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Rockburst Prediction of a Cut and Fill Mine by Using Energy Balance and Induced Stress

Bagaraja Sirait[a], Ridho Kresna Wattimena[a] and Nuhindro Priagung Widodo[a,]a*

[a]*Department of Mining Engineering, Institute Technology Bandung, Indonesia*

Abstract

Rockbursts have been the major hazard in deep hard rock mines,especially at an overhand cut and fill mine. It is caused a comprehensive prediction in accordance with strain energy issue. This study has been carried out by experiment to calculate the property of strain energy stored in rocks and by using numerical modeling to compute energy release rate (ERR), energy storage rate (ESR) and burst potential index as components of energy balance. Empirical analysis by using Q system is also done to see the ratio of σ_1/σ_c to predict rockburst.

1. Introduction

Strain energy become an important issue on predicting rockburst phenomenon at a crown pillar in an overhand cut and fill mine. It is generally characterized by a sudden release of energy in a highly stressed pillar that often cause local violent failure of the pillar.

Since the sixties, several techniques and methods have been developed in an attempt to assess rockburst potential of underground mine structures. Several of these techniques are based on the energy balance around excavations. Among those is the Energy Release Rate (ERR) that was developed in South Africa (Cook et al, 1966).

In recent years in Canada (Kaiser et al, 1995), significant achievements have been made in systematic studies on the dynamic behavior of mines upon the knowledge of rock mechanics. Many theoretical and numerical models and technical means have been developed in mechanism analysis and prevention of rockburst (Cundall and Lemos, 1988; Salamon, 1993; Brown, 1998).

Case history of this study was elected in Pongkor Underground Gold Mine at Level 400 – Level 500, about 400 metres depth beneath the surface.

Pongkor Underground Gold Mine, which belongs to PT. Aneka Tambang, Tbk, is one of the underground gold mining sites that implements overhand cut and fill method. In this method, the orebody is located in stope and mined in 50 m to 300 m depth. Currently, the company will increase its mining depth 100 m depth below.

The structure of orebody being mined is commonly in a form of a vein body, which consist of Ciguha vein, KubangCicau vein and Ciurug vein, and the thickness varies from 7 m to 20 m. The general orientation (strike/dip)

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx .

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of the vein orebody is N330^{0}E/60^0-70^0.

Figure 1. Research Location

2. Introduction of Rockburst Criterion

A typical stress-strain curve for the cyclic uniaxial compression on rock is shown in Fig. 2 where ε_p, ε_e, and ε_t represent plastic, elastic and total static strain respectively and EN_p and EN_e represent plastic and elastic strain energy respectively. Specifically, EN_p is irrecoverable energy and used for grain loosening, local crack propagation, and so on. Excessive stresses on the rock due to the excavation displace the boundary of the stope. This displacement equals the work done on the rock and is stored as potential strain energy if the rock is elastic. Since a rockburst is a sudden release of stored elastic strain energy, the occurrence of rockbursts depends on the rock's ability to accumulate elastic strain energy. In other words, rockbursts are decreased when the permanent plastic strain, ε_p, increase. Therefore thisphenomenon can be seen in a rock specimen subject to uniaxial compression and used to calculate energy index, strain energy density, strength index and stress index.

2.1. Energy Index

The potential for a rockburst can be expressed by the energy index (EN_i) which is the ratio of EN_e to EN_p as expressed in equation (1). According to Peng (1986), the larger the value of EN_i, the greater the susceptibility to bump which means sudden violent burst of coal. The potential for a coal bump can be classified as follows:

$$EN_i = \frac{EN_e}{EN_p} = \frac{\int_{\varepsilon p}^{\varepsilon t} f_2(\varepsilon)d\varepsilon}{\int_0^{\varepsilon t} f_1(\varepsilon)d\epsilon - \int_{\varepsilon p}^{\varepsilon t} f_2(\varepsilon)d\varepsilon} \tag{1}$$

$EN_i < 2.0$, not susceptible
$2.0 < EN_i < 5.0$, slightly susceptible, and$EN_i > 5.0$, severely susceptible

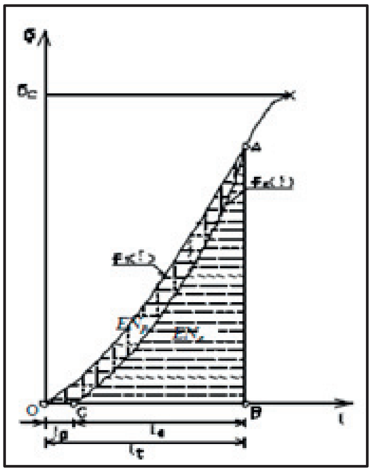

Figure 2. A typical stress-strain curve

2.2. Strain Energy Density

However, unlike coal, intact rocks of volcanic rock and granite rarely have plastic strain from the cyclic uniaxial compression test. It means that these types of competent rocks would have almost no plastic strain energy but have greater tendency to burst when failure. This tendency is estimated by a strain energy density (SED), the elastic strain energy per unit volume under the compression. The maximum elastic strain energy per unit volume would be as follows:

$$SED = \frac{\sigma_c^2}{2E} \tag{2}$$

Where, σ_c is uniaxial compressive strength, and E is the elastic modulus. According to the equation (2), the weakest rock would be the least likely to burst if other things are equal because weak rocks would reach their failure point far before they could store enough strain energy to burst. Wang (2001) illustrated Kwasniewski's work which scales the SED based on rockbursts hazard as follows:

$SED = 50$ kJ/m^3, very low
$50 < SED = 100$ kJ/m^3, low
$100 < SED = 150$ kJ/m^3, moderate
$150 < SED = 200$ kJ/m^3, high
$SED > 200$ kJ/m^3, very high

2.3. Determination of Energy Component

Referring to Fig. 3, σ_0 is the pre-mining state of stress before any excavation is made. The removal of the rock mass inside the boundary causes induced stresses, which can be higher (σ_A) or lower (σ_B) than σ_0. By examining the stress-strain curve, energy release rate (ERR) and energy storage rate (ESR) can then be calculated. It should be noted that, as illustrated in Fig. 4, the ERR can be reduced by mining in sequences.

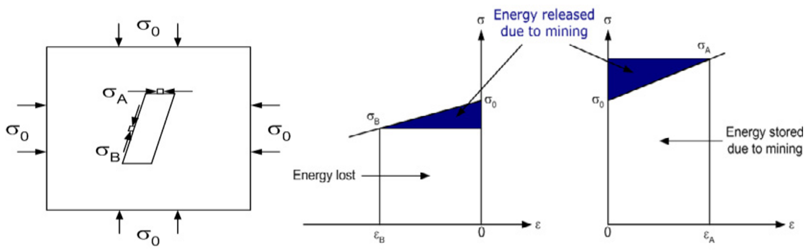

Figure 3.Mining-induced energy components.

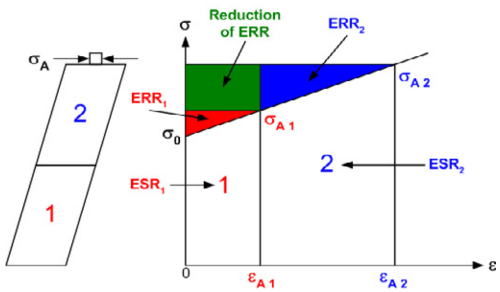

Figure 4.Mining-induced energy components in sequences.

It can be understood from the concepts given in Figure 3 that for the numerical modeling where the stress and strain are given in the tensor forms, the ERR and ESR can be calculated from the followings

$$ERR = \frac{1}{2}\int \Delta\sigma_{ij}\,\Delta\varepsilon_{ij}\,dV \quad (3)$$

and

$$ESR = \frac{1}{2}\int \sigma_{ij}\,\Delta\varepsilon_{ij}\,dV \quad (4)$$

where:
σ_{ij} = state of stress due to mining stage
ε_{ij} = state of strain due to mining stage
$\Delta\sigma_{ij}$ = incremental change in the state of stress due to mining
$\Delta\varepsilon_{ij}$ = incremental change in the state of strain due to mining

Mitri et al. (1999) proposed the so-called burst potential index (BPI) that is based on the ratio of ESR to maximum strain energy E_{max} that the rock mass can sustain before it fails. In a simple uniaxial test, E_{max} can be defined as the area under the stress-strain curve up to the point of peak stress or can be written as:

$$E_{max} = \int_0^{\varepsilon p} \sigma d\varepsilon \quad (5)$$

whereε_p is the uniaxial peak strain. It can be shown that in the absence of detailed stress-strain data of the rock mass, the E_{max} can be approximated from

$$E_{max} = \frac{\sigma_p^2}{2E} \quad (6)$$

whereσ_p is the peak strength of the rock mass and E is the elastic modulus of the rock mass. The BPI can be calculated from

$$BPI = \frac{ESR}{E_{max}} x100\% \quad (7)$$

2.4. Stress Reduction Factor of Q System

As one of stress parameter in Q system, SRF is a measure of: 1. loosing load in the case of an excavation through shear zones and clay bearing rock, 2. rock stress in competent rock, and 3. squeezing loads in plastic incompetent rocks. On the rock stress problem in competent rock, the value of σ_c/σ_1 is used to predict rockburst potential according to the classification given by Grimstad and Barton, 1993.

3. Numerical Prediction

The occurrence of rockburst depends not only on the property of storing large amounts of elastic strain energy in rock which could be released in a high rate at failure, but also on the environment for creating and storing such high stress and strain energy in the rock mass system (Stec et al., 1995; Park, 1995; Kwasniewski and Wang, 1999). In order to find out strain energy changes surrounding the mining pits, a two dimensional FEM numerical model was constructed in reference to insitu geological characteristics and mining configuration and the strain energy was calculated in the process of mining.

The mining of the 20 metres wide vein was conducted in 17 stages and simulated by deleting elements within the 5 metres high mining slice. The mechanical parameters used in the model are based on the measurements in the laboratory and are listed in Table 1. According to insitu stress measurement (Sulistianto et al, 2006), stress transformation to the strike of the orebody is done to get the principal stress and results are: σ_1 = 8.00 MPa, σ_2 = 7.12 MPa, σ_3 = 5.85 MPa.

Table 1.Geomechanicalparameter

	Vein Quartz	Host Rock
γ (kN/m3)	25.58	24.99
E (MPa)	2595	5079
ν	0.24	0.22
UCS (MPa)	23.91	58.82
mb	3.354	7.905
s	0.0039	0.0721
a	0.506	0.501

Stress and strain were investigated in 17 monitoring points located in the bottom left corner of the crown pillar in every stage, which were the location of high induced stress. The ERR, ESR and BPI in these points were then calculated and the results are given in the followings.

4. Results of Prediction

4.1. Prediction by using energy index and strain energy density

By using samples took from boreholes GTRD-01, and GTRD-06, cyclic uniaxial compression test was carried out upon them and then, calculation of the value of both energy index and strain energy density were done.

Table 2 and Table 3 below summarize the results of calculation of the two criterion.

Table 2.Results of Strain Energy Density.

Borehole	Depth (m)	Lithology	SED (kJ/m3)	Prediction
GTRD-01	140.15-141.65	Breccia	101.14	moderate
GTRD-01	172.65-174.00	Breccia	130.62	moderate
GTRD-01	191.60-193.32	Vein Quartz	36.72	very low
		Mean	115.88	low
GTRD-04	178.15-181.25	Breccia Polimic	49.39	very low
GTRD-04	215.00-217.95	Andesitic	180.76	high
GTRD-04	250.35-252.25	Breccia Tuff	142.40	moderate
		Mean	124.18	moderate
GTRD-06	115.03-116.65	Breccia Polimic	140.19	low
GTRD-06	133.85-136.00	Breccia Polimic	150.67	low
GTRD-06	168.90-170.45	Breccia Volcanic	352.13	moderate
		Mean	214.33	low

Table 3. Results of Energy Index

Sample Code	Depth (m)	Lithology	ENi	Prediction
GTRD-01	175.20-177.70	Breccia	6.69	severely susceptible
GTRD-01	185.15-187.70	Vein Quartz	2.34	slightly susceptible
		Mean	4.52	severely susceptible
Sample Code	Depth (m)	Lithology	ENi	Prediction
GTRD-04	222.50-224.00	Breccia Tuff	4.78	slightly susceptible
GTRD-04	260.00-261.50	Breccia Tuff	6.14	severely susceptible
		Mean	5.46	severely susceptible
Sample Code	Depth (m)	Lithology	ENi	Prediction
GTRD-06	171.65-171.75	Breccia Volcanic	1.64	not susceptible
GTRD-06	191.30-191.80	Breccia Volcanic	11.16	severely susceptible
		Mean	6.40	severely susceptible

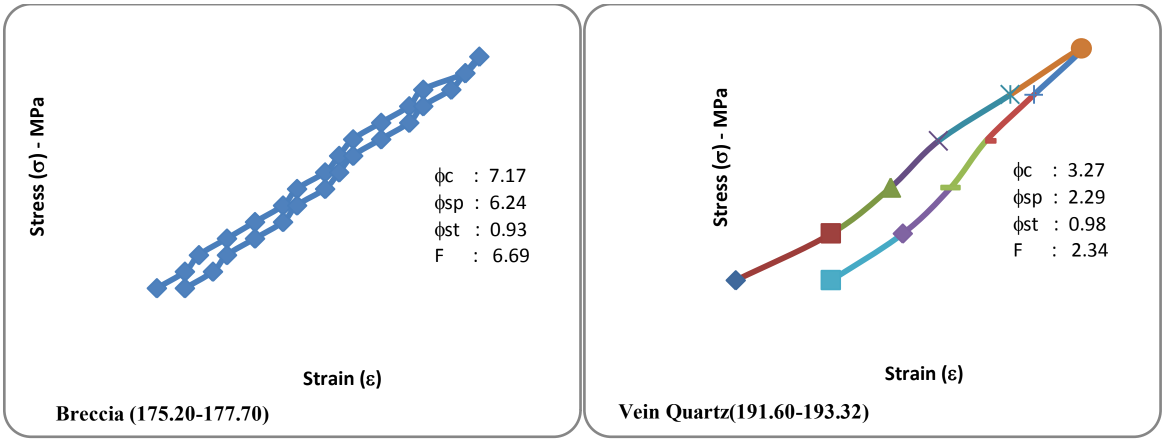

Figure 5. Graphics of Energy Index from GTRD-01

4.2. Prediction by using ERR, ESR and BPI

Strain energy components at 17 points were monitored. The values of strain energy at these points are shown in Table 4 and graphically in Figure 8.

Table 4. Numerical computation of ERR, ESR and BPI

Mining Sequence	Monitoring Point	σ1 max (MPa)	e1	ERR max (kJ/m3)	ESR max (kJ/m3)	BPI max
1	1	16.99	0.0020	5.091	9.131	7.88
2	2	19.41	0.0023	5.424	11.725	10.12
3	3	16.32	0.0019	2.537	8.177	7.06
4	4	23.08	0.0027	8.618	16.543	14.28
5	5	24.97	0.0029	10.386	19.290	16.65
6	6	19.90	0.0024	4.276	12.387	10.69
7	7	22.44	0.0027	6.377	15.816	13.65
8	8	28.79	0.0034	14.916	25.451	21.96
9	9	22.99	0.0027	6.069	16.578	14.31
10	10	23.68	0.0028	6.203	17.184	14.83
11	11	32.44	0.0038	18.700	32.267	27.84
12	12	26.15	0.0031	8.302	21.558	18.60
13	13	26.37	0.0031	7.927	21.482	18.54
14	14	35.63	0.0042	22.151	38.842	33.52
15	15	37.09	0.0044	24.808	42.238	36.45
16	16	31.43	0.0038	14.444	31.256	26.97
17	17	26.36	0.0032	7.335	21.510	18.56

Figure 6 shows the computed major and minor principal stress in the monitored points for every mining stage. It can be noticed that the major principal stress (σ_1) increase gradually as the mining progress approaching the points and rise significantly when the points become the skin points of the crown pillar. However, the minor principal stress (σ_3) in these skin points also increase at every final mining stage. This implies that in addition to stored energy produced by the increase of σ_1 there is lost energy caused by the increasing of σ_3.

Table 4 shows the numerical computation of ERR, ESR, and BPI in the monitored points for every mining stage. It is shown that all values of ERR and ESR below 50 kJ/m^3 where BPI values also below 100 %. It means that excavation at this level will make a very low rockburst.

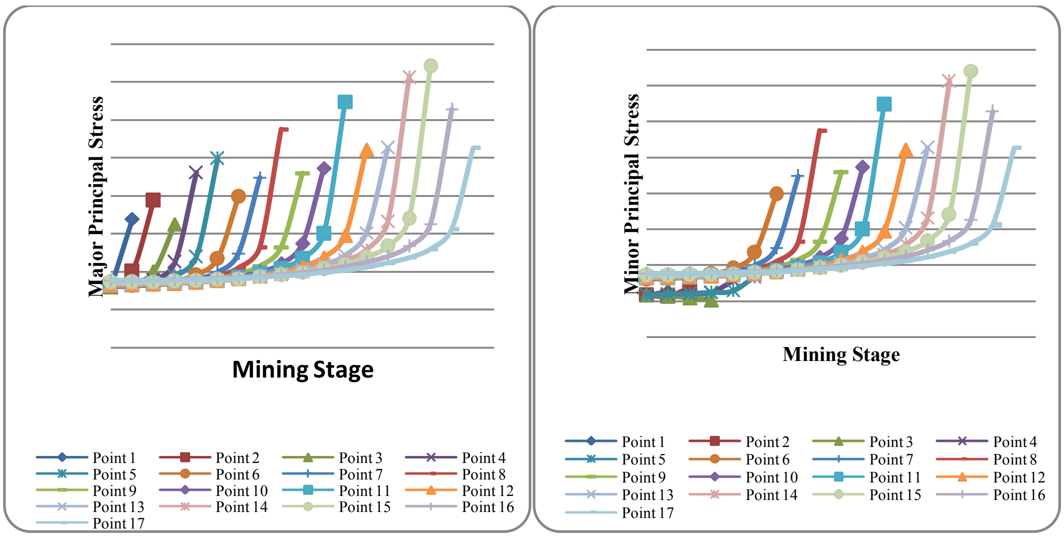

Figure 6. Principal stress at the monitored points

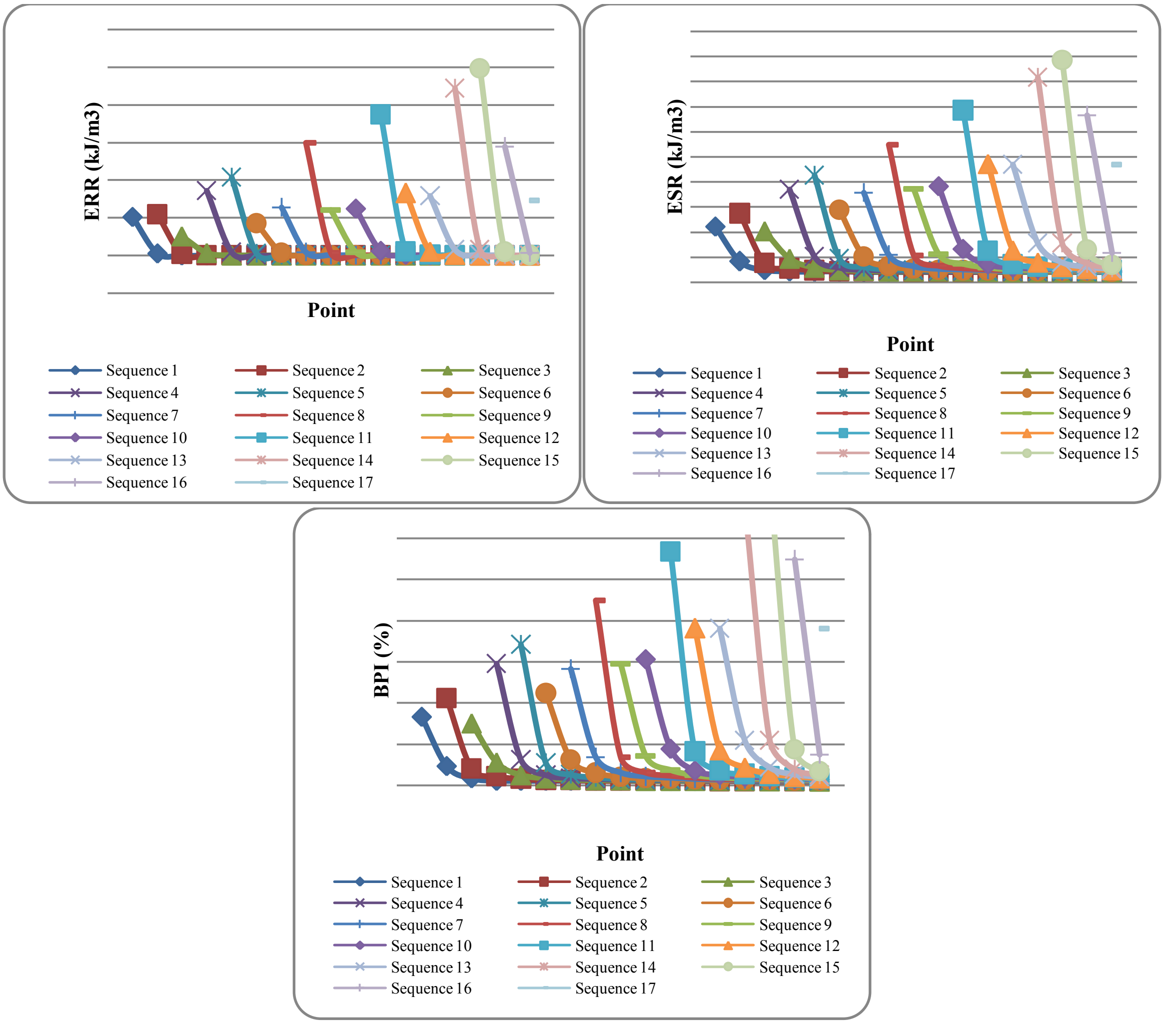

Figure 8. Variations of ERR, ESR and BPI

5. Conclusion

A comprehensive prediction that comprise the experimental, numerical and empirical analysis is needed in order to calculate the strain energy that contribute to the rockburst potential in mine. By using cyclic compression test in experimental analysis, the study predict that all most of the rock from GTRD-01, GTRD-04 and GTRD-06 have a low to moderate potential hazard of rockburst, in comparison with a few contemporary criteria of rockburst. Numerical modeling by using two dimensional FEM modeling shows that all ERR, ESR and BPI predict that this mining extraction have a low potential hazard of rockburst. Empirical analysis shows that extraction make the value of σ_1 increase gradually and the ratio of σ_c/σ_1 decrease. According to the Grimstad and Barton, all the values of σ_c/σ_1 predict that this mining extraction have a strong hazard of rockbust.

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