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Resilience of Building Structures in Mining Communities in Ghana

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Abstract

Ground vibrations produced by mine blasting negatively impact nearby structures. In Ghana, there have been allegations of blast induced ground vibrations resulting in building cracking in communities around mining pits. A pre-mining building condition survey was undertaken in selected mining communities in Ghana, a total number of 1904 buildings were surveyed in five mining areas. The results show majority of the building are not engineered and the thickness of the foundations are less than 450 mm. The age distribution of the building is between 1 and 100 years. Sandcrete blocks are the main wall cladding with a percentage of 60%, landcrete wall cladding are about 24%, cement rendered landcrete blocks are 11% and wood cladding are 5%. The commonest defects identified with structures includes the crocodile skin crack, surface cracks, horizontal cracks, vertical cracks, through cracks and diagonal cracks, and spalling-off of the mortar from the walls due to improper bonding. The study showed that, most of the structures are not designed to withstand the mine blast induced ground vibrations. It is recommended that blast designs should take into consideration the conditions of buildings within mine pit environs and comply strictly with blasting regulations to avert confrontations with local communities.

Keywords

Mining, Blasting, Vibrations, Buildings, Peck Particle Velocity, Airblast

1. Introduction

Mining consolidated ore deposits require the fragmentation of the host rock to liberate concentrate minerals for further processing. Drilling and blasting are the most common approach used for rock-bearing minerals fragmentation (Taiwo et al., 2022; Arthur et al., 2020). Holes are drilled into the rock and filled with explosives, which are then detonated to fragment the rock. Vasović et al. (2014) emphasised that blasting is therefore very significant in the mining process, the primary purpose is to fragment the rock into smaller sizes to facilitate the transportation to the crushing plant. Blasting is used to clear overburden to access mineral resources and leads to increased productivity and reduced costs in mining and quarrying operations. Appropriately fragmented rock decreases deterioration on equipment such as crushers, conveyors, and haul trucks, leading to lower maintenance costs and extended equipment life (Shehu and Hashim, 2021; Sharma et al., 2019). Blasting reduces the need for more expensive mechanical methods of rock breaking, such as hydraulic breakers or ripping with bulldozers.

Despite the numerous benefits of blasting in the mining process, there are severe environmental concerns that must be addressed for sustainable mining, it affects particularly the environment, safety, and nearby communities, there have been reported cases of the negative impacts of mine blasting (Feher et al., 2021; Hidayat, 2021; Bhatawdekar et al., 2021; Avornyotse, 2021). Large volumes of dust are produced during blasting, and this dust may include dangerous particles like silica, heavy metals, and other poisonous materials. This dust has the potential to disperse over wide regions, impairing the quality of the air and endangering the health of nearby residents and workers. Gases like nitrogen oxides and carbon monoxides are released into the atmosphere during blasting, these gases can pollute the air and endanger the health of workers and communities within the mining environment (Adhikari et al., 2022). Residues from explosives, such as nitrates, can leach into groundwater and surface water, causing contamination that can affect drinking water supplies and ecosystems (Daou et al., 2022).

Ground vibrations produced by blasting have the potential to seriously harm nearby mining infrastructure, buildings, and archaeological sites, The assessment of ground vibration levels and its deleterious effects have been of considerable interest within the scientific community (Li et al., 2022; Kraszewski, 2019; Torres et al., 2018; Sołtys et al., 2017; Norén-Cosgriff et al., 2020). Extended periods of vibration exposure can result in wall cracks, weakened foundations, and other structural problems. The uncontrolled ejection of rock fragments during blasting, also known as fly rock, can seriously jeopardize the safety of surrounding communities and mine workers (Raina and Bhatawdekar, 2022; Szendrei & Tose, 2023). According to (Davarzani et al., 2022) fly rock is one of the destructive consequences of blasting operations, which occurs in the form of uncontrolled and unintentional fly rock fragments out of the blast area with high energy and speed. Noise from blasting operations can disturb nearby residents, causing stress, sleep disturbances, and reduced quality of life, especially if the blasting is frequent or conducted at night. Miners and nearby communities are at risk of respiratory health issues due to the inhalation of dust and gases released during blasting (Paluchamy et al., 2021). Conditions such as silicosis, lung cancer, and other respiratory diseases can develop with prolonged exposure.

There are regulatory framework guiding blasting to maximize its benefit and minimise the potential environmental impacts. In Ghana, mine blasting is guided by the Minerals and Mining Act, 2006 (Act 703) which is the principal legislation that governs mining activities including mine blasting. However, Minerals and Mining (Explosives) Regulations (LI 2177) which relates to mine blast specify a maximum Peak Particle Velocity and airblast levels in residential areas at 2 mm/s and 117 dBL respectively due to the generally weak nature of buildings within communities where mining occurs.

In Ghana, there have been allegations of blast induced ground vibrations resulting in building cracking in communities around mining pits. The allegations have often brought about confrontations between mining companies and landlords in mining communities (Amegbey et al., 2012; Tiile, 2016). According to Bansah et al. (2016), damage to structures within the vicinity of mining operations is often attributed to blasting activities, leading to protests and conflicts between receptor communities and mine operator. The Inspectorate division of Mineral Commission (MinCom) and the Environmental Protection Agency (EPA) have recommended that prior to commencement of mining activities; mining companies should undertake a structural condition survey of all structures within a specified buffer zone around the blasting area to establish baseline data to monitor blasting impacts. The role of structural condition surveys prior to mining is crucial due to the significant impacts of mining activities, particularly blasting, can have on nearby structures and communities. Structural condition surveys provide a systematic assessment of the state of buildings in mining communities and are integral to ensuring safety, compliance, and community relations. It offers vital information for creating focused mitigation plans. Knowing the building premining state enables the application of strategies like structural reinforcement and controlled blasting methods. Structural condition survey in selected mining communities were carried in Ghana and this paper presents the state of the buildings in the communities to guide mine blasting for sustainable mining.

1.1. Objective

The objective of the study is to create a baseline data that documents the condition of building in mining areas to manage mining blasting and also reduce liability for potential damage claims and ensuring safety.

1.2. Study Area

The study area was undertaken in four of mining Regions in Ghana included the following:

- Western Region Tarkwa (Abekoase & Brahabobom, and Government Hill) Nzema (Anwia), Prestea (Nankaba)
- Eastern Region (Afosu and New Aberim)
- Central Region (Ayanfuri)
- Ahafo Region (Kenyasi)

The regional map of Ghana showing the study areas is presented in Figure 1.

Figure 1. Regional map of Ghana showing the study regions.

2. Materials and Methods

The approach adopted for the survey included the following:

- Walkover Survey;
- Meeting with Stake Holders;
- Building/structure fabric survey including photographic documentation.

2.1. Walkover Survey

A walkover survey was undertaken in the various communities with the community representatives, during which the types, number and general fabric makeup of the structures were observed. Courtesy calls were made on the community elders to announce the presence of the survey team and set dates for broader stakeholder consultations prior to commencement of the actual survey.

2.2. Meeting with Stakeholders

A meeting, comprising the community leaders was held to explain the methodology of the project and seek the consent of the communities for the project and the convenient day to start the survey.

2.3. Building/Structure Fabric Survey

Each building was surveyed using a Building Structural Survey form designed to capture all relevant information on the building. The information requested on each form consists of:

- House number (if any);
- Age of building/structure;
- Type of building—whether engineered or not;
- Type of wall fabric;
- Type of wall mortar plastering;
- Type of roof fabric;
- Available, type, general orientation and length of cracks;
- Plan layout of building and orientations (with respect to the north position);
- Position of cracks with respect to the plan layout;
- Photographs of cracks;
- GPS coordinates of the location of the structure.

A thorough inspection was conducted on each of the buildings and included looking at structural elements like foundations, walls, floors, roofs, windows, and doors. High-resolution photographs of every critical area of the buildings were taken to document pre-existing conditions such as cracks, settling, and any visible defects, timestamps were ensured for these photographs. A crack map of each of the buildings were created showing the location, length, and width of cracks in walls, ceilings, floors, and other parts of the building.

3. Results

The results of the survey are summarised and presented in Table 1.

Table 1. Summary of building condition survey.

Region	Town	Community	No. of Buildings Surveyed	Building Cladding	Building Foundation (mm)	Structural Defects	Age Yrs
Western Region	Tarkwa	Abekoase	10	70% Wod, 5% SB, 25% CSB	≤450	Surface, Through and Crocodile Cracks	>15
		Brahabobom	526	90% Wod & 10% SB	≤450		>15

Continued

		(Govt. Hill)	4	90% SB & 20% Wod	≥450		>50
	Prestea	Prestea Nakaba	77	76% SB, 15% wood, 9% LB	≤450		>15
	Nzema	Anwia	65	50% SB, 11% Wod, 20% CLB, 10% LB	≤450		>10
Central Region	Ayanfuri	Esrodo	166	62% SB, 29% LB, 9% Wod	≤450	Surface, Through and Crocodile Cracks	<25
		Kokoase	39	80% SB, 5% LB, 15% CLB	≤452		
		Kyeremekrom	222	84% SB, 10% LB, 6% Wod, 10% CLB	≤450		
		New Site	91	85% SB, 15% Wod	≤450		
		Zongo	16	50% SB & 30% LB, 20% CLB	NA		
Eastern Region	Akyem	Afosu	200	60% SB, 30% LB, 10% CLB	≤450	Surface and Through cracks	>10
		New Abirem	147	75% SB,5% Wod, 5% LB, 15% CLB	≤450		
Ahafo	Kenyasi	Habitat and Ahafo Kenyasi	341	60% SB 10% Wod, 30% LB	≤450	Surface and Through cracks	>10

Note: SB—Sandcrete Block, Wod—Wood, LB—Landcrete Block, CLB—Cement Rendered Landcrete Block.

4. Discussion

4.1. General Characteristics of Structures in the Regions

Most of the buildings were residential, engineered with proper foundations and some are also non-engineered without proper foundations to support the structure. Figure 1 shows the distribution of wall fabrics in the communities, the dominant wall fabrics are the sandcrete blocks. The most used materials for wall plastering are cement/sand mortar; some landcrete structures were not plastered exposing the buildings to erosions on the walls and the foundation level. Predominant roofing type was the corrugated iron sheets and a few thatch roofs located in the remote areas. The doors and window are made of wood, glass and metal. Table 2 and Figure 2 show the age distribution of wall fabrics in the communities.

4.2. Existing Defects on the Buildings

Four types of building walls were identified in the communities, landcrete, sandcrete, cement rendered landcrete and wooden walls. The existing defects on the building walls are described according to the building walls below.

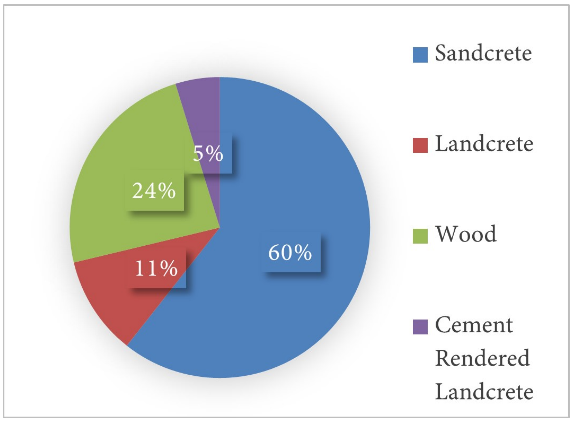

Figure 2. Distribution of wall fabrics in the communities.

Table 2. Age of structures.

Age (years)	No. of Structures
<1	154
1 - 20	524
21 - 40	450
41 - 60	421
61 - 80	251
81 - 100	104

4.3. Landcrete Structures

Major building material used in its construction is the earth material. The commonest defects identified are the crocodile skin crack. These cracks usually originate from the shrinkage of clay in the earth material. The floors were made of rammed earth which had resulted in very deep cracks on the building floors. Through cracks can be located on both the interior and exterior surface of the walls; it cut through the walls to the other side. There were also vertical, horizontal, diagonal cracks on the building walls. The foundations of these buildings have been eroded by rain. A typical landcrete structure with associated defects is shown in Figure 3.

Figure 3. Crocodile skin cracks on landcrete wall.

4.4. Cement Rendered Landcrete Structures

These buildings types have been constructed with earth material and are similar to the landcrete building but the walls have been rendered with cement mortar. Defects associated with these types of buildings spalling-off of the mortar from the walls due to improper bonding between them and different water absorption rates (Figure 4). Tiny hair line cracks were observed on the rendered surface. Vertical and diagonal surface cracks exist in the mortar plaster on the adobe and wattle and daub walls. The cracks originate from the corners of doors/window frames and propagate either downwards towards the ground or upwards towards the support of rafters on the walls. Horizontal cracks are identified at the edges of the door frames. Figure 5 shows vertical through on a cement rendered landcrete wall.

Figure 4. Spalling-off on cement rendered landcrete wall.

Figure 5. Vertical through crack on cement rendered landcrete wall.

4.5. Sandcrete Structures

Defects associated with these structures include all the major cracks: surface cracks, horizontal cracks, vertical cracks, through cracks and diagonal cracks. Older buildings (>10 years) were predominant with vertical through cracks from the door frames to the gable level. Surface cracks which were mostly located at the plinth level of the structure appeared to have been caused by persistent movement of rain water around the foundation and the rise of water table resulting in the wetting of the walls by capillary action of the walling material. Defects on the new structures were few and in most cases no defects were identified. Figure 6 & Figure 7 are typical defects found on sandcrete structures.

Figure 6. Vertical crack from lentil to door frame.

Figure 7. Horizontal crack emanating from a door frame.

4.6. Wooden Structures

These are structures constructed with wooden material, mini shops, local restaurants (chop bars), bathrooms, toilets are the main structures constructed with wooden materials in the community. The only defects associated with these structures were the deterioration of the wooden structure due to environmental factors and termite infestation. Where the floors of the structures were made with cement/sand mortar, cracks exist. Figure 8 illustrates a typical deteriorated wooden structure.

4.7. Possible Causes of the Defects on the Structures

Development of defects such as cracks on structures can be attributed to many factors. Observations made on the defects during the survey suggest that the defects may be caused by:

Figure 8. Deteriorated wooden structure.

4.7.1. Materials for Construction

Soils used for landcrete construction has high clay content. Since clay is an expansive soil, seasonal variation in the moisture content causes expansions of the materials thereby inducing cracks in the building. Wattle and daub wall constructions, when not covered externally by earth/cement mortar plaster have been shown eroded by driving rain. Combination of building materials used in the construction are susceptible to chemical reactions. The combination of cement and Atakpame can result in a reaction between sulphate from the earth material and cement. Cracks develop at the joint between cement and the earth material.

4.7.2. Type of Wall and Floor Construction

Most of the building walls were constructed with a foundation depth of less than 450 mm. The very thin floor screed covering and the construction method of compacting the interior floors (however poor the compaction) after the wall has been built has led to the cracks in the floor screed, spalling-off of screed cover and the separation cracks between the wall and the screed. These conditions are bound to worsen with increased human traffic on the floors and any movement.

4.7.3. Differential Settlement

Differential settlement of the foundation soils on loose, soft and highly compressible soils where the load imposed from the foundation overstress the soils supporting the foundation. Cracks caused by differential settlements are vertical in orientation and runs from the foundation level to the lentil.

4.7.4. Environmental Factors

Seasonal changes in weather conditions had caused deterioration in the building wall fabric and other structural members which initiate defects. Erosion of the foundation and plinth positions of the walls leading to hanging buildings has been observed and indeed is persistent in the communities. Unplastered landcrete walls have also been washed away by driving rain.

4.7.5. Age of Building/Structure

Building defects tend to worsen with the age because all building materials deteriorated with age. Regular and/or effective building maintenance will slow such a process. However, with the exception of rebuilding as a result of building collapse and painting, very little maintenance is evident in the buildings surveyed except the occasional attempt to patch up large through-wall cracks. The results of such attempts have not been very successful because the materials employed for repair, the methods adopted or the severity of crack in the parent wall are such that not very much could be achieved.

4.7.6. Vegetation

The roots of trees located in the vicinity of a wall can create cracks in walls due to growth of roots under foundation. The cracks occur in clay soil due to moisture contained by roots.

5. Conclusion

The survey revealed the prevailing conditions of building structures in mining communities in Ghana, the results provide useful information for stakeholders in the mining industry for blast impact prediction modelling and blast complaints. The results also indicate that, most of the structures are not designed to withstand the mine blast induced ground vibrations especially the landcrete structures. Even though these structures according to Amegbey et al. (2012) can withstand a peak particle velocity of 2 mm/s without any deformation, blasting designs in a very competent rock formation most often results in peak particle velocity above 2 mm/s which negatively impact these structures. It is recommended that the following is implemented to avert the blasting impacts and confrontations.

1) Monitoring of air blast and vibrations should be initiated once mining commences. Monitoring locations should be in the community and if possible, representatives from the community should be trained in such activities.

2) Blasting activities should be strictly conform to the blast design to avert any possible complaints from the community since many structures in the community are characterised by defects which are likely to be attenuated by minor vibration.

3) Buildings in the communities whose cracks are pronounced should be selected and their cracks monitored in relation to vibration and air blast.

Author Contributions

Conceptualization: B.O., F.U.U., F.A.M.; Methodology: B.O., F.U.U, F.A.M., J.A., A.A.; Software: A.A., AK.A.; Validation, B.O., F.U.U.; Formal analysis: B.O., F.U.U., F.A.M.; Investigation; B.O., F.U.U, F.A.M., J.A., A.A.; Resources: A.K.A; Data curation: B.O., F.U.U, F.A.M., J.A., A.A.; Writing, review and editing: B.O., F.U.U., F.A.M.; Supervision: B.O.; Project administration: B.O. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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