minimized disruption to road traffic, and complied with regulatory and safety standards.

**Data collection and analysis**

After nine months of blasting, data was collected on various parameters, including drill and blast details, explosive parameters, distances from blast locations to mine infrastructure and public roads, and flyrock characteristics. This data was used for analysis based on Equations 1 to 6. Different scenarios were considered, including flyrock in the forms of rifling, cratering, and face bursting. The various scenarios considered are flyrock in the form of rifling, cratering and face bursting (Sawmliana et al., 2020). The Equations 1 to 5 help determine the extent of flyrock while Equation 6 enable the determination of the Scaled Depth of Burial (SDOB).

**Equations for analysis**

Equations used for the analysis included equations proposed by Chiapetta et al. (1983) for calculating horizontal rock travel distance, initial velocity of flyrock, and size of projectile flyrock (Equations 1 to 3). Additionally, an empirical model by Lundborg et al. (1975) was used to determine maximum rock projection (Equation 4) and the SDOB was calculated using Equation 6.

where:

\[ FR_t = V_0 \left( \frac{2 \sin 2\Theta}{g} \right) \]  
(1)

\[ V_0 = \left( \frac{10D(2600)}{T_b \times \rho_t} \right) \]  
(2)

\[ T_b = 0.1 \left( \frac{D^{2/3}}{\rho_t} \right) \]  
(3)

\[ FR_m = 260 \left( \frac{D^{1/3}}{25} \right) \]  
(4)

\[ T_b = 0.1 \left( \frac{D^{2/3}}{\rho_t} \right) \]  
(5)

\[ SDOB = \frac{St + 0.0005s \times D \times \rho_t}{0.00923s (mDx_p)^{1/3}} \]  
(6)
FR is the distance travelled (m) by the rock along a horizontal line at the original elevation of the rock on the face; 

\( V_0 \) is the initial velocity of the flyrock,

\( \theta \) is the angle of departure with the horizontal; 

g is gravitational constant; 

d is hole diameter in inch; 

Tb is the size of rock fragment (m); 

\( \rho \) is density of rock in g/cm\(^3\). 

FR\(_m\) is the maximum rock projection in meters; 

Tb is the size of rock fragment in meters. 

St is stemming length; 
m is explosive charge length; 
D is blast hole diameter; 
\( \rho \) is explosive density; 
FoS is Factor of safety; and 
Range\(_{\text{Max}}\) is maximum flyrock range.

Field testing
To validate the theoretical findings, field test blasts were conducted over a nine-month period. These tests involved drill and blast designs, field visits, blast initiation, guard placement, video recording of blasts to monitor flyrock trajectories, and appropriate documentation.

Data summary and scenarios
The collected data, serving as inputs for Equations 1 to 6, were summarized in Table 1. Stemming length and drill and blast parameters were varied to create different scenarios in Table 2 (constant hole diameter of 115 mm) and Table 3 (constant hole diameter of 127 mm). Each set of parameter variations within Tables 2 and 3 constituted a distinct scenario, resulting in five scenarios for each case.

Results and Discussion
The International Society of Explosives Engineers (ISEE) Blasters’ Formulae, along with Equations 1 to 6 and data from Table 1, were employed to predict the maximum flyrock range. The results for various scenarios are presented in Tables 2 and 3. Additionally, visual representations of flyrock trajectories are depicted in Figures 3 to 8.

Table 2 presents calculations for flyrock range using a blast hole diameter of 115 mm under different scenarios. Parameters such as SDOB, stemming length, maximum flyrock range, and minimum clearance are tabulated. A safety factor of 2 is applied to the maximum flyrock range to ensure equipment and personnel safety. Tables 2 and 3 are populated ISEE Blasters’ Formulae, Chiapetta et al. (1983) and Lundborg et al. (1975) flyrock equations. Table 2 is analysis using a blast hole diameter of 115 mm. Similar to Table 2, Table 3 provides flyrock range calculations, but this time using a blast hole diameter of 127 mm.

The plot of the origin of the flyrock trajectory was generated to visualise the blast in the open pit. Figures 3 and 4 show how the flyrock is ejected at 35˚ and 70˚ respectively. The blue line represents the flyrock throw with baseline angle of flyrock projectile of 45 degrees while the pink indicates the chosen angle of flyrock projectile of 35 and 70 respectively.

During the initial month of blasting on the 960/957 m Reduced Level (RL) of Huni Pit (Figure 5), the authors actively participated as blast guards at the Koduakrom position. This involvement led to the development of a monitoring template to assist blast personnel in efficiently overseeing blasting activities.

The drill and blast parameters during this period included blast hole diameters of 115 mm and 127 mm, with varying burdens and spacing, bench height, subdrill, and stemming length. Figures 3 and 4 indicate that flyrock trajectories...
remained confined within the pit, except for the northern side with a maximum elevation of 93 m. Importantly, no incidents of flyrock reaching the public road were reported during monitoring. Maintaining the original drill and blast parameter with burden of 3.8 m, spacing of 3.8 m and/or burden of 3.7 m and spacing of 4.3 m, bench height of 9 m and with a subdrill of 1 m but varying blast hole diameters from 165 mm to 200 mm and a stemming length of 2 m, the flyrock projectile went above the pit wall with a projectile at 50˚ and 70˚ as shown in Figures 7 and 8 respectively.

When the stemming was reduced to 1.5 m for the 115 mm blast hole diameter, the clearance exceeded the minerals

### Table 1 Input parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Max</th>
<th>Min</th>
<th>Average</th>
<th>Average Deviation</th>
<th>Standard Deviation</th>
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<td>115.00</td>
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<td>115.00</td>
<td>123.24</td>
<td>6.99</td>
<td>9.84</td>
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<td>Powder Factor (kg/m³)</td>
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<td>0.71</td>
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<td>Spacing (m)</td>
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<td>Burden (m)</td>
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<td>Explosive Charge (kg)</td>
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<td>279.29</td>
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<td>Cost per Bank Cubic Meter ($/BCM)</td>
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<td>1.68</td>
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### Table 2 Calculation of flyrock range using ISEE Blasters’ formulae for 115 mm blast hole diameter

<table>
<thead>
<tr>
<th>Items/Parameters</th>
<th>Scenario 1</th>
<th>Various Scenarios</th>
<th>Scenario 2</th>
<th>Various Scenarios</th>
<th>Scenario 3</th>
<th>Various Scenarios</th>
<th>Scenario 4</th>
<th>Various Scenarios</th>
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<tr>
<td>Hole diameter (mm)</td>
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<td>115.00</td>
<td>115.00</td>
<td>115.00</td>
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<td>115.00</td>
<td>115.00</td>
<td>115.00</td>
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<tr>
<td>Scaled Depth of Burial (SDOB)</td>
<td>1.71</td>
<td>1.50</td>
<td>1.29</td>
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<tr>
<td>Stemming (m)</td>
<td>3.50</td>
<td>3.00</td>
<td>2.50</td>
<td>2.00</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Maximum Flyrock Range (m)</td>
<td>81.00</td>
<td>108.00</td>
<td>150.00</td>
<td>220.00</td>
<td>352.00</td>
<td></td>
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<tr>
<td>Minimum Clearance (m)</td>
<td>163.00</td>
<td>216.29</td>
<td>300.00</td>
<td>440.00</td>
<td>703.07</td>
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### Table 3 Calculation of flyrock range using ISEE Blasters’ formulae for 127 mm Blast hole diameter

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<th>Various Scenarios</th>
<th>Scenario 3</th>
<th>Various Scenarios</th>
<th>Scenario 4</th>
<th>Various Scenarios</th>
<th>Scenario 5</th>
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<td>Hole diameter (mm)</td>
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<td>127</td>
<td>127</td>
<td>127</td>
<td>127</td>
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</tr>
<tr>
<td>Scaled Depth of Burial (SDOB)</td>
<td>1.71</td>
<td>1.50</td>
<td>1.29</td>
<td>1.08</td>
<td>0.87</td>
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<tr>
<td>Stemming (m)</td>
<td>3.50</td>
<td>3.00</td>
<td>2.50</td>
<td>2.00</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Maximum Flyrock Range (m)</td>
<td>104.5</td>
<td>138.17</td>
<td>190.4</td>
<td>277.45</td>
<td>437.74</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum Clearance (m)</td>
<td>209.00</td>
<td>276.33</td>
<td>380.80</td>
<td>554.90</td>
<td>875.47</td>
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Figure 3 Flyrock trajectory of 115 mm diameter of blast hole and a stemming length of 2.0 m at 35° projectile with a baseline clearance of 45°

https://doi.org/10.56049/jghie.v24i1.96
Figure 4 Flyrock trajectory of 115 mm diameter of blast hole and a stemming length of 2.0 m at 70° projectile with a baseline clearance of 45°

Figure 5 Flyrock trajectory of 127 mm diameter of blast hole and a stemming length of 2.0 m at 40° projectile with a baseline clearance of 45°

Figure 6 Flyrock trajectory of 127 mm diameter of blast hole and a stemming length of 2.0 m at 70° projectile with a baseline clearance of 45°
Figure 7 Flyrock trajectory of 165 mm diameter of blast hole and a stemming length of 2.0 m at 70° projectile with a baseline clearance of 45°.

Figure 8 Flyrock trajectory of 200 mm diameter of blast hole and a stemming length of 2.0 m at 50° projectile with a baseline clearance of 45°.

Figure 9 The Huni Pit profile and extent and the surrounding infrastructure.
When the stemming was reduced to 2.0 m and 1.5 m for the 127 blast hole diameters, the clearance exceeded the minerals commission requirement of 500 m by 54.90 m and 203.07 m respectively (Table 2 scenario 4 and scenario 5). These exceedances were what informed the initial blast exclusive zone of 959.80 m during the time that the Huni pit was shallow. It was noticed that, the flyrock throw distance increases with decreasing stemming length for both the 115 mm and 127 mm diameter holes respectively and vice versa (Tables 1 and 2). The above scenarios depict bad drill and blast practices where the blast hole diameter is changed from 115 mm to 127 mm/165 mm/200 mm, the stemming lengths reduced from 3.0 m to 1.5 m/2.0 m final and quantity of explosives per hole increased from 84 kg to 117 kg/197 kg.

The mine conducts and control its drilling and blasting operations utilising methods, procedures and protocols that limit air blast (air overpressure), prevent fly rock being thrown beyond the Blast Exclusion Zone and achieve planned fragmentation as well as uniform minimize heave and movement over the whole blast, with minimum displacement of ore/waste zones. The QAQC of works for production drilling includes inclination of the drillhole within 2° of the design inclination and blast hole depth is within 150 mm of the planned depth. The correct charge-up instructions and procedures which include the quantity of explosives charged per hole is within 2 kg of planned quantity and the correct tie-up design. Therefore, supervision of blast hole depth, charging and correct tie-up gets high order and preference in the mine.

Supervisors and blast guards continue to diligently monitor the Koduakrom road for any signs of flyrock. All blast guards are tasked with promptly reporting any suspected flyrock incidents. Remarkably, no such reports or incidents have been received since the inception of blasting at Huni Pit.

A longitudinal section at 10 148.930, 27 446.157 to the north has a reduced level of 1 005 m. The reduced levels surrounding the Huni pit on the west is 1 050 m, East – 1 020 m, north is 1 005 m and on the south is 950 m. The current mining floor depth on 912 m RL ranges from 138 m to 93 m, depending on the location within the pit. This depth has led to a confinement of flyrock within the open pit, due to adherence to good drill and blast practices. Consequently, it is deemed safe and appropriate to revise the original blast exclusion zone, as depicted in Figure 10. Figures 2 and 10 show the Huni Pit with the initial and revised blast exclusive zone and blast guard positions.

No complaints regarding flyrock have been lodged by the public, and the horizontal distance from the current pit floor to the public road indicates a substantial safety margin (Figure 9). The horizontal distance from the current pit floor to the blast guard positions and Koduakrom Road per the Huni Pit Blast extent map shows that the current mining/blasting floor ranges from 619 m to 967 m to the public road (Figure 9). The absence of flyrock observations during the nine-month blasting period further supports the safety of the revised blast exclusion zone and the effectiveness of monitoring and control measures.

Since the flyrock throws were confined to the open pit because the pit has gone deeper and good drill and blast practices were adhered to, it is safe and convenient to revise the original blast exclusive zone. Figure 10 shows the revised blast exclusive zone and blast guard positions of the Huni Pit.

Conclusions
It can be concluded that mining of Huni Pit started on 960/957 m RL and is currently on 912 m RL; hence, the vertical height of the waste dump to the current floor is 138 m at the west, 108 m at the east and 93 m at the north. Additionally, there are waste dump surrounding the Huni Pit at the west, north and east sides of the Pit, which serves as a protection for the pit and against flyrock respectively. The maximum vertical height that the flyrock can reach is 52 m and 75 m for a final stemming length of 2.0 m for 115 mm and 127 mm blast hole diameters respectively. Therefore, blasting at the current depth will not pose any danger of flyrock to the public road since no flyrock can fly over the waste dump.

When the hole diameter is varied to 165 mm while all other parameters remain the same, the flyrock has high tendency of flying over the periphery of the pit. The stemming length of 3.0 m and Maximum Instantaneous Charge (MIC) of 84 kg and 102 kg of explosive are needed to ensure that the flyrocks are confined to the pit for 115 mm and 127 mm blast hole diameters respectively. The test blast for flyrock for the last 9 months have not recorded any incident of flyrock on the public road to Koduakrom. The horizontal distance from the Huni pit ranges from 619 m to 967 m to the public road is far greater than the maximum horizontal distance that the flyrock
can reach (220 m and 277.45 m for blast hole diameters of 115 mm and 127 mm respectively); hence, the original blast exclusive zone has been revised. The longer the stemming used the shorter the flyrock throw distance and vice versa for 115 mm and 127 mm diameter holes respectively.

The blast guard positions have been reduced from 9 to 4; hence, a revised blast guard positions have been established. The blast exclusive zone on the 967 m has been revised to 500 m as recommended by Minerals and Mining (Explosives) Regulations, 2012, LI 2177, Regulation 176(a) thereby reducing the inconvenience of road users around the Huni pit during blasting times (Minerals Commission of Ghana, 2012b).

Based on the above analysis, it is recommended that vigilant monitoring of the blast site and public roads by blast guards and supervisors must be maintained to promptly detect and report any signs of flyrock incidents. Additionally, smaller blast hole diameter should be employed in blasting operations surrounded by communities and infrastructure rather than using larger/bigger blast hole diameter.

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Conflict of Interest Declarations
The authors declare no conflict of interest.

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