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MODIFIED GEOMECHANICAL DEPENDANT SEISMIC MORNITORING ARRANGEMENT FOR PREDICTING ROCK BURSTS AND FAILURES IN SESIMICALLY ACTIVE MINING BLOCKS AT MUFULIRA MINE

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Abstract

Mufulira mine is predominantly rich in copper mineralization. Due to increase in mine depth (1,557m), the mine has been experiencing rock failures and rock bursts. This has necessitated changes in mining sequences to suit the present geo-mechanical conditions such as development of de-stressing cross-cuts between 62 and 64 blocks to prevent possible rock bursts and rock falls.

This study conducted geotechnical investigations for intact rock mass to determine unconfined compressive strength (UCS), secant and tangent Young’s Modulus (E Sec and E Tan), secant and tangent Poisson's Ratio (ν Sec and ν Tan), Brazilian and tri-axial compressive strength tests as well as geological field mapping to understand the Geo-mechanics mechanisms controlling rock burst prone mining blocks at Mufulira mine.

Laboratory findings have established high values of tensile strength ranging from 7 MPa to 12.1 MPa, Uniaxial Compressive Strength (UCS) ranging from 126 MPa to 226 MPa and tri-axial compressive strength ranging from 124 MPa to 466 MPa. Damage mapping conducted in the footwall drives, cross-cuts and mining drives excavations indicate that there is a changing stress loading as one move away from the retreating stope face to the east. Based on above results, an early warning monitoring system based on seismic monitoring system at Mufulira mine has been modified to suit the changing nature of geotechnical and geological parameters.

Introduction

Mufulira mine comprises three ore bodies, referred to as orebody *A*, *B* and *C*. Ore body A is the smallest of the three and stretches horizontally 300 m, orebody B is slightly larger and stretches horizontally 600 m, while orebody *C* is the main ore body. The ore body generally dips 45 degrees in the North East direction but at some places it flattens towards 35 degrees (Brandit, R.T.,1962). The Mufulira rock mass generally consists of a sequence of strong sedimentary formations overlying competent basement Schist and Granites, with rock strengths that range from 200 to 300 MPa.

Seismic monitoring at the mine

Mufulira underground mine has been experiencing rock bursts due to seismic events during mining operations. These seismic events are accompanied by rock falls and rock busts. The failures are accelerated by geological and geotechnical structures. Rock falls/rock bursts that result from seismic events are catastrophic hazards and require an early warning system to be put in place before they occur due to the damage that accompany them (Crouch, S.L., 1976; Dubinski, J., and K. Stec 2001 & Fei, L., M. Tianhui, T. Chun'an and C. Feng 2018).

To date no detailed study has been done at the mine to develop an early warning system for predicting rock bursts that is dependent on effect of changes in geo-technical and geological environment. As a result, the seismic monitoring system has not fully addressed lapses in timely responding to ground failures.

Materials and Methods

The following geo-mechanical tests were carried out: Brazilian test; Uniaxial Compressive Strength test and Tri-axial Compressive Strength test. Brazilian test was used to measure the indirect tensile strength of twenty-eight (28) NX disc rock samples.

A Digimax Compact line machine (Fig. 1) of 100 kN was used to carry out the test and pre-load was applied to all the specimens, average range was 80-90 N. Each 14 cm long NX core size sample was divided into smaller discs of 27 mm long, half the diameter of the core sample of 54 mm. Each disc was then weighed on the digital mass scale; the digital vernier caliper was used to measure both the diameter and thickness of the discs. Each disc was placed under the two platens and subjected to constant load as shown in fig. 1 *C*. At a given maximum load, deformation of the disc occurs as shown in fig. 1 *D* and results were recorded. The following formulae were used to find stress at failure;

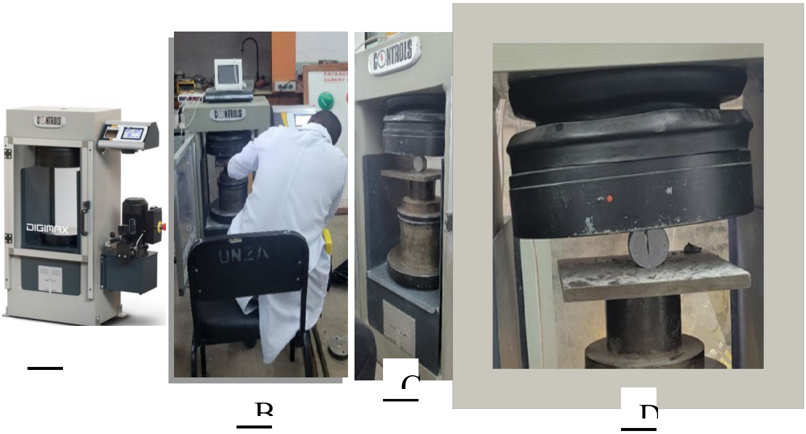


Fig. 1. Showing *A* Digimax Compact line machine, *B* Core disc placement between compression platens, *C* Core disc sample being subjected to constant load, *D* Core disc getting deformed

$$\sigma_1 = \frac{6P}{\pi Dt}; \ \sigma_2 = 0; \ \sigma_3 = \frac{2P}{\pi Dt}, \tag{1}$$

where P is the applied load, D is the core diameter and t the core thickness. The tensile strength, T_0, is given by the value of $\sigma_3 = (-T_o)$ at failure. 15 drilled core samples of diameter 47 mm (NQ) size were prepared according to the International Society of Rock Mechanics (ISRM) standard. The length of each sample was 140 mm and 47mm in diameter. The length to diametre ratio was 2.97.

$$T_0 = \frac{2P}{\pi Dt}. \tag{2}$$

Uniaxial Compressive Strength test

Sample preparations

The cylindrical surfaces were prepared in order to be flat and smooth, levelled within 0.02 mm tolerance and made sure that no more than 0.06 degrees departure from perpendicular occurred during the laboratory testing.

Apparatus

The apparatus (see Fig. 2) used to conduct the experiment consisted of the following: Loading Device; Platens and Strain measurement devices (electrical resistance strain gauges).

Testing procedure

The two plates were carefully cleaned before the specimen was placed in the testing chamber. The load was continuously applied at a rate of 1.0 MPa/s and failures occurred in approximately 10 minutes. Stress and deformation data were recorded through an electronic system that has the appropriate accuracy specifications. The maximum load was recorded in Newtons within 1% accuracy and results were recorded. The following formulae were used:

The axial strain is calculated as

$$\varepsilon_a^0 = \Delta l / L_0 \,, \tag{3}$$

where ε_a Axial strain, Δl Change in measured axial length and L_0: The initial length of the sample. The diametric strain is calculated as

$$\varepsilon_a^0 = \Delta_d^0 / D_0 \,, \tag{4}$$

where ε_d Diametric strain, Δ_d Change in diameter and D_0 -the initial diameter of the sample. The compressive stress is calculated as

$$\sigma = P / A_0 \,, \tag{5}$$

where σ - Compressive Stress, P - Load and A_0- the initial cross-section area of the specimen. The unconfined compressive

Fig. 2. Showing *A* setting up of an experiment, *B* Placing the sample on the platens of the testing chamber, connecting strain gauges to the core sample (*C*-Axial strain gauge and *D*-Radial strain gauge)

Strength was calculated for the maximum load applied:

The modulus of elasticity (Young's modulus) E which represents the ratio between axial stress and axial strain can be derived via several methods. It was calculated at stress-strain level of about 50% of the maximum load.

$$E = \Delta_\sigma^0 / \Delta\varepsilon_a \qquad \text{(At 50\% of maximum load)} \tag{6}$$

The Poisson's ratio that represents the ratio between diametric and axial strain, was calculated as

$$n = \left(\varepsilon_d^0 / \varepsilon_a \right) \tag{7}$$

Tri-axial Compressive Strength test

Sample preparation

15 drilled core samples were selected to be representative of the rock formation examined. The diameter of the samples was 47 millimeters and of 140 centimeters in length. The diameter was derived by taking measures at the top, mid and the bottom parts of the specimen with a tolerance of 0.1 millimeters. The height to diametre ratio was 2.97 within the ISRM standard of 2.0 to 3.0. The height was determined to the nearest millimeter. The ends of the samples were smoothed so that the top and bottom surfaces were flat with a tolerance of ±0.01 mm. This ensured that the applied loads were uniformly transmitted to the sample and there was no loading eccentricity.

Testing Procedure

A cylindrical rock specimen was placed in a specifically designed cell (Hoek cell). A specially designed membrane was attached to the cell so that it remained airtight. The lateral pressure is hydrostatic and was applied through a liquid (oil) which was pumped into the membrane. A hydraulic pump or a servomotor capable of regulating pressure within 1% accuracy was utilized. The specimen was axially enclosed by steel spherical seats. To derive the vertical and circumferential deformation of the sample, strain gauges were used and results were recorded. ArcGIS software was used to digitize the geological map of the study area.

Mapping of structural discontinuities

This was conducted by plotting and analysis of data using 3D Surpac modeling, Unwedge and Rick Allmendinger Stereonet software.

Results and discussion

Brazilian tensile test results

The test was done on disc shaped. In all, thirty (30) specimens of 27 mm long were obtained. The C-Quartzite had the highest average tensile strength of 11.5 MPa and Dolomite had the lowest average value of 6.2 MPa. During the test, all the rock samples showed brittle deformation with Quartzite being harder than Dolomite as can be seen in Fig. 3 on the basis of tensile strength values.

Uniaxial compressive strength results

The investigations of strains on rock specimens during uniaxial compression test were conducted and plotted graphically. Two components of strain in the cylindrical shape specimen, axial and radial components were studied. Strain gauges fixed on specimen surface were used in this study. Axial and radial components of strain were measured directly (see Fig. 5).

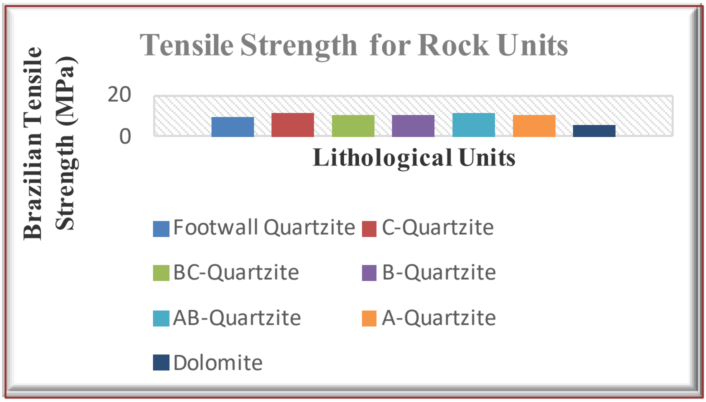


Fig. 3. Showing results from Brazilian Tensile Strength test, C-Quartzite with highest value & Dolomite with lowest

Strain measurement was necessary for determination of Young's modulus and Poisson's ratio. Fig. 5 shows the plotted results of one of the samples. The B-Quartzite had the highest average uniaxial compressive strength value and Dolomite had the lowest value (Fig. 4). This shows that Quartzite will require more compression load to deform than required by the Dolomite of the same rock mass size.

Stress and Strain Curves

The typical behaviour of strain component curves of the rock samples during Uniaxial Compressive Strength tests are illustrated in fig. 5.

Axial strain (red curves) performs the lowest sensitivity and the failure can be identified in relatively short advance only.

Radial strain (blue curves) shows more nonlinear trend than axial one, thus, recognition of approaching failure is earlier.

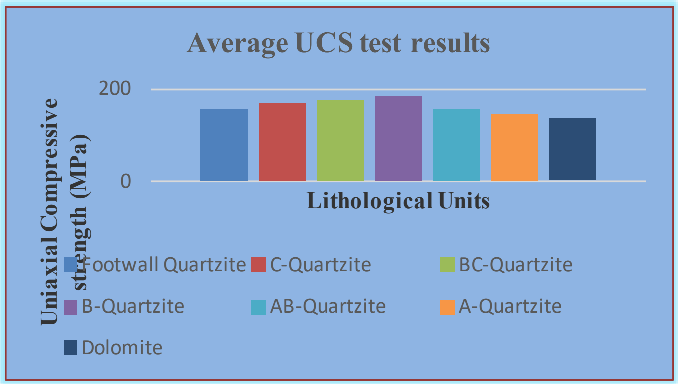
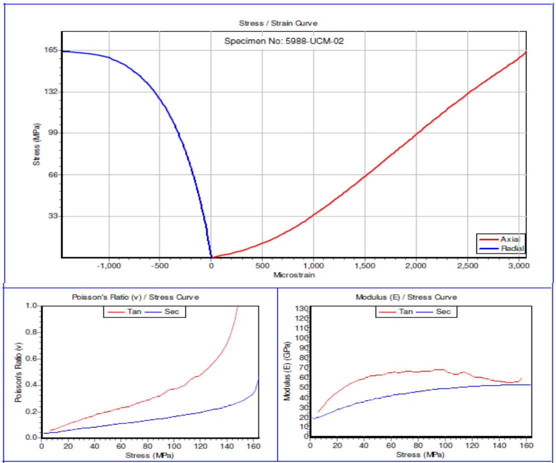


Fig. 4. Average Uniaxial Compressive Strength (UCS) for Lithological units



Failure Load: 288.2 kN Peak Strength: 164.2 MPa Axial Strain at Failure: 3072 microstrain

% Strength	Strength (MPa)	E Tan (GPa)	E Sec (GPa)	v Tan	v Sec
10	16.4	42.2	26.1	0.095	0.054
20	32.8	56.8	34.2	0.154	0.077
30	49.3	63	39.7	0.203	0.098
40	65.7	65.4	43.8	0.245	0.118
50	82.1	66.6	46.8	0.295	0.138
60	98.5	68.6	49.4	0.373	0.161
70	115	65.3	51.1	0.459	0.186
80	131	59.3	52.3	0.584	0.218
90	148	55.7	52.8	0.969	0.267

Fig. 5. showing Uniaxial Compressive Test results with elastic modulus and poisson's ratio for sample-02

Calculated Young’s modulus is dependent on considered interval of axial load.

Precariousness can occur if there is not specified stress level for Young's modulus determination.

Development of an early warning flow chart for predicting rock burst

Laboratory findings indicate that the area around the seismically active mining blocks in the deeps section have high values of tensile strength ranging from 7 MPa to 12. 1 MPa, uniaxial compressive Strength (UCS) ranging from 126 MPa to 226 MPa and Tri-axial Compressive Strength ranging from 124 MPa to 466 MPa. Rocks with high tensile strengths undergo brittle type of deformation, hence any rock burst or rock fall will be detected to enhance safe mining. Geological and geotechnical mapping results further indicate that the rocks found in the seismically active mining blocks are highly fractured, jointed and brittle. In line with above results, a modified flow Chart (Fig. 6) of Seismic Monitoring System for Predicting and Monitoring Rock Bursts and Rock Displacements was installed and tested at 1457 mL, 55P5 and 1473 ml, 67P5 closer to seismically

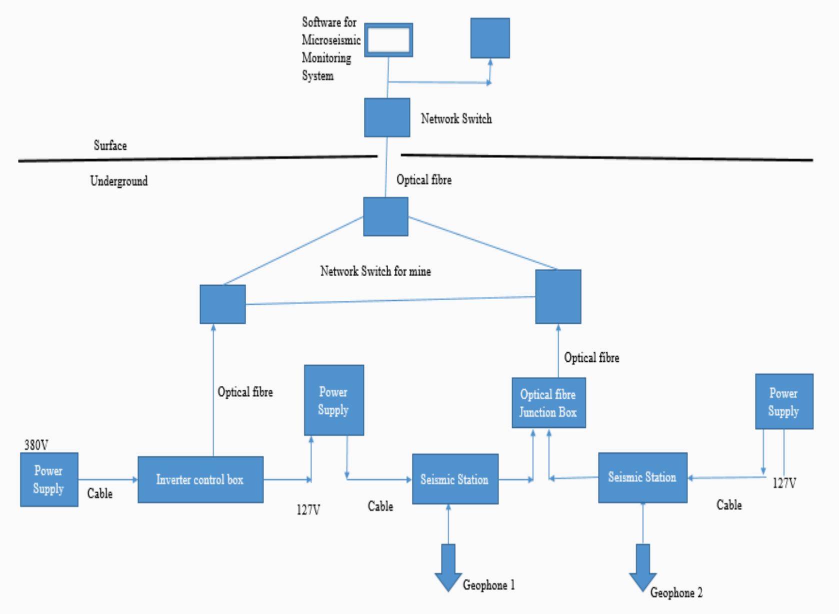


Fig. 6. Developed Flow Chart of Modified Seismic Monitoring System for Predicting and Monitoring Rock Bursts and Rock Displacements

Conclusion

This study was aimed at establishing the effects of changes in geotechnical and geological parametres on the positioning of seismic monitoring system for early warning prediction of rock busts and rock failures in seismically active mining blocks. Study findings have established high values of tensile strength from 7 MPa to 12.1 MPa, uniaxial compressive strength (UCS) from 126 MPa to 226 MPa and Tri-axial compressive strength from 124 MPa to 466 MPa.

These have the potential to induce premature failure and rock bursts.

In line with these findings, a modified Micro-seismic monitoring system at Mufulira mine deeps section was developed by installing additional geophones that take into account the changing nature of rock properties.

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