

Stope stability analysis of limestone ex-mined area at Ponjong sub-district Special Region of Yogyakarta using finite element method

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Preface

It has been twelve years Faculty of Mineral Technology Universitas Pembangunan Veteran Yogyakarta held an annual national or international conference on energy, mineral, and earth science. This year the conference was called International Conference on Earth Science, Mineral and Energy (ICEMINE) 2018 with the theme “Harmonizing on Exploration, Extraction and Conservation”. This conference was held on 11th October 2018 and hosted by the Faculty of Mineral Technology, Universitas Pembangunan Nasional Veteran Yogyakarta.

Geological conditions of Indonesia contribute a lot of mineral and energy resources. On the other hand, Indonesia also has high risks of geological disasters. We all have the right to explore and extract the mineral and energy resources in the earth through technology, but also have to maintain the environmental impacts and carry out conservation. Therefore, in this conference, we invite all geologists, geophysicists, petroleum engineers, mining engineers, metallurgist, environment and geo-tourism geoscientist as well as earth science students from all parts of society and institution of the world to share their knowledge, experience and concepts, in order an explore, extract and conserve. We wish those three activities could develop in harmony.

Yogyakarta, 11 October 2018

Editor in Chief

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The banner features a dark blue background with a globe. On the left, there are three circular logos: the top one is EGS (Electrochemical Society), the middle one is the International Union of Pure and Applied Chemistry (IUPAC), and the bottom one is The Korean Electrochemical Society. The central text reads "Joint International Meeting PRIME 2020 October 4-9, 2020". Below this, a light blue bar contains the text "Attendees register at NO COST!". On the right side, the PRIME logo is displayed, with "PRIME" in large white letters, "PACIFIC RIM MEETING" in smaller white letters below it, and "ON ELECTROCHEMICAL AND SOLID STATE SCIENCE" in even smaller white letters. Below the PRIME logo, the year "2020" is written in large white letters. At the bottom right, a blue button with white text says "REGISTER NOW" followed by a right-pointing arrow.

Stope stability analysis of limestone ex-mined area at Ponjong sub-district Special Region of Yogyakarta using finite element method

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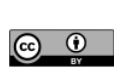
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Abstract. Limestone mining activity in Gunungsewu karst terrain of Gunung Kidul, Yogyakarta has been long time to be the livelihood for local communities. Evidently, by the number of ex-mining that have not been maintained and one of them looks like a stope hole in underground mining and failures could be occur at the stope. In this case, the sustainability of geoheritage area required geotechnical analysis to anticipate possibility of failure. This research conducted on traditional mining area in Sidorejo Village, Ponjong sub-district, Gunungkidul by comparing between the Hoek Brown and Mohr Coulomb failure criterion. Hoek-Brown criterion considering the geologic structures of rock mass and classification of rock mass using Geological Strength Index (GSI) whereas Mohr-Coulomb criterion is based on laboratory testing of intact rocks that will be affect to the value estimation of sigma 1, sigma 3, strength factor, and total displacement at the stope. Stability of stope will be analysed using finite element method that assisted with software Phase 2. The result of this research can be used as a reference to determine an appropriate acts to preserve the Gunungsewu geoheritage area.

1. Introduction

Mining activities karst area of Gunungkidul Regency has been long enough called the livelihood of the surrounding community. The consequence of limited information and communication technology and understanding of good mining practice at that time resulted in mining activities that did not consider the safety, health and environment (K3L). One of the influences that emerged was the hole of the former penangangang that has not been maintained and there is the potential collapse of Turi Hamlet, District Ponjong, Gunungkidul, DIY.

To anticipate the collapse of the opening hole is required the existence of geotechnical analysis in the opening hole of the former mining. In this stability analysis of openings, two criteria of rock collapse are Hoek-Brown collapse criteria and Mohr-Coulomb's criterion as a comparator in finite element method.



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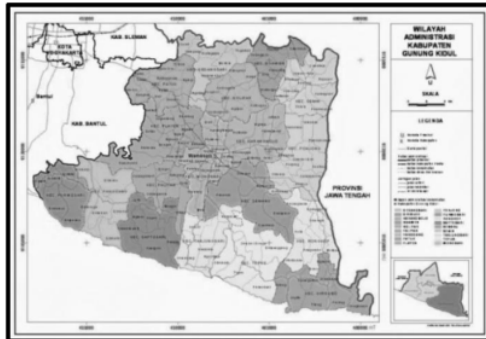


Figure 1. Map of the research area.



Figure 2. The opening stope location.

The purpose of this research are:

- Determining the mass classification of rocks at the opening holes.
- Estimating the value of Sigma 1, Sigma 3, total displacement, and strength factor in the openings.
- Compare the results of the calculations with Hoek-Brown and Mohr-Coulomb collapse criteria.

Scope of problem

Limitations of the problem in this study are:

- The stability analysis of the openings is limited to one opening of the former limestone mining at the study site.
- Interference parameters are not considered because there is no mining activity in the research location.
- The groundwater weight at the study site is considered dry.

2. Research Methodology

The research method applied is research and data processing. Activities undertaken in this study are literature study, field investigation, laboratory testing, data processing from the field and laboratory and analyzing the stability and geometry of the underground aperture in the research area.

Stages of research conducted on this research is described, as follows:

2.1. Study of literature

The study of literature is done by searching library materials that support and obtained from: Library, Internet, related institutions

Field observation

Conducted by reviewing directly to the field conditions, especially related data to be taken.

2.2. Data retrieval

Data collection in this research is as follows:

- Observation and measurement of rock mass classification parameters, in this case used rock mass classification system Geological Strength Index (GSI)
- Measurement of hole dimensions of openings.
- Intake of rock samples for testing at Laboratory (Physical and mechanical properties)

2.3. Testing in the laboratory

Laboratory tests include physical properties and mechanical properties of rocks to meet the parameters in the stability analysis of the openings.

2.4. Data Processing

After all the good data from the results of observations and test results in the next stage of the laboratory is to perform data processing to obtain openings by using the finite element method method.

3. Basic Theory

3.1. Classification of Rock Mass

In the rock mass classification, it is necessary to observe the geological condition in the research location and the special treatment of the rocks to know the characteristics of the rock mass to be studied. The treatment in question can be a test of physical properties and mechanical properties of the rock. In this study used rock mass classification system Geological Strength Index (Hoek & Brown, 1980). Geological Strength Index (GSI) mass classification systems can be directly related to engineering parameters such as Mohr-Coulomb, Power parameters such as Hoek-Brown or rock mass modulus.

3.2. Hoek-Brown Collapse Criteria

The Hoek-Brown collapse criterion is a criterion of empirical collapse that determines rock strength based on maximum and minimum effective stresses during rock failure. The criteria for the collapse of Hoek-Brown have been widely renewed, the most recent being The Generalized Hoek-Brown Criterion (Hoek, 2002) where the maximum and minimum effective voltage relationships are shown in the following equations:

$$\sigma'_1 = \sigma'_3 + \sigma_{ci} \left(m_b \frac{\sigma'_3}{\sigma_{ci}} + s \right)^a \quad (1)$$

Information:

σ_1 ^ = Maximum effective voltage

σ_3 ^ = Minimum effective voltage

σ_{ci} = Strong press rock intact

m_b = Hoek-Brown value constant

s and a = Constants that depend on the rock mass characteristics

The values of the constants m_b , s and a can be calculated as a function of GSI (Geological Strength Index).

3.3. Criteria for Mohr-Coulomb Collapse

To simplify calculations in rock mechanics the Mohr envelope is considered a straight line. Therefore Mohr-Coulomb criteria are defined as follows:

$$\tau = C + \mu \sigma \quad (2)$$

Information :

τ = Shear stress

C = Cohesion

μ = friction coefficient in rock ($\tan \phi$)

σ = Normal Voltage

Based on (2) the shear stress is expressed in the formula:

$$\sigma_m = \left(\frac{\sigma_1 + \sigma_3}{2} \right) \quad (3)$$

In the Cartesian Axis x and y:

$$R = \sqrt{\left(\frac{\sigma_y - \sigma_x}{2}\right)^2 + \tau_{xy}^2} \quad (4)$$

And according to Mohr:

$$a = \sigma_m \sin \phi + C \cos \phi \quad (5)$$

$$a = \left(\frac{\sigma_1 + \sigma_3}{2}\right) \sin \phi + C \cos \phi \quad (6)$$

$$R = \frac{\sigma_1 - \sigma_3}{2} \quad (7)$$

In the x and y Cartesian axis:

$$a = \left(\frac{\sigma_x + \sigma_y}{2}\right) \sin \phi + C \cos \phi \quad (8)$$

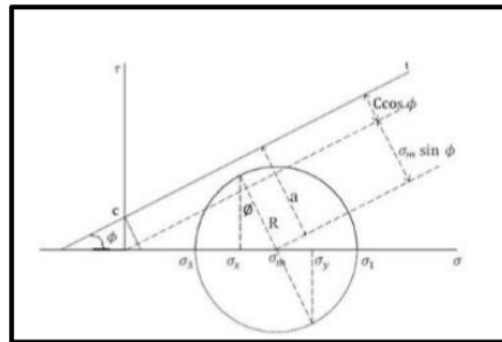


Figure 3. Mohr-Coulomb Curve.

Where :

σ_1 : Major Voltage (MPa)

σ_3 : Minor voltage (MPa)

τ : Shear stress (MPa)

ϕ : Inner friction angle ($^\circ$)

c: Cohesion (MPa)

a: The distance from the center of the circle to the intrinsic curve (cm)

R: The radius of the circle (cm)

t: Intrinsic curve

3.4. Finite Element Method (Finite Element Method)

The finite element method connects conditions at some point in the rock mass (nodal points) to a state within a finite closed region formed by these points (elements). Physical problems are numerically modeled by dividing the entire problem area into elements. However, the finite element is not suitable for modeling infinite boundaries, as occurs in underground excavation problems. One technique for dealing with infinite boundaries is to discretize outside the excavation zone and apply the appropriate boundary conditions to the outside edge.

4. Results and Discussion

4.1. Field Observation Results

Data retrieval at field observation activities yield some parameters which will be obtained parameters for calcification of rock mass using Geological Strength Index (GSI). The GSI rock mass classification

system is intended to estimate the reduced strength of a rock mass caused by different geological conditions. The result of field observation showed that the limestone in the research location has a GSI value of 70-80.



Figure 4. Location of GSI Data Collection.

GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS
 From the lithology, structure and surface conditions of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI = 35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.

STRUCTURE	SURFACE CONDITIONS		
	VERY GOOD Very rough, fresh, unweathered surfaces	GOOD Rough, highly weathered, less stained surfaces	POOR Smooth, moderately weathered and stained surfaces
INTACT OR MASSIVE - Intact rock specimens or massive in-situ rock with few widely spaced discontinuities	90	N/A	N/A
BLOCKY - Well interlocked undisturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets	70	60	50
VERY BLOCKY - Interlocked, partially disturbed mass with multi-directional angular blocks formed by 4 or more joint sets	60	50	40
BLOCKY/DISTURBED/SEAMY - Filled with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity	50	40	30
DISINTEGRATED - Poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces	30	20	10
LAMINATED/SHEARED - Lack of blockiness due to close spacing of the weak schistosity or shear planes	N/A	N/A	10

DECREASING SURFACE QUALITY

Figure 5. GSI Value Estimation.

In addition to the mass classification of rocks, the results of field observations are data on the dimensions of the openings being examined. Due to the form of irregular opening holes to facilitate the delivery of the results hole openings are divided into several parts, namely left wall, right wall, and roof. The dimensions of openings and portions are illustrated as follows:

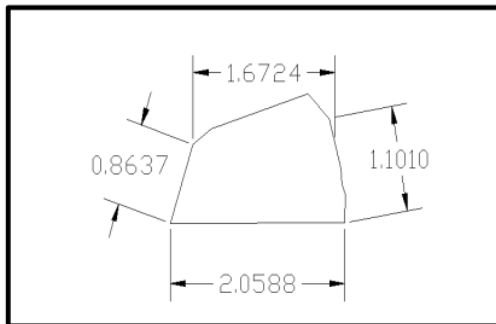


Figure 6. Dimensions of openings Stope.



Figure 7. Conditions of openings and parts thereof.

4.2. Testing at the Laboratory

After taking the rock samples on field observation activities, the samples were taken to the laboratory for testing. Examination of rock samples includes physical properties test, mechanical properties test to fulfill parameters in hole stability analysis. The results of testing in the laboratory are as follows:

Table 1. Result of Tests of Physical Properties

Sample Code	γ_n (gr/cm ³)	γ_d (gr/cm ³)	γ_w (gr/cm ³)
PJG - L - 1	2.14	2.08	2.26
PJG - L - 2	1.99	1.91	2.14
PJG - L - 3	2.06	2.04	2.24
Average	2.06	2.01	2.22

Information :

γ_n : The weight of the original content (gr / [cm]³)

γ_d : The weight of the dry content (gr / [cm]³)

γ_w : Weight of saturated content (gr / [cm]³)

Table 2. Mechanical Testing Results

Sample Code	σ_c (MPa)	E (Mpa)	ν	Peak		Residu	
				c (Mpa)	ϕ	c (Mpa)	ϕ
PJG - 1	4.00	200.00	0.21	42.19	22.88	25.59	14.35

Information :

σ_c : Uniaxial compressive strength (MPa)

E: Modulus of elasticity (MPa)

ν : Poisson ratio

c: Cohesion

ϕ : Inner friction angle (°)

Test results in the next laboratory will be used as parameters to make the modeling in the stability analysis of openings using Phase2 software.

4.3. Data processing

Data processing using Phase2 software aims to make numerical modeling of openings based on the parameters that have been obtained. After performing numerical modeling, we will get some values for this research are sigma value 1, sigma 3, strength factor, and total displacement.

4.3.1. Numerical Modelling

Numerical modelling using Phase 2 software would be facilitating the calculation of slope stability analysis with multiple selection of failure criterion. In this research, the Hoek-Brown and Mohr Coulomb failure criterion are used as comparators. The result of numerical modelling as follows :

4.3.2. Sigma 1 and Sigma 3

Sigma 1 is a vertical stress, while sigma 3 is a horizontal stress. Based on the result of numerical simulation is obtained the value of vertical stress greater than horizontal stress value.

Table 3. Sigma 1 and Sigma 3 Results.

Location	Hoek-Brown		Mohr-Coulomb	
	σ_1	σ_3	σ_1	σ_3
Left	222.96	118.4	169.41	64.77
Left	226.55	33.14	73.09	6.83
Left	198.65	27.2	75.42	7.09
Roof	171.61	26	92.41	11.29
Roof	137.74	8.93	57.66	0.14
Roof	162.64	13.17	61.99	2
Roof	201.4	67.75	141.03	28.76
Right	215.96	52.35	135.13	24.32
Right	199.43	34.14	81.07	10.7
Right	219.96	27.7	84.04	12.39
Right	248.81	32.55	85.52	13.09

4.3.3. Strength Factor

Strength factor is represents the strength of the material against the induced stress, at a certain point. Strength of material is based on the material strength properties.

Table 4. Strength Factor Results

Location	Strength Factor	
	Hoek-Brown	Mohr Coulomb
Left	4.96	1.41
Left	2.09	1.04
Left	2.16	1.02
Roof	2.35	1.18
Roof	2.23	1.05
Roof	2.15	1.09
Roof	3.23	1.18
Right	2.58	1.11
Right	2.29	1.03
Right	2.04	1.02
Right	1.97	1.02

4.3.4. Total Displacement

The rock mass displacement value is proposed to determine stability condition of the slope which is correlating with rock mass behaviour. The greater value of the rock displacement shows that the rock mass more unstable. Decreasing of value displacement could be indicating the stability of the rock mass in slope.

Table 5. Total Displacement Results.

Location	Total Displacement	
	Hoek-Brown	Mohr Coulomb
Left	2.42E-04	5.68E-04
Left	6.28E-04	1.49E-03
Left	7.08E-04	1.21E-03
Roof	7.66E-04	1.15E-03
Roof	8.39E-04	1.52E-03
Roof	7.42E-04	1.61E-03
Roof	4.16E-04	9.21E-04
Right	4.79E-04	9.29E-04
Right	6.11E-04	1.36E-03
Right	6.11E-04	1.43E-03
Right	5.81E-04	1.29E-03

5. Conclusion

Strength Factor

In this research, the variation value of strength factor is obtained from comparison between two failure criterion. The results of the calculation using Hoek-Brown failure criterion shows the more optimized strength factor value than Mohr Coulomb failure criterion. Analysis the strength factor value using Hoek-Brown failure criterion achieve the mean of strength factor value > 1 , whereas the analysis using Mohr Coulomb failure criterion on the certain point shows the critical condition.

Total Displacement

The total displacement value using Hoek-Brown failure criterion is smaller than Mohr Coulomb criterion. That means, analysis of the rock mass stability using Hoek-Brown failure criterion is more stable with the maximum displacement 0.000766 mm, and the maximum displacement of Mohr Coulomb failure criterion 0,00152 mm.

Acknowledgment

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